Aeroplane Construction And Operation

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Curtiss Type JN4D Biplane Used by The United States Air Mail Service

AEROPLANE CONSTRUCTION AND OPERATION

Including Notes On Aeroplane Design
And Aerodynamic Calculation,
Materials, Etc.

A Comprehensive Illustrated Manual of Instruction for
Aeroplane Constructors, Aviators, Aero-Mechanics,
Flight Officers and Students. Adapted
Either for Schools or Home Study.

BY

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AERONAUTICAL ENGINEER

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AEROPLANE CONSTRUCTION AND OPERATION

INTRODUCTION

Many aeronautical books of a purely descriptive nature have been written for the average man, but as a rule they contain little of interest for the more serious student of the subject. Other books of a highly technical and mathematical class have also been published, but their contents are all but unintelligible to anyone but a trained engineer. It is the purpose of the author to compromise between these two extremes, and give only that part of the theory and description that will be of practical use for the builder and flyer. The scope of the subjects covered in this volume has been suggested by the questions asked by students and clients, and is the result of many years' correspondence with beginner aviators and amateur aeroplane builders.

I have endeavored to explain the principles of the aeroplane in simple, concise language, starting with the most elementary ideas of flight and finishing with the complete calculations for the surfaces, power, weight, etc. When mathematical operations are necessary they are simple in form, and are accompanied by practical problems worked out numerically, so that a man with even the most elementary mathematical knowledge will have no difficulty in applying the principle to his own work. In cases where the calculations would necessarily be complicated, I have substituted tables of dimensions for the mathematical operations, these dimensions being taken from a number of representative machines.

While flying cannot be taught by books, and is only the result of actual experience, the chapter devoted to the use of controls under different flight conditions will be of great benefit to the prospective aviator. The portion of the book devoted to operation will be of use in flying schools and training camps since both training methods and control manipulation are covered in detail. In addition I have presented considerable data on the requirements of the modern aeronautical motor.

So many new firms are now entering the aeroplane industry that there is an ever increasing demand for trained mechanics, designers and flyers, and many technical men now working along other lines are taking a keen interest in aeronautical engineering. If the contents of this book will serve to inspire the technical reader to deeper interest and practical research in the fascinating subject of aeronautics, the author will be more than satisfied with the result of his labor. The aeroplane is rapidly assuming a great commercial importance, and there is no doubt but what it will develop into an industry rivaling that of the automobile.

To keep fully abreast of the times in aeronautic development, one should be a constant reader of the excellent aeronautical magazines. Too much praise cannot be given to the aeronautical press in its effort to maintain an interest in this subject, and as with all pioneering movements, these magazines have met with many discouragements and financial setbacks in the earlier days of flying. To the American magazines, ”Aerial Age” and ”Flying” (New York), the author owes a debt of gratitude for the use of several of the cuts appearing in this book. The English magazines, ”Flight,” ”Aeronautics” and the ”Aeroplane,” have been similarly drawn on. ”Aviation and Aeronautical Engineering” (New York) has suggested the arrangement of several of the tables included herein. All of these papers are of the greatest interest and importance to the engineer, aviator and aero-mechanic.

JOHN B. RATHBUN.

AERONAUTICAL MAGAZINES

The following list of American and English aeronautic publications will be of interest to those who wish to keep in touch with the latest developments in aeronautics:

- AVIATION AND AERONAUTICAL ENGINEERING (two issues per month). A technical magazine published by The Gardner-Moffat Co., Inc., 120 W. 32d St., New York.

- AERIAL AGE (weekly). Popular and technical. The Aerial Age Co., Foster Bldg., Madison Ave. and 40th St., New York.

- AIR SERVICE MAGAZINE (weekly). Military and popular subjects. Gardner-Moffat Co., Inc., 120 W. 32d St., New York.

- FLYING (monthly). Popular and military subjects. Published by Flying Association, Inc., 280 Madison Ave., New York.

- AIR TRAVEL (weekly). Popular subjects. Published by Air Travel, New York.

ENGLISH MAGAZINES.

- FLIGHT AND THE AIRCRAFT ENGINEER (weekly). Technical and popular. Published by Flight and Aircraft Engineer, 36 Great Queen St., Kingsway, W.C.2, London, England.
- AERONAUTICS (weekly). Technical and industrial. Published by Aeronautics, 6-8 Bouverie St., London, E.C.4, or may be had from 1790 Broadway, New York.
- THE AEROPLANE (weekly). Technical and popular. Published by ”The Aeroplane,” 166 Piccadilly, London, W.1.

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CHAPTER I. PRINCIPLES OF THE AEROPLANE.

Mechanical Flight. Although the elementary principles of mechanical flight are not of recent origin, the practical development of the flying machine is confined almost entirely to the present century. Gravity propelled gliders and small models have been flown with success from a comparatively early date, but the first actual sustained flight with a power driven machine was performed by the Wright Brothers in 1903. There was no single element on this first successful machine that had not been proposed many years before by Langley, Chanute, Montgomery, Henson, Mouillard, and others, but this first flight must be attributed principally to the fact that the Wrights started carefully and painstakingly to learn how to operate (By practicing with gliders) before starting on the first power machine. If Langley had studied the operation of his machine as carefully as he did its theory and design, he would have been flying long before the Wrights as his original machine was afterwards successfully flown by Curtiss.

When once actual flight was achieved, and the success of the Wright Brothers became generally known, the development proceeded with leaps and bounds. All the resources of science and engineering skill were at once applied to the new device until our present scientific knowledge of the aeroplane compares very favorably with the older engineering sciences. In the few years that have elapsed since the first flight, the aeroplane holds all records for speed, endurance, and radius of action. A great deal of the success so rapidly acquired can be credited to the automobile and motorcycle industries, since it was the development of the light internal combustion motors used on these machines that paved the way for the still lighter aeronautic motor. Again, the automobile industry was responsible for the light and powerful materials of construction, such as alloy steel, aluminum alloys, and also for the highly important constructional details, such as ball bearings, pneumatic tires, carburetors, magnetos, steel tubing, etc. The special methods developed in automobile work have helped to make the aeroplane an immediate commercial proposition.

[image]

Curtiss Type JN4-B Primary Trainer

Types of Flying Machines. In general, flight apparatus may be divided into two classes, (1) The Lighter Than Air Type, such as the balloon and dirigible, and (2) The Heavier Than Air Machine, represented by the aeroplane, helicopter and ornithopter. The lighter than air machine is supported in flight by ”buoyancy” in much the same manner that a piece of wood floats in water. When a balloon or dirigible, because of its large volume, displaces a volume of air equal to its own weight, the device will float. When the weight of air displaced exceeds the weight of the balloon or dirigible, it will continue to rise until it reaches an altitude where the diminished air density again results in an equality between the weight of the device and the air displaced. At this point it rests, or is in equilibrium. The flotation of such a device is entirely due to static forces and hence (1) is often called an ”aerostat.”

The sustenation of a Heavier Than Air Machine is due to an entirely different application of forces. Forces in motion (Dynamic Forces) are essential to the support of a heavier than air machine, and it is the resultant of these forces that performs the actual lifting operation, this resultant corresponding to the buoyant force of the aerostat. ”Dynamic” flight is obtained by an apparatus in which an arrangement of surfaces are moved in such a way as to cause an upward component of the forces generated by the impact of the air on the surfaces. The surfaces drive the air down and when the force necessary for the continuous downward deflection of air becomes equal to the weight of the machine it is sustained in flight. Dynamic flight therefore depends on the continuous downward deflection of masses of air, and when this motion ceases, sustentation also ceases.

An aeroplane is provided with a deflecting surface that is fixed rigidly in regard to the body of the machine, and the motion necessary for its support is provided by driving the machine forward, the forward motion being produced by the horizontal pull of air screws or propellers. It is at once evident that the forward horizontal motion of the aeroplane must be maintained for its support, for the surfaces are fixed and there is no other possible way of producing a relative motion between the wings and the air.

To overcome the objection of forward motion, several other machines have been proposed in which the surfaces are moved in relation to the body, as well as the air, thus making it possible for the device to stand stationary while the revolving or reciprocating surfaces still continue in motion in regard to the air. One type of the moving surface machine, the ”Helicopter,” is provided with revolving surfaces arranged in the form of vertical air screws or propellers, the blades of the propellers being inclined so that they drive down a continuous stream of air and produce the continuous upward reaction that supports the machine. While such machines have succeeded in raising themselves off the ground they are not yet practical flying devices. The ”ornithopter” or ”orthopter” is a flapping wing machine that maintains flight after the manner of the bird (Ornis). Like the helicopter, the ornithopter has not yet proved successful.

Principles of the Aeroplane. In its elementary principles, the aeroplane can be compared with the kite, as both are supported by the impact of a horizontal

[image]

Fig. 1. Comparison Between the Kite and Aeroplane; Fig. 2, Showing the Lift and Drag Forces Produced by the Air Stream. The Propeller (P), Acts in a Manner Similar to the Kite String (S) in Producing Relative Motion Between the Air and the Lifting Surfaces.

stream of air. In Diagram 1, the kite surface is indicated by X-X with the relative air stream W-W-W-W moving from left to the right as indicated by the arrow heads. On striking the surface, the air stream is deflected vertically, and in a downward direction, as shown by the streams lines R-R-R-R. The reaction of the air deflection produces the lift shown vertically and upwards by the arrow L. The kite surface is held against the impact of the air stream by the string S so that there is relative motion between the air and the kite, and so that the surface will not be carried along with the air current toward the right. If the kite were allowed to drift with the wind there could be no relative motion between the surface and the air stream, hence the kite would fall as soon as it attained the velocity of the wind. The horizontal force exerted by the wind tending to carry the kite toward the right is indicated by the arrow D and is known as the ”drag” or ”drift” force. There are thus three forces, the lift (L), the drag (D), and the resultant of the two forces indicated by the string (S). The forces of lift and drag are nearly at right angles to one another. The kite tail T is simply a stabilizing device whose purpose is to maintain a constant angle between the surface and the wind and it performs an almost negligible amount of lift.

A few more words in regard to the ”relative velocity” between the surface and wind. In the figure, the kite is assumed as being stationary, while the wind moves from left to right. With a thirty mile per hour wind, the relative air velocity in regard to the surface would be 30 M. P. H. If the air particles are now considered stationary, and if the kite is towed toward the left (opposite to figure) at 30 miles per hour, the relative velocity between the surface and air would still be 30 M. P. H. In other words, the kite may be stationary, or may move in regard to the earth, but its lift is unaffected as long as the relative motion between the surface and air remains constant. The motion between an aeroplane and the earth depends upon the difference of the aeroplane and wind velocities. For example, a aeroplane with a relative speed of 60 miles per hour, flying against a headwind of 30 miles per hour, moves 60-30 = 30 miles per hour in regard to the earth. The same aeroplane flying with the above wind would have a velocity of 60+30=90 miles per hour past a fixed point on the earth’s surface, yet in both cases, the relative velocity of the surface in regard to the air would be the same.

Fig. 2 is a diagram of an aeroplane that shows the connection between the kite and aeroplane principles. In this figure, the wing surface of the aeroplane, X-X corresponds to the kite surface X-X. The relative air W-WW-W striking the wing from the left is deflected down along the arrows R-R-R-R and results in an equivalent lift force L, and a drag force D as in the case of the kite. The resultant force required to maintain the relative velocity between the air and wings is indicated by D^1, opposite and equal to the drag force D. The resultant required for overcoming the drag is provided by the screw propeller P instead of the string S shown in Fig. 1. The propeller thrust (D^1) is parallel to the air stream instead of being inclined as in the case of the string, but the total effect is the same since both are ”Resultants of the lift and drag.” To sustain the aeroplane, the lift (L) must be equal and opposite to the weight shown by M. The fact that M and L are opposite and equal makes it only necessary for the propeller to overcome the horizontal drag, and hence the thrust can be made parallel to the air flow—or nearly so. The aeroplane is provided with a small tail surface (T) that corresponds to the kite tail (T). It maintains the lifting surfaces X-X at a given angle with the air stream. The tail may, or may not aid in supporting the machine, but in modern machines it is common to employ a tail surface that is non-lifting under ordinary conditions of normal flight. The body (B) contains the pilot, motive power, fuel, and such useful load as it may be necessary to carry.

[image]

Fig. 3. Caudron Monoplane. Side Elevation.

Fig. 3 shows a Caudron monoplane in side elevation. This view illustrates the application of the principles shown by Fig. 2, except for the vertical rudder at the rear. The latter is used for steering in a horizontal direction. Fig. 4 shows the construction even more clearly since it is a perspective view. The machine is a Morane ”Parasol” monoplane with the wing placed over the body. This location of the main lifting surface is for the purpose of improving the view of the pilot and in no way affects the principles just described. The wires shown above the wing are bracing stays. The tail is hinged near the rear so that the angle of the rear portion can be changed (Elevator flaps), and permits the angle of the main wings to be altered in regard to the air stream, thus causing the machine to ascend or descend. The tail also damps out oscillations or vibrations due to irregularities in the air current. The wheels and running gear (Chassis) allow the machine to be run over the ground until the relative air speed is sufficient to support the machine in flight.

[image]

Fig. 4. Morane Umbrella Type Monoplane. Courtesy of ”Flight.”

Multiplanes. In order to support a heavy load, and at the same time have a small compact machine, it is necessary to have more than one ”layer” of wing surface. It is evident that the wing length or ”span” can be made much less than that of the monoplane surface shown, if the total area could be divided into two or more parts. A machine having its main lifting surface divided into two or more separate sections is known as a ”multiplane,” this term becoming ”Biplane,” ”Triplane,” or ”Quadraplane,” depending on whether there are two, three or four independent lifting surfaces. There is almost a limitless variety of arrangements possible, but the most common arrangement by far is that of the biplane, in which there are two superposed surfaces as shown by Fig. 5. In this type, the two lifting surfaces are placed over one another with a considerable ”gap” or space between. The body is placed between the wings and the tail surfaces and chassis remain the same as in the monoplane. This is known as a ”Tractor” biplane since the propeller is in front and pulls the machine along while Fig.6 shows a ”Pusher” type biplane in which the propeller is mounted behind the wings and therefore pushes the machine.

[image]

Fig. 4-A. Deperdussin Monoplane with Monocoque Body. Gordon-Bennett Racer.

Biplanes. Besides the advantages of size, the biplane has a number of other good features. The deep spacing of the upper and lower surfaces permits of a powerful and light system of trussing being placed in the gap, and therefore the biplane can be made stronger (weight for weight) than the monoplane in which no such trussing can be economically applied. The vertical ”struts” of the bracing can be clearly seen in the figure. The efficiency of this interplane trussing greatly increases the possible size and capacity of the aeroplane. With monoplanes it is seldom possible to exceed a wing span of 36 feet without running into almost unsurmountable structural difficulties. The weight of the large monoplane also increases is leaps and bounds when this critical span is once exceeded. To maintain an equal degree of strength the monoplane requires very careful attention in regard to the design and construction, and is correspondingly more expensive and difficult to build than the biplane, although the latter has by far the greater number of parts. By suitable arrangements in the location of the biplane surfaces a very fair degree of stability can be obtained, an advantage which is impossible with the monoplane.

[image]

Fig. 5. S. P. A. D. Tractor Biplane Speed Scout.

A distinct disadvantage of the two superposed surfaces of the biplane is due to the fact that there is ”interference” between the upper and lower wings, and that the lift for equal areas is less than in the case of the monoplane. With a given form of wing, 100 square feet of monoplane surface will lift considerably more than the same area applied in biplane form. The amount of the ”drag” for the support of a given load is increased, and with it the amount of power required. The greater the separation or ”gap” between the wings, the greater will be the lift, but when the gap is unduly increased to obtain a great lift the length of the interplane bracing is increased to such an extent that the resistance of the bracing will more than overcome the advantages due to the large gap. There is a fixed limit to the gap beyond which it is not practical to go. The bracing has a very material effect on the air resistance, no matter how small the gap.

[image]

Fig. 6. Pusher Type Biplane in Which the Propeller Is Placed Behind the Wings.

Triplanes. Of late the triplane has been rapidly increasing in use, and in certain respects has many advantages over either the monoplane or biplane. This type has three superposed surfaces which still further diminishes the size for a given area. The interference between the surfaces is even greater than with the biplane, and hence the lift is less for a given area and aspect ratio. This latter defect is partly, or wholly overcome by the possibility of using long narrow wings, and because of the reduced span there is a corresponding reduction in the bracing resistance. It should be noted at this point that the efficiency of a lifting surface is greatly increased when the ratio of the length to the width is increased, that is, a long, narrow wing will be more efficient than a short, wide shape. The relation of the length to the width is called ”aspect ratio,” and will be described in more detail in a following chapter.

[image]

Fig. 6-A. Farman Type Pusher Biplane.... Note the Propeller At the Rear of Body, and the Position of the Pilot and Passenger.

[image]

Fig. 6-B. The Mann Two-Propeller Pusher Biplane. The Propellers Are Mounted on Either Side of the Body, and Are Driven by a Single Motor Through a Chain Transmission. This Drive Is Similar to the Early Wright Machines.

Fig. 7 is a sketch of a Sopwith Triplane Scout and shows clearly the three superposed wings. The small amount of interplane bracing, and the great aspect ratio, makes this type very suitable for high speed. The body, tail and chassis arrangements are practically the same as those of a biplane. The Curtiss Triplane Scout is the pioneer of this type of machine, although experimental work on the triplane had been performed in England by A. V. Roe many years ago. The Roe triplane was lightly powered and for its time was successful in a way, but the Curtiss is the first to enter into active competition against the biplane scout. Owing to the small span required for a given area, and the possibilities of very light and simple bracing, the triplane is an ideal type for heavy duty machines of the ”bombing” species. Enormous triplanes have been made that are capable of a useful load running up into the tons, the large Curtiss and Caproni’s being notable examples. As the triplane is much higher than the biplane of equal area, the interplane bracing is deeper and more effective without causing proportionately higher resistance.

[image]

Fig. 7. Sopwith Triplane Speed Scout.

Quadraplane. The use of four superposed surfaces has not been extended, there probably being only one or two of these machines that can be said to be successful. The small ”quad” built by Matthew B. Sellers is probably the best known. The power required to maintain this machine in flight was surprisingly small, the machine getting off the ground with a 4 horsepower motor, although an 8 horsepower was afterwards installed to maintain continuous flight. The empty weight was 110 pounds with the 8 horsepower motor. The span of the wings was 18’ 0” and the width or ”chord” 3’ 0”, giving a total area of about 200 square feet.

[image]

Fig. 7-A. Curtiss Triplane Speed Scout. Courtesy ”Aerial Age.”

Tandem Aeroplanes. A tandem aeroplane may be described as being one in which the surfaces are arranged ”fore and aft.” The Langley ”Aerodrome” was of the tandem monoplane type and consisted of two sets of monoplane wings arranged in tandem. This pioneer machine is shown in Fig. 8, and is the first power driven model to achieve a continuous flight of any length. Instead of two monoplane surfaces, two biplane units or triplane units can be arranged fore and aft in the same manner.

While there have been a number of tandem machines built, they have not come into extensive use. Successful flight was obtained with a full size Langley Aerodrome, and this machine flew with a fair degree of stability. The failure of other tandem machines to make good was due, in the writer’s opinion, to poor construction and design rather than to a failure of the tandem principle. The Montgomery glider, famed for its stability, was a tandem type but the machine was never successfully built as a powered machine.

The wings must be separated by a sufficient distance so that the rear set will not be greatly influenced by the downward trend of the air caused by the leading wings. As the rear surfaces always work on disturbed air they should be changed in angle, increased in area, or be equipped with a different wing curvature if they are to carry an equal proportion of the load. Usually, however, the areas of the front and rear wings are equal, and the difference in lift is made by changes in the wing form or angle at which they are set. In some cases the wings are approximately the same, the difference in lift being compensated for by moving the load further forward, thus throwing more of the weight on the front wings.

The Aeroplane in Flight. Up to the present we have only considered horizontal flight at a continuous speed. In actual flight the altitude is frequently varied and the speed is changed to meet different conditions. Again, the load is

[image]

Fig. 8. Langley's "Aerodrome," An Early Type of Tandem Monoplane.

not an absolutely constant quantity owing to variations in the weight of passengers, and variations in the weight of fuel, the weight of the latter diminishing directly with the length of the time of flight. To meet these variations, the lift of the wings must be altered to suit the loading and speed—generally by altering the angle of the wings made with the line of flight.

Fig.9 shows an aeroplane in horizontal flight and lightly loaded, the machine traveling along the horizontal flight path F-F. With the light load, the angle made by the wings with the flight path is shown by (i), the tail and body remaining horizontal, or parallel to the flight path. With an increased load it is necessary to increase the angle of the wings with the flight line, since within certain limits the lift increases with an increase in the angle of incidence (i). Fig. 10 shows the adjustment for a heavier load (W_2), the angle of incidence being increased to (i'), and the body is turned down through a corresponding angle. The increased angle is obtained by turning the elevator flaps (T) up, thus causing a downward force (t) on the tail. The force (t) acts through the body as a lever arm, and turns the machine into its new position. It will be noted that when the angle of incidence is great that the rear of the body drags down and causes a heavy resistance. This position of a dragging tail is known to the French as flying "Cabré." With high angles cabré flight is dangerous, for should the propeller thrust cease for an instant the machine would be likely to "tail dive" before the pilot could regain control. This sort of flight is also wasteful of power. Cabré flight is unnecessary in a variable incidence machine, the wing being turned to the required angle independently of the body, so that the body follows the flight line in a horizontal position, no matter what the angle of incidence may be. In this type of machine the wings are pivoted to the body, and are operated by some form of manual control.

In Fig. 11, the large angle (i') is still maintained, but the load is reduced to the value given in Fig. 9. With an equal load, an increased angle of incidence causes the machine to climb, as along the new flight line f-f. With the load (W) equal to that in Fig. 9, the angle of incidence will still be (i) but this will be along a new flight line if the large angle (i') is maintained with the horizontal as shown by Fig. 11. With the wings making an angle of (i') with the horizontal, and angle of incidence (i) with the flight line, it is evident from Fig. 11 that the new flight

[image]

Figs. 9-10-11-12. Showing the Use of Elevators in Changing Angle of Incidence. - Machine Shown in Four Principal Attitudes of Flight. As the Body and Wings Are in a Single Unit, the Body Must Be Turned for Each Different Wing Angle.

line f-f must make an angle (c) with the original horizontal flight line F-F. This shows how an increased angle with a constant load causes climbing, providing, of course, that the speed and power are maintained. With a given wing and load there is a definite angle of incidence if the speed is kept constant. Should a load be dropped, such as a bomb, with the wing angle kept constant, the new path of travel will be changed from F-F to f-f.

Fig. 12 shows the condition when the rear end of the body is elevated by depressing the elevator flap T. This occasions an upward tail force that turns the wings down through the total angle (i’). With the former loading and speed, the angle of incidence is still (i) degrees with the new flight path f-f, the new flight path being at an angle (c) with the horizontal F-F. The body is turned through angle (i’), but the angle (i) with the flight path f-f is still constant with equal loads and speeds.

To cause an aeroplane to climb, or to carry a heavier load, the elevator ”flap” is pointed up. To descend, or care for a lighter load, the elevator is turned down. In normal horizontal flight the machine should be balanced so that the tail is horizontal and thus creates no drag. When the elevator **must** be used to keep the tail up in horizontal flight, the machine is said to be ”tail heavy.”

Longitudinal Stability. In Figs. 9-10-11-12 the machine was assumed to be flying in still air, the attitudes of the machine being simply due to changes in the loading or to a change in altitude. The actual case is more complicated than this, for the reason that the machine is never operating in still air but encounters sudden gusts, whorls, and other erratic variations in the density and velocity of the air. Each variation in the surrounding air causes a change in the lift of the wings, or in the effect of the tail surfaces, and hence tends to upset the machine. If such wind gusts would always strike the wings, body, and tail simultaneously, there would be no trouble, but, unfortunately, the air gust strikes one portion of the machine and an appreciable length of time elapses before it travels far enough to strike another. Though this may seem to be a small fraction of time, it is in reality of sufficient duration to have a material effect on the poise of the aeroplane. Vertical gusts due to the wind passing over buildings, hills, cliffs, etc., not only tend to upset the machine, but also tend to change the altitude since the machine rises with an up gust and sinks with a down trend in the Stream.

Assume a machine as in Fig. 9 to be traveling steadily along a horizontal path in still air. A sudden horizontal gust now strikes the machine from the front, thus causing a sudden lift in the main wings. As this gust strikes the wings before the tail, the tail will stand at the old altitude while the wings are lifted, thus giving the position shown by Fig. 10. After passing over the wings it lifts the tail, this effect probably not being sufficient to restore the wing and the tail to their old relative attitude since the gust generally loses velocity after passing the wings. A head gust of this type often strikes the front wings diagonally so that it never reaches the tail at all. To remedy this upsetting action of the gust, the pilot must move his rear elevator so that the elevator is in the position shown by Fig. 12, that is, the flap must be turned down so as to raise the tail.

A gust striking from behind may, or may not affect the elevator flaps, this depending on their position at the time that the gust strikes. If the flaps are turned up, the rear end will be raised by the gust and the machine will head dive: if turned down, the gust will depress the tail, raise the head and tend to ”stall” the machine. If the tail is of the lifting type, the rear entering gust will reduce the relative velocity, and the lift, and cause the tail to drop. On passing over the tail and striking the wings, the rear gust will reduce the velocity and cause a loss in lift. This will either cause the machine to head dive or drop vertically through a certain distance until it again assumes its normal velocity.

All of these variations cause a continually fore and aft upsetting movement that must be continually corrected by raising and lowering the elevator flaps, and in very gusty weather this is a very tedious and wearing job. It requires the continual attention of the pilot unless the action is performed automatically by some mechanical device, such as the Sperry Gyroscopic, or else by some arrangement of the surfaces that give ”inherent” stability. Control by means of the elevator flaps (which raise and lower the body in a fore and aft direction, as shown) is known as ”longitudinal control,” and when the machine is so built that correction for the longitudinal attitude is obtained ”inherently,” the machine is said to be ”longitudinally stable.” Modern machines can be made very nearly longitudinally stable, and are comparatively unaffected by any than the heaviest gusts.

Lateral Stability. The gusts also affect the side to side, or ”lateral” balance by causing a difference in lift on either end of the wings. Should the gust strike one tip before the other, or should it strike one tip harder than the other, the tendency will be to turn the machine over sidewise. This is a more difficult problem to solve than the longitudinal moment, although perfect inherent stability has been attained in one or two machines without the use of additional automatic control mechanism. Inherent lateral stability has always been attended by a considerable loss in the efficiency of the aeroplane and speed due to the peculiar arrangements in the main lifting surfaces. At present we must make a decision between efficiency and stability, for one feature must be attained at a sacrifice in the other. Contrary to the general opinion, perfect stability is not desirable, for almost invariably it affects the control of a machine and makes it difficult to maneuver. Should the stability appliances be arranged so that they can be cut out of action at will, as in the case of the Sperry Gyroscopic Stabilizer, they will fulfill the needs of the aviator much more fully than those of the fixed inherent type. The first thoroughly stable machine, both longitudinally and laterally, was that designed by Lieutenant Dunne, and this obtained its distinctive feature by a very peculiar arrangement of the wing surfaces. It was excessively stable, and as with all very stable machines, was difficult to steer in a straight line in windy weather, and was correspondingly difficult to land.

[image]

Fig. 12.A. Diagram of the Tractor Biplane

The first machine of the ordinary biplane type that proved inherently stable was the R. E.-1 designed in England by Edward Busk. This machine was flown from Farnborough to Salisbury Plain, and during this flight the only control touched was the vertical rudder used in steering. Since then, all English machines have been made at least partially stable, the degree depending upon the service for which it was intended. It has been found that in fighting, a very controllable machine is necessary, hence stability must be sacrificed, or the control surfaces must be made sufficiently powerful to overcome the stable tendency of the machine. War machines are made to be just comfortably stable over the range of ordinary flight speeds, and with controls powerful enough so that the inherent stability can be overcome when maneuvering in battle. The present war machine always contains an element of danger for the unskilled pilot.

Dihedral Angle. This was the first lateral stability arrangement to be applied to an aeroplane, but is only effective in still air. In rough weather its general tendency is to destroy stability by allowing dangerous oscillations to take place. Fig. 13 is a front view of a monoplane in which the wings (w) and (w’) are set at an angle (d), this angle being known as the ”dihedral angle.” The dotted line (m-m) shows the line of a pair of perfectly horizontal wings and aids in illustrating the dihedral. Assuming the center of lift at CL on the wings, it will be seen that an increase in the dihedral raises the center of lift above the center of gravity line C. G. by the amount (h). With the center of gravity below the center of lift it is evident that the weight of the machine would tend to keep it on a level keel, although the same effect could, of course, be attained in another way. The principal righting effect of the dihedral is shown by Fig. 14 in which the wings (w) and (w') are set as before. The machine is tipped or "listed" toward the left (seen from aviator's seat) so that wing (w') is down. By drawing vertical lines down until they intersect the horizontal line X-X (the line of equilibrium), it will be seen that wing (w') presents more horizontal lift surface than (w) since the projected or effective wing length (C) is greater than (b). Since (w') presents the greater surface, the lift (L) tends to restore the machine to its original level position. If the wings were both set on the same straight line, the projected lengths (b) and (c) would be the same and there would be no restoring effect.

[image]

The dihedral would be very effective in still air, but in turbulent air, and with the body swinging back and forth, the dihedral would act in the nature of a circular guiding path, and thus tend to allow the swinging to persist or increase rather than to damp it down, as would be the case with level straight wings. Again, with the wing bent up at a considerable angle, a side gust as at (S) would tend to throw the machine still further over, and thus increase rather than diminish the difficulty. In practical machines, the dihedral is usually made very small (d = 176 degrees), the angle of each wing with the horizontal being about 2 degrees, or even less. I think the advantage of such a small angle is rather more imaginary than actual, and at present the greater number of war machines have no dihedral at all. In the older monoplanes the angle was very pronounced.

Fig. 15 shows the dihedral applied both to the upper wing (U) and the lower wing (L), the usual method of applying dihedral to large biplanes. Fig. 16 shows the method of applying the dihedral to small, fast machines, such as speed scouts, the dihedral in this case being used only on the lower wing. The dihedral on the bottom wing is usually for the purpose of clearing the wing tips when turning on the ground rather than for stability. A lower wing with a dihedral is less likely to strike the ground or to become fouled when it encounters a side gust in landing or "getting off." The use of straight upper wings makes the construction much simpler, especially on the small machines where it is possible to make the wing in one continuous length.

Ailerons and Wing Warping. Since the dihedral is not effective in producing lateral stability, some other method must be used that is powerful enough to overcome both the upsetting movements and the lateral oscillations caused by the pendulum effect of a low center of gravity. In the ordinary type of aeroplane this righting effect is performed by movable surfaces that increase the lift on the lower wing tip, and decrease the lift on the high side. In Some cases the lateral control surfaces are separate from the wing proper (Ailerons), and in some the tip of the wing is twisted or ”warped” so as to produce the same effect. These control surfaces may be operated manually by the pilot or by some type of mechanism, such as the gyroscope, although the former is the method most used. The lateral control, or side to side balancing of an aeroplane, can be compared to the side to side balancing of a bicycle in which the unbalance is continually, being corrected by the movement of the handle bars.

Fig. 17 shows the control surfaces or ”Ailerons” (A-A’), mounted near the tips, and at the rear edge of the wing W. As shown, they are cut into and hinged to the main wings so that they are free to move up and down through a total angle of about 60 degrees. In a biplane they may be fitted to the upper wing alone or to both top and bottom wings, according to conditions. For simplicity we will consider only the monoplane in the present instance.

In Fig. 18, a front view of the monoplane, the machine is shown ”heeled over” so that the wing tip (w) is low. To correct this displacement, the aileron (A) on the low side, is pulled down and the aileron (A’) on the opposite end is pulled up. This, of course, increases the lift on the low end (w) and decreases the lift on the high side (w’). The righting forces exerted are shown by L-L’. The increased angles made by A-A’ with the wind stream affects the forces acting on the wings, although in opposite directions, causing a left hand rotation of the whole machine. In Fig. 19, conditions are normal with the machine on an even keel and with both ailerons brought back to a point where they are level with the surface of the wing, or in ”neutral.” Fig. 20 shows the machine canted in the opposite direction with (w’) low and (w) high. This is corrected by bringing down aileron (A’) and raising (A), the forces L-L’ showing the rotation direction. By alternately raising and lowering the ailerons we can correspondingly raise or lower the wing tips. It should be noted here that in some machines the ailerons are only single acting, that is, the aileron on the low side can be pulled down to increase the lift, but the opposite aileron remains in the plane of the wings, and does not tend to ”push down” the high side. Since all of the aileron resistance in a horizontal direction is now confined to the low side, it turns the machine from its path, the high wing swinging about the lower tip with the latter as a pivot. In the double acting control as shown in Figs. 17 to 23, the resistance is nearly equal at both tips and hence there is no tendency to disturb the flight direction. With single acting ailerons, the directional disturbance is corrected with the rudder so that when the aileron is pulled down it is necessary to set the rudder to oppose the turn. On early Wright machines the rudder and lateral controls were interconnected so that the rudder automatically responded to the action of the ailerons.

Fig. 21 is a detailed front elevation of the machine and shows the control wheel (C) and cable connections between the wheel and the ailerons A-A’. When the wheel C is turned in the direction of the arrow K, the aileron A’ is pulled down by the flexible cable (i), and a corresponding amount of cable (h) is paid off the wheel to the rising aileron A. Aileron A is pulled up by the connecting cable (e) which is attached to A’ at one end and to A at the other. Pulleys (f) and (g) guide the interconnection cable. On turning the wheel in the opposite direction, aileron A is pulled down and A’ is elevated. In flight, especially in rough weather, there is almost continuous operation of the control wheel. Figs. 22 and 23 are sections taken through the wing W and the ailerons, showing the method of hinging and travel. Fig. 22 shows the aileron depressed for raising the wing in the direction of L, while Fig. 23 shows the aileron lifted to lower the wing. In normal flight, with the machine level, the aileron forms a part of the wing outline (in neutral position).

In the original Wright aeroplane, and in the majority of monoplanes, no ailerons are used, the rear of main wing tip being bent down bodily to increase the lift. This is known as ”wing warping,” and is practically a single acting process since the depressing force on the high tip is seldom as effective as the lift on the low. Warping is not generally used on modern biplanes since it is impossible to maintain a strong rigid structure with flexible tips. The control warping and twisting of such wings soon loosens them up and destroys what remaining strength they may have had.

[image]

Figs. 17-23. Showing Use of Ailerons in Maintaining Lateral Balance.

Banking and Turning. In making a sharp turn the outer wing tip must be elevated to prevent slipping sidewise through the effects of the centrifugal force (side slip). This is known as ”banking.” The faster and sharper the turn, the steeper must be the ”bank,” or the angle of the wings, until in some cases of ”stunt” flying the wings stand almost straight up and down. Should the bank be too steep there will be an equal tendency to slip down, and inwardly, since the end resistance against side slip is very slight. Some aeroplanes assume the correct angle of bank automatically without attention from the pilot since the extra lift due to the rapid motion of the outer tip causes it to rise. On other machines the natural banking effort of the machine is not sufficient, and this must be increased by pulling down the aileron on the outer wing tip. Machines that have a tendency to ”over-bank” must have the ailerons applied in the reverse direction so as to depress the outer tip. In cases of under, or overbanking machines it formerly required experience and judgment on the part of the pilot to obtain the correct banking angle. There are now ”banking indicators” on the market that show whether the machine is correctly banked or is side-slipping.

[image]

Fig. 24. A Deperdussin Monoplane Banking Around a Sharp Turn at High Speed. Note the Elevation of the Outer Wing Tip and the Angle Made with the Horizontal by the Wings. Speed, 105 Miles Per Hour.

[image]

Standard ”H-3” Training Biplane.

CHAPTER II. TYPES OF MILITARY AEROPLANES.

Divisions of Service. In the army and navy, aeroplanes are used both for offensive and defensive operations. They must carry out their own work and intentions and prevent hostile craft from carrying out theirs. In offensive operations the machines fly continuously over the enemy’s country and attack every hostile craft sighted, thus creating a danger zone within the enemy’s lines where no opposing machine can work without being threatened with an overwhelming attack. The offensive also includes bombing operations and the destruction of supply depots and transportation centers. Defensive aerial operation consists in driving out the enemy craft from our own lines, and in protecting working machines when on photographing or observation trips. With a powerful offensive there is of course little need for defense. The former method is a costly one, and is productive of severe material and personal losses.

At the present time there are eight principle functions performed by military aeroplanes:

1. Offensive operations against enemy machines.

2. Reconnaissance, observation, special missions.
3. Bombing supply centers, railways, etc.
4. Photography.
5. Spotting for the artillery.
6. Signalling for infantry operations.
7. Submarine hunting.
8. Patrol and barrage.

[image]

Fig. 1. Curtiss "Baby". Biplane Speed Scout. Equipped with 100 Horsepower Water Cooled Motor.

Probably the most important service of all is performed by machines under heading (1). If a successful offensive can be maintained over the enemy's lines he is unable to intelligently direct his artillery fire, and can obtain no information regarding reinforcements, or troop concentrations for an impending attack. With fighting aeroplanes clearing the way for our own observation machines and artillery spotters, the enemy is not only blinded, but is blocked in any attempt to attack or concentrate his forces. The fact that the French aerial offensive at Verdun was so efficiently and well maintained accounts for the failure of the heavy German artillery. Driven far back over their own lines, the German aviators were seldom able to observe the placing of the shells, and as a result their gunners were practically trusting to luck in reaching their target. An immediate and accurate bombardment always followed one of the very infrequent German air raids over the French lines. Whenever the French, partially abandoned their aerial offensive in favor of a defensive campaign, they soon lost their mastery of the air. As long as enemy machines can be kept back of their own lines, new trench systems can be constructed, transportation lines can be extended and ammunition dumps arranged, undertakings that would be highly precarious with enemy observation machines continually passing overhead.

To maintain an effective offensive places a tremendous strain on both the men and the machines, for though the aeroplanes do not penetrate far beyond the lines they usually meet with superior numbers, and in addition are continually in

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Fig. 1. Italian "Pomilio" Two Seater Biplane. Courtesy "Flying."

range of the anti-aircraft guns. In an attack over hostile country a slight mishap may cause the loss of a 'plane, for usually the distance from its base is so great as to prevent a gliding return. Over its own lines an engine failure is usually only a temporary inconvenience. Fighting aeroplanes, for the offensive, are small high powered machines generally of the single seater type, and are capable of high horizontal and climbing speeds. The armament consists of a machine gun of the Lewis type, and occasionally a few light bombs may be included in the equipment. As they do not carry out operations far to the rear of the enemy's lines they are provided with fuel for only two or three hours, and this reduced fuel load is necessary for the high speeds that must necessarily be attained. The area is limited to permit of quick maneuvers in attack and escape, and at the same time to reduce the head resistance and weight. The horizontal speed may run up to 150 miles per hour, with a climbing velocity that may exceed 1,000 feet per minute. Such machines are variously known as "Speed Scouts," "Chasers," or "Pursuit Type" (French "DeChasse"). At the beginning of the war the chasers were largely of the monoplane type, but at present the biplane is in almost exclusive use.

[image]

Fig. 2. Machine Gun Mounting on Morane Monoplane. Gun Fires Directly Through the Propeller Disc. The Deflecting Plate Attached to the Root of the Propeller Blade Protects the Propeller When in Line of Fire. Ammunition in This Gun Is Furnished in Straight Strips or "Clips."

The aeroplane employed for surveys of the enemy country and battle front (2) are of an entirely different type and are much larger and slower. These "Reconnaissance" machines are generally of the two-seater type, the personnel consisting of an observer and the pilot, although in some cases a third man is carried as an assistant to the observer, or to handle a machine gun against an attack. Since their speed is comparatively low, they are generally provided with an escort of chasers, especially when employed on distant missions, this escort repelling attacks while the observations are being made.

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Fig. 2-a. Machine Gun Mounting on S. P. A. D. Biplane. Gun Is Rigidly Attached to Fuselage Top in Front of Pilot.

For accurate observation and mapping, the speed of an observation machine must be necessarily low, and as they are additionally burdened with a wireless set, an observer, a large fuel reserve, and other impedimenta, they have a comparatively great area and are therefore lacking in the maneuvering qualities of the chaser. The span will average about 40 feet, and the weight carried per horsepower is greatly in excess of that of the chaser. From a number of examples, the reconnaissance type will average from 16 to 18 pounds per horsepower, while the loading of the scout is from 8 to 12. This means that the former has comparatively little reserve power for rapid climbing. The present reconnaissance type is always armed, and must not be confused with the early machine by that name, which, in fact, was merely an enlarged training machine and had neither offensive nor defensive powers. The Observer acts as gunner, and is located at a point where he has the greatest possible range of vision, and where the angle of fire is as little obstructed as possible.

The radius of action, or the distance traveled per tank of fuel, is greater with the reconnaissance than with the chaser, present machines having a capacity of from 10 to 12 hours on a single filling at normal flight speed.

In bombing operations (3), the loading is very heavy and consequently a ”Bomber” must be a weight lifter to the exclusion of all other qualities. Not only is the bomb load requirement severe, but the fuel load is also of great importance, since bombing is usually carried out at considerable distances from the base. Such machines may carry from three to six men. All this calls for a tremendous area and a large power plant. The Handley-Page ”Giant,” and the Caproni Triplane are examples of Allied machines of this type while the German ”Gotha,” used in the London air raids, is an equivalent enemy machine. As an example of the weight carrying capacity of a typical bomber, the Handley-Page has carried a test crew of 21 men, or a personnel load of 3,570 pounds. The total weight, fully loaded, has been given as 11,500 pounds with a power plant of 540 horsepower. The maximum speed is 90 miles per hour with a climbing velocity of about 330 feet per minute. Duration is about 5% hours at normal speed and full load.

Bombing is of great importance, not only because of the damage caused to munition factories, transportation lines, store houses, etc., but also because of the moral effect on both the enemy troops and the civil population. A well-timed

[image]

Fig. 3. Handley-Page ”Giant” Bombing Type Biplane. Courtesy ”The Aeroplane.”

[image]

Fig. 4. Curtiss Twin Motor Biplane-Type JN.

bombing raid will do more to disorganize an army than almost any other form of attack, and this is attended with a much less loss of life, and with less cost and equipment. Points in enemy territory that could be reached in no other way are readily attacked by bombing planes with all the disastrous effects of heavy artillery fire. The aeroplane is better adapted for this service than dirigibles of the Zeppelin type, for they require fewer men for their operation, and in addition cost less to operate and build.

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Fig. 4a. Curtiss ”Wireless” Speed Scouts (S-2). By an Ingenious Arrangement of the Interplane Struts There Is No Exposed Wire or Cable.

Bombing operations against well protected objectives are best made at night since there is less chance of loss through anti-aircraft gun fire, and also because of the difficulty that the defense machines have in locating the raiders. Even when well equipped with searchlights and listening stations, it is not the easiest thing in the world to pick out and hold the location of an attacking squadron, for the searchlights immediately betray themselves and can then be put out of action by fire from the invaders. With the searchlights out of commission, it is almost impossible for the defending chasers to locate and engage the raiders, even before the bombs have been dropped. After the bomb dropping has been accomplished (and with comparative accuracy because of the flares dropped by the bombing party), the raiders are lightened of a considerable portion of their load, and are correspondingly increased in their ability to climb and to evade the enemy chasers.

Night flying in squadrons always introduces the danger of collision, and to

[image]

Fig. 5. Sopwith Speed Scout or ”Chaser.”

[image]

Fig. 6. Nieuport Biplane Scout with Machine Gun Pivoted Above the Upper Wing. This Gun Fires Above the Propeller.

minimize this danger, by decreasing the number of machines, the size and carrying capacity of the bombers has been continually increased. Again, bombing requires the steady platform that only a large machine can give, and for accuracy the span and area must be greater than that of the reconnaissance type. In night flying a large machine is safer to handle owing to its lower landing speed and ability to come to rest quickly after landing, and this is of the greatest importance when landing outside of the aerodrome. For daylight work at comparatively short distances the smaller bomb carrier used at the beginning of the war is probably preferable as it has better maneuvering qualities, and as the bombs are divided among a greater number of machines they are not so likely to be defeated before accomplishing their object. Because of their great size, these bombing aeroplanes are nearly always of the ”twin motor” type with two, or even three, independent power plants. The use of a twin power plant is an added insurance against forced landings in hostile country, or over unsuitable ground, and even with one dead engine the machine can be flown home at a fair speed.

[image]

Fig. 8. Fokker Synchronized Machine Gun. The Gun Is Driven by the Motor in Such a Way That the Bullets Pass Between the Propeller Blades. ”L’Aerophile.”

”Spotting” for the guidance of the artillery is a duty usually performed by the reconnaissance type, or small bombing type, and is usually done under the escort of chasers. Their duty is to direct the battery as to the placing of shots. The ideal machine for such a purpose would be the direct lift type similar to a helicopter which could hover over one particular spot until its object had been accomplished in making measurements, and plotting enemy positions. Since no such machine is at present available, the duty must be performed by a low speed aeroplane, that is large enough to provide a fairly steady platform and at the same time has sufficient speed for a quick getaway. A dirigible has the necessary hovering qualities but lacks the speed necessary for avoiding attack from even the slowest of aeroplanes, and in addition is a magnificent target for anti-craft guns if kept at an altitude low enough for accurate observation. A large speed range is a desirable characteristic in such service.

Photography is of the greatest importance in reconnaissance, since the camera distinctly records objects on the terrain, so small and obscure that they may entirely escape the eye of the observer. Again, the photograph is a permanent record that may be studied at leisure in headquarters, or may be used in comparisons with photographs taken at an earlier date in the same territory. Thus changes in the disposition of enemy batteries, trenches, and troops can be quickly identified. With modern aeroplane photographic equipment, a vast territory may be investigated and mapped out by a single machine in a few hours. Camouflage has but few terrors for the camera, and the photographs often clearly reveal that which has been passed over time and time again by the observers. When sent out on a specific mission, the aeroplane returns the films in an amazingly short length of time, and within a few minutes they are developed and are ready for the inspection of the officers in charge. The analysis of these photographs has rapidly developed into a science well worthy of a Sherlock Holmes. Changes in the position of shadows, suspiciously sudden growths of underbrush, changes in the direction of paths, and fresh mounds of earth all have a definite meaning to the photographic expert.

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Fig. 9. Types of Aeroplane Bombs. The Tail Surfaces Guide the Bomb So That It Strikes on the Firing Pin and at the Same Time ”Safeties” the Bomb So That it Will Not Explode Until it Has Fallen for Some Distance. In Falling, the Tail Blades Rotate and Release the Firing Mechanism After the Bomb Has Fallen Clear of the Aeroplane. Courtesy of ”Flying.”

In the navy the aeroplane has proved of much value in scouting and particularly in defense against the submarine. Because of its great speed it has a daily radius of action many times that of a torpedo boat, and because of its altitude the effective range of vision is still further increased. At a fair height the observer can easily detect a submarine even when submerged to a considerable depth, a

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Fig. 9-a. Curtiss "JN" Twin Motor Biplane. Observer Is Seated in Front.

feat impossible when near the sea level. For disclosing the conditions existing in an enemy harbor the aeroplane is fully the equal of the dirigible since it can approach and retreat rapidly, and without much danger at comparatively low altitudes. While the dirigible can float indefinitely at one point, it must be done at an altitude that is safely out of range of the enemy guns, and this is usually at a point where observation is a difficult proposition. It does not take long to get the range of such a target as a hovering dirigible, yet at a much lower altitude it is difficult to handle naval anti-aircraft guns effectively against a speeding aeroplane. The smaller scouting seaplanes can report the position of a submarine to a torpedo boat or "sub-chaser," while the larger machines are perfectly capable of dealing with the submarine at first hand. On the large bombing type, a three-pounder gun and a number of large bombs can be carried, either of which would be sufficient for the purpose.

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Fig. 10. Explosion of a German Aeroplane Bomb Near Mesopotamia. Courtesy of "Flying."

In land defense chasers and fighters are used for patrol, and to maintain a barrage against the entrance of enemy machines into our lines. The patrol machines work along the front line trenches, while the machines maintaining the barrage are generally arranged in two parallel lines back of the trenches, the first being about five miles, and the second about ten miles from the front. All three lines are generally placed between the enemy and the principal stations and railroad centers to insure protection from enemy bombers and reconnaissance machines. Should the first line patrol fail to keep raiders from crossing the first line trenches, they will have to pass through at least two more zones of organized fighting squadrons before reaching a vulnerable spot in our lines. The machines used for patrol and barrage are of the high speed and fast climbing chaser type. The response to an attack involves rapid climbing, and a high degree of maneuvering.

Except for the bombers and battle planes, the machine gun or "Mitraleuse"

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Fig. 11. Caproni Triplane with Three Independent Power Plants. The Motor in the Central Body Drives a Pusher Propeller, While the Other Power Plants Are Mounted in the Two Outer Bodies and Drive Tractor Screws. This is an Example of the Larger Bombing Aeroplanes. The Gun Is Mounted in the Front of the Center Body. Courtesy ”The Aeroplane.”

has been the only form of arm in common use on aeroplanes. These use ammunition approximating service rifle caliber and are furnished in bands, strips or drums according to the type of gun. With larger guns, the weight of the ammunition has been found excessive with all but the largest bombing machines, and the recoil of a large caliber gun has also been difficult to overcome. In a modern American aeroplane gun of large caliber the recoil has been reduced to almost a negligible degree, even up to the four-pounder size, by a system of balanced projectile reactions. This gun has met successful tests, but whether it has met with general adoption would be difficult to say at the present time. In Europe, large caliber aeroplane guns have been used on large ”battle planes” or ”gun planes” for shelling dirigibles, or in destroying searchlight stations in bombing raids. The battle planes are nearly always of the ”Twin” type with the gun mounted in the front end of the fuselage.

Summary of Types. To sum up the types required in military operations, we have: (1) High speed ”Chaser” or ”Scout” (Single seater), (2) High speed ”Chaser” (Two-seat type), (3) Reconnaissance type, (4) Bombing type, (5) Gun or Battle Planes. This does not include the training machines of the two place and ”Penguin” types, but as these are simply unarmed modifications of the two place reconnaissance and single seat machine, respectively, we will not go into further details at this point regarding their construction.

The Chaser or Pursuit Type. The most important factors in the design of a chaser are speed and maneuvering ability. The speed must be at a maximum in both the horizontal and vertical directions, for climbing ability is fully of as much importance as horizontal speed. Second in importance is the maximum altitude or ”Height of ceiling” to which the machine can ascend. This maximum ”Ceiling” generally goes hand in hand with the climbing speed, since a fast climber generally has a correspondingly high maximum altitude. The combination of weight and head resistance must be such that the climb interferes as little as possible with the forward velocity.

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[image]

De Havilland. V. Single Seat "Chaser" or "Speed Scout" with a Single Rigidly Mounted Machine Gun on Top of Hood (To Left). It will Be Noted That the Top Wing is Staggered Back Instead of Forward as in the Usual Type, Thus Allowing the Pilot to Look Directly Up and in Front of the Top Wing. Dimensions Are in Millimeters.

Great climbing ability means a large power reserve, hence the weight carried per horsepower is reduced to from 8 to 12 pounds on the fastest machines, against the 16 to 18 pounds carried on the larger and slower reconnaissance types. Strength must be sacrificed to meet these conditions, so that instead of having a safety factor of from 8 to 12 as in the larger machines, it is cut to about 5.5, or in other words, the strength is relatively only half that of the usual type of aeroplane. This great reduction in strength calls for careful handling, especially in landing, and also painstaking care in the design and choice of materials.

High speeds and maneuvering ability both call for small wing areas and short spans, the areas being so adjusted that the resistance is at a minimum at the highest speeds. The short spans have a minimum of exposed interplane bracing and thus indirectly reduce both the head resistance and the weight. Unfortunately, the most favorable areas at high speeds are too small for safe landing speeds. With a fixed area, the minimum landing speed is only a little less than one-half of the maximum flying speed, hence with a maximum of 150 miles per hour the minimum will probably be little less than 70 miles per hour. The most efficient wing sections, and the greatest refinement in the body design, bracing, and chassis are necessary at speeds of over 100 miles per hour. All other conditions being equal, the resistance varies as the square of the velocity, hence at 150 miles per hour, the resistance is 2.25 times that at 100 miles per hour.

The following table gives approximately the apportionment of the head resistance producing items in a typical speed scout or chaser.

Body (Fuselage)	68 per cent
Chassis, wheels, struts, etc.	15 per cent
Tail, rudder, fin, elevator	5 per cent
Wing structure, struts, wire, fittings.	12 per cent

The aerodynamic drag due to the lift of the wings is not included in the above, the useless or parasitic resistance alone being considered. It will be noted that the body causes by far the greater part of the resistance, and as a result, the one of the most difficult items to reduce. It has been suggested by several people that the chassis could be stored away in the body while in flight, but this adds additional mechanism and weight, and any automatic mechanism for folding up the chassis members would likely prove unreliable.

Chaser Armament. A single seat chaser is provided with one or two machine guns mounted on top of the fuselage, and directly in front of the pilot, the length of the barrel being parallel with the fore and aft center line. They may either be fixed rigidly to the fuselage top, or so that they can be pointed up, and over the top of the upper wing. With the machine guns fixed rigidly to the body, as in the early chaser monoplanes used by Garros and Vedrines, it was necessary at all times to fire directly through the disc area swept out by the propeller.

Two plans were tried for preventing the propeller from being broken by the bullets. The first consisted of a device operated by the motor that stopped the gun whenever the propeller blade came within the path of the bullets. This early mechanism proved unreliable, since the frequent stopping, with the propellers running 1200 revolutions per minute, soon put the apparatus out of order. Soon after the failure of this method, designers mounted curved protective steel plates on the inner portions of the propeller blades at points where they were likely to be struck with bullets. According to calculations in probability and chance, only one bullet out of every eighteen will strike the protective plate on the propeller blade, and hence only one out of eighteen bullets will be wasted. This, however, was a makeshift, and on modern machines the gun is driven, or ”Synchronized” with the motor so that the bullets pass between the blades.

[image]

Curtiss Biplane in Flight. Taken from Another Machine. Courtesy ”Aerial Age.”

Many modern single seat chasers have the gun pivoted to the top of the fuselage so that the pilot can fire above the top plane and to either side of the body. This does away with the difficulty of keeping the machine headed directly at the enemy when in action, a method that is imperative with the fixed type of gun. Two seater chasers are generally arranged so that the gunner is seated back of the pilot, and the gun is so pivoted and supported that it can be swung through a wide radius both toward the front and on either side. This freedom of gun action at least partly compensates for the slower maneuvering qualities of the two seater type, since the gun may be swung with the target through quite a range of field, and without changing the flight direction of the machine. A gun of this type is provided with stops which prevent the gunner from shooting into the outlying parts of his own machine. The gun mounting in many cases of two seater construction consists of a light circular track that runs around the edge of the cockpit opening. The gun standard runs on this track, and the gun is pivoted at the upper end of the standard so that the muzzle can be raised or lowered. The gun turns in a horizontal plane by sliding on the track, and can be followed around by the gunner who is seated in the center on a pivoted seat. With this mounting it is possible to guard against a rear attack, to shoot straight up, or nearly straight down over the sides of the fuselage.

In a few machines of the two seater type, two machine guns are provided, one pivoted gun in the rear, and one gun rigidly fastened to the fuselage in front of the pilot. It is very seldom that both guns can be brought into action at once unless engaged with a number of enemy machines, although the front gun is handy in pursuit, and at a time when the rear gun is ineffective because of the pilot in front of him. Even with the double equipment, the superior maneuvering qualities of the single seater makes matters more even than would commonly be supposed. An added advantage of the single seater is that it is smaller and therefore more difficult to hit.

English speed scouts have largely adopted the American Lewis gun. The cartridges in this gun are arranged radially in a circular drum, and are fed to the gun as the drum revolves. The drum is mounted on the barrel near the breech and is operated automatically by the successive explosions. This feeds the cartridges and rejects the empty shells without the attention of the pilot. It fires about 600 shots per minute. When one drum is exhausted, another drum of new cartridges can be quickly and easily inserted. The French use the belt system to a large extent. In this system the cartridges are attached side by side on a cotton web belt as in the older types of army machine guns. As in the Lewis gun, the cartridges are fed automatically by the recoil of the explosions, and the belt moves through the breech with a step by step movement until the ammunition is exhausted. This is not nearly as compact an arrangement as the Lewis gun, and is more difficult to pivot on account of the dangling belts.

On the right hand side of the Nieuport body there is a drum on which the belt with the loaded cartridges is wound. The empty end of the belt is wound on a drum at the left, this drum being provided with a spring to keep the belt taut. The empty cartridges are discharged through a tube that passes through the side of the body. On the 1916 Fokker the gun is of the Maxim type, and is immovably fastened above the engine cowl and slightly to the right. To fire the gun, the pilot presses down a small lever fastened to the control column, and from this lever the connecting Bowden wire closes the motor clutch and starts the gun. A cam is fixed to the motor shaft in relation to the propeller blades. When firing, the elevator control is locked fore and aft, while the lateral control movement is operated by the pilot's knees. Steering is by the action of his feet on the rudder bar. Thus the pilot can balance laterally, and steer with his hands free for the manipulation of the gun, but he cannot change his elevation.

[image]

Aeromarine Training Seaplane

Power Plant of the Chaser. In the smaller speed scouts, the motor is of the rotary air cooled type, the output ranging from 80 to 110 horsepower, but as the power demands increased the water-cooled motor came into use, and at the present time has found favor with a large number of builders. When the power exceeds about 120 horsepower it is difficult to thoroughly cool the rotary engine, and although the Gnome, Clerget and Le Rhone are extremely desirable on a chaser because of their light weight, they cannot be used profitably on the larger scouts. Up to the present time, the Nieuport and Sopwith use the Clerget and Le Rhone rotary motors, but the S. P. A. D. and several others have adopted the water-cooled type. Nearly all of the German chasers, such as the Roland and Albatros, are water-cooled. Such motors must weigh well below 3 pounds per horsepower if there is to be sufficient power reserve for fast climbing. The Curtiss scouts are also water-cooled, although the rating is only 100 horsepower. The French and German machines are very heavily powered, motors of 175 horsepower being very common, even on single seaters. The fuel capacity is very limited, probably not exceeding 2.5 to 3 hours in any case.

General Dimensions of Scouts. The following table will give a better idea of the principal characteristics of these machines. It gives the overall dimensions, power, speed, climb, etc. It will be noted that the Nieuport biplane scouts have a smaller lower chord (*). The speeds given are the sea level speeds since a great change in altitude affects the performance to a marked degree.

Reconnaissance Type Arrangement. These machines are almost invariably of the two seater type, and are equipped either with one machine gun for the observer, or with a rigidly fixed gun for the pilot and a pivoted gun at the rear for the observer. In the majority of cases the observer is seated in the rear cockpit (Tractor types), and at a point where he has a greater visual radius and field of fire. With the pusher type, the observer is, of course, seated in the extreme front of the body, where he has an extremely wide angle of vision. The pilot in the rear seat of the pusher is effectually screened from any gun action, either from the front, side or rear, as the propeller cuts off the field at the back and the observer and interplane bracing blocks the way at the front and sides. The observer’s cock-pit is equipped with the signalling apparatus, photographic equipment, map boards, etc., as well as the ammunition for the gun. The pilot’s compartment contains the navigating instruments and controls.

[image]

Armament. At the beginning of the war nearly all of the French two seaters were of the pusher type, this arrangement, of course, resulted in almost a completely dead angle of fire in the rear, and a front horizontal angle that was practically restricted to 160 degrees. Owing to the forward position of the gun the vertical angle was quite good, 230 degrees or even better. In the tractor two seater, with a single movable gun mounted ”En barbette” at the rear, the horizontal angle is about 180 degrees, but the vertical angle is less than with the pusher type. When the rear gun is supplemented with a front rigidly mounted gun, there is some protection at the front, but the rigid gun is far from being as effective as the pivoted rear gun. The front gun of course fires through the propeller. This armament is used by the German machines ”Aviatic,” ”Rumpler,” ”Albatros,” and ”L. V. G.” The forward rigid gun is usually of the infantry type, while the movable rear gun is lighter. The latter is fed by drums, or rolled bands on spools, so that reloading can be performed in the wind stream.

With the two seater type used in reconnaissance, artillery spotting, or photography, the power is generally in the neighborhood of 220-260 horsepower, and the speed varies from 85 to 100 miles per hour. The area is approximately 400 to 480 square feet. A single engine is generally used.

[image]

General Dimensions and Speeds. Reconnaissance machines of various types and makes are listed in the following table. A pusher is indicated by (P) and a tractor by (T). The German aeroplanes (G), and the Allied aeroplanes (A), are both listed for comparison: It will be noted that several types of machines have been made by the same firms, and that in some cases the same machines have different power plants. The Albatros C-III has been furnished with both the 170 and 220 Mercedes motor. The Ago biplane has a tapering wing, and the chord width (*) given is taken at the body. While very recent machines cannot be described, because of certain restrictions, the horsepower of the latest two seaters will average about 240 horsepower. If the dates and power items are noted, it will be seen that the machines used in 1917 have much larger motors than those built in 1916. The weight per square foot of surface will average about 6.5 pounds. The loading per horsepower rarely exceeds 17.0 pounds.

Bombing Type Aeroplanes. These large aeroplanes are fitted with either two or three independent power plants. The German bombers are represented by the Gotha, A. E. G., Friedrichshafen, and Rumpler G, while the Allied bombers are the Caproni, Handley-Page, Farman, Voisin, etc. The speed is about that of the reconnaissance type, and will seat three or more men. The motors average 500 560 horsepower per power plant, and the wing area is usually well over 1,000 square feet. The small two seaters are generally equipped with two pivoted machine guns, while the three seaters have a third machine gun arranged so that it can be lowered and fired through a trap door in the bottom of the body. Defense may thus be had from the rear, or below. In some of the pusher types, a rapid fire gun of comparatively heavy caliber is mounted at the front of the body in place of the usual machine gun. This is usually the case with the sea planes used for submarine chasing.

[image]

[image]

In addition to bombing operations, these large machines are also used for the protection of ”spotting” aeroplanes, or for the direct protection of the lines against land attacks. These heavily armed bombers are very difficult to attack, even for the smaller and more agile ”Chasers,” as they can fire from below as well as from the front, top, or sides. In the bombers which have only a single gun in the rear, the gunner is working at a disadvantage if his adversary forces him to continually raise and lower his gun from the top of the body to the lower trap door. This is very tiring to the rear gunner, and if the chaser’s tactics are carried out for a sufficient length of time, it can wear out the gunner by continually rising and dropping at the tail of the bombing plane. In regard to the front gun, the twin motor type offers many of the advantages of the pusher, and as a whole, the twin arrangement will nearly double the field of fire of either the tractor or pusher.

The bombing planes must have a very large radius of action, particularly those that are used in night bombing operations. The Gothas in bombing London fly several hundred miles from their base, and recently a Handley-Page bombing plane flew from London to Constantinople, Turkey, making only a few stops on the way. Starting out from Hendon, England, the Handley-Page machine flew to Paris, down the Rhone valley to Lyons and Marseilles, and then to Pisa, and Rome (Italy), where they landed. From Rome the machine passed over Naples, over Oranto and then over the Albanian Alps to the base at Salonica. Making preparations at this base they flew the final stage of the trip to Constantinople, a distance of 250 miles over hostile country. The bombing of the Turkish capital was done at night after a flight of 2 1/2 hours from Salonica. When over the sea of Marmora, the ship ”Goeben” was bombed, and in addition a hit was scored on the two submarines lying at her side. Four bombs struck the ”Goeben” directly, from an altitude of 800 feet. Two more bombs were dropped on the German ship, ”General,” which was the headquarters of the German staff. Finally, after 30 minutes over the city of Constantinople, the Turkish War Office was the recipient of two more bombs. In the words of the Turkish communiqué this ”Was not entirely destroyed.” On its return to Salonica it was found that the machine had been struck by 26 shrapnel bullets. This disabled one of the power plants so that the greater part of the return journey was made on a single motor.

From London to Salonica five men were carried. In addition was their luggage, bedding, two tool boxes, spare parts equivalent in weight to one engine, and two 11’-6” spare propellers. Complete, the machine weighed over 6 tons, with a useful load of about 6,000 pounds. In crossing the Albanian Alps the machine frequently was at an altitude of 10,000 feet. The power plant consisted of two 275 horsepower Rolls-Royce motors, and even at this high altitude, and with the heavy loading, no trouble was experienced. During the bombing, only three men were carried, the remainder of the useful weight being made up of bombs and other ammunition. While this record will probably be beaten before this book goes to press, it will at least give an idea as to the requirements and capabilities of the bombing type aeroplane.

Military Training Machines. The military training machines used in the United States are generally of the two seater tractor type, similar in external appearance to the reconnaissance type machines already described. They are low powered, 90 to 125 horsepower, and will have an average span of 40’-0”. The controls are in duplicate so that the student’s controls move in unison with the instructor’s.

[image]

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CHAPTER III. ELEMENTARY AERODYNAMICS

Definition. Aerodynamics treats of the forces produced by air in motion, and is the basic subject in the study of the aeroplane. It is the purpose of this chapter to describe in detail the action of the wing in flight, and the aerodynamic behavior of the other bodies that enter into the construction of the aeroplane. At present, aerodynamic data is almost entirely based on experimental investigations. The motions and reactions produced by disturbed air are so complex and involved that no complete mathematical theory has yet been advanced that permits of direct calculation.

Properties of Air. Air being a material substance, possesses the properties of volume, weight, viscosity and compressibility. It is a mechanical mixture of the two elementary gases, oxygen and nitrogen, in the proportion of 23 per cent of oxygen to 77 per cent of nitrogen. It is the oxygen element that produces combustion, while the nitrogen is inert and does not readily enter into combination with other elements, its evident function being to act as a dilutant for the energetic oxygen. In combustion, the oxygen enters into a chemical combination with the fuel while the nitrogen passes off with the products of combustion unchanged.

Air is considered as a fluid since it is capable of flowing like water, but unlike water, it is highly compressible. Owing to the difference between air and water in regard to compressibility, they do not follow exactly the same laws, but at ordinary flight speeds and in the open air, the variations in the pressure are so slight as to cause little difference in the density. Hence for **flight alone**, air may be considered as incompressible. It should be noted that a compressible fluid is changed in density by variations in the pressure, that is, by applying pressure the weight of a cubic foot of a compressible fluid is greater than the same fluid under a lighter pressure. This is an important consideration since the density of the air greatly affects the forces that set it in motion, and for this reason the density (weight per cubic foot) is always specified in a test.

Every existing fluid resists the motion of a body, the opposition to the motion being commonly known as ”resistance.” This is due to the cohesion between the fluid particles and the resistance is the actual force required to break them apart and make room for the moving body. Fluids exhibiting resistance are said to have ”viscosity.” In early aerodynamic researches, and in the study of hydrodynamics, the mathematical theory is based on a ”perfect fluid,” that is, on a theoretical fluid possessing no viscosity, and while this conception is an aid in studying the reactions, the actual laboratory results are far from the computed values. Such theory would assume that a body could move in a fluid without encountering resistance, which in practice is, of course, impossible.

In regard to viscosity, it may be noted that air is highly viscuous—relatively much higher than water. Density for density, the viscosity of air is about 14 times that of water, and consequently the effects of viscosity in air are of the utmost importance in the calculation of resistance of moving parts.

Atmospheric air at sea level is about 1/800 of the density of water. Its density varies with the altitude and with various atmospheric conditions, and for this reason the density is usually specified ”at sea level” as this altitude gives a constant base of measurement for all parts of the world. As the density is also affected by changes in temperature, a standard temperature is also specified. Experimental results, whatever the pressure and temperature at which they were made, are reduced to the corresponding values at standard temperature and at the normal sea level pressure, in order that these results may be readily comparable with other data. The normal (average) pressure at sea level is 14.7 pounds per square inch, or 2,119 pounds per square foot at a temperature of 60° Fahrenheit. At this temperature 1 pound of air occupies a volume of 13.141 cubic feet, while at 0° F. the volume shrinks to 11.58 cubic feet, the corresponding densities being 0.07610 and 0.08633 pounds per cubic foot, respectively. This refers to dry air only as the presence of water vapor makes a change in the density. With a reduction in temperature the pressure increases with the density increase so that the effect of heat is twofold in its effect.

With a constant temperature, the pressure and density both decrease as the altitude increases, a density at sea level of 0.07610 pounds per cubic foot is reduced to 0.0357 pounds per cubic foot at an altitude of 20,000 feet. During this increase in altitude, the pressure drops from 14.7 pounds per square inch to 6.87 pounds per square inch. This variation, of course, greatly affects the performance of aeroplanes flying at different altitudes, and still more affects the performance of the motor, since the latter cannot take in as much fuel per stroke at high altitudes as at low, and as a result the power is diminished as we gain in altitude. The following table gives the power variations at different heights above sea level.

This air table also gives the properties of air through the usual range of flight altitudes. The pressures corresponding to the altitudes are given both in pounds per square inch and in inches of mercury so that barometer and pressure readings can be compared. In the fourth column is the percentage of the horsepower available at different altitudes, the horsepower at sea level being taken as unity. For example, if an engine develops 100 horsepower at sea level, it will develop 100 × 0.66=66 horsepower at an altitude of 10,000 feet above sea level. The barometric pressure in pounds per square inch can be obtained by multiplying the pressure in inches of mercury by the factor 0.4905, this being the weight of a mercury column 1 inch high.

In aerodynamic laboratory reports, the standard density of air is 0.07608 pounds per cubic foot at sea level, the temperature being 15 degrees Centigrade

[image]

*NOTE.-Densities marked * are interpolated from a graph, but are close enough for all ordinary purposes.*

(59 degrees Fahrenheit). This standard density will be assumed throughout the book, and hence for any other altitude or density the corresponding corrections must be made. Owing to the fact that the temperature decreases as we gain altitude, further corrections must be made in the tabular values, but as the changes are rather difficult to make and are relatively small we will not take the matter up at this point.

[image]

Fig. 1. Air Flow About a Flat Normal Plate. Pressure Zone at Front and .#. Turbulent Zone at Rear (H). Arrows Show Direction O OW.

Air Pressure on Normal Flat Plates. When a flat plate or "plane" is held at right angles or "normal" to an air stream, it obstructs the flow and a force is produced that tends to move it with the stream. The stream divides,as shown in Fig. 1 and passes all around the edges of the plate (P-R), the stream reuniting at a point (M) far in the rear. Assuming the air flow from left to right, as in the figure, it will be noted that the rear of the plate at (H) is under a slight vacuum, and that it is filled with a complicated whirling mass of air. The general trend of the eddy paths are indicated by the arrows. At the front where the air current first strikes the plate there is a considerable pressure due to the impact of the air particles. In the figure, pressure above the atmospheric is indicated by *, while the vacuous space at the rear is indicated by fine dots. As the pressure in front, and the vacuum in the rear, both tend to move the surface to the right in the direction of the air stream, the total force tending to move the plate will be the difference of pressure on the front and rear faces multiplied by the area of the plate. Thus if F is the force due to the impact pressure at the front, and G is the force due to the vacuum at the rear, then the total resistance (D) or "Drag" is the sum of the two forces.

Contrary to the common opinion, the vacuous part of the drag is by far the greater, say in the neighborhood of from 60 to 75 per cent of the total. When a body experiences pressure due to the breaking up of an air stream, as in the present case, the pressure is said to be due to "turbulence," and the body is said to produce ”turbulent flow.” This is to distinguish the forces due to impact and suction, from the forces due to the frictional drag produced by the air stream rubbing over the surface.

Forces due to turbulent flow do not vary directly as the velocity of the air past the plate, but at a much higher rate. If the velocity is doubled, the plate not only meets with twice the volume of air, but it also meets it twice as fast. The total effect is four times as great as in the first place. The forces due to turbulent flow therefore vary as the square of the velocity, and the pressure increases very rapidly with a small increase in the velocity. The force exerted on a plate also increases directly with the area, and to a lesser extent the drag is also affected by the shape and proportions. Expressed as a formula, the total resistance (D) becomes: $D = KAV^2$, where K = co-efficient of resistance determined by experiment, A = area of plate in square feet, and V= velocity in miles per hour. The value of K takes the shape and proportion of the plate into consideration, and also the air density.

Example. If the area of a flat plate is 6 square feet, the co-efficient $K = 0.003$, and the velocity is 60 miles per hour, what is the drag of the plate in pounds? **Solution**. $D = KAV^2 = 0.003 \times 6 \times (60 \text{ X } 60) = 64.80$ pounds drag. For a square flat plate, the co-efficient K can be taken as 0.003.

Aspect Ratio. The aspect ratio of a plate is the ratio of the length to the width. Thus, with an aspect ratio of 2.0, we understand that the plate is twice as long as it is wide. The ratio of the length to the width has a very considerable influence of the resistance or drag, this increasing as the ratio is made greater. If the resistance of a square plate is taken as 1.00, the resistance of a plate with an aspect ratio of 20 will be about 1.34 times as great. The following table will give the effects of aspect ratio on the resistance of a flat plane.

To convert the values of a square plate into a flat plate of given aspect ratio, multiply the resistance of the square plate by the factor under the ”K” heading. For example: The resistance of a certain square plate is 20 pounds, find the resistance of a plate of the same area, but with an aspect ratio of 15. **Solution**. The factor for a ratio of 15 will be found to be 1.26, hence the resistance of the required plate will be 20 × 1.26=25.2 pounds.

[image]

Fig. 2. Air Flow About a Streamline Body Showing an Almost Complete Absence of Turbulence Except at the Extreme Rear Edge. Resistance Is Principally Due to Skin Friction.

EFFECTS OF ASPECT RATIO ON FLAT PLATES.

Aspect Ratio. Length/Width	Resistance K as a Multiple of a Square Plate.
1.00 (square)	1.00
1.50	1.04
2.00	1.05
3.00	1.07
4.00	1.08
5.00	1.09
6.00	1.10
7.00	1.12
9.00	1.14
10.00	1.15
15.00	1.26
20.00	1.34
30.00	1.40

Streamline Forms. When a body is of such form that it does not cause turbulence when moved through the air, the drag is entirely due to skin friction. Such a body is known as a ”streamline form” and approximations are used for the exposed structural parts of aeroplanes in order to reduce the resistance. Streamline bodies are fishlike or torpedo-shaped, as shown by Fig. 2, and it will be noted that the air stream hangs closely to the outline through nearly its entire length. The drag is therefore entirely due to the friction of the air on the sides of the body since there is no turbulence or ”discontinuity.” In practical bodies it is impossible to prevent the small turbulence (I), but in well-designed forms its effect is almost negligible.

In poor attempts at streamline form, the flow discontinues its adherence to the body at a point near the tail. The poorer the streamline, and the higher the resistance, the sooner the stream starts to break away from the body and cause a turbulent region. The resistance now becomes partly turbulent and partly frictional, with the resistance increasing rapidly as the percentage of the turbulent region is increased.

The fact that the resistance is due to two factors, makes the resistance of an approximate streamline body very difficult to calculate, as the frictional drag and the turbulent drag do not increase at the same rate for different speeds. The drag due to turbulence varies as V squared while the frictional resistance only varies at the rate of V to the 1.86th power, hence the drag due to turbulence increases much faster with the velocity than the frictional component. If we could foretell the percentage of friction, it would be fairly easy to calculate the total effect, but this percentage is exactly what we do not know. The only sure method is to take the results of a full size test.

Fig. 2 gives the approximate section through a streamline strut such as used in the interplane bracing of a biplane. The length is (L) and the width is (d), the latter being measured at the widest point. The relation of the length to the width is known as the ”fineness ratio” and in interplane struts this may vary from 2.5 to 4.5, that is, the length of the section ranges from 2.5 to 4.5 times the width. The ideal streamline form has a ratio of from 5. to 5.75. Such large ratios are difficult to obtain with economy on practical struts as the small width would result in a weak strut unless the weight were unduly increased. Interplane struts reach a maximum fineness ratio at about 3.5 to 4.5. Fig. 3 shows the result of a small fineness ratio, the short, stubby body causing the stream to break away near the front and form a large turbulent region in the rear.

An approximate formula showing the relation of fineness ratio and resistance (curvature equal) was developed by A. E. Berriman, and published in ”Flight” Nov. 12, 1915. Let D = resistance of a flat plate at a given speed, and R = resistance of a strut at the same speed and of the same area, then the relation between the resistance of the flat plate, and the strut will be expressed by the formula $R/D=4L/300d$, where L = length of section and d = width as in Fig. 2. This can be transposed for convenience, by assuming the drag of a flat plate as $D = 0.003AV^2$, where A = area in square feet, and V = velocity in miles per hour. The ratio of the strut resistance to the flat plate resistance, given by Berriman's formula, can now be multiplied by the flat plate resistance, or strut resistance = $R = 0.003AV^2 \text{ X } 4L/300d. = 0.012LAV^2/300d$. It should be understood that the area mentioned above is the greatest area presented to the wind in square feet, and hence is equal to the length of the strut (not section) multiplied by the width (d).

[image]

Fig. 3. Imperfect Streamline Body with a Considerable Turbulence Due to the Short, Stubby Form. Fig. 4 Shows the Flow About a Circular Rod or Cylinder.

Assuming the length (L) of the section as 7.5 inches, and the width (d) as one inch, the fineness ratio will be 7.5. Using the Berriman formula in its original form, the relative resistance of the strut and flat plate of same area will be found as $R/D=4L/3000 = 0.1$, that is, the resistance of a streamline form strut of above fineness ratio will be about 0.1 of a flat plate of the same area. It should be understood that this is only an approximate formula since even struts of the same fineness vary among themselves according to the outline. Results published by the National Physical Laboratory show streamline sections giving 0.07 of the resistance of a flat plate of the same area, with fineness ratio = 6.5. In Fig. 4 the effects of flow about a circular rod is shown, a case where the fineness ratio is 1. The stream follows the body through less than one-half of its circumference, and the turbulent region is very large; almost as great as with the flat plate. A circular rod is far from being even an approach to a perfect form.

In all the cases shown, Figs. 1-2-3-4, it will be noticed that the air is affected for a considerable distance in front of the plane, as it rises to pass over the obstruction before it actually reaches it. The front compression may be perceptible for 6 diameters of the object. From the examination of several good low-resistance streamline forms it seems that the best results are obtained with the blunt nose forward and the thin end aft. The best position for the point of greatest thickness lies from 0.25 to 0.33 per cent of the length from the front end. From the thickest part it tapers out gradually to nothing at the rear end. That portion to the rear of the maximum width is the most important from the standpoint of resistance, for any irregularity in this region causes the stream to break away into a turbulent space. From experiments it has been found that as much as one-half of the entering nose can be cut away without materially increasing the resistance. The cut-off nose may be left flat, and still the loss is only in the neighborhood of 5 per cent.

Resistance Calculations (Turbulency). In any plate or body where the resistance is principally due to turbulent action, as in the flat plate, sphere, cone, etc., the resistance can be computed from the formula $R = KAV^2$, where R is the resistance in pounds and K, A, and V are as before. The resistance co-efficient (K) depends upon the shape of the object under standard air conditions, and differs greatly with flat plates, cones, sphere, etc. The area (A) is the area presented to the wind, or is the greatest area that faces the wind, and is taken at right angles to its direction. The following table gives the value of K for the more common forms of objects. See Figs. 4 to 12, inclusive:

[image]

There are almost an infinite number of different forms, but for the present the above examples will fill our purpose. As an example in showing how greatly the form of an object influences its resistance, we will work out the resistance of a flat plate and a spherical ended cone, both having the same presented diameter. The cone is placed so that the spherical end will face the air stream. The area A of both objects will be: 0.7854 × 2 × 2 = 3.1416 square feet. With an assumed wind velocity of 100 miles per hour, the resistance of the circular flat disc will be: $R = KAV^2 = 000282 \times 3.1416 \times (100 \times 100) = 87.96$ lbs. For the cone, $R = KAV^2 = 0.000222 \times 3.1416 \times (100 \times 100) = 6.97$ lbs. From this calculation it will be seen that it is advisable to surround the object with a spherical cone shaped body rather than to present the flat surface to the wind. In the above table the value of K is given for two positions of the spherical based cone, the first is with the apex toward the wind, and the second condition gives the value with the base to the wind. With the blunt end forward, the resistance is about one-half that when the pointed apex enters the air stream. This is due to the taper closing up the stream without causing turbulence.

[image]

Figs. 4a-5-6-7-8-9-10-11-12. The Values of the Resistance Coefficient K for Different Forms and Positions of Solid Objects. Arrows Indicate the Direction of the Relative Wind. (Eiffel.)

With the apex forward there is nothing to fill up the vacuous space when the air passes over the large diameter of the base as the curve of the spherical end is too short to accomplish much in this direction.

Skin Friction. The air in rubbing over a surface experiences a frictional resistance similar to water. At the present time the accepted experiments are those of Dr. Zahm but these are still in some question as to accuracy. It was found in these experiments that there was practically no difference caused by the material of the surfaces, as long as they were equally smooth. Linen or cotton gave the same results as smooth wood or zinc as long as there was no nap or lint upon the surface. With a fuzzy surface the friction increased rapidly. This is undoubtedly due to a minute turbulence caused by the uneven surface, and hence the increase was not purely frictional, but also due to turbulence. In the tests, the air current was led parallel to the surface in such a way that only the friction could move the surface. The surface was freely suspended, and as the wind moved it edgewise, the movement was measured by a sharp pointer. End shields prevented impact of the air on the end of the test piece so that there was no error from this source. The complete formula given by Dr. Zahm is rather complicated for ordinary use, especially for those not used to mathematical computations. If Rf = resistance due to friction on one side of surface, L= length in direction of wind in feet, b = width of surface in feet, and V= velocity in feet per second, then

$Rf = 0.00000778L^{0.93}V^{1.86}b$.

It will be noted that the resistance increases at a lower rate than the velocity squared, and at a less rate than the area. That is to say, that doubling the area will not double the resistance, but will be less than twice the amount. Giving the formula in terms of area and miles per hour units, we have: $Rf = 0.0000167A^{0.93}V^{1.86}$. Where A = area in square feet and V = miles per hour. The area is for one side of the surface only. A rough approximation to Zahm's equation has been proposed by a writer in "Flight," the intention being to avoid the complicated formula and yet come close enough to the original for practical purposes. The latter formula reads: $Rf = 0.000009V^2$ where Rf and V are as above. Up to 40 miles per hour the results are very close to Zahm's formula, and are fairly close from 60 to 90 miles per hour. This approximation is only justified when the length in the direction of the wind is nearly equal to the length. If the length is much greater, there is a serious error introduced.

This formula is applied to surfaces parallel to the wind such as the sides of the body, rudder, stabilizer, and elevator surfaces (when in neutral). A second important feature of the friction formula is that it illustrates the law of "similitude" or the results of a change in scale and velocity, hence it outlines what we must expect when we compute a full size aeroplane from the results of a model test.

The Inclined Plane. When a flat plate is inclined with the wind, the resistance or drag will be broken up into two components, one at right angles to the air stream, and one parallel to it. If the plate is properly inclined, the right angled component can be utilized in obtaining lift as with an aeroplane wing. This is shown in Fig. 13 where L is the vertical lift force at right angles to the air stream and D is the horizontal drag acting in the direction of the wind. As in the case of the plate placed normal to the wind, there is pressure at the front of the plate and a partial vacuum behind. The resultant force will be determined by the difference in pressure between the front and the back of the plate. The forces will vary as V^2 since the reaction is caused by turbulent flow. Both the lift and drag will vary with the angle made with the stream, and there will be a different value for the co-efficient K for each change in the angle. The angle made with the air stream is known as the "Angle of incidence" or the "Angle of attack." The change of drag and lift does not vary at a regular rate with the angle.

A line OR is the resultant of the lift and drag forces L and D, this resultant being the force necessary to balance the two forces L-D. It is on the point

[image]

Fig. 13. Flow About, Inclined Plane and Forces Produced by Stream. Fig. 14. Normal Plane with C.P. at center of Plate. Fig. 15.. C.P. Moves Toward Entering Edge When Plate Is Inclined to Wind.

of application O that the plate balances, and this point is sometimes known as the "Center of pressure." The center of pressure is therefore the point at which the resultant intersects the surface of the flat plate. The resultant OR is approximately at right angles to the surface at small incident angles, and the point O is nearer the front or "leading edge" (A) of the plane. The smaller the angle of incidence the nearer will the point O approach the leading edge A. By drawing OL to scale, representing the lift, and OD to scale representing the drag, we can find the resultant OR by drawing LR parallel to the drag OD and DR parallel to the lift line OL. All lines drawn through the intersection of LR and DR will give the resultant OR to scale. All of the lines must be started from the center of pressure at O.

The least resultant will, of course, occur when the plane is parallel to the air stream. The maximum resultant will occur when the angle of incidence is about 40 degrees, and on a further increase in the angle, the value of the resultant will gradually decrease. When the plane is parallel with the stream, the resultant is parallel to the plate, but rapidly approaches a position at right angles at about an incidence of 6 to 10 degrees. Beyond 10 degrees incidence the angle of the resultant increases past the normal.

The center of pressure (O), or the point where the resultant force intersects the plane, moves forward as the angle of incidence is decreased from 90°. When at right angles to the air current, the center of pressure is exactly in the center of the plane as shown by Fig. 14. In this case the drag (D) is the resultant, and acting in the center, exactly balances the air forces. In Fig. 15 the angle of incidence is reduced, consequently the center of pressure moves nearer the leading edge (A). As the angle continues to decrease, the C. P. moves still further forward until it lies directly on the front edge when the plate becomes parallel with the air stream. The center of pressure movement is due to the fact that more and more work is done by the front part of the surface as the angle is decreased. Consequently the point of support, or C. P., must move forward to come under the load. It should be understood that the plane will balance about the C. P. if a knife edge bearing were applied as at R in Fig. 15.

Calculation of Inclined Planes. We will now consider the inclined plane as a lifting surface for an aeroplane, and make the elementary calculations for such purpose. The lift will first be calculated for the support of the given load, at the given velocity, and then the drag. For several reasons, that will afterwards be explained, the flat plate or plane is not used for the main lifting surfaces, but the experience gained in computing the plate will be of great assistance when we start calculating actual wings.

Lift and Drag Co-efficients. The lift component (L) of the inclined flat plate depends on the velocity, area, aspect ratio and angle of incidence. Instead of using the co-efficient (K) formerly used for the total drag, we will use the lift co-efficient Ky. The formula for lift now becomes: $L = KyAV^2$ where A = area in square feet, and V = velocity in miles per hour. The lift co-efficient Ky, depends upon the angle of incidence. The horizontal drag D will be calculated from the drag co-efficient Kx, which is used in the same way as the co-efficient K in the case of the normal plate. The subscript (x) is used to distinguish it from the lift co-efficient. Both Ky and Kx must be corrected for aspect ratio. The drag can be calculated from the formula: $D = KxAV^2$ where the letters A and V are the same as above.

For the calculation of the drag, we will use a new expression—the "Lift-Drag Ratio"—or as more commonly given, "L/D." This shows the relation between the lift and drag, so that by knowing the lift and the ratio for any particular case, we can compute the drag without the necessity of going through the tedious calculation $D = KxAV^2$. The lift-drag ratio for a flat plate varies with the angle of incidence, and the aspect ratio, and hence a separate value must be used for every inclination and change in aspect. To obtain the drag, divide the lift by the lift-drag ratio. Hence if the lift is 1200 pounds, and the ratio equals 6.00, the drag will be: 1200/6=200 pounds, or in other words, the lift is 6 times the drag force. Changing the angle of incidence through angles ranging from 1 degree to 7 degrees, the lift-drag ratio of a flat plate will vary from 1.5 to 7.5. When the plane is parallel to the wind stream and gives no lift, the drag is computed from Zahm's skin friction formula.

The following tables give the values of Ky, Kx, L/D, and center of pressure movement for flat plates of various aspect ratios. The center of pressure (C. P.) for each angle is given as a decimal fraction of its distance from the leading edge, in terms of the width or "Chord."

Fig. 16 shows the top view or plan of a lifting surface, with the direction of the wind stream indicated by the arrows w-w-w = w. The longer side or "span" is indicated by S, while the width or chord is C. Main lifting surfaces, or wings, have the long side at right angles to the wind as shown. When in this position, the surface is said to be in "Pterygoid Aspect," and when the narrow edge is presented to the wind, the wing is in "Apteroid Aspect." The word "Pterygoid" means "Bird

[image]

Fig. 16. Plan View of Plate with Long Edge to Wind. Fig. 17. Plate with Narrow Edge to Wind, Showing Loss in Lift. 17a Shows Effect of Raked Tips.

like," and was chosen for the condition in Fig. 16, as this is the method in which a bird's wing meets the air. Contrary to the case with true curved aeroplane wings, flat planes usually give better lift in apteroid than in pterygoid aspect at high angles. The aspect ratio will be the span (S) divided by the chord (C), or Aspect ratio = S/C.

[image]

It will be seen from the above that the lift coefficient Ky increases with the aspect ratio, and that it generally declines after an angle of 30 degrees. The center of pressure moves steadily back with an increase in angle.

Example for Lifts. A certain flat plane has an area of 200 square feet, and moves at 50 miles per hour. The angle of incidence is 10 degrees, and the aspect ratio is 6. Find the total lift and the drag in pounds. Also the location of the center of pressure in regard to the leading edge, if the chord is 5.8 feet.

Solution. Under the table headed, ”Aspect Ratio = 6” we find that Ky at 10° = 0.00173, and that the lift drag ratio is 5.2. The center of pressure is 0.333 of the chord from the front edge. The total lift then becomes: $L = KyAV^2 = 0.00173 \times 200 \times (50 \times 50) = 865$ pounds. Since the lift drag ratio is 5.2, the drag = $D = 865/5.2 = 166.3$ pounds. The center of pressure will be located $5.8 \times 0.333 = 1.4$ feet from the leading edge.

[image]

[image]

Under the same conditions, but with an aspect ratio of 3, the lift will become: $L = KyAV^2 = 0.0014 \times 200 \times (50 \times 50) = 700$ pounds. In this case the lift drag ratio is 5.1, so that the drag will be 137.8 pounds. Even with the same area, the aspect ratio makes a difference of 865−700 = 165 pounds. If we were compelled to carry the original 865 pounds with aspect 3 wing, we would also be compelled to increase the area, angle, or speed. If the speed were to be kept constant, we would be limited to a change in area or angle. In the latter case it would be preferable to increase the area, since a sufficient increase in the angle would greatly increase the drag. It will be noted that the lift-drag ratio decreases rapidly with an increase in the angle.

[image]

Burgess Seaplane Scout.

Calculation of Area: Let us assume that we are confined to the use of an aspect ratio of 6, a speed of 50 miles per hour, weight = 2500 pounds, and wish to obtain the area that will give the most efficient surface (Least lift-drag ratio.) The equation can be now transposed so that the area = $A = KyV^2$. On examination of the table it will be seen that the greatest lift-drag ratio is 6.4 at 5 degrees, and that the Ky at this angle is 0.00103. Substituting these values in the equation for area, we have $A = L/KyV^2 = 2500/000103 \text{ x } (50 \text{ x } 50) = 971$ square feet.

[image]

[image]

Wind Tunnel at Washington Navy Yard in Which the Air Circulates Continuously Through a Closed Circuit

CHAPTER IV. EXPERIMENTAL LABORATORIES.

Test Methods in General. As already explained, the behavior of a body in an air stream cannot be predicted with any certainty by direct mathematical calculation, and for this reason, each and every aerodynamic body must be tested under conditions that are as nearly similar to the actual working conditions as possible. Prior to Professor Langley's first experiments in 1887, mechanical flight with a heavier than air machine was derided as an impossibility, even by such scientists as Navier, Von Helmotz, Gay-Lussac, and others, who proved by the most intricate calculations that a body larger than a bird could not be supported by its own energy. Such calculations were, of course, based on a wrong understanding of air flow, and as no experimental work had been done up to that time, the flow was assumed according to the individual taste and belief of the demonstrator. The presence of a vacuum on the back of a plate was not understood, and as this contributes full two-thirds of the lift, it is an easy matter to see why all of the early predictions fell short of the actual lifting forces. To quote one classic absurdity, the scientist Navier proved mathematically that if mechanical flight were possible, then 17 swallows would be capable of developing one horsepower.

In spite of these discouraging computations, Langley proceeded with a very carefully conducted series of experiments, first investigating the laws of surface sustenation on various forms of plates, and when the data collected was sufficient for his needs, he started to construct a number of model flyers with various wing arrangements and aerofoil forms. It was Langley's experiments upon aerofoils that cleared the way for the Wright Brothers, who started a further and more complete investigation in 1896. Experiments were made on the effect of curvature, aspect ratio and angle of incidence, and the results obtained in their ”wind tunnel” were afterwards applied to their successful full size machine. During 1901 to 1902 the Wrights investigated the properties of at least 100 different aerofoil forms. Both Langley's and Wrights' experiments were with models, although they were made in a different manner. It was in this way that experimental evidence gained precedence over theory.

Langley's specimens were mounted at the end of a revolving arm, so that with the arm revolving, a relative air stream of known velocity could be had. The aerofoil was mounted in such a way that the lift and drag could be measured. In the early experiments of the Wrights, the models were placed in an enclosed channel through which a stream of air was maintained by a fan. The model was attached to a balance system so that the lift and resistance could be measured. This is what is now known as a ”wind tunnel,” and at present is almost exclusively used in model tests. Several investigators immersed their model aerofoils in running water so that the direction of flow could be visibly observed. While this latter method is of great service in determining disturbances, stream line flow, and general characteristics, it is qualitative rather than quantitative, and cannot be used in obtaining accurate numerical results. A more accurate method of mapping out the direction of flow, eddies, etc., is to introduce smoke into the air stream.

Full Size Experiments. The old ”rule of the thumb” method of building a full size machine without model test data or other experimental evidence to begin with has seen its day. It is not only exceedingly expensive, but is highly dangerous, and many a flyer has met his death in the endeavor to work out untried principles on a full size machine. The first cost of the machine, the continual breakage and operating expense, to say nothing of the damage suits and loss of time, make a preliminary full size tryout an absurdity at the present time. Again, the results of full size experiments are not always reliable, as so much depends upon the pilot and weather conditions. The instruments used on a large machine are far from being as accurate as those used in model tests. These are also likely to be thrown out of adjustment unknowingly by falls or collisions. The great number of variables that enter into such a test make it almost an impossibility to obtain accurate data on the result of minor alterations, and, in fact, it is almost impossible to get the same results twice without further alterations than changing the pilot. Full scale tests are necessary after sufficient data has been obtained and applied in a scientific manner to the design of the machine, but successful performance cannot be expected from a powered machine built by guess work.

When performed in connection with a wind tunnel, or based on dependable data from other sources, full size wing tests are very instructive and useful if care is taken to have the tests conducted under uniform and known conditions. Many full size experiments of this nature have been carried out by Saint-Cyr University in France, and by the Royal Aircraft Factory in Great Britain. Both of these institutions have a wind tunnel and an almost unlimited fund of performance data, and last but not least, have the services of skilled observers.

At Saint-Cyr, the full size wings, or the entire machine, are carried on an electric car or "chariot." The speed of the car, the lift and drag, can be determined at any moment during the run through suitable recording devices. Actual flying tests have also been made, the measurement of the propeller thrust giving the drag, while the lift is known as being equal to the weight of the machine. The R.A.F. have carried out a very extensive series of flight tests, the experiments on the old "B. E.-2" probably being the best known.

The greater part of the experiments performed with the car at Saint-Cyr differed considerably from the results obtained by model tests, and apparently these differences followed no specific law. According to theory, and the results obtained by different laboratories, the performance of a full size wing should be better than with a model, but the Saint-Cyr tests showed that such was not always the case. The center of pressure movement differed in almost every case, and as a direct result, the pressure distribution of the large wings was materially different than with the model. The lift-drag ratio results varied, sometimes being better for the model than for the large wing. These differences can probably be explained as being due to variation in air currents, side winds, etc.

Model Tests. Since lift and resistance are due to relative motion between a body and the air stream, a model can either be towed through the air, or it can be held stationary while the air is forced past it. There has been some controversy on the relation between the results obtained by the two methods, but for the present we will accept the common belief that the results obtained by either method are the same. In testing ship models, they are always towed through the tank, but in the case of aero-dynamic bodies this is complicated and not desirable. In towing models through the air a very high velocity is needed and this necessitates either a very long track or a short time length for making the observations. Again, it is almost impossible to avoid errors because of vibration, inequality of movement due to uneven track, or air eddies caused by differences in temperature and by the movement of the towing device. In fact, the same difficulties apply to towed model tests as to the full size ”electric chariot.”

The whirling arm method of testing as used by Langley, Maxim-Vickers, and others, is a form of ”towed testing,” but is also open to serious objections. Unless the arm is very long, every part of the model surface will not move at the same velocity, the outer portions moving the faster. As the forces produced by an air stream vary as the square of the velocity, this may introduce a serious error. The fact that the body passes repeatedly over the same path introduces error, as the body after the first revolution is always working in disturbed air. The centrifugal force, and the currents set up by the arm itself all reduce the accuracy of the method.

When a model is placed in a uniform current of air in a properly designed channel or tunnel, the greater part of the errors due to towed tests are eliminated. The measuring instruments can be placed on a firm foundation, the air stream can be maintained at a nearly uniform speed and with little error due to eddies, and the test may be continued under uniform conditions for an indefinite period. While there are minor errors due to wall friction and slight variations in the velocity at different points in the cross section of the tunnel, they are very small when compared to the errors of towing. For this reason the wind tunnel is the accepted means of testing.

Eiffel’s Wind Tunnel. The Eiffel Laboratory at Auteuil, France, is probably one of the best known. The results in Chapters III and V were obtained in this laboratory and thousands of similar experiments have been carried out at this place. Two tunnels, a large and small, are placed side by side in the main laboratory room, the tunnels being supported midway between the floor and ceiling. The air is drawn from this room into an airtight experimental chamber through a bell-mouthed circular opening. A grill or honeycomb baffle is placed in the opening to straighten out the flow, and from this point the air passes across the chamber and exits through a circular duct to the suction side of a large fan. From the fan the air is discharged into the room. The same air thus circulates through the tunnel continuously. The test chamber is considerably wider than the openings so that the walls do not influence the flow around the model. A cylinder of air passes through the chamber at a remarkably uniform velocity, and without any appreciable eddies. Diameter of the stream approximates 6.6 feet in the large tunnel and 3 feet in the smaller. In the large tunnel the maximum velocity is 105 feet per second, and 131 feet per second is attained in the smaller. A 50-horsepower electric motor is used with a multiblade fan of the ”Sirocco” type.

The observer and weighing mechanism are supported above the air stream on a sliding floor, and a standard extends from the model in the wind stream to the balances on the weighing floor. These balances determine the lift and drag of the models, the center of pressure, etc.

The N. P. L. Tunnel. The National Physical Laboratory at Teddington, England, has a remarkably complete and accurate aerodynamic equipment. This consists of a large tunnel of 7 square feet area, a small tunnel of 4 square feet, and a whirling table house. The large tunnel is 80 feet in length with an air flow of 60 feet per second, the air being circulated by a four-bladed propeller driven by an electric motor of 30 horsepower. The velocity is uniform within one-half per cent, and the most accurate of results have been obtained. The smaller tunnel is about 56 feet long and the wind velocity is about 40 miles per hour maximum. The propeller revolves at 600 revolutions and is driven by a 10-horsepower electric motor. There is no chamber and the models are suspended in the passage half way between the ”Diffuser” in the entering end, and the baffles in the exit. The Massachusetts Institute of Technology, and the Curtis Aeroplane Company both have similar tunnels.

United States Navy Tunnel. In this tunnel the air is confined in a closed circuit, the return tunnel being much larger than the section in which the tests are performed. The cross-sectional area is 8 square feet at the point of test, and the stream is uniform within 2 per cent. The balance and controls are mounted on the roof of the tunnel, with an arm extending down through the air stream to the model, as in the Eiffel tunnel. The balance is similar to Eiffel’s and is sensitive to less than 2/1000 pound. A velocity of 75 miles per hour may be attained by the 500-horsepower motor, but on account of the heating of the air stream through skin friction, the tests are generally made at 40 miles per hour. Models up to 36-inch span can be tested, while the majority of models tested at M. I. T. are about 18 inches.

CHAPTER V. AERODYNAMICS OF LIFTING SURFACES (AEROFOILS).

General Wing Requirements. The performance of flat plates when used as lifting surfaces is very poor compared with curved sections or wing forms. It will be remembered that the greatest lift-drag ratio for the flat plate was 6.4, and the best Ky was 0.00294. Modern wing sections have a lift-drag ratio of over 20.0, and some sections have a lift coefficient of Ky−0.00364, or about 60 per cent higher than the lift obtained with a flat plate. In fact, this advantage made flight possible. To Langley, above all other men, we owe a debt of gratitude for his investigations into the value of curved wing surfaces.

Air Flow About an Aerofoil. To distinguish the curved wing from the flat plane, we will use the term ”Aerofoil.” Such wings are variously referred to as ”Cambered surfaces,” ”Arched surfaces,” etc., but the term ”Aerofoil” is more applicable to curved sections. The variety of forms and curvatures is almost without limit, some aerofoils being curved top and bottom, while others are curved only on the upper surface. The curve on the bottom face may either be concave or convex, an aerofoil of the latter type being generally known as ”Double cambered.” The curves may be circular arcs, as in the Wright and Nieuport wings, or an approximation to a parabolic curve as with many of the modern wings.

Fig. 1-b shows the general trend of flow about an aerofoil at two different angles of incidence, the flow in the upper view being characteristic for angles up to about 6 degrees, while the lower view represents the flow at angles approximating 16°. At greater angles the air stream breaks away entirely from the top surface and produces a turbulence that greatly resembles the disturbance produced by a flat plate. It will be noted in the top figure (At small angles) that the flow is very similar to the flow about a streamline body, and that the air adheres very closely to the top surface. The flow at small angles is very steady and a minimum of turbulence is produced at the trailing edge.

[image]

Figs. 1a, 1b. Aerofoil Types and Flow at Different Angles.

When increased beyond 6°, turbulence begins, as shown in the lower figure, and a considerable change takes place in the lift-drag ratio. This is known as the ”Lower Critical Angle.” The turbulence, however, is confined to the after part of the wing, and little or no disturbance takes place in the locality of the lower surface. We observe that an increase in angle and lift produces an increased turbulent flow about the upper surface, and hence the upper surface is largely responsible for the lift. Below 10° the trend of the upper portion of the stream is still approximately parallel to the upper surface.

From 16° to 18°, the stream suddenly breaks entirely away from the wing

[image]

Fig. 2. Showing How Lift Is Obtained When an Aerofoil Is Inclined at a Negative Angle, the Line of Flight Being Along X-X.

surface, and produces an exceedingly turbulent flow and mass of eddies. The lift falls off suddenly with the start of the discontinuous flow. The angle at which this drop in lift takes place is known variously as the ”Second Critical Angle,” the ”Burble Point,” or the ”Stalling Angle.” Any further increase in angle over the stalling angle causes a drop in lift as the discontinuity is increased. With the flat plane, the burble point occurs in the neighborhood of 30° and movement beyond this angle also decreases the lift. In flight, the burble point should not be approached, for a slight increase in the angle when near this point is likely to cause the machine to drop or ”Stall.” The fact that the maximum lift occurs at the critical angle makes the drop in lift at a slightly greater angle, doubly dangerous.

A peculiar feature of the aerofoil lies in the fact that lift is still obtained with a zero angle of incidence, and even with a negative angle. With the aerofoil shown in Fig. 2 there will be a considerable lift when the flat bottom is parallel with the direction of travel, and some lift will still be obtained with the front edge dipped down (Negative Angle). The curved upper surface causes the air stream to rise toward the front edge, as at E, hence the wing can be dipped down considerably in regard to the line of motion X-X, without going below the actual air stream.

Action in Producing Lift. At comparatively high angles of incidence, where there is turbulent flow, the lift and drag are due principally to the difference in pressure between the upper and lower surfaces as in the case of the flat plate.

There is a positive pressure below as in the front of a flat inclined plane, and a vacuous region above the upper surface. The drag with the plane below the burble point, and above the ”Lower Critical Angle,” is due both to skin friction and turbulence—principally to the latter. Below the first critical angle (6°), the skin friction effect increases, owing to the closeness with which the air stream hangs to the upper surface.

Since there is but little turbulence at the small angles below 6°, the theory of the lift at this point is difficult to explain. The best explanation of lift at small angles is given by Kutta’s Vortex Hypothesis. This theory is based on the fact that a wing with a practically streamline flow produces a series of whirling vortices (Whirlpools) in the wake of the wings, and that the forward movement of the plane produces the energy that is stored in the vortices. The relation between these vortices is such, that when their motion is destroyed, they give up their energy and produce a lifting reaction by their downward momentum. The upward reaction on the wing is thus equal and opposite to the downward momentum of the air vortices.

Drag Components. At large angles of incidence where turbulence exists, the lift and also the drag are nearly proportional to the velocity squared (V^2). Where little turbulence exists, and where the air stream hugs the surface closely, the drag is due largely to skin friction, and consequently this part of the drag varies according to Zahm’s law of friction (V^2). For this reason it is difficult to estimate the difference in drag produced by differences in velocity, since the two drag components vary at different rates, and there is no fixed proportion between them. Since the frictional drag does not increase in proportion to the area, but as $A^{0}.^{98}$, difficulty is also experienced in estimating the drag of a full size wing from data furnished by model tests.

Incidence and Lift. Up to the burble point the lift increases with an increase in the angle; but not at a uniform rate for any one aerofoil, nor at the same rate for different aerofoils. The drag also increases with the angle, but more rapidly than the lift after an incidence of about 4° is passed, hence the lift-drag ratio is less at angles greater than 4°. Decreasing the angle below 4° also decreases the lift-drag, but not so rapidly as with the larger angles. At the angle of ”No Lift” the drag is principally due to skin friction.

Fig. 3 shows a typical lift and incidence chart that gives the relation between the angle of incidence Θ and the lift coefficient. This curve varies greatly for different forms of aerofoils both in shape and numerical value, and it is only given to show the general form of such a graph. The curve lying to the left, and above the curve for the ”Flat plate,” is the curve for the particular aerofoil shown above the chart. The ”Lift-Coefficients” at the left hand vertical edge correspond to the coefficient Ky, although these must be multiplied by a factor to convert them into values of Ky. As shown, they are in terms of the Absolute units used by the National Physical Laboratory and to convert them into the Ky unit they must be multiplied by $0.0051V^2$ where V is in miles per hour, or $0.00236v^2$ where v = feet per second. The incidence angle is in degrees.

[image]

Fig. 3. Chart Showing Relation Between Incidence And Lift.

It will be noted that the lift of the aerofoil is greater than that of the plate at every angle as with nearly every practical aerofoil. The aerofoil has a lift coefficient of 0.0025 at the negative angle of -3°, while the lift of the flat plate of course becomes zero at 0°. As the incidence of the aerofoil increases the lift coefficient also increases, until it reaches a maximum at the burble point (Stalling angle) of about 11.5°. An increase of angle from this point causes the lift coefficient to drop rapidly until it reaches a minimum lift coefficient of 0.46 at 17°. The flat plate as shown, reaches a maximum at the same angle, but the lift of the plate does not drop off as rapidly. The maximum coefficient of the aerofoil is 0.58 and of the plate 0.41. The rapid drop in pressure, due to the air stream breaking away at the burble point, is clearly shown by the sharp peak in the aerofoil curve. The sharpness of the drop varies among different aerofoils, the peaks in some forms being very flat and uniform for quite a distance in a horizontal direction, while others are even sharper than that shown. Everything else being equal, an aerofoil with a flat peak is the more desirable as the lift does not drop off so rapidly in cases where the aviator exceeds the critical angle, and hence the tendency to stall the machine is not as great. This form of chart is probably the simplest form to read. It contains only one quantity, the lift-coefficient, and it shows the small variations more clearly than other types of graphs in which the values of Kx, lift-drag, and the resultant force are all given on a single sheet.

Center of Pressure Movement. As in the case of the flat plate the center of pressure on an aerofoil surface varies with the angle of incidence, but unlike the plate the center of pressure (C. P.) moves backward with a decrease in angle. The rapidity of travel depends upon the form of aerofoil, in some types the movement is very great with a small change in the angle, while in others the movement is almost negligible through a wide range. In general, aerofoils are inherently unstable, since the C. P. moves toward the trailing edge with decreased angles, and tends to aggravate a deficiency in the angle. If the angle is too small, the backward movement tends to make it still smaller, and with an increasing angle the forward movement of the center of pressure tends to make the angle still greater.

Fig. 4 is a diagram showing the center of pressure movement for a typical aerofoil with the aerofoil at the top of the chart. The left side of the chart represents the leading edge of the aerofoil and the right side is the trailing edge, while the movement in percentages of the chord length is shown by the figures along the lower line. Thus figure ”.3” indicates that the center of pressure is located 0.3 of the chord from the leading edge. In practice it is usual to measure the distance of the C. P. from the leading edge in this way.

For an example in the use of the chart, let us find the location of the C. P. at angles of 0°, 3° and 7°. Starting with the column of degrees at the left hand edge of the chart, find 0°, and follow along the dotted line to the right until the curve is reached. From this point follow down to the lower row of figures. It

[image]

Fig. 4. Chart Giving Relation Between Incidence and C.P. Movement.

will be found that at 0° the C. P. lies about half way between 0.5 and 0.6, or more exactly at 0.55 of the chord from the leading edge. Similarly at 3° the C. P. is at 0.37 of the chord, and at 7° is at 0.3 of the chord. From 11° to 19°, the C. P. for this particular aerofoil moves very little, remaining almost constant at 0.25 of the chord. Reducing the angle from 3° causes the C. P. to retreat very rapidly to the rear, so that at −1° the C. P. is at 0.8 of the chord, or very near the trailing edge of the wing.

Other Forms of Charts. The arrangement of wing performance charts differs among the various investigators. Some charts show the lift, drag, lift-drag ratio, angle of incidence, center of pressure movement, and resultant pressure on a single curve. This is very convenient for the experienced engineer, but is somewhat complicated for the beginner. Whatever the form of chart, there should be an outline drawing of the aerofoil described in the chart.

Fig. 5 shows a chart of the ”Polar” variety in which four of the factors are shown by a single curve. This type was originated by Eiffel and is generally excellent, except that the changes at small angles are not shown very clearly or sharply. The curve illustrates the properties of the ”Kauffman” wing, or better known as the ”Eiffel No. 37.” A more complete description of this aerofoil will be found under the chapter ”Practical Wing Sections.” A single curve is marked at different points with the angle of incidence (0° to 12°). The column at the left gives the lift-coefficient Ky, while the row at the bottom of the sheet gives the drag-coefficients Kx. At the top of the chart are the lift-drag ratios, each figure being at the end of a diagonal line. In this way the lift, drag, liftdrag and angle of incidence are had from a single curve.

Take the characteristics at an angle of 10 degrees for example. Find the angle of 10° on the curve, and follow horizontally to the left for Ky. The lift-coefficient will be found to be 0.0026 in terms of miles per hour and pounds per square foot. Following down from 10°, it will be found that the drag-coefficient Kx = 0.00036. Note the diagonal lines, and that the 10° point lies nearest to the diagonal headed 7 at the top of the chart. (It is more nearly a lift-drag ratio of 7.33 than 7.) In the same way it will be found that an angle of 8 degrees lies almost exactly on the lift-drag diagonal marked 9. The best lift-drag is reached at about 2 degrees at which point it is shown as 17.0. The best lift-coefficient Ky is 0.00276 at 12 degrees.

[image]

Fig. 5. Polar Type Chart Originated By Eiffel.

A third class of chart is shown by Fig. 6. This single chart shows three of the factors by means of three curves; one for the lift-coefficient, one for the drag-coefficient, and one for the C. P. movement. Follow the solid curves only, for the dotted lines are for comparison with the results obtained by another laboratory in checking the characteristics of the wing. The curves refer to the R.A.F.-6 section described in the chapter on "Practical Wing Sections." The lift-coefficients Ky will be found at the right of the chart with the drag-coefficients Kx at the left and in the lower column of figures. The upper column at the left is for the C. P. movement and gives the C. P. location in terms of the chord length. The angles of incidence will be found at the bottom. Values are in terms of pounds per square foot, and miles per hour.

[image]

Fig. 6. Chart of R.A.F.-6 Wing Section with Three Independent Curves.

In using this chart, start with the angle of incidence at the bottom, and follow up vertically to the lift or drag curves. If the value of Ky is desired, proceed from the required incidence and up to the "Lift" curve, then horizontally to the right. To obtain the drag, follow up from the angle of incidence to the "drift" curve, and then horizontally to the left. For the position of the C. P., trace up from angle until the "Center of Pressure" curve is reached, and then across horizontally to the left. If the angle of 8 degrees is assumed, the lift-coefficient will be found as Ky = 0.0022, the drag Kx =0.00016, and the center of pressure will be located at 0.32 of the chord from the leading edge. This test was made with the air density at 0.07608 pounds per cubic foot, and at a speed of 29.85 miles per hour. The peak at the burble point is fairly flat, and gives a good range of angle before the lift drops to a serious extent. The aerofoil R.A.F.-6 is a practical wing form used in many machines, and this fact should make the chart of special interest.

Surface Calculations. The calculation of lift and drag for an aerofoil are the same as those for a flat plate, that is, the total lift is expressed by the formula: $L = KyAV^2$ where A is the area in square feet, and V is the velocity in miles per hour.

From this primary equation, the values of the area and velocity may be found by transposition.

$A = L/KyV^2$ and $V = L/KyA$.

The drag can be found from the old equation, $D = KxAV^2$, or by dividing the lift by the lift-drag ratio as in the case of the flat plate.

Example: A wing of the R.A.F.-6 form has an area of 200 square feet, and the speed is 60 miles per hour. What is the lift at 6° incidence?

Solution. From Chart No. 6 the lift coefficient Ky is 000185 at 6°, hence the total lift is: $L = KyAV^2 = 0.00185 \times 200 \times (60 \times 60) = 1332$ pounds. With an angle of 8 degrees, and with the same speed and area, the lift becomes,

$L = 0.0022 \times 200 \times (60 \times 60) = 1584$ pounds. The drag coefficient Kx at an angle of 6° is 0.00012, and at 8° is 0.00016. The drag at 6° becomes $D = KxAV^2 = 0.00012 \times 200 \times (60 \times 60) = 86.4$ pounds. The lift-drag ratio at this angle is $L/D = 1332/864 = 15.4$. The drag at 8° is $D = KxAV^2 = 0.00016 \times 200 \times (60 \times 60) = 115.2$ pounds. The lift-drag at 8° is $L/D = 1584/115.2 = 13.8$.

Forces Acting on Aerofoil. Fig. 7 is a section through an aerofoil of a usual type, with a concave under-surface In an aerofoil of this character all measurements are made from the chordal line X-X which is a straight line drawn across (and touching) the entering and trailing edges of the aerofoil. The angle made by X-X with the horizontal is the angle of incidence (i). The width of the section, measured from tip to tip of the entering and trailing edges, is called the "Chord." In this figure the entering edge is at the left. The direction of lift is "Up" or as in the case of any aerofoil, acts away from the convex side.

In the position shown, with horizontal motion toward the left, the lift force is indicated by L, and the horizontal drag force by D, the direction of their action being indicated by the arrow heads. The force that is the resultant of the lift and drag, lies between them, and is shown by R. The point at which the line of the resultant force intersects the chordal line X-X is called the "Center of Pressure" (C. P.) The resultant is not always at right angles to the chordal line as shown, but may lie to either side of this right angle line according to the angle of incidence (i). A force equal to and in the same direction as R, will hold the forces L and D in equilibrium if applied at the center of pressure (C. P.) Owing to the difference in the relative values of L and D at various angles of incidence, the angle made by R with the chordal line must vary. The lift and drag are always at right angles to one another. The resultant can be found by drawing both the lines L and D through the C. P., and at right angles to one another, and then closing up the parallelogram by drawing lines parallel to L and D from the extreme ends of the latter. The resultant force in direction and extent will be the diagonal R drawn across the corners of the parallelogram.

The forces acting on the upper and lower surfaces are different, both in di-

[image]

Fig. 7. Forces Acting on an Aerofoil, Lift, Drag, and Resultant. Relative Wind Is from Left to Right.

rection and magnitude, owing to the fact that the upper and lower surfaces do not contribute equally to the support of the aerofoil. The upper surface contributes from 60 to 80 per cent of the total lift. A change in the outline of the upper curved surface vitally affects both the lift and lift-drag, but a change in the lower surface affects the performance to an almost negligible amount.

In the case of thin circular arched plates the curvature has a much more pronounced effect. When the curvature of a thin plate is increased, both the upper and lower surfaces are increased in curvature, and this undoubtedly is the cause of the great increase in the lift of the sheet metal aerofoils tested by Eiffel.

The drag component of the front upper surface is ”Negative,” that is, acts with the horizontal force instead of against it. The lower surface drag component is of course opposed to the horizontal propelling force by enough to wholly overcome the assisting negative drag force of the front upper surface. The resultants vary from point to point along the section of the aerofoil both in extent and direction. A resultant true for the entering edge would be entirely different at a point near the trailing edge.

Distribution of Pressure. To fully understand the relative pressures and forces acting on different parts of the aerofoil we must refer to the experimental results obtained by the Eiffel and the N. P. L. laboratories. In these tests small holes were drilled over the aerofoil surface at given intervals, each hole in turn being connected to a manometer or pressure gauge, and the pressure at that point recorded. While the reading was being taken, the wind was passed over the surface so that the pressures corresponded to actual working conditions. It was found that the pressure not only varied in moving from the entering to trailing edge, but that it also varied from the center to the tips in moving along the length of the plane. The rate of variation differed among different aerofoils, and with the same aerofoil at different angles of incidence.

On the upper surface, the suction or vacuum was generally very high in the immediate vicinity of the entering edge. From this point it decreased until sometimes the pressure was actually reversed near the trailing edge and at the latter point there was actually a downward pressure acting against the lift. The positive pressure on the under surface reached a maximum more nearly at the center, and in many cases there was a vacuum near the entering edge or at the trailing edge. With nearly all aerofoils, an increase in the curvature resulted in a decided increase in the vacuum on the upper surface, particularly with thin aerofoils curved to a circular arc.

[image]

Fig. 8. Pressure Distribution for Thin Circular Section. Fig. 9. Shows the Effect of Increasing the Camber. (Eiffel)

By taking the sum of the pressures at the various parts of the surface, it was found that the total corresponded to the lift of the entire aerofoil, thus proving the correctness of the investigation. The sum of the drag forces measured at the different openings gave a lower total than the total drag measured by the balance, and this at once suggests that the difference was due to the skin friction effect that of course gave no pressure indication. The truth of this deduction is still further proved by the fact that the drag values were more nearly equal at large angles where the turbulence formed a greater percentage of the total drag.

Figs. 8, 9, 10, 11, 12 are pressure distribution curves taken along the section of several aerofoil surfaces. These are due to Eiffel. In Fig. 8 is the pressure curve for a thin circular aerofoil section, the depth of the curve measured from the chordal line being 1/13.5 of the chord. The vacuum distribution of the upper surface is indicated by the upper dotted curve, while the pressure on the bottom surface is given by the solid curve under the aerofoil. The pressures are given by the vertical column of figures at the right and are in terms of inches of water, that is, the pressure required for the support of a water column of the specified height. Figures lying above 0 and marked (-), refer to a vacuum or negative pressures, while the figures below zero are positive pressures above the atmospheric. The entering edge is at the right, and the angle of incidence in all cases is 6°.

It will be seen that the vacuum jumps up very suddenly to a maximum at the leading edge, and again drops as suddenly to about one-half the maximum. From this point it again gradually increases near the center, and then declines toward the trailing edge. It will also be seen that the pressure on the lower surface, given by the solid curve, is far less than the pressure due to the upper surface. Since the lower pressure curve crosses up, and over the zero line at a point near the trailing edge, it is evident that the supper surface near the trailing edge is under a positive pressure, or a pressure that acts down and against the lift. The pressures in any case are very minute, the maximum suction being 0.3546 inch of water, while the maximum pressure on the under surface is only 0.085 inch.

Fig. 9 shows the effect of increasing the curvature or camber, the aerofoil in this case having a depth equal to 1/7 the chord, or nearly double the camber of the first. The sharp peak at the entering edge of the pressure curve is slightly reduced, but the remaining suction pressures over the rest of the surface are much increased, indicating a marked increase in the total pressure. The pressure at the center is now nearly equal to the front peak, and the pressure is generally more evenly distributed. There is a vacuum over the entire upper surface and a positive pressure over the lower. The general increase in pressure due to the increased camber is the result of the greater downward deviation of the air stream, and the corresponding greater change in the momentum of the air. The speed at which the tests were made was 10 meters per second, or 22.4 miles per hour. The curves are only true at the center of the aerofoil length and for an aspect ratio of 6.

The average pressure over the entire surface in Fig. 8 is 1.202 pounds per square foot, and that of Fig. 9 is 1.440 pounds, a difference of 0.238 pound per square foot due to the doubling camber (16.5 per cent). Another aerofoil with a camber of only 1/27 gave an average pressure of 0.853 pound per square foot under the same conditions. A flat plane gave 0.546. Tabulation of these values will show the results more clearly.

Camber of Surface	**Av. Pres. Per Sq. Ft.**	**Inc. in Pres. in Lbs./Sq. Ft.**	**Efficiency**	
			Top.	**Bottom.**
Flat Plane.	0.546	0.000	0.89	0.11
1/27	0.853	0.307	0.72	0.28
1/13.5	1.202	0.349	0.71	0.29
1/7	1.440	0.238	0.59	0.41

In this table, the ”Efficiencies” are the relative lift efficiencies of the top and bottom surfaces. For example, in the case of the 1/7 camber the top surface lifts 59 per cent, and the bottom 41 per cent of the total lift.

Fig. 10 is a thin aerofoil of parabolic form, while Fig. 11 is an approximation to the comparatively thick wing of a bird. In both these sections it will be noted that the front peak is not much greater than the secondary peak, and that the latter is nearer the leading edge than with the circular aerofoils. Also that the drop between the peaks is small or entirely lacking. The lower surface of the trailing edge is subjected to a greater down pressure in the case of the thin parabola, and there is also a considerable down pressure on the upper leading edge. The pressure in Fig. 10 is 1.00 pound per square foot, and that of No. 11 is

1.205, while the efficiency of the top surfaces is respectively 72 and 74 per cent.

[image]

Fig. 10. Thin Parabolic Aerofoil with Pressure Distribution. Fig. 11. Pressure Distribution of Thick Bird's Wing Type. (Eiffel)

Fig. 12 shows the effect of changing the angle of the bird wing from zero to 8 degrees. The lift per square foot in each case is shown at the upper left hand corner of the diagram while the percentages of the upper and lower surface lifts are included above and below the wing. For these curves I am indebted to E. R. Armstrong, formerly of "Aero and Hydro." As the angle is increased, the suction of the upper surface is much increased (0.541 to 1.370 pounds per square foot), and the pressure at the leading edge increases from depression to a very long thin peak. The maximum under pressure is not much increased by the angle, but its distribution and average pressure are much altered. At 0° and 2° the usual pressure is reduced to a vacuum over the front of the section as shown by the lower curve crossing over the upper side of the wing, and at this point the under surface sucks down and acts against the lift.

[image]

Fig. 12. Effect of Incidence Changes on the Pressure Distribution of a Thick Bird's Wing. (After Eiffel)

Distribution of Drag Forces. The drag as well as the lift changes in both direction and magnitude for different points on the wing. In the front and upper portions the drag is "Negative," that is, instead of producing head resistance to motion it really acts with the propelling force. Hence on the upper and front portions the lift is obtained with no expenditure of power, and in fact thrust is given up and added to that of the propeller. The remaining drag elements at the rear, and on the lower surface, of course more than overcome this desirable tendency and give a positive drag for the total wing. The distribution is shown by Fig 13 which gives the lift, drag and resultant forces at a number of different points on two circular arc aerofoils having cambers of 1/13.5 and 1/7 respectively. In this figure, the horizontal drag forces are marked D and d, and the direction of the drag is shown by the arrows. The lift is shown by L and the resultant by R as in the Fig. 7.

As shown, the arrows pointing to the right are the ”Negative” drag (d) forces that assist in moving the plane forward, while the drag indicated by arrows (D) pointing to the left are the drag forces that oppose or resist the horizontal motion. With the smaller camber (1/13.5) the drag forces are very much smaller than those with the heavier camber of 1/7, and the negative drifts (d) are correspondingly smaller. All of the drag due to the lower surface, point to the left (D), and hence produce head resistance to flight. The drag to the rear of the center of the upper surface are the same. In front of the upper center we have right hand, or negative drifts (d), that aid the motion. These forward forces obtained by experiment prove the correctness of Lilienthal’s ”Forward Tangential” theory advanced many years ago.

[image]

Fig. 13. Direction of Drag Over Different Portions of Circular Arc - Aerofoils.

[image]

Fig. 14a. Distribution for Wright Wing. (b) M. Farman Wing. (c) Breguet Wing. (d) Bleriot Wing. (e) Bleriot 11-Bis.

[image]

Fig. 15. Pressure Distribution at Various Points Along the Length of a Nieuport Monoplane Wing.

Distribution on Practical Wings. With the exception of the bird wing, the distributions have been given for thin plates that are of little value on an aeroplane. They do not permit of strong structural members for carrying the load. The actual wing must have considerable thickness, as shown by the aerofoils in Figs. 1, 2, 3, etc., and are of approximately stream line form. Fig. 14 shows the distribution for actual aeroplane wings: (a) Wright, (b) M. Farman, (c) Breguet, (d) Bleriot 11.(d), (e) Bleriot 11-bis. The Wright wing is very blunt and has an exceedingly high lift at the leading edge. The M. Farman, which is slightly less blunt, has a similar but lower front peak. The Breguet is of a more modern type with the maximum thickness about 25 per cent from the leading edge. The latter shows a remarkably even distribution of pressure, and is therefore a better type as will be seen from the relative lifts of 0.916 and 0.986 pounds per square foot. The lift-drag ratio of the Breguet is also better, owing to the greater predominance of the negative drag components. Decreasing the thickness and the undercamber of Bleriot 11, resulted in an unusual increase of 10 per cent of the under pressure, and a decrease in the Suction, shown by Bleriot 11-bis. The Bleriot has the sharpest entering edge and the least upper pressure. In the above practical wing sections the aspect ratio is variable, being the same in the test model as in the full-size machine. The Bleriot being a monoplane has a lower aspect ratio (5), than the biplanes (a), (b) and (c). The Breguet with an aspect of 8 has a lift of 0.986 pounds per square foot as against the 0.781 of the Bleriot, and undoubtedly part of this difference is due to the aspect ratio. The pressure falls off around the tips as shown by the successive sections taken through a Nieuport monoplane wing in Fig. 15. Section (f) was taken near the body and shows the greater lift. Section (g) is midway between the tips and body, and (h) and (i) are progressively nearer the tips. As we proceed toward the tips from the body the pressure falls off as shown in the sections, this reducing from 1.07 to 0.55 pounds per square foot. This wing also thins down toward the tips or "washes out," as it is called.

[image]

Fig. 16. Showing Pressure Distribution on the Plan View of a Typical Wing, Leading Edge Along A-A, Trailing Edge D-C. Center of Pressure. Marked "C.P." The Proportion Pressures Are Indicated by the Shading on the Surface, the Pressure Being Negative at the Tips and Near the Rear Edge.

CHAPTER VI. PRACTICAL WING SECTIONS.

Development of Modern Wings. The first practical results obtained by Wright Brothers, Montgomery, Chanute, Henson, Curtiss, Langley, and others, were obtained by the use of cambered wings. The low value of the lift-drag ratio, due to the flat planes used by the earlier experimenters, was principally the cause of their failure to fly. The Wrights chose wings of very heavy camber so that a maximum lift could be obtained with a minimum speed. These early wings had the very fair lift-drag ratio of 12 to 1. Modern wing sections have been developed that give a lift-drag ratio of well over 20 to 1, although this is attended by a considerable loss in the lift.

As before explained, the total lift of a wing surface depends on the form of the wing, its area, and the speed upon which it moves in relation to the air. Traveling at a low speed requires either a wing with a high lift co-efficient or an increased area. With a constant value for the lift-drag ratio, an increase in the lift value of the wing section is preferable to an increase in area, since the larger area necessitates heavier structural members, more exposed bracing, and hence, more head resistance. Unfortunately, it is not always possible to use the sections giving the heaviest lift, for the reason that such sections usually have a poor lift-drag ratio. In the practical machine, a compromise must be effected between the drag of the wings and the drag or head resistance of the structural parts so that the combined or total head resistance will be at a minimum. In making such a compromise, it must be remembered that the head resistance of the structural parts predominates at high speeds, while the drag of the wings is the most important at low speeds.

In the early days of flying, the fact that an aeroplane left the ground was a sufficient proof of its excellence, but nowadays the question of efficiency under different conditions of flight (performance) is an essential. Each new aeroplane is carefully tested for speed, rate of climb, and loading. Speed range, or the relation between the lowest and highest possible flight speeds, is also of increasing importance, the most careful calculations being made to obtain this desirable quality.

Performance. To improve the performance of an aeroplane, the designer must increase the ratio of the horsepower to the weight, or in other words, must either use greater horsepower or decrease the weight carried by a given power. This result may be obtained by improvements in the motor, or by improvements in the machine itself. Improvements in the aeroplane may be attained in several ways: (1) by cutting down the structural weight; (2) by increasing the efficiency of the lifting surfaces; (3) by decreasing the head resistance of the body and exposed structural parts, and (4) by adjustment of the area or camber of the wings so that the angle of incidence can be maintained at the point of greatest plane efficiency. At present we are principally concerned with item (2), although (4) follows as a directly related item.

Improvement in the wing characteristics is principally a subject for the wind tunnel experimentalist, since with our present knowledge, it is impossible to compute the performance of a wing by direct mathematical methods. Having obtained the characteristics of a number of wing sections from the aerodynamic laboratory, the designer is in a position to proceed with the calculation of the areas, power, etc. At present this is rather a matter of elimination, or ”survival of the fittest,” as each wing is taken separately and computed through a certain range of performance.

Wing Loading. The basic unit for wing lift is the load carried per unit of area. In English units this is expressed as being the weight in pounds carried by a square foot of the lifting surface. Practically, this value is obtained by dividing the total loaded weight of the machine by the wing area. Thus, if the weight of a machine is 2,500 pounds (loaded), and the area is 500 square feet, the ”unit loading” will be: w = 2,500/500 = 5 pounds per square foot. In the metric system the unit loading is given in terms of kilogrammes per square meter. Conversely, with the total weight and loading known, the area can be computed by dividing the weight by the unit loading. The unit loading adopted for a given machine depends upon the type of machine, its speed, and the wing section adopted, this quantity varying from 3.5 to 10 pounds per square foot in usual practice. As will be seen, the loading is higher for small fast machines than for the slower and larger types.

A very good series of wings has been developed, ranging from the low resistance type carrying 5 pounds per square foot at 45 miles per hour, to the high lift wing, which gives a lift of 7.5 pounds per square foot at the same speed. The medium lift wing will be assumed to carry 6 pounds per square foot at 45 miles per hour. The wing carrying 7.5 pounds per square foot gives a great saving in area over the low lift type at 5 pounds per square foot, and therefore a great saving in weight. The weight saved is not due to the saving in area alone, but is also due to the reduction in stress and the corresponding reduction in the size and weight of the structural members. Further, the smaller area requires a smaller tail surface and a shorter body. A rough approximation gives a saving of 1.5 pounds per square foot in favor of the 7.5 pound wing loading. This materially increases the horsepower weight ratio in favor of the high lift wing, and with the reduction in area and weight comes an improvement in the vision range of the pilot and an increased ease in handling (except in dives). The high lift types in a dive have a low limiting speed.

As an offset to these advantages, the drag of the high lift type of wing is so great at small angles that as soon as the weight per horsepower is increased beyond 18 pounds we find that the speed range of the low resistance type increases far beyond that of the high lift wing. According to Wing Commander Seddon, of the English Navy, a scout plane of the future equipped with low resistance wings will have a speed range of from 50 to 150 miles per hour. The same machine equipped with high lift wings would have a range of only 50 to 100 miles per hour. An excess of power is of value with low resistance wings, but is increasingly wasteful as the lift co-efficient is increased. Landing speeds have a great influence on the type of wing and the area, since the low speeds necessary for the average machines require a high lift wing, great area, or both. With the present wing sections, low flight speeds are obtained with a sacrifice in the high speed values. In the same way, high speed machines must land at dangerously high speeds. At present, the best range that we can hope for with fixed areas is about two to one; that is, the high speed is not much more than twice the lowest speed. A machine with a low speed of 45 miles per hour cannot be depended upon to safely develop a maximum speed of much over 90 miles per hour, for at higher speeds the angle of incidence will be so diminished as to come dangerously near to the position of no lift. In any case, the travel of the center of pressure will be so great at extreme wing angles as to cause considerable manipulation of the elevator surface, resulting in a further increase in the resistance.

Resistance and Power. The horizontal drag (resistance) of a wing, determines the power required for its support since this is the force that must be overcome by the thrust of the propeller. The drag is a component of the weight supported and therefore depends upon the loading and upon the efficiency of the wing. The drag of the average modern wing, structural resistance neglected, is about 1/16 of the weight supported, although there are several sections that give a drag as low as 1/23 of the weight. The denominators of these fractions, such as ”16” and ”23,” are the lift-drag ratios of the wing sections.

Drag in any wing section is a variable quantity, the drag varying with the angle of incidence. In general, the drag is at a minimum at an angle of about 4 degrees, the value increasing rapidly on a further increase or decrease in the angle. Usually a high lift section has a greater drag than the low lift type at small angles, and a smaller drag at large angles, although this latter is not invariably the case.

Power Requirements. Power is the rate of doing work, or the rate at which resistance is overcome. With a constant resistance the power will be increased by an increase in the speed. With a constant speed, the power will be increased by an increase in the resistance. Numerically, the power is the product of the force and the velocity in feet per second, feet per minute, miles per hour, or meters per second. The most common English power unit is the ”horsepower,” which is obtained by multiplying the resisting force in pounds by the velocity in feet per minute, this product being divided by 33,000. If D is the horizontal drag in pounds, and v = velocity of the wing in feet per minute, the horsepower H will be expressed by:

$H = Dv / 33{,}000$

Since the speed of an aeroplane is seldom given in feet per minute, the formula for horsepower can be given in terms of miles per hour by:

$H = DV / 375$

Where V = velocity in miles per hour, D and H remaining as before. The total power for the entire machine would involve the sum of the wing and structural drags, with D equal to the total resistance of the machine.

Example. The total weight of an aeroplane is found to be 3,000 pounds. The lift-drag ratio of the wings is 15.00, and the speed is 90 miles per hour. Find the power required for the wings alone.

Solution. The total drag of the wings will be: D = 3,000/15 = 200 pounds. The horsepower required: H = DV/375 = 200 × 90/375=48 horsepower. It should be remembered that this is the power absorbed by the wings, the actual motor power being considerably greater owing to losses in the propeller. With a propeller efficiency of 70 per cent, the actual motor power will become: Hm = 48/0.70=68.57 for the wings alone. To include the efficiency into our formula, we have:

H = DV/375E

where E = propeller efficiency expressed as a decimal. The greater the propeller efficiency, the less will be the actual motor power, hence the great necessity for an efficient propeller, especially in the case of pusher type aeroplanes where the wings do not gain by the increased slip stream.

The propeller thrust must be equal and opposite to the drag at the various speeds, and hence the thrust varies with the plane loading, wing section, and angle of incidence. Portions of the wing surfaces that lie in the propeller slip stream have a greater lift than those lying outside of this zone because of the greater velocity of the slip stream. For accurate results, the area in the slip stream should be determined and calculated for the increased velocity.

Oftentimes it is desirable to obtain the ”Unit drag”; that is, the drag per square foot of lifting surface. This can be obtained by dividing the lift per square foot by the lift-drag ratio, care being taken to note the angle at which the unit drag is required.

Advantages of Cambered Sections Summarized. Modern wing sections are always of the cambered, double-surface type for the following reasons:

1. They give a better lift-drag ratio than the flat surface, and therefore are more economical in the use of power.

2. In the majority of cases they give a better lift per square foot of surface than the flat plate and require less area.

3. The cambered wings can be made thicker and will accommodate heavier spars and structural members without excessive head resistance.

Properties of Modern Wings. The curvature of a wing surface can best be seen by cutting out a section along a line perpendicular to the length of the wing, and then viewing the cut portion from the end. It is from this method of illustration that the different wing curves, or types of wings, are known as ”wing sections.” In all modern wings the top surface is well curved, and in the majority of cases the bottom surface is also given a curvature, although this is very small in many instances.

Fig. 1. shows a typical wing section with the names of the different parts and the methods of dimensioning the curves. All measurements to the top and bottom surfaces are taken from the straight ”chordal line” or ”datum line” marked X-X. This line is drawn across the concave undersurface in such a way as to touch the surface only at two points, one at the front and one at the rear of the wing section. The inclination of the wing with the direction of flight is always given as the angle made by the line X-X with the wind. Thus, if a certain wing is said to have an angle of incidence equal to 4 degrees, we know that the chordal line X-X makes an angle of 4 degrees with the direction of travel. This angle is generally designated by the letter (i), and is also known as the ”angle of attack.” The distance from the extreme front to the extreme rear edge (width of wing) is called the ”chord width” or more commonly ”the chord.”

In measuring the curve, the datum line X-X is divided into a number of equal parts, usually 10, and the lines 1-2-3-4-5-6-7-8-9-10-11 are drawn perpendicular to X-X. Each of the vertical numbered lines is called a ”station,” the line No. 3 being called ”Station 3,” and so on. The vertical distance measured from X-X to either of the curves along one of the station lines is known as the ”ordinate” of the curve at that point. Thus, if we know the ordinates at each station, it is a simple matter to draw the straight line X-X, divide it into 10 parts, and then lay off the heights of the ordinates at the various stations. The distances from datum to the upper curve are known as the ”Upper ordinates,” while the same measurements to the under surface are known as the ”Lower ordinates.” This method allows us to quickly draw any wing section from a table that gives the upper and lower ordinates at the different stations.

A common method of expressing the value of the depth of a wing section in terms of the chord width is to give the ”Camber,” which is numerically the result obtained by dividing the depth of the wing curve at any point by the width of the chord. Usually the camber given for a wing is taken to be the maximum camber; that is, the camber taken at the point of greatest depth. Thus, if we hear that a certain wing has a camber of 0.089, we take it for granted that this is the camber at the deepest portion of the wing. The correct method would be to give 0.089 as the ”maximum camber” in order to avoid confusion. To obtain the maximum camber, divide the maximum ordinate by the chord.

Example. The maximum ordinate of a certain wing is 5 inches, and the chord is 40 inches. What is the maximum camber? The maximum camber is 5/40 = 0.125. In other words, the maximum depth of this wing is 12.5 per cent of the

[image]

Fig. 1. Section Through a Typical Aerofoil or Wing, the Parts and Measurements Being Marked on the Section. The Horizontal Width or "Chord" Is Divided Into 10 Equal Parts or "Stations," and the Height of the Top and Bottom Curves Are Measured from the Chordal Line X-X at Each Station. The Vertical Distance from the Chordal Line Is the "Ordinate" at the Point of Measurement.

chord, and unless otherwise specified, is taken as being the camber of the top surface.

The maximum camber of a modern wing is generally in the neighborhood of 0.08, although there are several Successful sections that are well below this figure. Unfortunately, the camber is not a direct index to the value of a wing, either in regard to lifting ability or efficiency. By knowing the camber of a wing we cannot directly calculate the lift or drag, for there are several examples of wings having widely different cambers that give practically the same lift and drift. At the present time, we can only determine the characteristics of a wing by experiment, either on a full size wing or on a scale model.

In the best wing sections, the greatest thickness and camber occurs at a point about 0.3 of the chord from the front edge, this edge being much more blunt and abrupt than the portions near the trailing edge. An efficient wing tapers very gradually from the point of maximum camber towards the rear. This is usually a source of difficulty from a structural standpoint since it is difficult to get an efficient depth of wing beam at a point near the trailing edge. A number of experiments performed by the National Physical Laboratory show that the position of maximum ordinate or camber should be located at 33.2 per cent from the leading edge. This location gives the greatest lift per square foot, and also the least resistance for the weight lifted. Placing the maximum ordinate further forward is worse than placing it to the rear.

Thickening the entering edge causes a proportionate loss in efficiency. Thickening the rear edge also decreases the efficiency but does not affect the weight lifting value to any great extent. The camber of the under surface seems to have but little effect on the efficiency, but the lift increases slightly with an increase in the camber of the lower surface. Increasing the camber of the lower surface decreases the thickness of the wing and hence decreases the strength of the supporting members, particularly at points near the trailing edge. The increase of lift due to increasing the under camber is so slight as to be hardly worth the sacrifice in strength. Variations in the camber of the upper surface are of much greater importance. It is on this surface that the greater part of the lift takes places, hence a change in the depth of this curve, or in its outline, will cause wider variations in the characteristics of the wing than would be the case with the under surface. Increasing the upper camber by about 60 per cent may double the lift of the upper surface, but the relation of the lift to the drag is increased. From this, it will be seen that direct calculations from the outline would be most difficult, and in fact a practical impossibility at the present time.

[image]

Fig. 2. (Upper). Shows a Slight ”Reflex” or Upward Turn of the Trailing Edge. Fig. 3. (Lower) Shows an Excessive Reflex Which Greatly Reduces the C.P. Movement.

By putting a reverse curve in the trailing edge of a wing, as shown by Fig. 2, the stability of the wing may be increased to a surprising degree, but the lift and efficiency are correspondingly reduced with each increase in the amount of reverse curvature. In this way, stability is attained at the expense of efficiency and lifting power. With the rear edge raised about 0.037 of the chord, the N. P. L. found that the center of pressure could be held stationary, but the loss of lift was about 25 per cent and the loss of efficiency amounted practically 12 per cent. With very slight reverse curvatures it has been possible to maintain the lift and efficiency, and at the same time to keep the center of pressure movement down to a reasonable extent. The New U.S.A. sections and the Eiffel No. 32 section are examples of excellent sections in which a slight reverse or ”reflex” curvature is used. The Eiffel 32 wing is efficient, and at the same the center of pressure movement between incident angles of 0° and 10° is practically negligible. This wing is thin in the neighborhood of the trailing edge, and it is very difficult to obtain a strong rear spar.

Wing Selection. No single wing section is adapted to all purposes. Some wings give a great lift but are inefficient at small angles and with light loading. There are others that give a low lift but are very efficient at the small angles used on high speed machines. As before explained, there are very stable sections that give but poor results when considered from the standpoint of lift and efficiency. The selection of any one wing section depends upon the type of machine upon which it is to be used, whether it is to be a small speed machine or a heavy flying boat or bombing plane.

There are a multitude of wing sections, each possessing certain admirable features and also certain faults. To list all of the wings that have been tried or proposed would require a book many times the size of this, and for this reason I have kept the list of wings confined to those that have been most commonly employed on prominent machines, or that have shown evidence of highly desirable and special qualities. This selection has been made with a view of including wings of widely varying characteristics so that the data can be applied to a wide range of aeroplane types. Wings suitable for both speed and weight carrying machines have been included.

The wings described are the U.S.A. Sections No. 1, 2, 3, 4, 5 and 6; the R.A.F. Sections Nos. 3 and 6, and the well known Eiffel Wings No. 32, 36 and 37. The data given for these wings is obtained from wind tunnel tests made at the Massachusetts Institute of Technology, the National Physical Laboratory (England), and the Eiffel Laboratory in Paris. For each of these sections the lift co-efficient (Ky), the lift-drift ratio (L/D), and the drag co-efficient (Kx) are given in terms of miles per hour and pounds per square foot. Since these are the results for model wings, there are certain corrections to be made when the full size wing is considered, these corrections being made necessary by the fact that the drag does not vary at the same rate as the lift. This ”Size” or ”Scale” correction is a function of the product of the wing span in feet by the velocity of the wind in feet per second. A large value of the product results in a better wing performance, or in other words, the large wing will always give better lift-drag ratios than would be indicated by the model tests. The lift co-efficient Ky is practically unaffected by variations in the product. If the model tests are taken without correction, the designer will always be on the safe side in calculating the power. The method of making the scale corrections will be taken up later.

Of all the sections described, the R.A.F.-6 is probably the best known. The data on this wing is most complete, and in reality it is a sort of standard by which the performance of other wings is compared. Data has been published which describes the performance of the R.A.F.-6 used in monoplane, biplane and triplane form; and with almost every conceivable degree of stagger, sweep back, and decalage. In addition to the laboratory data, the wing has also been used with great success on full size machines, principally of the ”Primary trainer” class where an ”All around” class of wing is particularly desirable. It is excellent from a structural standpoint since the section is comparatively deep in the vicinity of the trailing edge. The U.S.A. sections are of comparatively recent development and are decided improvements on the R.A.F. and Eiffel sections. The only objection is the limited amount of data that is available on these wings—limited at least when the R.A.F. data is considered—as we have only the figures for the monoplane arrangement.

WING SELECTION.

(1) Lift-Drag Ratio. The lift-drag ratio (L/D) of a wing is the measure of wing efficiency. Numerically, this is equal to the lift divided by the horizontal drag, both quantities being expressed in pounds. The greater the weight supported by a given horizontal drag, the less will be the power required for the propulsion of the aeroplane, hence a high value of L/D indicates a desirable wing section—at least from a power standpoint. In the expression L/D, L = lift in pounds, and D = horizontal drag in pounds. Unfortunately, this is not the only important factor, since a wing having a great lift-drag is usually deficient in lift or is sometimes structurally weak.

The lift-drag ratio varies with the angle of incidence (i), reaching a maximum at an angle of about 4° in the majority of wings. The angle of incidence at which the lift-drag is a maximum is generally taken as the angle of incidence for normal horizontal flight. At angles either greater or less, the L/D falls off, generally at a very rapid rate, and the power increases correspondingly. Very efficient wings may have a ratio higher than L/D=20 at an angle of about 4°, while at 16° incidence the value may be reduced to L/D = 4, or even less. The lift is generally greatest at about 16°. The amount of variation in the lift, and lift-drag, corresponding to changes in the incidence differs among the different types of wings and must be determined by actual test.

After finding a wing with a good value of L/D, the value of the lift co-efficient Ky should be determined at the angle of the maximum L/D. With two wings having the same lift-drag ratio, the wing having the greatest lift (Ky) at this point is the most desirable wing as the greater lift will require less area and will therefore result in less head resistance and less weight. Any increase in the area not only increases the weight of the wing surface proper, but also increases the wiring and weights of the structural members. With heavy machines, such as seaplanes or bomb droppers, a high value of Ky is necessary if the area is to be kept within practical limits. A small fast scouting plane requires the best possible lift-drag ratio at small angles, but requires only a small lift co-efficient. At speeds of over 100 miles per hour a small increase in the resistance will cause a great increase in the power.

(2) Maximum Lift (Ky). With a given wing area and weight, the maximum value of the lift co-efficient (Ky) determines the slow speed, or landing speed, of the aeroplane. The greater the value of Ky, the slower can be the landing speed. For safety, the landing speed should be as low as possible.

In the majority of wings, the maximum lift occurs at about 16° of incidence, and in several sections this maximum is fairly well sustained over a considerable range of angle. The angle of maximum lift is variously known as the ”Stalling angle” or the ”Burble point,” since a change of angle in either direction reduces the lift and tends to stall the aeroplane. For safety, the angle range for maximum lift should be as great as possible, for if the lift falls off very rapidly with an increase in the angle of incidence, the pilot may easily increase the angle too far and drop the machine. In the R.A.F.-3 wing, the lift is little altered through an angle range of from 14° to 16.5°, the maximum occurring at 15.7°, while with the R.A.F.-4, the lift drops very suddenly on increasing the angle above 15°. The range of the stalling angle in any of the wings can be increased by suitable biplane or triplane arrangements. If large values of lift are accompanied by a fairly good L/D value at large angles, the wing section will be suitable for heavy machines.

(3) Center of Pressure Movement. The center of pressure movement with varying angles of incidence is of the greatest importance, since it not only determines the longitudinal stability but also has an important effect upon the loading of the wing spars and ribs. With the majority of wings a decrease in the angle of incidence causes the center of pressure to move back toward the trailing edge and hence tends to cause nose diving. When decreased beyond 0° the movement is very sharp and quick, the C. P. moving nearly half the chord width in the change from 0° to -1.5°. The smaller the angle, the more rapid will be the movement. Between 6° and 16°, the center of pressure lies near a point 0.3 of the chord from the entering edge in the majority of wing sections. Reducing the angle from 6° to 2° moves the C. P. back to approximately 0.4 of the chord from the entering edge.

There are wing sections, however, in which the C. P. movement is exceedingly small, the Eiffel 32 being a notable example of this type. This wing is exceedingly stable, as the C. P. remains at a trifle more than 0.30 of the chord through nearly the total range of flight angles. An aeroplane equipped with the Eiffel 32 wing could be provided with exceedingly small tail surfaces without a tendency to dive. Should the elevator become inoperative through accident, the machine could probably be landed without danger. This wing has certain objectionable features, however, that offset the advantages.

It will be noted that with the unstable wings the center of pressure movement always tends to aggravate the wing attitude. If the machine is diving, the decrease in angle causes the C. P. to move back and still further increase the diving tendency. If the angle is suddenly increased, the C. P. moves forward and increases the tendency toward stalling.

If the center of pressure could be held stationary at one point, the wing spars could be arranged so that each spar would take its proper proportion of the load. As it is, either spar may be called upon to carry anywhere from three-fourths of the load to entire load, since at extreme angles the C. P. is likely to lie directly on either of the spars. Since the rear spar is always shallow and inefficient, this is most undesirable. This condition alone to a certain extent counterbalances the structural disadvantage of the thin Eiffel 32 section. Although the spars in this wing must of necessity be shallow, they can be arranged so that each spar will take its proper share of the load and with the assurance that the loading will remain constant throughout the range of flight angles. The comparatively deep front spar could be moved back until it carried the greater part of the load, thus relieving the rear spar.

With a good lift-drag ratio, and a comparatively high value of Ky, the center of pressure movement should be an important consideration in the selection of a wing. It should be remembered in this regard that the stability effects of the C. P. movement can be offset to a considerable extent by suitable biplane arrangements.

(4) Structural Considerations. For large, heavy machines, the structural factor often ranks in importance with the lift-drag ratio and the lift co-efficient. It is also of extreme importance in speed scouts where the number of interplane struts are to be at a minimum and where the bending moment on the wing spars is likely to be great in consequence. A deep, thick wing section permits of deep strong wing spars. The strength of a spar increases with the square of its depth, but only in direct proportion to its width. Thus, doubling the depth of the spar increases the strength four times, while doubling the width only doubles the strength. The increase in weight would be the same in both cases.

While very deep wings are not usually efficient, when considered from the wing section tests alone, the total efficiency of the wing construction when mounted on the machine is greater than would be supposed. This is due to the lightness of the spars and to the reduction in head resistance made possible by a greater spacing of the interplane struts. Thus, the deep wing alone may have a low L/D in a model test, but its structural advantages give a high total efficiency for the machine assembled.

Summary. It will be seen from the foregoing matter that the selection of a wing consists in making a series of compromises and that no single wing section can be expected to fulfill all conditions. With the purpose of the proposed aeroplane thoroughly in mind, the various sections are taken up one by one, until a wing is found that most usefully compromises with all of the conditions. Reducing this investigation to its simplest elements we must follow the routine as described above: (1) Lift-drift ratio and value of Ky at this ratio. (2) Maximum value of Ky and L/D at this lift. (3) Center of pressure movement. (4) Depth of wing and structural characteristics.

Calculations for Lift and Area. Although the principles of surface calculations were described in the chapter on elementary aerodynamics, it will probably simplify matters to review these calculations at this point. The lift of a wing varies with the product of the area, and the velocity squared, this result being multiplied by the co-efficient of lift (Ky). The co-efficient varies with the wing section, and with the angle of incidence. Stated as a formula: $L = KyAV^2$ where A

= area in square feet, and V = velocity of the wing in miles per hour. Assuming an area of 200 square feet, a velocity of 80 miles per hour, and with K = 0.0025, the total life (L) becomes: $L = KyAV^2 = 0.0025 \text{ x } 200 \text{ x } (80 \times 80) = 3{,}200$ pounds. Assuming a lift-drag ratio of 16, the "drag" of the wing, or its resistance to horizontal motion, will be expressed by $D = L/r = 3{,}200/16 = 200$ pounds, where r = lift-drag ratio. It is this resistance of 200 pounds that the motor must overcome in driving the wings through the air. The total resistance offered by the aeroplane will be equal to the sum of the wing resistance and the head resistance of the body, struts, wiring and other structural parts. In the present instance we will consider only the resistance of the wings.

When the lift co-efficient, speed, and total lift are known, the area can be found from $A = L/KyV^2$, the lift, of course, being taken as the total weight of the machine. The area of the supporting surface for a speed of 60 miles per hour, total weight of 2,400 pounds, and a lift co-efficient of 0.002 is calculated as follows:

$A = L/KyV^2 = 2{,}400/0.002 \times (60 \times 60) = 333$ sq. ft.

A third variation in the formula is that used in finding the value of the lift co-efficient for a particular wing loading. From the weight, speed and area, we can find the co-efficient Ky, and with this value we can find a wing that will correspond to the required co-efficient. This method is particularly convenient when searching for the section with the greatest lift-drag ratio. $Ky = L/AV^2$, or when the loading per square foot is known, the co-efficient becomes $Ky = L'/V^2$. For example, let us find the co-efficient for a wing loading of 5 pounds per square foot at a velocity of 80 miles per hour. Inserting the numerical values into the equation we have, $Ky = L'/V^2 = 5/(80 \times 80) = 0.00078$. Any wing, at any angle that has a lift co-efficient equal to 0.00078 will support the load at the given speed, although many of the wings would not give a satisfactory lift-drag ratio with this co-efficient.

It should be noted in the above calculations that no correction has been made for "Scale," aspect ratio or biplane interference. In other words, we have assumed the figures as applying to model monoplanes. In the following tables the lift, lift-drag and drag must be corrected, since this data was obtained from model tests on monoplane sections. The effects of biplane interference will be described in the chapter on "Biplane and Triplane Arrangement," but it may be stated that superposing the planes reduces both the lift co-efficient and the liftdrag ratio, the amount of reduction depending upon the relative gap between the surfaces. Thus with a gap equal to the chord, the lift of the biplane surface will only be about 80 per cent of the lift of a monoplane surface of the same area and section.

Wing Test Data. The data given in this chapter is the result of wind tunnel tests made under standard conditions, the greater part of the results being published by the Massachusetts Institute of Technology. The tests were all made on the same size of model and at the same wind speed so that an accurate comparison can be made between the different sections. All values are for monoplane wings with an aspect ratio of 6, the laboratory models being 18x3 inches. The exception to the above test conditions will be found in the tables of the Eiffel 37 and 36 sections, these figures being taken from the results of Eiffel's laboratory. The Eiffel models were 35.4x5.9 inches and were tested at wind velocities of 22.4, 44.8, and 67.2 miles per hour. The tests made at M. I. T. were all made at a wind speed of 30 miles per hour. The lift co-efficient Ky is practically independent of the wing size and wind velocity, but the drag co-efficient Kx varies with both the size and wind velocity, and the variation is not the same for the different wings. The results of the M. I. T. tests were published in "Aviation and Aeronautical Engineering" by Alexander Klemin and G. M. Denkinger.

The R.A.F. Wing Sections. These wings are probably the best known of all wings, although they are inferior to the new U.S.A. sections. They are of English origin, being developed by the Royal Aircraft Factory (R.A.F.), with the tests performed by the National Physical Laboratory at Teddington, England. The R.A.F.-6 is the nearest approach to the all around wing, this section having a fairly high L/D ratio and a good value of Ky for nearly all angles. It is by no means a speed wing nor is it suitable for heavy machines, but it comprises well between these limits and has been extensively used on medium size machines, such as the Curtiss JN4–B, the London and Provincial, and others. The R.A.F-3 has a very high value for Ky, and a very good lift-drag ratio for the high-lift values. It is suitable for seaplanes, bomb droppers and other heavy machines of a like nature that fly at low or moderate speeds. The outlines of these wings are shown by Figs. 7 and 8, and the camber ordinates are marked as percentages of the chord. In laying out a wing rib from these diagrams, the ordinate at any point is obtained by multiplying the chord length in inches by the ordinate factor at that point. Referring to the R.A.F.-3 diagram, Fig. 8, it will be seen that the ordinate for the upper surface at the third station from the entering edge is 0.064. If the chord of the wing is 60 inches, the height of the upper curve measured above the datum line X-X at the third station will be, 0.064 × 60 = 3.84 inches. At the same station, the height of the lower curve will be, 0.016 × 60= 0.96 inch.

The chord is divided into 10 equal parts, and at the entering edge one of the ten parts is subdivided so as to obtain a more accurate curve at this point. In some wing sections it is absolutely necessary to subdivide the first chord division as the curve changes very rapidly in a short distance. The upper curve, especially at the entering edge, is by far the most active part of the section and for this reason particular care should be exercised in getting the correct outline at this point.

Aerodynamic Properties of the R.A.F. Sections. Table 1 gives the values of Ky, Kx, L/D, and the center of pressure movement (C. P.) for the R.A.F.-3 section

[image]

Figs. 7-8. R.A.F. Wing Sections. Ordinates as Decimals of the Chord.

through a range of angles varying from -2° to 20°. The first column at the left gives the angles of incidence (i), the corresponding values for the lift (Ky) and the drag (Kx) being given in the second and third columns, respectively. The fourth column gives the lift-drag ratio (L/D). The fifth and last column gives the location of the center of pressure for each different angle of incidence, the figure indicating the distance of the C. P. from the entering edge expressed as a decimal part of the chord. As an example in the use of the table, let it be required to find the lift and drag of the R.A.F.-3 section when inclined at an angle of 6° and propelled at a speed of 90 miles per hour. The assumed area will be 300 square feet. At 6° it will be found that the lift co-efficient Ky is 0.002369. From our formulae, the lift will be: $L = KyAV^2$ or numerically, $L=0.002369 \times 300 \times (90 \times 90) = 5{,}7567$ lbs. At the same speed, but with the angle of incidence reduced to 2°, the lift will be reduced to $L = 0.001554 \times 300$ x $(90 \times 90) = 3{,}776.2$ pounds, where 0.001554 is the lift co-efficient at 2°. It will be noted that the maximum lift co-efficient occurs at 14° and continues at this value to a little past 15°. The lift at the stalling angle is fairly constant from 12° to 16°.

[image]

The value of the drag can be found in either of two ways: (1) by dividing the total lift (L) by the lift-drag ratio, or (2) by figuring its value by the formula $D = KxAV^2$. The first method is shorter and preferable. By consulting the table, it will be seen that the L/D ratio at 6° is 14.9. The total wing drag will then be equal to $5{,}756.7/149 = 386.4$ lbs. Figured by the second method, the value of Ky at 6° is 0.000159, and the drag is therefore: $D = KxAV^2 = 0.000159 \times 300 \times (90 \times 90) = 386.4$. This checks exactly with the first method. The lift-drag ratio is best at 4°, the figure being 15.6, while the lift at this point is 0.001963. With the same area and speed, the total lift of the surface at the angle of best lift-drift ratio will be $0001963 \times 300 \times (90 \times 90) = 4{,}770$ lbs.

[image]

At 4° the center of pressure is 0.385 of the chord from the entering edge. If the chord is 60 inches wide, the center of pressure will be located at 0.385 × 60 = 23.1 inches from the entering edge. At 15°, the center of pressure will be 0.29 × 60 = 17.4 inches from the entering edge, or during the change from 4° to 15° the center of pressure will have moved forward by 5.7 inches. At -2°, the pressure has moved over three-quarters of the way toward the trailing edge -0.785 of the chord, to be exact Through the ordinary flight angles of from 2° to 12°, the travel of the center of pressure is not excessive.

The maximum lift co-efficient (Ky) is very high in the R.A.F.-3 section, reaching a maximum of 0.003481 at an incidence of 14°. This is second to only one other wing, the section U.S.A.-4. This makes it suitable for heavy seaplanes.

Table 2 gives the aerodynamic properties of the R.A.F-6 wing, the table being arranged in a manner similar to that of the R.A.F.-3. In glancing down the column of lift co-efficients (Ky), and comparing the values with those of the R.A.F.-3 section, it will be noted that the lift of R.A.F.-6 is much lower at every angle of incidence, but that the lift-drag ratio of the latter section is not always correspondingly higher. At every angle below 2°, at 6°, and at angles above 14°, the L/D ratio of the R.A.F.-3 is superior in spite of its greater lift. The maximum L/D ratio of the R.A.F.-6 at 4° is 16.58, which is considerably higher than the best L/D ratio of the R.A.F.-3. The best lift co-efficient of the R.A.F.-6, 0003045, is very much lower than the maximum Ky of the R.A.F.-3.

The fact that the L/D ratio of the R.A.F.-3 wing is much greater at high lift co-efficients, and large angles of incidence, makes it very valuable as at this point the greater L/D does not tend to stall the plane at slow speed. A large L/D at great angles, together with a wide stalling angle tends for safety in slow speed flying.

Both wing sections are structurally excellent, being very deep in the region of the rear edge, the R.A.F.-6 being particularly deep at this point. A good deep spar can be placed at almost any desirable point in the R.A.F-6, and the trailing edge is deep enough to insure against rib weakness even with a comparatively great overhang.

Scale corrections for the full size R.A.F. wings are very difficult to make. According to the N. P. L. reports, the corrected value for the maximum L/D of the R.A.F.-3 wing is 18.1, the model test indicating a maximum value of 15.6. I believe that L/D = 17.5 would be a safe full size value for this section. The same reports give the full size L/D for the R.A.F.-6 as 18.5, which would be probably safe at 18.0 under the new conditions.

Properties of the Eiffel Sections (32-36-37). Three of the Eiffel sections are shown by Figs. 10, 11 and 12, these Sections being selected out of an enormous number tested in the Eiffel laboratories. They differ widely, both aerodynamically and structurally, from the R.A.F. aerocurves just illustrated.

[image]

Fig. 10-11-12 Ordinates for Three Eiffel Wing Sections

Eiffel 32 is a very stable wing, as has already been pointed out, but the value of the maximum L/D ratio is in doubt as this quantity is very susceptible to changes in the wind velocity—much more than in the average wing. Since Eiffel's tests were carried out at much higher velocity than at the M. I. T., his lift-drift values at the higher speeds were naturally much better than those obtained by the American Laboratory. When tested at 67.2 miles per hour the lift-drift ratio for the Eiffel 32 was 184 while at 22.4 miles per hour, the ratio dropped to 13.4. This test alone will give an idea as to the variation possible with changes in scale and wind velocity. The following table gives the results of tests carried out at the Massachusetts laboratory, reported by Alexander Klemin and G. M. Denkinger in "Aviation and Aeronautical Engineering." Wind speed, 30 miles per hour.

[image]

The C. P. Travel in the Eiffel wing is very small, as will be seen from Table 3. At -2° the C. P. is 0.33 of the chord from the leading edge and only moves back to 0.378 at an angle of 20°, the intermediate changes being very gradual, reaching a minimum of 0.304 at 6° incidence. The maximum Ky of Eiffel 32 is 0.002908, while for the R.A.F.-6 wing, Ky = 0.003045 maximum, both co-efficients being a maximum at 16° incidence, but the lift-drag at maximum Ky is much better for the R.A.F.-6.

Structurally, the Eiffel 32 is at a disadvantage when compared with the R.A.F. sections since it is very narrow at points near the trailing edge. This would necessitate moving the rear spar well up toward the center with the front spar located very near the leading edge. This is the type of wing used in a large number of German machines. It will also be noted that there is a very pronounced reverse curve or "Reflex" in the rear portion, the trailing edge actually curving up from the chord line.

Eiffel 36 is a much thicker wing than either of the other Eiffel curves shown, and is deficient in most aerodynamical respects. It has a low value for Ky and a poor lift-drag ratio. It has, however, been used on several American training machines, probably for the reason that it permits of sturdy construction.

Eiffel 37 is essentially a high-speed wing having a high L/D ratio and a small lift co-efficient. The maximum lift-drag ratio of 20.4 is attained at a nega-

[image]

Fig. 13 Characteristic Curves for Eiffel Wings Sections

tive angle -08°. The value of Ky at this point is 0.00086, an extremely low figure. The maximum Ky is 0.00288 at 14.0°, the L/D ratio being 4.0 at this angle. Structurally it is the worst wing that we have yet discussed, being almost ”paper thin” for a considerable distance near the trailing edge. The under surface is deeply cambered, with the maximum under camber about one-third from the trailing edge. It is impossible to use this wing without a very long overhang in the rear of the section, and like the Eiffel 32, the front spar must be very far forward. For those desiring flexible trailing edges, this is an ideal section. This wing is best adapted for speed scouts and racing machines because of its great L/D, but as its lift is small and the center of pressure movement rapid at the point of maximum lift-drag, it would be necessary to fly at a small range of angles and land at an extremely high speed. Any slight change in the angle of incidence causes the lift-drag ratio to drop at a rapid rate, and hence the wing could only be manipulated at its most efficient angle by an experienced pilot. Again, the angle of maximum L/D is only a few degrees from the angle of no lift.

U.S.A. Wing Sections. These wing sections were developed by the Aviation Section of the Signal Corps, United States Army, and are decided improvements on any wing sections yet published. The six U.S.A. wings cover a wide range of application, varying as they do, from the high speed sections to the heavy lift wings used on large machines. The data was first published by Captains Edgar S. Gorrell and H. S. Martin, U.S.A., by permission of Professor C. H. Peabody, Massachusetts Institute of Technology. An abstract of the paper by Alexander Klemin and T. H. Huff was afterwards printed in ”Aviation and Aeronautical Engineering.” While several of the curves are modifications of the R.A.F. sections already described, they are aerodynamically and structurally superior to the originals, and especial attention is called to the marked structural advantages.

U.S.A.-1 and U.S.A.-6 are essentially high speed sections with a very high lift-drag ratio, these wings being suitable for speed scouts or pursuit machines. The difference between the wings is very slight, U.S.A.-1 with K-000318 giving a better landing speed, while U.S.A.-6 is slightly more efficient at low angles and high speeds.

With 0° incidence, the ratio of U.S.A-1=11.0 while the lift-drag of U.S.A.-6 at 0° incidence is 13.0. The maximum lift of U.S.A.-1 is superior to that of Eiffel 32, and the maximum lift-drag ratio at equal speeds is far superior, being 17.8 against

[image]

Fig. 14. U.S.A. Wing Sections Nos. 1-2-3-4-5-6, Showing the Ordinates at the Various Štations Expressed as Decimals of the Chord. U.S.A.-4 is a Heavy Lift Section, While U.S.A.-1 and U.S.A.-6.are High Speed Wings. For Any Particular Duty, the Above Wings Are Very Deep and Permit of Large Structural Members. The Center of Pressure Movement Is Comparatively Slight.

14.50 of the Eiffel 32. Compared with the Eiffel 32 it will be seen that the U.S.A. sections are far better from a structural point of view, especially in the case of U.S.A.-1. The depth in the region of the rear spar is exceptionally great, about the same as that of the R.A.F.-6. While neither of the U.S.A. wings are as stable as the Eiffel 32, the motion of the C. P. is not sudden nor extensive at ordinary flight angles.

Probably one of the most remarkable of the United States Army wings is the U.S.A.-4 which has a higher maximum lift co-efficient (Ky) than even the R.A.F.-3. The maximum Ky of the U.S.A.-4 is 0.00364 compared with the R.A.F.-3 in which Ky (Maximum)=0.003481. Above 4° incidence, the lift-drag ratio of the U.S.A.-4 is generally better than that of the R.A.F.-3, the maximum L/D at 4° being considerably better. This is a most excellent wing for a heavy seaplane or bomber. The U.S.A.-2 has an upper surface similar to that of the R.A.F.-3, but the wing has been thickened for structural reasons, thus causing a modification in the lower surface. This results in no particular aerodynamic loss and it is much better at points near the rear edge for the reception of a deep and efficient rear spar.

U.S.A.-3 is a modification of U.S.A.-2, and like U.S.A.-2 would fall under the head of ”All around wings,” a type similar, but superior to R.A.F.-6. These wings are a compromise between the high speed and heavy lift types—suitable for training schools or exhibition flyers. Both have a fairly good L/D ratio and a corresponding value for Ky.

U.S.A.-5 has a very good maximum lift-drag ratio (16.21) and a good lift-drag ratio at the maximum Ky. Its maximum Ky is superior to all sections with the exception of U.S.A.-2 and 4. Structurally it is very good, being deep both fore and aft.

In review of the U.S.A. sections, it may be said that they are all remarkable in having a very heavy camber on both the upper and lower surfaces, and at the same time are efficient and structurally excellent. This rather contradicts the usual belief that a heavy camber will produce a low lift-drag ratio, a belief that is also proven false by the excellent performance of the Eiffel 37 section. The maximum Ky is also well sustained at and above 0.003. There is no sharp drop of lift at the ”Stalling angle” and the working range of incidence is large.

Curtiss Wing and Double Cambered Sections. An old type of Curtiss wing is shown by Fig. 15. It is very thick and an efficient wing for general use. It will be noticed that there is a slight reflex curve at the trailing edge of the under surface and that there is ample spar room at almost any point along the section. The nose is very round and thick for a wing possessing the L/D characteristics exhibited in the tests. The conditions of the test were the same as for the preceding wing sections.

Fig. 16 shows a remarkable Curtiss section designed for use as a stabilizing surface. It is double cambered, the top surface being identical with the lower, and is therefore non-lifting with the chord horizontal. The force exerted by the surface is equal with equal positive or negative angles of incidence, a valuable feature in a control surface. In spite of its great thickness, it is of excellent stream line form and therefore has a very good lift-drag ratio. At 0° angle of incidence the resistance is at a minimum, and is much less than that of a thin, square edged, flat plate. This double cambered plane reduces the stay bracing and head resistance necessary with the flat type of stabilizer surface.

[image]

[image]

[image]

Fig. 15. Old Type of Curtiss Wing. 16. Curtiss Double Camber for Control Surfaces.

The Curtiss sections mentioned above were described in ”Aviation and Aeronautical Engineering” by Dr. Jerome C. Hunsaker, but the figures in the above table were obtained by the author on a sliding test wire arrangement that has been under development for some time. At the time of writing several of the U.S.A. sections are under investigation on the same device.

[image]

CORRECTION FACTORS FOR WING FORM AND SIZE.

Aspect Ratio. As previously explained, the aspect ratio is the relation of the span to the chord, and this ratio has a considerable effect upon the performance of a wing. In the practical full size machine the aspect ratio may range from 5 in monoplanes, and small biplanes, to 10 or 12 in the larger biplanes. The aspect in the case of triplanes is even greater, some examples of the latter having aspects of 16 to 20. In general, the aspect ratio increases with the gross weight of the machine. Control surfaces, such as the rudder and elevator, usually have a much lower aspect ratio than the main lifting surfaces, particularly when flat non-lifting control surfaces are used. The aspect of elevator surfaces will range from unity to 3, while the vertical rudders generally have an aspect of 1.

With a given wing area, the span increases directly with an increase in the aspect ratio. The additional weight of the structural members due to an increased span tend to offset the aerodynamic advantages gained by a large aspect ratio, and the increased resistance due to the number and size of the exposed bracing still further reduces the advantage.

Effects of Aspect Ratio. Variations in the aspect ratio do not give the same results in all wing sections, and the lift co-efficient and L/D ratio change in a very irregular manner with the angle of incidence. The following tables give the results obtained by the N. P. L. on a Bleriot wing section, the aspect ratio being plotted against the angle of incidence. The figures are comparative, an aspect factor of unity (1,000) being taken for an aspect ratio of 6 at each angle of incidence. To obtain an approximation for any other wing section at any other aspect ratio, multiply the model test (Aspect=6) by the factor that corresponds to the given angle and aspect ratio. At the extreme right of the table is a column of rough averages, taken without regard to the angles.

[image]

The column of average values is not the average of the tabular values but is the average of the results obtained by a number of investigators on different wing sections. Through the small angles of 0° and 2° the low aspect ratios give a maximum Ky greater than with the larger aspects. The larger aspects increase the lift through a larger range of angles but have a lower maximum value for Ky at small angles. Beyond 2° the larger aspect ratios give a greater Ky.

Aspect for Flat Plates. For flat plates the results are different than with cambered sections. The lift-drag ratios are not much improved with an increase in aspect, but the highest maximum lift is obtained with a small aspect ratio. For this reason, a small aspect ratio should be used when a high lift is to be obtained at low speeds with a flat plate as in the case of control surfaces. An aspect ratio of unity is satisfactory for flat vertical rudders since a maximum effect is desirable when taxi-ing over the ground at low speeds. The flat plate effects are not important except for control surfaces, and even in this case the plates are being superseded by double cambered sections.

Reason for Aspect Improvement. The air flows laterally toward the wing tips causing a very decided drop in lift at the outer ends of the wings. The lift-drag ratio is also reduced at this point. The center of pressure moves back near the trailing edge as we approach the tips, the maximum zone of suction on the upper surface being also near the trailing edge. The lift-drag ratio at the center of the plane is between 4 or 5 times that at a point near the tips. All of the desirable characteristics of the wing are exhibited at a point near the center.

When the aspect ratio is increased, the inefficient tips form a smaller percentage of the total wing areas, and hence the losses at the tips are of less importance than would be the case with a small aspect. The end losses are not reduced by end shields or plates, and in attempts to prevent lateral flow by curtains, the losses are actually often increased. Proper design of the form of the wing tip, such as raking the tips, or washing out the camber and incidence, can be relied upon to increase the lift factor. This change in the tips causes the main wind stream to enter the wings in a direction opposite to the lateral leakage flow and therefore reduces the loss. Properly raked tips may increase the lift by 20 per cent.

Effects of Scale (Size and Velocity). In the chapter ”Elementary Aerodynamics” it was pointed out that the lift of a surface was obtained by the motion of the air, or the ”turbulence” caused by the entering of the plane. It was also explained that the effect of the lift due to turbulence varied as the square of the velocity and directly as the area of the wings. This would indicate that the lift of a small wing (Model) would be in a fixed proportion to a large wing of the same type. This holds true in practice since nearly all laboratories have found by experiment that the lift of a large wing could be computed directly from the results obtained with the model without the use of correction factors. That is to say, that the lift of a large wing with 40 times the area of the model, would give 40 times the lift of the model at the same air speed. In the same way, the lift would be proportional to the squares of the velocities. If the span of the model is taken at ”1” feet, and the velocity as V feet per second, the product IV would represent both the model and the full size machine. The lift is due to aerodynamic forces strictly, and hence there should be no reason why the ”V^2” law should be interfered with in a change from the model to the full size machine.

In the case of drag the conditions are different, since the drag is produced by two factors that vary at different rates. Part of the drag is caused by turbulence or aerodynamic forces and part by skin friction, the former varying as V^2 while the skin friction varies as $V^{1.88}$. The aerodynamic drag varies directly with the area or span while the skin friction part of the drag varies as $1^{0.93}$, where 1 is the span. From considerations of the span and the speed, it will be seen that the frictional resistance increases much slower than the aerodynamic resistance, and consequently the large machine at high speed would give less drag and a higher value of L/D than the small model. In other words, the results of a model test must be corrected for drag and the lift-drag ratio when applied to a full size machine. Such a correction factor is sometimes known as the ”Scale factor.”

Eiffel gives the correction factor as 1.08, that is the liftdrag ratio of the full size machine will be approximately 1.08 times as great as the model.

A series of full size tests were made by the University of St. Cyr in 1912-1913 with the object of comparing full size aeroplane wings with small scale models of the same wing section. The full size wings were mounted on an electric trolley car and the tests were made in the open air. Many differences were noted when the small reproductions of the wings were tested in the wind tunnel, and no satisfactory conclusions can be arrived at from these tests. According to the theory, and the tests made by the N. P. L., the lift-drag ratio should increase with the size but the St. Cyr tests showed that this was not always the case. In at least three of the tests, the model showed better results than the full size machine. There seemed to be no fixed relation between the results obtained by the model and the large wing. The center of pressure movement was always different in every comparison made.

One cause of such pronounced difference would probably be explained by the difference in the materials used on the model and full size wing, the model wing being absolutely smooth rigid wood while the full size wing was of the usual fabric construction. The fabric would be likely to change in form under different conditions of angle and speed, causing a great departure from the true values. Again, the model being of small size, would be a difficult object to machine to the exact outline. A difference of 1/1000 inch from the true dimension would make a great difference in the results obtained with a small surface.

Plan Form. Wings are made nearly rectangular in form, with the ends more or less rounded, and very little is now known about the effect of wings varying from this form. Raking the ends of the wing tips at a slight angle increases both the lift-drag and lift by about 20 per cent, the angle of the raked end being about 15 degrees. Raking is a widely adopted practice in the United States, especially on large machines.

Summary of Corrections. We can now work out the total correction to be made on the wind tunnel tests for a full size machine of any aspect ratio. The lift co-efficient should be used as given by the model test data, but the corrections can be applied to the lift-drag ratio and the drag. The scale factor is taken at 1.08, the form factor due to rake is 1.2, and the aspect correction is taken from the foregoing table. The total correction factor will be the product of all of the individual factors.

Example. A certain wing section has a lift-drag ratio of 15.00, as determined by a wind tunnel test on a model, the aspect of the test plane being 6. The full size wing is to have an aspect ratio of 8, and the wing tips are to be raked. What is the corrected lift-drag ratio of the full size machine at 14°?

Solution. The total correction factor will be = 1.08 × 1.10 × 12 = 1.439. The lift-drag ratio of the full size modified wing becomes 15.00 x 1.439 = 21.585.

As a comparison, we will assume the same wing section with rectangular tips and an aspect ratio of 3. The total correction factor for the new arrangement is now 1.08 X 0.72 = 0.7776 where 0.72 is the relative lift-drag due to an aspect of 3. The total lift-drag is now 15.00 X 0.7776 = 11.664.

Having a large aspect ratio and raked tips makes a very considerable difference as will be seen from the above results, the rake and aspect of 8 making the difference between 21.585 and 11.664 in the lift-drag. Area for area, the drag of the first plane will be approximately one-half of the drag due to an aspect ratio of three.

Lift in Slip Stream. The portions of a monoplane or tractor biplane lying in the propeller slip stream are subjected to a much higher wind velocity than the outlying parts of the wing. Since the lift is proportional to the velocity squared, it will be seen that the lift in the slip stream is far higher than on the surrounding area. Assuming for example, that a certain propeller has a slip of 30 per cent at a translational speed of 84 miles per hour, the relative velocity of the slip stream will be 84/0.70 = 120 miles per hour. Assuming a lift factor (Ky)=0.0022, the lift in the slip stream will be L = 0.0022 × 120 × 120 = 31.68 pounds per square foot. In the translational wind stream of 84 miles per hour, the lift becomes L = 0.0022 X 84 X 84 = 15.52 pounds per square foot. In other words, the lift of the portion in the slip stream is nearly double that of the rest of the wing with a propeller efficiency of 70 per cent.

CHAPTER VII. BIPLANES AND TRIPLANES.

Biplane Characteristics. From an aerodynamic standpoint, the monoplane wing is more efficient than the superposed wings of the biplane type, since the proximity of the two surfaces in the latter causes a decided loss in the total lift. Other practical advantages, however, offset the losses due to the superposed surfaces, and hence the total efficiency of the complete biplane may be even greater than that of the monoplane. For the same area the structural parts of the biplane are lighter, and this advantage increases rapidly with the size of the machine so that when a span of 36 feet is exceeded, any other arrangement than that of the biplane or triplane becomes almost a practical impossibility. A biplane is easier and cheaper to make than a monoplane, since the wing bracing of the former can be arranged to better advantage, the load-bearing members can be simpler, and the safety factor made higher for an equal weight. By suitable adjustments between the wings of a biplane, it is possible to obtain a very high degree of inherent longitudinal stability without incurring much loss in efficiency, an arrangement that is of course impossible with a single monoplane surface. By "staggering," the view of the pilot is increased, and the generally smaller size of the machine permits of better maneuvering qualities for a given load.

Interference. Due to "interference," or to the choking of the air stream between the upper and lower surfaces, the lift of both wings is reduced, with the drag remaining about the same as with a single surface. This, of course, reduces the total lift-drag ratio at all except certain angles. The relative lift-drag ratios of the monoplane and biplane depend to some extent upon the form of the wing. Interference causes a loss on the opposing faces of the wings, the lift being reduced on the top surface of the lower wing, and on the bottom surface of the top wing. Since the upper surface of the lower wing is under suction, and therefore produces the greater proportion of lift, it is natural that the lower wing lift should be reduced to a greater extent than in the upper wing, since it is only the lower surface of the latter that is affected. At normal flight angles the upper wing carries about 55 per cent of the total load. At zero degrees incidence, the upper wing carries as high as 62 per cent of the total load, while at 12 degrees this may be reduced to 54 per cent.

Gap-Chord Ratio. Calling the distance between the upper and lower wings the "gap," it may be said that the ratio of the gap to the wing chord greatly influences the lift. This ratio is called the "gap-chord ratio," and may vary from 0.8 to 1.0 in small machines or 1.0 to 1.2 in slow, heavy aeroplanes. With the drag remaining practically constant, the lift-drag is of course affected by a change in the gap-chord ratio, this quantity being diminished at small gap ratios. Compared with a monoplane, the lift of a biplane is about 0.77 when the gap is 0.8 of the chord, and about 0.89 of the monoplane value when the gap-chord ratio is increased to 1.6. In this range the lift-drag approximates 0.82 and 0.89, respectively. The center of pressure movement is not greatly changed with any gap-chord ratio, and to all practical purposes remains the same as with the monoplane. It should be understood that these remarks apply only to the ”Orthogonal” biplane arrangement in which the wings are vertically over one another.

While biplane efficiency is increased by having a large gap-chord ratio (wing efficiency alone), the total efficiency of the aeroplane is not always increased by a large gap, principally because of the great head resistance due to the longer struts and interplane bracing. At high speeds the longer bracing members often more than offset the gain due to wing efficiency, and as a result the gap of high speed scouts will generally be found in the neighborhood of 0.8 the chord. With slow, heavy machines, where lift is of great importance, and where slow speed does not affect the structural resistance to so great an extent, the gap-chord ratio will range from 1.0 to 1.2.

In making the above comparisons between monoplanes and biplanes, equal aspect ratios have been assumed for both types, but in actual practice the aspect ratio of biplanes is always greater than with monoplanes, and as a result the biplane loss is usually less than indicated above. When correction has been made for the aspect ratio, the disparity in the monoplane and biplane values of Ky and L/D is not as great as commonly supposed. ”Biplane reduction factors,” or the factors used in reducing monoplane values to those of the biplane, depend to a great extent upon the wing section as well as upon the gap, and for exact values of the factors we should have the tests report of the wings in biplane form. Lacking this information, we can adopt the values obtained by the N. P. L. for an old type of wing in order to get approximate results. To obtain the biplane values, multiply the monoplane values obtained by the wind tunnel test by the factors found under the required gap-chord ratio. These factors apply to an aspect ratio of 6.

BIPLANE REDUCTION FACTORS (N. P. L.) (At Normal Flight Angles)

Gap-Chord Ratio.	0.8	1.0	1.2	1.6
Ky Reduction Factor	0.77	0.82	0.86	0.89
L/D Reduction Factor	0.82	0.84	0.85	0.89

Dr. Hunsaker conducted experiments at the Massachusetts Institute of Technology on biplane and triplane combinations, and the results were reported in ”Aviation and Aeronautical Engineering,” Nov. 1, 1916. The R.A.F.-6 section was used with a gap-chord ratio of 1.2. The biplane portions of the experiments are as follows, the actual Ky and L/D values and reduction factors being arranged according to the angle of incidence:

[image]

It will be noted that there is steady improvement in the lift factor with an increase in the angle from 2° up (except at 8°), and that the same holds true with the L/D factor. That is, the biplane values become nearly monoplane values at high angles, and in the case of the L/D ratio the biplane actually is 24 per cent greater than the monoplane value at an angle of 16°. The lift coefficient Ky above, is not far from the corresponding Ky, for gap-chord ratio = 1.2 in the first table. The maximum biplane value of L/D occurs at the same point as in the monoplane wing, that is, at 4°. The fact that the lift-drag is so high at 16° is very favorable, since the biplane would be less likely to stall when flying slowly, and with a big demand on the engine. The range of angles at the stalling angle is much greater than with the monoplane wing, and the lift does not fall off so rapidly after the maximum is reached.

[image]

Biplane Arrangements. In the foregoing data we have assumed that the upper wing was placed directly above the lower, and with the leading edges on the same vertical line as shown by Fig. 3. This is known as an ”Orthogonal” biplane, and the gap is indicated by G and the chord by C. In Fig. 4 the forward edge of the top wing is advanced beyond the lower, or is ”Staggered,” the amount of the stagger being indicated by S. This allows of better view, and slightly increases both the lift and L/D values. With a comparatively large stagger the range of the stalling angle is increased, and the lift does not fall off as rapidly after the maximum is reached as with the orthogonal type. In Fig. 5 the top wing is given a backward stagger, but the exact effects of this arrangement are not generally known. There are few machines using the reversed stagger, the only example, to the writer’s knowledge, being the De Havilland speed scout. By staggering, the resistance of the interplane bracing struts (3) is somewhat reduced, because of their inclination with the wind, although they are longer for the same gap than in Fig. 3.

Fig. 6 shows the chord of the lower wing (C’) shorter than the upper chord, a type used in the Nieuport speed scout. In effect, this is a form of stagger, and it undoubtedly widens the view of the pilot, and to some extent increases the efficiency and the range of the stalling angle. Neither the stagger in (4) nor the small lower chord alone improves the stability to any extent. To obtain any marked advantage with the short lower chord, the chord C' must be very much shorter than the upper chord, say from 0.80C to 0.50C. The loss of area is so great that this would not be permissible on any except the fastest machines, where lift is not a primary consideration. The pilot's view, however, is very much improved with the short lower chord, and in battle this is an important consideration.

Fig. 7 shows the chord of the upper wing inclined at an angle with the lower chord by the amount (d). This is known as "Decalage" and is productive of a great degree of longitudinal stability when taken in combination with stagger. The stability attained by decalage and stagger is without a great loss in the L/D ratio, while the lift and stalling angle range are both increased. This latter stable combination is shown by Fig. 8, in which the wings are given both stagger and decalage.

[image]

Slow Speed, Two-Seat Biplane, with a Large Gap-Chord Ratio. The Large Gap Is Permissible in a Slow Machine, as the Strut Resistance Is Less Than the Gain in Lift-Drag Ratio Obtained by the Greater Gap. It Will Be Noted That These Wings Have a Considerable Amount of Stagger. The Position of the Bottom Wing Allows the Observer to See Almost Directly Below.

[image]

A High Speed, Two-Seat Fighting Biplane, with a Small Gap-Chord Ratio. In This Case, the Strut Resistance Would Be Greater Than the Aerodynamic Gain of the Wings with a Greater Gap Chord Ratio. The Gunner Is Located in the Rear Seat, and Behind the Trailing Edge of the Lower Wings. He Has a Clear Field to the Rear an Over the Top Wing.

Forward Stagger. Eiffel performed experiments with Dorand wings, and found that when the top surface was staggered forward by 1/2.5 of the chord (0.4C), and with a gap-chord ratio of 0.9, an increase in lift of from 6 to 10 per cent was obtained. The L/D was the same as with no stagger. With thin circular plates, 1/13.5 camber, and a gap-chord ratio = 0.66, the lift-drag was better (than with no stagger) only when the value of Ky was greater than 0.066 (metric). Then the L/D improved progressively with the amount of stagger. Ky was improved by 5 per cent when the stagger was equal to half the chord, and by 10 per cent when the stagger was equal to the chord. The N. P. L. with a Bleriot wing, aspect ratio=4, found that Ky was increased by 5 to 6 per cent with a stagger of 0.4C, and the L/D was increased by about 4 percent. The gap-chord ratio was 1.00.

[image]

A Single Seat Biplane Speed Scout with an Air Cooled Motor.

In a series of tests made by A. Tcherschersky, the backward stagger as in Fig. 5 gave about 15 per cent greater lift than the orthogonal biplane, or about 4 per cent less lift than a monoplane surface of the same area. The stagger in this experiment was about 0.33C. In default of more accurate information, it would seem that backward stagger would give better results than forward stagger, since the air swept down by the upper surface would pass further to the rear of the lower plane and hence would not so greatly affect the vacuum on the upper surface of the lower wing. This would, however, destroy the view of the pilot to a greater extent than any of the other arrangements.

Stagger always introduces structural difficulties, makes the wings difficult to assemble, and the wires are of varying lengths. A simple orthogonal cell is more compact and better from a manufacturing standpoint, as it simplifies the fittings, and to a slight extent decreases the weight. When combined with sweep back, the complication is particularly in evidence. It is pleasing to note the prevalence of orthogonal cells on modern battle-planes.

Influence of Camber. The amount of air swept down by the upper wing is largely determined by the curvature of the under surface of the upper wing. By decreasing, or flattening out the curvature of this surface, the velocity is increased in a horizontal direction and reduced in a vertical direction, so that the lower wing is less affected. The upper surface of the upper wing is not influenced by interference. It should be noted at this point that air in striking a convex surface is increased in horizontal speed while the reverse is true of the lower concave surface. If the under surface of the upper wing were made convex, the down trend of the air would be still further reduced, and the loss on the lower wing reduced in proportion.

Increasing the camber on the upper surface of the lower wing increases its horizontal velocity and hence affects the upper wing to a less extent, but as the upper wing loss is comparatively slight, the camber increase below is not of great consequence. This has only been tried in one machine to the writer's knowledge, one of the Standard seaplanes, in which the upper wing was an R.A.F.-6 and the lower wing was a deeply cambered U.S.A.-2 section. The lower surface of the R.A.F.-6 is comparatively flat.

Effects of Decalage. When the upper wing incidence is increased in regard to that of the lower wing, or is given decalage, the stability is increased with a slight increase in the power or drag. This angle shown by (d) in Figs. 7 and 8, must be accompanied by stagger to obtain stability, the angle (d) ranging from 1° to 4°. With a decalage of 2.5°, and a stagger of half the chord, a high degree of stability is attained with a loss in the lift-drag of from 4 to 6 percent. The lift and the range of the stalling angle are both increased, the former by about 3 percent, while the latter is nearly double. By increasing the decalage to 4°, the lift-drag is still 4 percent less than with the orthogonal cell, but the range of the stalling angle is nearly tripled. The 4° decalage is very stable and is suitable for training machines or for amateurs. In either case, the stagger-decalage system is usually better than sweep back, reflex curves or negative wing tips.

Without regard to the stability, and only with the idea of a greater L/D in mind, it has been usual in several European machines to adopt a ”negative” decalage; that is, to increase the angle of the lower wing in regard to the upper chord. With the top chord horizontal, a negative decalage of 4° would make the incidence of the lower wing equal to 4°. This has not been generally found advantageous in model tests, but in full size machines there is a considerable increase in the L/D ratio. The greater incidence of the lower wing also improves the lift of this surface and thus requires less surface for obtaining the same total lift, especially when top wing is staggered forward. Incidence of top wing of Nieuport = 1°-30'. Lower wing is set at 3°.

Varying Incidence. With several types of European speed scouts, and in the case of the old Handley-Page monoplane, the angle of incidence is reduced from the center of the wing to the tip. Thus in one speed scout, the incidence at the body is 4°, and 2° at the tips. A decrease in angle toward the tips has much the same effect as an increase in aspect ratio; that is, it decreases the lateral flow and end leakage. It also has an effect in aiding the lateral stability because there is less lift at the tips, and hence they are less affected by side gusts. ”Washed out” incidence is an aid to longitudinal stability, as the center of pressure at the tips is moved further back than at the center of the wing, and therefore the C. P. is distributed over a longer distance fore and aft than it would be with a uniform angle of incidence.

In driving the propeller, the motor tends to turn the body in a direction opposite to that of the propeller rotation, and if no other provision is made this must be overcome by means of the ailerons. The ”Motor torque” on small span machines is particularly difficult to overcome in this way, owing to the short lever arm length of the ailerons. To practically overcome the torque, without excessively loading the ailerons, it is usually the practice to set the lower left wing tip at a greater angle than the lower right wing. The greater angle at the left gives a lift that opposes the turning moment of the motor. This compensation can never be complete, for the motor torque varies with the motor output, hence an average angle is selected so that the incidence will cover the usual horizontal flight speeds.

Triplane Arrangement. When a biplane exceeds a certain weight the area required for a given landing speed makes it desirable to increase the number of lifting surfaces to more than two, if the span and stress are to be kept down within reasonable limits. Thus the biplane has its limits as well as the monoplane, and in the biplane this limit is generally reached when the span approaches 80 feet. In addition to the increased weight due to spans of over 80 feet, there are other troubles in regard to the space required for housing, and awkwardness in maneuvering. On the smaller and faster aeroplanes, the triplane arrangement permits of space condensation, and also allows of larger aspect ratios than with the biplane. The greater depth of the triplane structure makes the interplane bracing even more effective than in the case of the biplane. For equal spans there is less bracing exposed to the wind, and the weight of the wing spars and ribs can be considerably reduced. The shorter ribs of the triplane alone contribute in no small degree to the saving in weight.

Considering the wings alone, without reference to the head resistance of the bracing, etc., there is a greater loss of lift and L/D when three tiers of wings are superposed than with a biplane. In experiments by Dr. Hunsaker upon R.A.F.-6 and Curtiss wing sections, it was found that at about 4°, that the triplane required about 6 percent more power than the corresponding biplane. At this angle, the L/D for the triplane was 12.8, against the ratio of 13.8 for the biplane. The gap-chord ratio in each case was maintained at 1.2. Both the R.A.F.-6 and the Curtiss wings gave results of the same general character, and there was not a great deal of difference in the numerical values. At very high angles, 12° to 16°, the lift of the biplane and triplane only differed by about 2 percent, but at very small angles such as are used at normal flight speeds, the reduction of lift in the triplane was very marked.

The drag was not greatly different below 12°, but at 16° the drag-coefficient is less than that of either the biplane or monoplane, and for machines flying at low speeds, or heavily loaded, this decrease is of great advantage since it relieves the motor at a time when power is particularly required. At this point it should be noted that at high angles, the L/D generally is better for multiplanes in an almost direct proportion to the number of surfaces. In this experiment, the lift-drag ratios for a monoplane, biplane, and triplane were respectively 4.5, 5.6, and 6.5. The drop in lift after the point of maximum lift, or the stalling angle, is not as rapid as in the case of the biplane or monoplane, and hence there is less danger of stalling the triplane. With the same area, and loading, the landing speed of the biplane and triplane will be about the same.

The following tables give the lift, and lift-drag ratios as determined in these experiments, the factors being in terms of the monoplane values of an R.A.F.-6 wing. Thus to obtain triplane values, multiply the given monoplane values by that number opposite the required angle of incidence. Aspect ratio = 6.

[image]

Curtiss Triplane Speed Scout. Note the Great Aspect Ratio of the Wings, and the Relatively Great Gap-Chord. Ratio. Only One Set of Struts Are Used in a Single Row, Hence the Head Resistance Is at a Minimum. The Span Is 25’-0” and the Chord 2’-0”, Giving an Aspect Ratio of 12.5.

[image]

Thus, if the monoplane lift value for the R.A.F.-6 wing at 4° is Ky = 0.001.45, then the triplane value will be 0.00145 + 0.757 = 0.001097 as given in the table. The monoplane lift-coefficient of any other wing section can be handled in the same way with fair accuracy. To obtain the corrected lift-drag ratio for any wing section, multiply the lift-drag of the monoplane wing by the factor in the above table corresponding to the incidence of the monoplane test wing.

[image]

The Italian Caproni Triplane of the Heavy Lift or Bombing Type. Motors Are Installed in Each of the Three Bodies, Tractor Propellers Being Used in the Two Long Outer Bodies, While a Pusher Screw Is Used at the Rear of the Central Passenger Body. The Enormous Size of This Triplane Can Be Seen by Comparing it with the Caproni Monoplane Shown at the Right. Courtesy ”Flying.”

The upper wing gives the greatest percentage of lift, and the middle wing the least, since the latter suffers from interference on both sides. It has been found that the sum of the top and bottom wings of a triplane group gives the same lift as the two wings of a biplane under equal conditions. It was also found that the lift-coefficients and lift-drag of the upper plane alone was very nearly equal to the lift of the combined effects of all three wings, and at all angles. Calling the lift of the middle wing 1.00 (4°), the lift of the upper wing will be 1.91 and the lower wing 1.64. Calling the L/D of the middle wing 1.00 (4°), the relative life-drag will be L/D = 2.59 for the upper wing and 1.69 for the lower. With the middle wing still assumed at unity, the lift of the top plane is at 1.49 at 16°, and the lower wing 1.20. The liftdrag at 16 degrees will be respectively 1.00, 1.22, and 1.117 for middle top and bottom. At 0°, the upper wing will carry 2.68, the middle 1.00, and the bottom 1.82. At 0°, the lift-drag of the top is 3.63, the middle 1.00, and bottom 2.30. These relative figures are only useful in comparing the loading when computing the strength of the structural parts. See "Aviation and Aeronautical Engineering" Nov. 1, 1916.

Overhanging Wing Tips. In many American machines, and in some European machines, such as the Farman, the upper wing is given a much greater span than the lower. Of late, the tendency has been to make the wings of equal, span and fully 90 per cent of the modern machines will be found to be arranged in this way. While the overhanging tips may slightly increase the efficiency of the biplane by reducing interference at the ends, it makes the span unduly long and difficult to brace at the end. The added end bracing due to the overhang probably offsets any aerodynamic advantage to be obtained, although I have no accurate data on this point. Compactness is certainly not a feature. It is said that ailerons are more effective when mounted on the upper overhang, and this may be so, but I note that the area is about the same in any case. With overhanging tips, the ailerons are generally placed on upper wings, only while with equal or nearly equal spans, they are placed top and bottom. The overhanging section and the ailerons form a single detachable unit as a general rule. With nearly equal spans, the upper and lower ailerons are generally interconnected with a small strut in such a way that they act together.

Small speed scouts, rarely if ever, have any overhang since the object of these machines is to make them as small and compact as possible.

CHAPTER VIII. EFFECTS OF PLAN FORM. (TANDEM AEROPLANES.)

General Notes. Up to the present we have considered only two wing outlines, the rectangular and the wing with raked tips. In addition, we have considered only the effect taking place on monoplane surfaces. For the purpose of obtaining longitudinal stability, or for distributing the lift upon two or more following surfaces, the plan view in some aeroplanes has been somewhat modified as in the Dunne, Langley and Ago. Undoubtedly the simple rectangular wing, or the wing with raked tips, have proved the most efficient from an aerodynamic standpoint, but as the layman is usually interested in distorted wing shapes, or odd-looking outlines, I will describe the effect of such stabilizing forms upon the lift and drag.

Figs. 1-9 show the usual range of wing forms, at least those that have been used on well known machines, and all of them have flown with varying results. In any case, the variations in the values of the lift and lift-drag are not excessive, the extreme cases varying possibly not more than 20 per cent on either side of the values for a plain rectangular wing. While almost perfect longitudinal stability can be obtained in other ways, by less loss than by changing the plan form, certain manufacturers still adhere to one or more deviations from the more usual rectangular form.

Fig. 1 shows a plan view of a machine with a rectangular wing, and No. 2 shows the machine provided with raked tips. Fig. 3 is a wing with an inclined entering edge, as used on the English Mann biplane. Fig. 4 is the German Ago with a diamond form surface, the evident purpose of which is to simplify the wing spar bracing as shown by the dotted lines. By bringing the wing spars ’together at the tips, the spars themselves form a triangle to resist the drag stresses. Fig. 5 is the common form of ”sweep back” or ”retreated wing” as used in the Standard H-3 training biplane, and several other modern biplanes. While this arrangement undoubtedly assists longitudinal stability, it causes certain losses that will be described later. The inherently stable Dunne is shown by Fig. 6 in which the sweep back is increased to almost 90 degrees. In fact the retreat is so great that no tail or stabilizing surfaces are used at all, the elevator functions being performed by the ailerons. It should be noted that the swept back tips really act as stabilizers since they trail back far behind the center of gravity and center of pressure. The ailerons (a) are not needed for lateral balance, hence ascent and descent—and also turning in a horizontal plane—are performed by the ailerons in setting them in different relative positions. Being far to the rear they are very effective elevators, although their action and the extreme retreat of the wings, causes a considerable drag. This is somewhat offset by the absence of tail resistance. An Austrian or German ”Taube” is shown by Fig. 7 with the negative trailing wing tips (a), that greatly assist longitudinal stability, but which are decidedly inefficient. This is evidenced by the fact that neither the Germans nor Austrians build this machine at present—at least for active service. The tips (a) are bent up at the rear and thus form a ”negative” angle of incidence with the main lifting surface. This was the original invention of Igo Etrich, an Austrian, and as with everything else, the idea was promptly grabbed by the Germans at the beginning of the war and claimed as their own idea. Etrich was one of the pioneers in aviation, a science that did not prosper in Germany until the impracticability of the Zeppelin for universal service was an accepted fact.

[image]

Figs. 1-9. Plan Views of Different Wing Arrangements and Wing Outlines.

Fig. 8 is the wing outline of the Bleriot monoplane, a representative wing used on the earlier monoplanes. This is really reversed rake, and hence does not stand for efficiency in lift. A tandem aeroplane is shown by Fig. 9 in which the leading surface is (m) and the trailing wing is (n). The tail (t) may, or may not be included. This is a type that has been neglected in its practical development although it has been repeatedly proposed. The Langley machine, the Montgomery glider, and the Richardson are of this type.

In all the figures the wing ribs are indicated by the thin full lines passing across the width of the wing, with the tail at (t). The arrow represents the line of flight. It will be noted that with any but rectangular wing outlines the rib lengths are different, throughout the wing. This makes this wing a bad manufacturing proposition, and a difficult and expensive wing to repair. To provide against emergencies the aviator must keep a complete extra wing in reserve for repair parts, while the manufacturer is put to the expense of a great number of rib molds, and must also keep a large number of ribs in stock. There is a constant difficulty due to the fact that mistakes are often made in ordering the ribs for repair, and altogether, anything but a rectangular wing is a decided nuisance.

Sweep Back or Retreat. With swept back wings, as shown in Fig. 5, the center of pressure movement is peculiar. The C. P. moves forward when reducing the incidence at small angles, and thus tends to reduce head diving, but at very large angles the C. P. again moves forward, tending to increase the angles further and thus stall the machine. This reversal of C. P. movement takes place at about 10° to 12°, and the movement is sharper and further with each increase in the sweep back. At ordinary angles of flight, say at from 0° to 6° the forward C. P. movement is satisfactory, but at low speeds and high angles stability is only partially secured, and hence for the total performance sweep back is not to be desired. The wing section used in the above investigation was an R.A.F.-6 with an aspect ratio of 6.

In regard to the lift coefficient Ky, it was noted that this factor was decreased with every degree in the angle of sweep back. At the incidence angle of 4° for the maximum value of L/D, the value of Ky decreased from 0.00143 with a sweep back of 0° (Straight wings), to 0.00120 with a sweep back of 30°. At the same incidence, but with a sweep back of 10°, the lift became: Ky = 0.00130. With a retreat of 20°, Ky- 0.00129. The lift-drag also suffered with an increase in retreat, this being 17.00 with straight wings, at 16.5 at 10°, 16.2 at 20°, and 12.8 at 30°. Up to, and including a retreat of 20°, the loss in lift-drag is not so bad, but in the change from 20° to 30° there is a very great loss.

[image]

Fig. 10. (Upper) Various Angles Made by Wings During Experiments. (Below) The Center of Pressure Movement with Varying Angles.

The ”angle of retreat” herein specified is such that each wing is moved back through an angle of one-half the total given retreat (r) angle in Fig. 5. That is, with a retreat of 30°, each wing section makes an angle of 15° with the entering edge of a pair of straight wings. It is more usual to specify the included angle between the leading edges as indicated by (S) in Fig. 5. In the upper portion of Fig. 10 is shown the various angles of the wings during the experiments, while below is the C. P. movement according to the different angles of retreat. The above is based on experiments made by H. E. Rossell and C. L. Brand, assistant Naval Constructors, U. S. Navy, and published in ”Aerial Age.”

The center of pressure referred to is that at the forward point of the middle longitudinal section of each wing, and with a given incidence the C. P. is thrown to the rear by about 0.2 of the chord by a sweep back of 10 degrees, and 0.4 of the chord for a sweep back of 20°. The center of gravity of the machine will thus have to be moved to the rear if sweep back is employed.

In making a turn a machine with sweep back has a natural tendency to bank up in the correct attitude, and even a retreat of 10° will add nearly 100 per cent to the banking tendency when compared to a pair of straight wings. It will be seen that with swept back wings, the leading edge is radial, consequently meets the air stream at more nearly a right angle. This gives more lift to the outer wing than would be the case with straight entering edges, while the inner end losses increase correspondingly in lift and hence tends further to depress the inner tip. The greatest value of sweep back is found in its resistance to side slip. If the machine should be ”over banked,” and tend to slip down toward the inner side of the turn, the backward angle of the inner wings will cause the entering edge to meet the side stream at more nearly right angles, and thus tend to reduce the bank and the inner slide slip. In this respect the retreat is an aid to lateral stability. On the other hand, the sweep back tends to keep the machine rolling in rough weather for side gusts then meet the inclined wing edges at an effective angle. This is particularly noticeable in landing.

Raked Tips. This subject was discussed under "Standard Wing Section," but it may be repeated here, that Eiffel in an experiment with the Coanda Wing (Eiffel 38), found that the L/D of the raked wing was 20 per cent higher than with the same wing in rectangular form. This value would not be safe to assume with all sections.

[image]

Fig. 11. Influence of "Wash Down" on the Rear Wings of a Tandem Pair.

[image]

Fig. 12. Tandem Arrangements Used in Eiffel Experiments. (1) Chords in Straight Line, (2) Rear Wing at 2.5°, (3) Rear Wing at 5°.

Tandem Arrangement. In tandem wings as shown by Fig. 9, the downward wash of the front wing (m) will affect the rear wing (n) by causing a change in the relative direction of the flow. If the front wings are at an incidence of (i) degrees (Fig. 11), the deviation or washdown of the air stream to the rear will be expressed by: $d = (0.5i + 1)$. If i = incidence of rear wing measured from the chord of the front wing, then the angle of incidence made by the rear chord to the horizontal will be: $I = (i\text{-}i') - (0.5i + 1)$, where I is the incidence of the rear plane with the horizontal.

Experiments by Eiffel on tandem planes with circular cambered aerofoils gave exceedingly good results for certain combinations (Fig. 12). These arrangements were used, (1) Chords in a straight line (2), Rear aerofoil tilted down at a negative angle of 2.5°, (3), Rear Plane tilted down at a negative angle of 5°. In all cases the camber was 1/13.5 of the chord, and the front and rear wings were spaced two chord widths apart. While the drag did not change much for any of the arrangements, the lifts varied widely, and arrangement (2) is by far the more efficient in lifting capacity. No. 2 is 50 per cent greater than (1), and has twice the lifting ability of (3). For the same angle of incidence, the front wing does the same amount of lifting in all cases, the difference being entirely due to the changes in the rear surface. In (2) the lift of the rear aerofoil is actually 13 per cent greater than the front plane. The following tables give the results:

Demo Table TABLE OF LIFTS IN GRAMS FOR THREE ARRANGEMENTS.

ANGLE OF INCIDENCE	ARRANGEMENT (1)	ARRANGEMENT (2)	ARRANGEMENT (3)
3	665	1094	334
6	987	1568	703
9	1315	2068	965
12	1540	2326	1347
Average at all angles	1127	1764	837
Percentage	0.64	1.00	0.47

[image]

Fig. 13. Drzewiecki Tandem Arrangement for Longitudinal Stability.

The lifts in the above table are for the two planes working together, and the angle of incidence is the angle of the front aerofoil, or rather the angle of the combination. The wings were 15 x 90 centimeters, aspect ratio = 6. Fig. 12 shows the construction clearly. This is only true for circular arched surfaces of the camber given.

[image]

Fig. 14. Drzwiecki Tandem Wing Arrangement for Stability.

M. Drzewiecki working with Eiffel's results on the above combinations, produced an inherently stable tandem monoplane, in which the front and rear wings were of different cambers and were set at different incidences. The front wing is Eiffel No. 8 set normally at 8° incidence, and the rear wing is Eiffel No. 13-bis (Bleriot 11-bis), set normally at 5°. The center of gravity is approximately half-way between the two wings, and the front is smaller than the trailing surface. Because of the difference in area, the lift of the front wing varies less rapidly than the rear when the angle of the machine changes because of disturbed air. Should the machine ”head up,” the rear wing increases faster in lift than the front, and hence restores the machine to a horizontal position. Should the front surface drop, the incidence is reduced, but as incidence of the rear wing is less than the front (8°), the rear wing is reduced to nearly a zero angle of incidence—(With little lift). The front wing is still inclined at a considerable incidence: (3°) when the rear is at zero. This drops the rear, and raises the front wing so that the normal attitude is restored. Lateral stability is obtained by moving the two halves of the front wing in relation to one another, the relative movement being similar to that of ailerons.

[image]

Typical Wing Assembling Shop

CHAPTER IX. WING CONSTRUCTION.

General Wing Frame Layout. In many ways, the frame of the wing is one of the most important structural parts of the aeroplane. It not only maintains the proper aerodynamic form of the aerofoil, but also transmits the air pressure and lift to the body of the machine, and therefore carries the entire weight of the aeroplane when in flight. In spite of the heavy loading on this frame it has been brought to a remarkable degree of strength and lightness. Not only is ”Brute” strength necessary, but it must also be rigid enough to properly retain the outlines of the aerofoil with the heaviest loadings, hence the efficiency of the aeroplane greatly depends upon the stiffness as well as strength. The contour of the entering edge must be particularly accurate and well supported since it is at this point that the greater part of the lift is obtained, and where a slight deviation in form will materially affect the lift and drag.

The fabric surface, on which the air pressure is exerted, must transmit the pressure and lift to the main structural members through the parts that give form to the surface. The fabric surfacing, being flexible and pliant, must be supported at frequent intervals by the forming members which in effect are similar to the joists of a floor system. The forming members are then supported in turn by longitudinal beams, or girders, that transmit the pressure to the point where the load is applied. The girders not only carry the lifting force, but must also take care of the drag which acts at right angles to the lift. To pass girders that are sufficiently strong, and yet within the limits of weight, through the narrow space between the top and bottom surfaces of the wing is not always the simplest of problems.

Figs. 1 and 2 show typical wing frames in diagrammatic form, the upper views are the plans, while at the bottom are sections taken through the wing. The outlines of the sections are curved to the outlines of the aerofoil adopted for the wings, and after this outline is drawn out to scale, we must maneuver our structural members so that they will lie entirely between the surfaces.

In Fig. 1, the forming ribs are indicated by R, these being the members curved to the aerofoil form. They are spaced along the length of the wing at intervals of about one foot and the fabric is applied to the top and bottom edges of the rib. The ribs are fastened to the front spar F, and the rear spar S. The spars are equivalent to beams, and are for the purpose of transmitting the lift of the ribs to the body. A thin strip E (nosing) running along the entering edge of the wing, serves to hold the fabric taut at this point and also forms it to the shape of the aerofoil entering edge. The thin trailing edge strip (T) performs the same purpose, and the wing outline is completed by the ”End bow” (A) which retains the fabric at the wing tips. Between the front spar F and the rear spar S is the trussed ”Drag bracing,” which binds the two spars into a truss in a horizontal direction, and against the drag of the surfaces. This consists of the ”Drag” wires or cables (d) and the short wood struts (e), although in many cases the ribs are strengthened at the point of attachment of the drag wires and serve as struts. The aileron G is located at the outer tip and is hinged to the rear spar or to an extension of the rear spar. Between the spars are thin strips known as ”battens” which stiffen the ribs sideways, these are shown by (F).

[image]

Fig. 1. (Left) Wing Assembly with Spar to the Rear of the Entering Edge. Fig. 2. (Right) Assembly with the Front Spar at the Entering Edge.

Metal connection clips C, at the end of the wing spars, are for attaching the wings to the body, or for connection of the two halves of the upper wing of a biplane. Looking at the lower sectional view we see the interplane struts of a biplane attached to the front and rear spars as at (m) and (n). Referring to the plan view, the location of the struts is indicated by * * * at the points where the drag-bracing is attached to the spars.

Fig. 2 is a form of wing in which the spar F' also forms the entering edge, thus eliminating one part of the wing. One objection to this construction is that the front spar must necessarily be shallower than the spar shown in Fig. 1. The rear spar is in the usual location at S', the two spars being connected through the usual end bow A'. The trailing edge T' may be either a thin strip, or it may be a thin cable as indicated. This wing is similar to the wing used on the early Wright machines, and is still used by Farman, Voisin and other European manufacturers of biplanes. Usually the trailing ends of the ribs overhang the rear spar for quite a distance, in this type of wing, giving a flexible trailing edge. The front and rear interplane struts (m) and (n) are shown, the former connecting with the front spar at a point near the entering edge.

[image]

Fig. 3. Sub-Rib Construction, the Sub-Ribs (r) Are Placed at the Entering Edge.

Fig. 3 shows the usual construction except that short "Sub-ribs" marked (r) are placed between the main ribs R at the entering edge. These short ribs increase the support and accuracy of the curve at the entering edge, or else allow wider spacing of the main ribs R. The fabric must be well supported at this point, not only to maintain the best efficiency of the aerofoil, but to relieve the stress on the fabric, as it is here (Top surface) that the greatest suction pressure comes. Should there be a rip or tear near the entering edge, in the lower surface, the upper fabric will be subjected to both the pressure underneath and the vacuum above. This adds fully 25 per cent to the load on the upper facing.

The main spars may be of wood or steel tubing, although the former material is generally used. They are of a variety of forms, the "I" beam section, solid rectangular, hollow box, or a combination of plate and I sections, the total object being to obtain the greatest strength with the least possible weight. When made up of several pieces of wood they are known as "Built up" spars.

[image]

Fig. 4. Effects of C.P. Movement on Spar Loading

The load on the spars varies with the total weight carried, and also with the movement of the center of pressure due to changes in the angle of incidence.

When the center of pressure moves to any extent, the loads on the two spars may vary between wide limits, and in extreme cases, either spar may carry the full load. This is shown clearly by Fig. 4, a section taken through the wing. The front spar F and the rear spar S are spaced by the distance L, the respective spar loads being indicated by Y and Z. As before explained, the center of pressure moves forward at large angles (CP), while at small angles it moves back say to position (CP’). Should it move back as far as CP-2, the load will come directly under the rear spar and this member will therefore carry the entire load. When at the forward position CP, the greater part of the load will come on the front spar, and only a small portion will now come on S. In the same way, when at a small angle of incidence, the center of pressure will be at CP’, a distance (K) from the rear spar. The greater part of the load will now be on S. The action is the same as if the entire weight W or lift, were concentrated at the center of pressure.

When intermediate between the two spars, the center of pressure causes a bending moment in the rib R, and is at a maximum when the CP is midway between the two spars. It will be seen that the C. P. movement has an important effect outside of the question of stability, and this travel must be taken into careful consideration when the strength of the spars is calculated. To find the load on the rear spar, for example, with the center of pressure at CP, multiply the lift W by the distance P, and divide by the spar spacing L. This will give the load Z. With the C. P. in the same position, the load on the front spar will be the difference between the total lift W and the load on the rear spar, or Y = W-Z. With the load at CP’, the load on the front spar will be: Y = WxK/L, and the load on S will be Z = W - Y.

For example, we will assume that the lift W = 1000 pounds, and the distance P = 12 inches. The spar spacing L = 30 inches and the center pressure is at CP. The load Z on the rear spar, will be: Z = WxP/L = 1000 x 12/30 = 400 pounds. The load on the front spar can be found from the formula, $Y = W - Z = 1000-400 =$ 600 pounds.

[image]

Fig. 5. Perspective View of Wing Construction (Rear Spar Omitted), Showing Hollowed Entering Edge and Built-Up Spar. Rib Is of the ”I” Beam Type. Courtesy ”Flight.”

Fig. 5. shows a typical form of wing construction (rear spar omitted). The front spar is of the ”Built up type,” and the trailing edge is a flattened steel tube. The rear spar is simply a solid rectangular beam. A central ash ”I” beam is used

as the front spar, with vertical spruce plates on either side. The spruce entering edge, or ”nosing,” is formed to the shape of the entering edge and is hollowed out for lightness. The rib is also of the built up type, the upper and lower flanges are of spruce and the middle portion (Web) is cotton-wood. At the point where the spar passes through the rib, the rib flanges pass over, and are tacked to the spar. The spruce nosing fits closely over the front web of the rib. The rib flanges are cut away so that the outside of the nosing will come flush with the flange line of the rib.

[image]

Fig. 6. Caudron Monoplane Wing with Steel Tube Spars and Flexible Trailing Edge. A Slot in the Rear of the Rib Web Permits the Deflection of the Trailing Edge. Drag Wire Bracing Is Used Between the Front and Rear Spars. Courtesy ”Flight.”

A wing of decidedly different construction is the Caudron monoplane wing shown by Fig. 6, the front and rear spars of this wing being steel tubes with an entering edge of thin wood. The drag bracing wires may be seen connected at alternate ribs by small steel plates and the latter also serve to attach the ribs to the spars. Instead of being cut out entirely, the webs of the ribs are hollowed out between the spars. Probably the most unique feature is the construction of the long flexible trailing ends of the rib at the right. The trailing rib edge is divided into an upper and lower section by a long slot, the upper sections being rigid, while the lower edge is thin and flexible. The flexible edges allow the lower ends of the ribs to give locally, and reduce the camber when struck by a heavy gust. This aids in the lateral stability, since the lift is thus considerably reduced at the point of impact, and it also relieves the wing of unnecessary stresses. The rigid upper section of the rib acts as a limit stop to the lower half, and prevents the flexure from exceeding a certain amount. Owing to the flexibility of the trailing edges a steel wire or cable must be used for the trailing edge.

[image]

Fig. 7. Standard H-3 Wing Construction. Spar, Rib and Drag Strut Connections at Left. Body Connection Fitting or Hinge at Right. Note Drag Wire Fittings. Courtesy ”Aerial Age.”

Details of the framing of the Standard H-3 are shown by Fig. 7. The figure at the left gives a clear idea of the connections between the drag struts and spar, while the view at the right shows the body connection at the end of the spar. I am indebted to ”Aerial Age” for these sketches. The main spar is in a solid piece, channeled out to ”I” beam form, except at the point where the spruce drag strut is attached. At the end of this strut is attached a sheet steel fitting that affords a means of connecting the drag wires, and for fastening the strut to the main wing spar. At the point of attachment, wooden plates are fastened to either side of the spar. These prevent the fitting bolts and the fitting from sliding along the spar when subjected to an uneven pull in the wires. A veneer top and bottom plate still further strengthen this joint and hold the sub-rib in place. The main ribs are strengthened, at the point where the spar passes through the rib web, by small vertical blocks. In the right hand figure the steel clevis is shown bolted to the spar. A lug for the wing drag wire is brought out from the fitting. The clevis on the wing engages with a similar clevis on the body of the machine, and the two are fastened together with a bolt or pin.

[image]

Fig. 8. Typical Biplane Wing. Gap for Aileron Shown at Right End of Wing. Left End Rests Against Fuselage, the Observation Port Being Cut Out at the Upper Left Hand Corner. Drag Wire Bracing Clearly Shown. Courtesy ”Aerial Age.”

Fig. 8 is a photograph of a biplane wing with the framing members completed and ready for the application of the fabric. At the right is the opening left for the aileron, and at the left is the observation port, the latter coming next to the body. As this is a lower wing, the sockets for the attachment of the interplane struts can be seen on the upper and near edges of the main spar. Between the spars are very thin wood strips running with the length of the wing. These are the ”Battens” used for stiffening the ribs between the points of support at the spars. As the distance between the spars is comparatively great, in respect to the thickness of the rib flanges, some sidewise support of this kind is necessary. The drag-bracing cables cross three rib spaces, or are fastened to every fourth rib. Between the front spar (at the bottom), and the entering edge, are the small strips that serve as sub-ribs. Double cross bracing is used at the inner end of the wing (left), while additional knee braces are placed at the aileron opening, and at the outer tips. This is necessary to withstand the stresses due to assembling and handling, rather than for the flight stresses.

Fig. 9 is a Standard Wing ready for covering. Before the fabric is applied, a narrow cloth strip is wrapped over the trailing edge, as shown, and is stitched to the frame. This forms a means of stitching the main covering at the rear edge, where the ends of the upper and lower surfaces meet.

Wing Fabric or Covering. At the present time unbleached Irish linen is used almost exclusively for covering the wing structure, although in the early days of flying rubberized fabrics were used to a great extent.

[image]

Fig. 9. Standard H-3 Wing Ready for Covering. Opening for Aileron Flap Shown at Upper Left Hand Edge (Trailing Edge).

After the linen is stretched on the wing frame, it is given several coats of a special preparation commonly known as ”Dope” to proof the fabric against moisture. In addition to waterproofing, the dope adds considerably to the strength of the fabric and shrinks it tightly on the ribs—much more evenly than could be done by hand. When completely ”Doped,” the linen should be proof against the effects of salt water, moisture, or extreme dryness, and the fabric must be ”Drum tight” at every point on the surface of the wing.

The linen should have a tensile strength of at least 75 pounds per inch of width in any direction, and weigh from 3.75 to 4.4 ounces per square yard. It must be wet spun, free from filling matter and uncalendered. As a usual thing, the width should not be less than 36 inches, although the width can be altered to meet conditions of rib spacing, etc. The U.S.A. seaplane specifications (1916) require a minimum strength along the warp of 75 pounds per inch width, and 85 pounds per inch of width along the weft. The following table gives the properties of well known wing fabrics:

[image]

Wing Dope. Wing dopes are in nearly every case based on cellulose—either cellulose acetate or nitrate being the most common base. This has proven far superior to the resin, copal, gum or oil bases contained in ordinary varnish, since the cellulose of the dope seems to amalgamate with the cellulose of the flax fiber and bond the whole into an integral structure. The fact that the dope must be elastic bars the use of shellac or other hard resin solutions. The solvents used for the cellulose dopes vary with the makers, some using amyl-acetate, tetrachlorethane, etc., while others use special secret compounds that are best adapted for their bases. Many of the solvents give off poisonous gases in drying, and this must be guarded against by good ventilation. The vapor of tetrachlorethane is particularly dangerous, and has resulted in many deaths.

[image]

Fig. 10. Complete Framing Plan of Typical Monoplane Structure. (A) Pilot. (B) Passenger. (M) Motor. (S) Stabilizer. (E) Elevator. (R) Vertical Rudder.

Doped surfaces have from 10 to 25 per cent greater tensile strength and resistance to tearing than the undoped linen, and increases the weight of the fabric by about 0.7 ounce per square yard for each coat applied. Under ordinary weather conditions, dope will require from 20 to 40 minutes per coat for drying, and at least one-half hour should be allowed between each coat. Weather conditions have a great effect on the action of dope, and with cellulose compounds the best results are obtained in a clean dry room, well warmed, and without drafts. On rainy days the linen is damp and the dope does not set well, and this trouble is not greatly helped by artificial heat. Drafts cause white spots and streaks, especially if cold air is allowed to enter directly upon the warm wing surface. To prevent drafts the ventilating ducts should be near the floor, and as the vapor is heavier than the air, and flows downwards, this means of ventilation is entirely practicable.

Applying the Dope. The number of coats depend upon the character of the job, but at least five coats should be applied, and preferably seven. On the best grade of work, the dope is generally covered with three or more final coats of spar varnish, although this is not absolutely necessary. For ordinary work, dope alone on Irish linen has proved very satisfactory for land machines, five coats being the usual amount applied on exhibition aeroplanes and planes for amateur use. Seven coats of dope with three coats of spar varnish are specified for military machines that are to be used on salt water. Seaplanes are subjected to conditions that are particularly hard on fabric and must be protected accordingly.

In applying the dope, at least one-half hour should be allowed for drying between each coat, and more if possible. The first two coats should be painted on lightly, the purpose being simply to fill the pores of the fabric and to prevent the succeeding coats from sinking through. If the first two coats are too heavy, the dope filters through the mesh of the linen and drops on the lower surface, causing spots and a waste of a very expensive material. Dope is expensive even with the greatest care exercised in its application, and the writer has seen cases where the first two coats were so heavily applied that fully 50 per cent of the fluid ran through and caked in among the structural parts of the machine. This ran the doping expense up to a terrific figure. The cloth should be dry, and the work performed, if possible, on a dry day. To save dope, never take out of the supply drum more than can be used for one coat, for the dope soon becomes tacky on exposure to the air, and a satisfactory job is hard to obtain if it gets in this condition.

[image]

Fig. 10a. Testing the Wing Structure of a Curtiss Biplane by Means of Sand Bag Loading. The Wings Are Turned Upside Down and a Sand Load Is Laid Uniformly Over the Wings. So That They Produce a Load Equal to, or Greater Than, the Flight Load.

In placing the fabric on the wings, particular care must be taken in stretching so as not to have it too tight when cellulose dope is used. The dope shrinks the linen to a very considerable extent, and if it is too tight to begin with, the stress due to shrinkage will place an excessive stress on both the fabric and the structure. When of the proper tautness, the fabric should sound like a drum when snapped with the finger. Any less tension than this will permit the fabric to sag badly when under the air pressure and reduce the efficiency of the wings. In fastening the cloth it should be just stretched taut and no more. In damp weather the cloth can be stretched a little tighter than in dry weather.

Transparent Coverings. In some types of battle-planes and scouts, a part of the wing section directly above the pilot is covered with a transparent fireproof cellulose sheet, much resembling celluloid. This permits the pilot to see above him through the overhanging wing, and is of great value in action. In some cases, a strip is placed on the lower wings along the sides of the body so that the ground is also easily visible. These cellulose sheets will not crack nor splinter, and are nearly as flexible as rubber. Celluloid of the ordinary variety must not be used, for this is easily ignited and is likely to start a disastrous fire.

Placing the Fabric on the Wings. In some aeroplanes the seams of the fabric are run parallel to the ribs, and are tacked or sewed directly to them, while in other cases the seams are run diagonally across the plane or on the ”bias.” Diagonal seams are most satisfactory, and if care is taken there is no more waste of linen than with the straight seam. The seams should be of the double-lapped or ”English welt” type, and this of course necessitates sewing before the fabric is placed on the wings. The seams used on overcoats are satisfactory for this purpose, and give a covering that will not stretch nor bag. Some use linen thread and others use silk, but the linen is preferable, since dope often causes silk to rot. The seams should be covered with linen to protect them from the weather and to prevent the entrance of water to the interior woodwork.

Ordinarily, the wing is turned upside down for covering, with the concave side uppermost. The seams are sewed together so that the completed fabric is wider than the length of the wing and is a little longer than is necessary to wrap entirely around the width of the wing. The fabric is then temporarily fastened along the trailing edge, is passed under the wing to the front edge, and over the concave upper side back to the trailing edge. At this point the excess material will hang down over the rear edge. With the wing in its upside down position, the convex side will be at the bottom, and if a weight is hung on the overhanging material at the rear edge, the cloth will be pulled tight against the lower convex side and straight across and above the concave side. The fabric at the top is then stretched along the cordal line of the ribs. By laying a narrow board on top of the fabric, and near the entering edge, the fabric can be brought down uniformly along the concave edge of the ribs, and by tacking or sewing as the board is moved back the concave face can be covered without further trouble. After the concave face is disposed of, the wing can be turned over and the fabric is then fastened to the convex side of the ribs.

[image]

Fig. 11. Method of Stretching Fabric on Wings. Fabric Passes Under and Then Over Concave Side and Is Pressed Down into Hollow by a Board as Shown.

One method of fastening the linen is to lay tape over the ribs, and then drive tacks through the tape and fabric into the rib. The tape keeps the tacks from tearing through the linen. The tape should be heavy linen of from 3/4 to 1 1/4 inches wide, and laid in cellulose before tacking, so that the tape will be cemented to the fabric and the solution will be driven into the tack holes. After the tape is in place, it should be covered with not less than three coats of cellulose dope before the main surface is treated. This gives an additional three coats over the tape where it is most needed for protection against moisture. In any case, the seam or tacking strip should be pressed down so that it projects as little as possible above the general surface of the wing.

Tacking is not desirable, for tacks and nails always tend to split the thin members of the rib, and very often corrode the cloth and weaken the fabric. This has resulted in the whole fabric being ripped off while in flight. Iron or steel tacks should never be used, as they destroy the strength of the fabric very rapidly by the formation of rust, and particularly with sea-planes used on salt water. Sewing the fabric to the ribs with linen thread is the most satisfactory method and is in general use among high-grade builders.

The fabric can be stitched to bands of thread or tape, the latter being wrapped about the rib. Stitches can also be taken from one surface straight through to the other. The thread or tape bands on the ribs are merely wrappings taken around the rib flange, and through the lightening holes, these bands usually being about 4 inches apart. They at once tie the flange to the web and form a soft surface into which to take the stitches. Fig. 4 in Chapter X shows the thread bands (d) wrapped around the rib flange (G), and through the lightening hole, the fabric lying above and below the rib flanges as shown. A section view through the rib and fabric is shown at the right.

Varnishing. When varnish is to be used over the dope, only the best grade of spar varnish should be used, since any other kind is soon destroyed by moisture. From two to three varnish coats will be sufficient, and each coat should be thoroughly dried and sandpapered before the next is applied, care being taken not to injure the fabric with the sandpaper. Sandpapering between the dope layers is not necessary, since each successive coat partially dissolves the preceding coat, and thus welds the layers together. Varnish, however, does not act in this way, and the coats must be roughened. Shellac rots the linen and should not be used.

The Government specifies one coat of flexible white enamel in which a small quantity of lead chromate is mixed. This is applied over the last coat of varnish. The lead chromate filters out the actinic rays of the sun, thus reducing the injurious effect of the sunlight on the covering. If coloring matter is added to the dope, it should be in liquid form, as powders destroy the strength and texture of the dope deposit.

[image]

Fig. 12. Wing Structure of Handley-Page Giant Biplane. Courtesy "Aerial Age."

Patching Fabric. The majority of dopes can be used as cement for patching, but as dope will not stick to varnish, all of the varnish around the patch must be thoroughly removed with some good varnish remover. The varnish must be thoroughly cleaned off or there will be no results. Before applying the dope, the patch must be well stitched all around the edges, then cemented with the dope. The patch must now be covered with at least five coats of thin dope as in finishing the surface. Particular attention must be paid to filling the dope in the stitching.

CHAPTER X. WING CONSTRUCTION DETAILS.

Types of Ribs. The rib first used by the Wright Brothers consisted of two spruce strips separated by a series of small pine blocks. Practically the same construction was used by Etrich in Austria. With the coming of the monoplane, and its deep heavy spars, the old Wright rib was no longer suitable for the blocks were not efficient in thick wing sections. The changes in the wing form then led to the almost universal adoption of the ”I” type rib in which an upper and lower flange strip are separated by a thin vertical web of wood. At present the ”I” rib is used on nearly every well known machine. It is very strong and light, and is capable of taking up the end thrust of the drag wires, as well as taking care of the bending stresses due to the vertical loading or lift.

Fig. 1 shows the original Wright rib with the ”Battens” or flanges (g) and the spacing blocks B. The front spar is at the leading edge (F), and the rear spar at S. An ”I” beam, or ”Monoplane” type is shown by Fig. 2, and as will be seen is more suitable for deep spars such as (F’) and S’. The upper and lower flanges (g) are separated by the thin perforated web (w), the sectional view at the right showing the connection between the flanges and the web. Lightening holes (h) reduce the weight of the web, with enough material left along the center of the web to resist the horizontal forces. The web is glued into a slot cut in the flanges, and the flanges are then either tacked to the web with fine nails, or bound to it by turns of thread around the flange.

On the average machine, the web is about 3/16 thick, while the flanges are from 3/4 to 1 inch wide, and from 3/16 to 1/4 inch thick. On the very large machines, the dimensions of course are materially increased. At the strut locations in biplanes, and the point of cable bracing attachment in monoplanes, the ribs are increased in strength unless the end thrust of the stay wires is taken up by a separate strut. At the point of stay connection in the old Nieuport monoplane the rib was provided with a double web thus making a hollow box form of section great enough to account for the diagonal pull of the stays.

Fig. 3 shows the Nieuport monoplane ribs, which are good examples of box ribs. The sections at the left are taken through the center of the ribs. The wing chord tapers from the body to the wing tip, while the thickness of the wing section is greatest at the middle, and tapers down both toward the tips and toward the body. The upper section is located at the body, the second is located midway

[image]

Fig. 1. Wright Type Rib with Battens and Block Separators. Fig. 2. Monoplane or "I" Type of Rib with Solid Web.

between the body and the tip, and the other two are near the tips, the bottom being the last rib at the outer end. The ribs shown are of box form as they are at points of connection, but the intermediate ribs are of the "I" type shown by Fig. 2.

[image]

Fig. 3. Nieuport Monoplane Ribs. This Wing Is Thickest in the Center and Washes Out Toward Either End, Thus Making All of the Ribs Different in Curvature and Thickness. At the Point of Stay Wire Attachment Double Webbed Box Ribs Are Used.

Rib Material. In American aeroplanes, the flanges of the ribs are generally made of spruce. The webs are of poplar, whitewood, cottonwood or similar light material. There is not a great deal of stress on a rib, and the strongest material is not necessary, but as there are a great many ribs in a wing assembly lightness is a primary consideration. A few ounces difference on each rib makes a great deal of difference in the total weight, especially when there are 80 or more ribs in a complete machine. Exception to the above materials will be found in the Curtiss "Super-American" Flying Cruiser which has ribs with pine webs and birch flanges. European aeroplane practice makes use of hardwood in the ribs.

Web Stiffeners. The webs being thin and deep, and cut for lightening as well, need bracing at the points where concentrated loads are placed, such as at the front and rear spars, and at points between the lightening holes. By gluing thin strips to the webs (in a vertical direction), and so that the tops and bottoms of the strips come tight against the upper and lower flanges, a great deal of the strain on the web can be avoided. The stiffening blocks are shown by (x) in Fig. 4, and are placed on both sides of the front and rear spars F and S, and also between the lightening holes H.

Flange Fastenings. In the section at the right of Fig. 4 it will be seen that the web is inserted into a groove cut in the flanges and is then glued into place. It would be unsafe to trust entirely to the glue, owing to the effects of aging, moisture and heat, and consequently some additional means of fastening must

[image]

Fig. 4. Details of ”I” Type Rib, Showing Lightening Holes and Stiffeners.

be had. It has been customary to nail through the flange into the web, but as the web is only about 3/16 inch thick it is likely to split.

An approved method is shown in Fig. 4 in which Irish linen thread wraps (d) are passed through the lightening holes (H), and over the flanges (G). The thread is coated with glue before wrapping and after, and when dry it is thoroughly varnished for protection against moisture. The bands are spaced from 3 to 4 inches apart. If nails are used they should be brass nails—never steel or iron.

At the points (F) and (S) where the spars pass through the web, the web is entirely cut out so that the flanges ordinarily lie directly on the spars. In this case it is necessary to bevel the spar so that it at least approximately fits the curve of the flange. Sometimes when a full size spar is impossible, as in cases where the spar tapers toward the tips, wood packing pieces may be placed between the flange and the spar; tapered to make up for the curve. The flanges in any case must be securely fastened to the spar by brass wood screws as at (e), and the edges of the web should fit tightly against the sides of the spars.

Wing Battens. The wing battens run along the length of the wings, from end to end, and between the spars, and serve to brace the ribs sideways as shown in some of the general views of the wing assembly. To accommodate the battens, the openings (f) are cut directly under the flange. Usually the battens are thin spruce strips from 3/16 to 1/4 inch thick and 1/2 inch wide, and should be run through the web at a point near the stiffeners. The thickness from the top of the flange to the under side of the lightening hole is from 1/2 to 3/4 inch as indicated by (C).

Strength of Wood Ribs. The strength of a rib for any individual case can be found by the method used in computing beams, the rib usually being assumed to have a uniformly distributed load, although this is not actually the case, as before explained. The greater part of the load in normal flight is near the front spar, but this shifts back and forth with the angle of incidence so that there is no real stationary point of application, and the rib must be figured for the maximum condition. The total load carried by one of the intermediate ribs is due to the area between the ribs, or to the unit loading multiplied by the rib spacing and chord. The portion of the rib between the spars can be calculated as a uniformly loaded beam, supported at both ends. The entering edge in front of the spar, and the trailing edge to the rear may be taken as uniformly loaded beams supported at one end. The proportion of the loads coming on the ends and center position can be taken from the pressure distribution diagrams as shown under ”Aerofoils.”

A number of tests were made on ribs by Mr. Heinrich of the Heinrich Aeroplane Company, the ribs being built up on short pieces of spar so that actual conditions were approached. Instead of using a distributed load, such as usually comes on the rib, a concentrated load was placed at the center. If the rib were uniform in section the equivalent uniformly distributed load could be taken as one-half the concentrated load, but because of the lightening holes this would not be very exact. It would be on the safe side, however, as such a test would be more severe than with a uniform load. The ribs were of the same type as shown in Fig. 5, and were placed 32.5 inches apart. The front spar was 2 7/16 inches deep, the rear spar 2 1/16 inches deep, and the overall depth of the rib at the center was 3 1/8 inches. The rib flanges were of white wood 3/4 inch wide, and 3/16 inch thick. In rib No. 1 the web was solid whitewood, 3/16 inch thick, and in ribs Nos. 2 and 3, the webs were mahogany three-ply veneer (5/32 inch thick).

Test of Rib No. 1. There are 5 lightening holes between spars, with 2 inches of material left between the holes, and 1/2 inch between first hole and front spar opening. With 95 pounds concentrated load at the center, the first rupture appeared as a split between the first hole and spar opening. At 119 pounds, the flanges had pulled away from one side of the spar, and 1/8 inch away from the web. Full failure at 127.5 pounds. Web was split between each lightening hole with a complete cross break at center of web, the latter being caused by a brad hole in the web.

Test of Rib No. 2. Laminated web, with no brads driven opposite lightening holes. At 140 pounds rib deflected 5/16 inch, and when relieved sprang back only 3/16 inch. With 175 pounds, the deflection again was 5/16 inch, but the rib continued to bend slowly, the flanges pulling away from the web and spars. The wood was not broken anywhere, the failure being in the brads and glue.

Test of Rib No. 3. Same materials as No. 2, but web was fitted inside of the ”I” beam spar and the rib flanges were screwed to the spar. At 175 pounds there was no sign of rupture anywhere, and the deflection was 5/16 inch. At 185 pounds the rib broke very suddenly and cleanly, and in such a way as to indicate that this was the true strength of the rib. The normal loading on the rib in flight was 17.5 pounds, uniformly distributed, so that with a concentrated load of 370 pounds equivalent, the safety factor was 21.1.

The conclusions to be arrived at from this test are as follows:

(1) When a solid soft wood web is used, there should be at least 2 1/2 to 3 inches between lightening holes.

(2) A laminated or three-ply web is the best.

(3) No brads should be driven opposite lightening holes.

(4) The web should fit closely to the spar sides and the flange of the rib should be tightly screwed to the top and bottom of spar.

The above gives an idea as to the strength of the usual form of wood rib, and can be used comparatively for other cases if the reader is not familiar with strength calculations.

[image]

Fig. 7. Rib Bending Press for Curving the Rib Flanges.

Making the Rib. Wooden webs are cut out on the band saw, and the webs are so simple that there is not much more to be said on the subject. The flanges, however, must be steamed and bent to the nearly correct form before assembly. After planing to size and cutting the groove for the reception of the web, the ribs are placed in the steamer and thoroughly steamed for at least an hour. A rib flange press shown by Fig. 7 consists of two heavy blocks with the inner faces cut approximately to the rib outline. The steamed ribs are then placed between the blocks, the bolts are screwed down tight, and is left for 24 hours so that the strips have ample time to cool and dry. For the amateur or small builder, the steamer can be made of a galvanized ”down-spout” connected with an opening cut in the top of an ordinary wash boiler. One end of the spout is permanently sealed, while the other is provided with a removable cover so that the strips can be inserted. A hole cut near the center of the spout is connected to the opening in the boiler cover by a short length of spouting or pipe. The spout should be made large enough in diameter to contain all of the ribs that can be pressed at one time, and should be long enough to accommodate longer pieces such as the fuselage longerons, etc.

When removed from the press, the rib flanges can be glued to the webs taking care that the glue is hot, and that it thoroughly covers the groove surface. The rib must now be held accurately in place in a second form, so that the true rib outline will be retained until the glue drys. A great deal depends upon the accuracy of the second form, and the accuracy with which the web outline is cut. The larger manufacturers use metal rib forms or ”jigs,” but the small builder must be content with a wooden form consisting of a board fitted with suitable retaining cleats, or lugs. The outline of the aerofoil is drawn on the board, the tips of the cleats are brought to the line, and are screwed to the board so that they can be turned back and forth for the admission and release of the ribs. The strip bending press in Fig. 7 is only intended to bend the flanges approximately to form, and hence two layers may be put in the press at one time without much error.

Wing Spars. In American aeroplanes these members are usually of the solid "I" form for medium size exhibition and training machines, but for small fast aeroplanes, where every ounce must be saved, they are generally of the built up type, that is, made up of two or more members. In Europe, built up construction is more common than in this country, and is far preferable for any machine that justifies the additional time and expense. The wing spars are the heaviest and most important members in the wing and no trouble should be spared to have them as light as the strength and expense will permit. They are subjected to a rather severe and complex series of stresses; bending due to the load carried between supports, compression due to the pull of the stay wires, bending due to the twist of non-central wire fittings, stresses due to drag and those caused by sudden deviations in the flight path and by the torque of the motors. These should be accurately worked out by means of stress diagrams if the best weight efficiency is to be obtained.

[image]

Fig. 9. Types of Wing Spars. (A) Is the "I" Beam Type. (B) Box Spar. (C) Is Composite Wood and Steel, Wrapped with Tape.

A number of different wing spar sections are shown by Figs. 9, 10, 11. Spar (A) in Fig. 9 is the solid one piece "I" type (generally spruce), channeled out along the sides to remove the inefficient material at the center. The load in this case is assumed to be in a vertical direction. In resisting bending stresses, it should be noted that the central portion of the material is not nearly as effective as that at the top and bottom, and that the same weight of material located top and bottom will produce many times the results obtained with material located along the center line. At points of connection, or where bolts pass through the spar, the channeling is discontinued to compensate for the material cut away by the bolt and fittings.

Spar (B) is of the hollow type, made in two halves and glued together with hardwood dowel strips. The doweling strips may be at the top and bottom as shown, or on the horizontal center line as shown by Spar (J). The material of the box portion is generally of spruce. This is a very efficient section as the material lies near the outer edge in every direction, and offers a high resistance to bending, both horizontally and vertically. Unfortunately a great deal depends upon the glued joints, and these require careful protection against moisture. There is absolutely no means of nailing or keying against a slipping tendency or horizontal shear. The best arrangement to insure against slipping of the two halves is to tape around the outside as shown by spar (E). This is strong linen tape and is glued carefully to the spar, and the whole construction is proofed against moisture by several coats of spar varnish and shellac. In addition to the strengthening effect of the tape, it also prevents the wood from splintering in accidents.

[image]

Fig. 10. Four Types of Wing Spars, the Spar D Being a Simple Steel Tube as Used in the Caudron and Breguet Machines.

Spar (C) consists of a central ash "I" section, with steel strips in the grooves. Two spruce side strips are placed at either side as stiffeners against lateral flexure, and the entire construction is taped and glued. This is very effective against downward stresses, and for its strength is very compact. Since spruce is much stiffer than either the thin steel strip, or the ash, it is placed on the outside. Spar (D) in Fig. 10 has been described before.

Fig. (F) consists of two spruce channels placed back to back, with a vertical steel strip between them. Again the spruce is used as a side stiffener, and in this case probably also takes a considerable portion of the compression load. Spar (G) is a special form of box spar used when the spar is at the entering edge of the wing, the curved nose being curved to the shape of the aerofoil nose. In Fig. 11 (H), a center ash "I" is stiffened by two spruce side plates, the ash member taking the bending moment, and the spruce the compression. Spar (I) has a compound central "I," the upper and lower flanges being of ash and the center web of three ply veneer. The two outer plates are of spruce. This should be a very efficient section, but one that would be difficult and costly to build. Fig. (J) is the same as (B), except that the parting lies in a horizontal plane. Spar (K) has ash top and bottom members, and spruce or veneer side plate. The resistance of this shape to side thrust or twist would be very slight. The sides are both screwed and glued to the top and bottom members.

The front end of a Hansa-Brandenburg wing is shown by Fig. 12, the box spar and its installation being drawn to scale and with dimensions in millimeters. The top and bottom are sloped in agreement with the rib flange curve, and the rib web is strengthened by stiffeners at either side of the spar. The hardwood dowel

[image]

Fig. 11. Built-Up Wooden Wing Spars, Commonly Used with European Aeroplanes.

strips are at top and bottom as in Fig. B, and when placed in this position the glued joint is not subjected to the horizontal shear forces. The walls are thicker at top and bottom than at the sides, in order to resist the greater vertical forces. For the same reason is deeper than it is wide. As will be remembered, the drag is very much less than the lift, and again, the drag stress is greatly reduced by the internal drag wire bracing.

[image]

Leading Edge Construction. In the early Bleriot monoplanes the leading edge was of sheet aluminum, bent into ”U” form over the nose of the rib. In modern biplanes, this edge is generally of ”U” form hollow spruce, about 3/16 inch thick. Another favorite material is flattened steel tubing, about 1/2” x 1/4”, and of very light gauge, the long side being horizontal. The tube has the advantage of being much thinner and much stiffer than the other forms, and the thin edge makes it very suitable for certain types of aerofoils. The wing tip bows are generally of hollowed ash and are fastened to the spar ends, leading edges, and trailing edges with maple dowels, the joint being of a long scarfed form. When the scarfed joint is doweled together, it is wrapped with one or two layers of glued linen tape. In some types of machines the top surface of leading edge is covered with thin two ply wood from the extreme front edge to the front spar. This maintains the aerofoil curve exactly at the most critical point of lifting, and also stiffens the wing against the drag forces.

[image]

Fig. 12b. An Old Type of Curtiss Biplane Strut Socket, at Left. At the Right Is a More Modern Type in Which the Bolts Do Not Pierce the Spar.

Trailing Edges. These are either of thin beveled ash or Steel tube. On army machines, the rear part of the trailing edge fabric is pierced with holes about 3/16 inch diameter, the holes being provided with rust proof eyelets. This relieves an excess of pressure due to rips or tears; one opening being located between each rib and next to the body.

[image]

Fig. 12c. A Standard H-3 Interplane Strut Socket Is Shown at the Left, the Bolts in This Case Passing on Either Side of the Spar. Note the Stay Wire Attachment Clips and Pinned Strut Connection. A German Strut Socket at Right. Courtesy ”Aerial Age.”

Protection of Wing Wood Work. In protecting the wood framework of the wings from the effects of moisture, at least three coats of good spar varnish should be carefully applied, with an extra coat over the glued surfaces and taping. Shellac is not suitable for this purpose. It cracks with the deflection of the wings and finally admits water. The steel parts of the wing should be given two coats of fine lead paint, and then two coats of spar varnish over the paint. Wires are treated with some flexible compound, as the vibration of the thin wires, or cables, soon cracks off any ordinary varnish. The use of shellac cannot be too strongly condemned; it is not only an indifferent protection, but it causes the fabric to rot when in contact with the doped surface.

Monoplane Wing Spars. A few representative monoplane wing spars are shown by Fig. 13, the R. E. P., Bleriot XI, and the Nieuport. Except at points where the stay wires are connected, the Bleriot spar is channeled out into ”I” beam form as indicated in the figure. It will be noted that the top and bottom faces of the spar are slanted to agree with the curvature of the ribs. A. steel connection plate is bolted to the sides of the spar by through bolts, and with a lug left top and bottom for the top and bottom guy wires. The R. E. P. is also an ”I” type, the section. ”A” being taken through the channeled portions, while ”B” is taken through one of the connection points where the beam is a solid rectangle. The channeling should always stop at connection points; first, so that the plates have a good bearing surface, and second, to allow for the material removed by the bolt holes.

Probably the most interesting of all the spars is the Nieuport, which is a combined truss and girder type. This spar tapers down from the center to both ends, being thickest at the points where the guys are attached. The top flange (J), and the

[image]

Fig. 13. Typical Monoplane Wing Spar Construction.

bottom flange (L), are ash, while the side plates and diagonals (H) are spruce. The diagonals resist the shear, and are held in place by the tie bolts (I). At the left, the spruce cover plate is removed, while at the right it is in place with the interior construction shown in dotted lines. The dimensions are in millimeters.

[image]

Fig. 14. Plate Connection for Monoplane Stay Wire Connection to Spar. A Compression Member or Drag Strut Is Shown in the Center of the Spar Which Takes Up the Thrust Due to the Angularity of the Stays and Also the Drag Stress.

Location of Spars. There are a number of items that affect the location of the spars in regard to the leading edge. The most important factors in the choice of location are: (1) Shape and depth of wing section, (2) Center of pressure movement, (3) Drag bracing requirements, (4) Width of ailerons, (5) Method of attaching the interplane struts.

CHAPTER XI FUSELAGE (BODY) CONSTRUCTION.

Purpose of Fuselage. The fuselage of a monoplane or tractor biplane is the backbone of the machine. It forms a means of connecting the tail surfaces to the main wing surfaces, carries the motor, fuel and pilot, and transmits the weight of these items to the wings and chassis. With the exception of the wing structure, the fuselage is the most important single item in the construction of the aeroplane. Fig. 1 shows a typical arrangement of a two-place biplane fuselage equipped with a water-cooled motor. The motor E, propeller Y, and radiator R are placed in the front of the fuselage, and considerably in advance of the wings W and D. Immediately behind the motor is the passenger's seat A and the fuel tank F. The pilot's seat B is placed behind the trailing edge of the wings and is behind the passenger's seat. The cockpit openings G and H are cut in the fuselage top for the passenger and pilot respectively. The rear extension of the fuselage carries the control surfaces, L being the vertical fin, M the rudder, O the fixed tail or stabilizer, and P the elevator.

Resistance. To reduce the resistance in flight, the fuselage is of as perfect streamline form as possible, the fuselage being deepest at a point about one-third from the front. From this point it tapers out gradually to the rear. With the motors now in use it is only possible to approximate the ideal streamline form owing to the front area of the radiator and to the size of the motor. Again, the projection of the pilot's head above the fuselage adds considerably to the resistance. The wind shields I disturb the flow of air. The connections to the tail surfaces and to the chassis members K also add to the total resistance. An arched "turtle deck" J is generally provided, of such a shape that the pilot's head is effectively "streamlined," the taper of this deck allowing the disturbed air to close in gradually at the rear. The flat area presented by the radiator R is probably the greatest single source of resistance, and for this reason the radiator is sometimes placed at the side of the fuselage, or in some other position that will allow of a better front end outline. An example of this construction is shown by Fig. 2 in which the radiator R is placed behind and above the motor E. The front fuselage end Z can now be made of a more suitable streamline form.

[image]

Figs. 1-2-3. Fuselage and Motor Arrangement of Tractor Biplanes.

Fig. 3 is a view of the front end of a typical fuselage in which an air-cooled rotary type of motor is installed. Since the diameter of this type of motor is seldom much less than three feet, it is necessary to have a very great diameter in the extreme front. The motor housing or "cowl" marked E has a diameter "d" which should smoothly blend into the outline of the fuselage at "b." In the older types of construction there was often a very considerable break in the outline at this point, especially in cases where the circular cowl was abruptly connected to a square fuselage. A break of this sort greatly increases the head resistance. A "spinner" or propeller cap marked Z in Fig. 3 is an aid in reducing the resistance offered by the motor cowl and also reduces the resistance of the inner, and ineffective, portion of the propeller blades. The cap in any case is smaller than the cowl opening in order that cooling air be admitted to the enclosed cylinders.

Distribution of Loads. Returning to Fig. 1, we note that the weight of the fuselage, pilot, passenger, fuel, control surfaces and motor are carried to the upper wing W by the "cabane" strut members C-C and stays, the lower wing being connected directly into the sides of the fuselage. Continuations of the cabane members on the interior of the fuselage inter-connect the upper and lower wings (shown in dotted lines). The interplane stays in connection with the cabane members bind the wings and fuselage into a unit. A vertical line ”CP” passes through the center of pressure of both wings, and approximately through the center of gravity of the machine. In other Words, the machine is nearly balanced on the center of pressure line. The turning moments of weights behind the CP must approximately balance the opposite turning moments of the masses located in front of the CP. The exact relation between the center of pressure and the center of gravity will be taken up later.

Variable loads such as the passenger, gasoline and oil, are placed as nearly as possible on the center of pressure line, so that variation in the weight will not affect the balance. In the figure, the passenger’s seat A, and the fuel tank F are on the CP line, or nearly so. Thus, a reduction in the weight of the fuel will not affect the ”trim” of the machine, nor will a wide variation in the weight of the passenger produce any such effect. As shown, the passenger’s seat is placed directly on the top of the fuel tank, an arrangement widely used by European constructors. In the majority of American machines the fuel tank is placed at the top of the fuselage instead of in the position illustrated. As the pilot is considered as a constant weight, his location does not affect the balance.

When at rest on the ground, the weight of the rear end of the fuselage is supported by the tail skid N. The length of this skid must be such that the tail surfaces are kept well clear of the ground. The center of the chassis wheel Q is placed in front of the center of gravity so that the weight of the machine will cause the tail skid to bear on the ground when the machine is at rest. If the wheel were behind the center of gravity, the machine would ”stand on its nose” when making a landing. The wheels must be located so that the tendency to ”nose over” is as small as possible, and yet must not be set so far forward that they will cause an excessive load on the tail skid. With too much load on the skid, the tail will not come up, except after fast and prolonged running, and heavy stresses will be set up in the framework due to the tail bumping over the ground at high speed. The skids should not be dragged further than absolutely necessary, especially on rough ground. With proper weight and wheel adjustment, the tail should come up in a short run. The wheel adjustment will be taken up under the head of ”Chassis.”

Position in Flight. In normal horizontal flight, the center line of thrust CT is horizontal or nearly so. This line of thrust passes through the center of the motor crankshaft and propeller. In an upward climb, the CT is inclined at the angle of climb, and since the CT indicates the line of flight, the streamline curves of the body should be laid out so that the axis of least body resistance will coincide with the line of thrust. When flying horizontally at the normal speed, the body must present the minimum of resistance and the wings must be at the most efficient angle of incidence. In climbing, or flying at a very low speed, the tail must necessarily be depressed to gain a large angle of wing incidence, and hence the body resistance will be comparatively high owing to the angle of the body with the flight line. It is best to have the least resistance of the fuselage coincide with the normal horizontal flight speed. This condition at once establishes the angle of the wings in regard to the fuselage center line.

Center Line of Resistance. The center line of thrust should pass through the center of total head resistance as nearly as possible. The total resistance referred to is composed of the wing drag, body and chassis resistances. In an ordinary military type of aeroplane this line is located approximately at one-third of the gap from the bottom wing. Owing to variations in the drag of the Wings at different angles, this point varies under different flying conditions, and again, it is affected by the form and size of the fuselage and chassis. The exact location of the center of resistance involves the computation of all of the resistance producing items.

In addition to passing through the center of resistance, the center line of thrust should pass slightly below the center of gravity of the machine. In this position the pull of the motor tends to hold the head up, but in-case of motor failure the machine immediately tends to head-dive and thus to increase its speed. The tendency to dive with a dead motor automatically overcomes the tendency to ”stall” or to lose headway. With the centerline of thrust determined, and with given motor dimensions, the fuselage position can be located at once in regard to the wings. This is good enough for a preliminary layout, but must be modified in the final design. As before explained, the centerline of thrust is located at a point between the two wings, approximately one-third of the gap from the lower wing.

In machines having a span of 35 feet and over, it is a trifle less than one-third the gap, while in small speed scouts it is generally a trifle over one-third. This rule checks very closely with the data obtained from 22 standard machines. Thus, in a machine having a 6-foot gap, the propeller centerline will be located about 2 feet above the lower wing. The top of the fuselage (measured under the stabilizer surface) is from 5 to 8 inches above the center line of thrust. At the motor end, the height of the fuselage above the CT is controlled by a number of factors, either by the type of motor, or by the arrangements made for access to the motor parts. In a number of European machines, the motor sits well above the top of the fuselage, this always being the case when a six-cylinder, vertical water-cooled motor is used. With an air-cooled type, the top is governed by the cowl diameter.

Motor Compartment. The space occupied by the motor and its accessories is known as the ”motor compartment,” and in monoplane and tractor biplane fuselage it is located in the extreme front of the body. The interior arrangement varies with different types of motors and makes of machines. With rotary cylinder motors, the ”compartment” is often nothing but a metal cowl, while with large water-cooled motors it occupies a considerable portion of the body. Water-cooled motors are generally covered with automobile type hoods, these usually being provided with ”gilled” openings for ventilation. Owing to the heat generated in the motor, some sort of ventilation is imperative at this point. Whatever the type, the compartment is always cut off from the rest of the fuselage by a fire-proof metal partition to guard against fire reaching the passenger or fuel tanks. The fuel and oil should always be separated from the motor by substantial partitions since a single carbureter ”pop” may cause serious trouble.

[image]

Fig. 4. Mounting and Cowls for Rotary Cylinder Motors. Courtesy ”Flight.”

Accessibility is a most important feature in the design of the motor end, and hence the hood should be of the hinged automobile type so that it can be easily raised for inspection or repairs. In the Curtis JN4-B Military Training Tractor, the cylinder heads and valve mechanism project slightly above the top of the hood so that these parts are amply cooled and are entirely accessible. Access to the carbureter can be had through a small hand-hole in the side of the hood. The radiator in this Curtiss model is located in the extreme front end of the fuselage—automobile fashion. The propeller shaft passes through a central opening in the radiator. In Fig. 6 the vertical motor E is set down low in the frame, the upper part of the fuselage F ending at H. The engine bearer B, which carries the motor, forms the top part of the fuselage at this point. The engine is thus in the clear and access can easily be had to every part of the motor. The radiator is in front of the motor at R. When in flight the motor is covered by a sheet metal hood similar to the folding hood used on automobiles. This type is used in the Martin, Sturtevant, and several European machines.

Fig. 7 is a very common front end arrangement used with side radiators. The top fuselage member F is brought down in a very low curve, leaving the greater part of the motor projecting above the fuselage. At the extreme front, the upper

[image]

Fig. 5. Motor Compartment of a Curtiss Tractor Biplane Using a Front Type Radiator. Note the Two Exhaust Pipes Which Carry the Gases Over the Top of the Wings.

fuselage member F joins the engine bearer B, the connection being made with a pressed steel plate. The radiator R is shown at the side of the fuselage. The cylinders are not usually covered when in flight. In the front view it will be noted that the radiators are arranged on either side of the fuselage. A side view of the H. and M. Farman Fighter is shown by Fig. 10. This is a very efficient French machine which has seen much active service in the war. The front end is much like that shown in Fig. 7 except that a spinner cap is fitted to the propeller boss. A ”V” type motor allows of the radiator being mounted between the two rows of cylinders, and in a position where it will cause the least possible head resistance.

[image]

Figs. 6-7. Various Motor Arrangements, and Radiator Locations.

[image]

Fig. 10. A Type of H. and M. Farman Tractor Fighting Biplane. This Machine Uses a ”V”. Type Motor, with the Radiator in the Valve Alley. The Gunner and the Machine Gun Are Mounted in the Rear Cock-pit. It Will Be Noted That the Body Is Raised Well Above the Lower Wing So that the Gun Field Is Increased. The Pilot Is Well Ahead of the Entering Edge of the Lower Wing. Courtesy of ”Aerial Age.”

The fuselage is of excellent streamline form and shows careful study in regard to the arrangement of the power plant. Unlike the majority of machines, the fuselage is raised well above the bottom wing, this being done evidently to increase the range of the gun in the rear cockpit. The increased height allows the gun to shoot over the top plane at a fairly small angle, and the height above the ground permits the use of a very large and efficient propeller without having an excessively high chassis. At the rear the fuselage tapers down to a very thin knife edge and therefore produces little disturbance.

[image]

Fig. 11. Radiator Mounted at Leading Edge of Upper Wing. This Type Is Used with the Sturtevant and Lawson Aeroplanes and Is Very Effective Because of the Improved Circulation.

Fig. 11 shows a Sturtevant Training Biplane in which the radiator is mounted at the front edge of the upper plane. This arrangement was originally introduced by the Sturtevant Company in their steel biplanes and has proved a very efficient type for cooling, although the radiator must affect the lift of the top plane to a very considerable extent.

Pilot and Passenger Compartments. These compartments contain the seats, controls, and instruments, and in the military types contain the gun mounts and ammunition. In some battle-planes, the passenger or ”observer” occupies the rear seat, as this position gives a wider range of fire against rear or side attacks. This arrangement is true of the H. and M. Farman machine just illustrated and described. In the large German ”Gotha” the gunner occupies the rear position and fires through, or above, a tunnel built through the rear end of the fuselage. In some forms of training machines, the pilot and passenger sit side by side instead of in tandem, as this arrangement allows better communication between the pilot and student, and permits the former to keep better watch over the movements of the student. A notable example of this type is the Burgess Primary Trainer. A side-by-side machine must have a very wide fuselage and therefore presents more head resistance than one with the seats arranged in tandem, but with proper attention to the streamline form this can be reduced so that the loss is not as serious as would be imagined from a view of the layout.

The seats may be of several types, (a) the aluminum ”bucket” type similar to, but lighter than, the bucket seats used in racing automobiles; (b) the woven wicker seat used in many types of German machines, or (c) the modified chair form with wooden side rails and tightly stretched leather back and bottom. Whatever the type, they should be made as comfortable as possible, since the operation of a heavy machine is trying enough without adding additional discomfort in the form of flimsy hard seats. In the older machines the seats were nothing more than perches on which the pilot balanced himself precariously and in intense discomfort. A few pounds added in the form of a comfortable seat is material well spent since it is a great factor in the efficient operation of the machine. Wicker seats are light, yielding and comfortable, and can be made as strong or stronger than the other types. It seems strange that they have not been more widely adopted in this country.

All seats should be slightly tilted back so that the pilot can lean back in a comfortable position, with a certain portion of his weight against the back of the seat. Sitting in a rigid vertical position is very tiring, and is especially so when flying in rough weather, or on long reconnaissance trips. The backs of the seats should be high and head rests should be provided so that the pilot's head can be comfortably supported against the pressure of the wind. If these head rests are "streamlined" by a long, tapering, projecting cone running back along the top of the fuselage, the resistance can be considerably reduced. This arrangement was first introduced in the Gordon-Bennett Deperdussin and has been followed in many modern machines. In the Deperdussin, the pilot's head was exposed directly to the full blast of the propeller slipstream and a head support was certainly needed. Small, transparent wind shields are now fastened to the front edge of the cockpit openings which to a certain extent shield the pilot from the terrific wind pressure. These are quite low and present little resistance at high speeds.

[image]

Fig. 12. Hall-Scott Motor and Side Type Radiator Mounting on a Typical Tractor.

A heavy leather covered pad, or roll, should be run entirely around the edge of the cockpit opening as a protection to the pilot in case of an accident or hard landing. The roll should be at least 3 1/2" in diameter and should be filled with horse hair. All sharp edges in the cockpit should be similarly guarded so that in the event of the pilot being thrown out of his seat, he will not be cut or bruised. Each seat should be provided with an improved safety strap that will securely hold the pilot in his seat, and yet must be arranged so that it can be quickly and easily released in an emergency. In flight the occupants must be securely strapped in place to prevent being thrown out during rapid maneuvers or in rough weather. Buckles should be substantial and well sewed and riveted to the fabric so that there will be no danger of their being torn out. The straps must be arranged so that they will not interfere with the free movement of the pilot, and so that they will not become entangled with the controls. It is best to copy the sets approved by the government as these are the result of long continued experiment and use.

[image]

Fig. 13. Deperdussin Monoplane with Monocoque Body. Note the Streamline Form of the Body and the Spinner Cap at the Root of the Propeller.

Care must be taken to have the seats located at the correct height from the floor so that the legs will not become cramped. In the majority of machines, the vertical rudder is operated by the feet. Unless the seat is at the proper height, the pilot will be in a strained position as he cannot shift around nor take his feet from the rudder bar. Either the rudder bar or the seat should be adjustable for different lengths of legs. Usually the adjustment is made in the rudder bar since it is not usually advisable to shift the seats owing to the necessity of having the pilot's weight in a fixed position. In some old types of monoplanes, the pilot sat on a small pad placed on the floor of the fuselage. Needless to say, this was a horribly uncomfortable position to be in, but as the flights of that time were of short duration it did not matter much. If the feet could be removed occasionally from the rudder bar the matter of seat position would not be of so much importance, but to sit flat on the floor, with the legs straight out, for a couple of hours is a terrible strain and has undoubtedly caused many accidents through cramps.

As both the passenger and the fuel are varying weights, the fuel tank seat idea is good. This allows both of these items to be placed at the center of gravity of the machine where weight variation will have no effect on the balance of the plane. In this position, however, the fuel must be pumped up to a higher auxiliary tank since the main tank would be too far below the carbureter for gravity feed.

The flooring of the cockpits can be either of veneer, or can be built up of small spruce slats about 1/2" x 1/2", the slats being spaced about 1/2" apart. The latter floor is specified by the government for seaplane use, and is very light and desirable. The floor is placed only at points where it will be stepped on. Observation holes are cut in the floor on a line with the edge of the seats so that the occupants can view the ground without looking over the edge of the fuselage. The observation port holes are about 9 inches in diameter. Glass should never be used in the cockpits except for the instrument covers, unless it is of the non-splintering "triplex" laminated type of glass. The use of inflammable celluloid should also be avoided as being even more dangerous than the glass. The triplex glass is built up of two or more layers of glass, which are cemented together with a celluloid film applied under heavy pressure. This form of construction is very strong, and while it can be broken, it will not fly apart in the form of splinters.

All instruments should be placed directly in front of the pilot so that he can take observations without turning his head. Usually all of the instruments, with the exception of the compass, are mounted on a single "instrument board" placed in front of the pilot and directly under the forward edge of the cockpit opening. The compass can be placed on the floor as in American machines, or inserted in the upper wing as in some European machines. The motor control apparatus is placed where it can be reached conveniently from the seat. Oil gages, gasoline gages, and revolution counters are generally placed on the instrument board where they can be easily observed. If a wireless set is carried, the switches are placed on, or near, the instrument board. Owing to the uses to which the different machines are put it is impossible to give a list of instruments that would be suitable for every machine. The simplest machine should have the following instruments:

Altimeter for measuring altitude.

Clock of special aeroplane type.

Incidence indicator.

Air speed indicators for measuring the speed of the machine relative to the air.

Gasoline, oil and pressure gages for determining amount of fuel.

Instruments for Navy and Army machines are of course more complete. In the specifications for Army Hydroaeroplanes (twin motor type 1916) the following instruments are specified:

Aneroid Barometer. Graduated in feet, and reading from sea-level to 12,000 feet.

Compasses. One in each cockpit. To be of the Sperry Gyroscopic type with an elastic suspension and properly damped. Shall be attached to, and synchronized with, the ground drift indicator.

Ground Drift Indicator. Located in observer's cockpit. For noting drift due to side winds. See illustration on page 244.

Clock. Special aeroplane type, built to resist vibration. Located in pilot's cockpit.

[image]

Fig. 14. Aeroplane Compass of the McCreagh-Osborn Type. (Sperry)

Gasoline Supply Gage. To indicate the amount of fuel in gravity service tank at all attitudes of flight, and shall be visible from pilot's seat. A gage in the main tank will also be desirable that will register the approaching exhaustion of fuel. This indicator should register when 75% of the fuel in the main tank is exhausted, and then record the remainder continuously.

Air Speed Indicator. One in pilot's cockpit.

Angle of Incidence Indicator. Sperry type. To be located in pilot's cockpit.

Inclinometer. For measuring angle of inclination of longitudinal axis of machine. In pilot's cockpit, and placed on instrument board in the vicinity of tachometers.

Bank Indicator. For indicating the proper amount of bank on turns. In pilot's cockpit.

Map Board. One revolving map board placed in pilot's cockpit.

Map Desk. One folding map desk in observer's cockpit.

[image]

Fig. 15. Sperry Ground Drift Indicator.

Tachometers. For measuring speed of motors in revolutions per minute. Pilot's cockpit.

Self-Starter Switch. For operating self-starter. On instrument board in pilot's cockpit.

Among the other accessories specified in the cockpit for the above machines are a Pyrene fire extinguisher; a 2-gallon water breaker; a speaking tube for communication between the pilot and observer (1" to 1 1/8"); a flashlight signal for speaking tube; and a tool kit. The weight of the tool kit shall not exceed 11 lbs.

[image]

Fig. 16. Cock-pit of a ”London and Provincial” Biplane. Control Lever in Foreground and Instrument Board Under Cowl. Courtesy of ”Flight.”

General Proportions of the Fuselage. The total length of the fuselage depends upon the type of power plant, upon the span or chord of the wings, and upon the arrangement of the tail surfaces. The rear end of the fuselage should be far enough away from the wings to insure that the rear surfaces are not unduly affected by the ”down-wash” or the ”wake-stream” of the wings. A very short fuselage gives a short lever arm to the control surfaces, hence these surfaces must be very large with a short body. With the stabilizer surface close to the wings, the ”damping” effect is slight, that is, the surface does not effectively kill or ”damp down” oscillations. Large tail surfaces are heavy, difficult to brace, and cause a very considerable amount of head resistance. The extra weight of a long fuselage is generally offset by the increased weight caused by the large tail area of the short body type.

When machines are crated and shipped at frequent intervals, a very long fuselage is objectionable unless it is built in two sections. It also requires much storage space and a very long hangar. Machines for private use must often be sacrificed from the efficiency standpoint in order to keep the dimensions within reasonable limits. An aeroplane requiring an enormous hangar has certainly no attraction for the average man. Every effort must be made to condense the overall dimensions or to arrange the extremities so that they can be easily dismounted. Exhibition flyers require specially portable machines since they ship them nearly every day, and the expense of handling a long awkward fuselage may alone determine the choice of a plane. It is usually best to divide the body at a point just to the rear of the pilot’s seat, although many flyers look upon a two-part body with disfavor unless they can be shown that the joint connections are as strong as the rest of the fuselage.

As a guide in the choice of fuselage proportions, a set of diagrams and a table are attached which gives the general overall dimensions of several prominent makes of machines. The letters in the diagram refer to the letters heading the columns in the tables so that the general dimensions of any part can be readily determined. I do not claim that these dimensions should be followed religiously in every case, but they show what has been done in the past and will at least suggest the limits

[image]

Fig. 19. Fuselage Dimension Chart for Two Place Aeroplane Fuselage. Upper Diagram Is the Water Cooled Type and the Lower Figure Applies to a Machine with a Rotating Air Cooled Motor. See Table of Dimensions on Page 248.

within which a new machine can be built.

[image]

Fig. 20. Fuselage Dimension Diagrams Giving the Principal Dimensions of Speed Scout Machines. Upper Figure Shows Typical Scout with Water Cooled Motor (Curtiss), While Lower Diagram Shows an Arrangement Common with Rotary Air Cooled Motors (Nieuport)

[image]

Fig. 19 gives the outline and dimension letters for two-place machines of what is known as the ”Reconnaissance Type.” Both water-cooled and air-cooled motor equipments are shown, the top machine being of the water-cooled type while the lower figure shows a typical two-place machine with a rotary air-cooled motor. Underneath this side elevation is a front view of the fuselage, and a section taken through the point of greatest depth. As shown, the fuselage is of square cross-section, but the dimension B applies equally to the diameter of a circular cross-section. Dimension C gives the height of the curved upper deck, or ”turtle deck” of the fuselage. Dimension D shows the extreme length extending in front of the leading edge of the lower wing, and T shows the length of the rear portion back of the leading edge of the lower wing, the leading edge being taken as a base of measurement. The location of the deepest section, measured from the extreme front of the fuselage, is given by E, the depth at this point being indicated by B. The extreme width is shown by I. In the machine shown, side radiators are used, the blunt front end dimensioned by G and K being the dimension of the front engine plate. When front radiators are used, the dimensions G and K also apply to the size of the radiator. The amount of advance, or the distance of the chassis wheel center from the leading edge is given by S, and the distance of the wheel center below the leading edge is given by R. V is the length of the engine projecting above the fuselage top. The passenger or observer is indicated by 1 and the pilot by 2. The top plane is 3 and the bottom plane 4. The engine is located by 5, and the top fuselage-rail, or "longeron," by 7. Turtle deck is 6.

[image]

** Round monocoque body, dimensions (B) and (F) measured from outer diameter or top of circle*

Fig. 20 gives the diagrams of speed scout machines, both of the air-cooled and water-cooled types. These are the small, fast, single seat machines so much used in the European war for repelling air attacks and for guarding the larger and slower bombing and observation machines. The upper drawing shows a Curtiss Speed Scout equipped with a "V" type water-cooled motor and a circular front radiator. While the front of the body is circular, it gradually fades out into a square cross-section at the rear. The lower machine is a Nieuport speed scout equipped with a rotating cylinder air-cooled motor. In this scout, the diameter of the motor cowl is given by dimension K. Body is of square cross-section. It will also be noted that the chord of the lower plane is less than that of the upper plane and that the deep body almost entirely fills the gap between the two wings.

[image]

Fig. 21. Curtiss J N 4-B Fuselage Boxed for Shipment.

With some of the later speed scouts, the body entirely fills the gap between the wings and the top plane is fastened directly to the top members of the fuselage. This makes windows necessary in the sides of the fuselage. When vertical water-cooled motors are used on speed scouts, the front view is entirely cut off, for these are very large motors and project above the fuselage for a considerable distance. This obstruction is avoided in the Curtiss speed scout shown, by the use of a "V" type motor. It will be noted that these two scouts, especially the Nieuport, are of excellent stream line form, a very important item with such high speed machines. The propeller of later Nieuports is provided with a conical spinner cap which evidently reduces the head resistance to a considerable extent. The different portions of the machine are indicated by the same figures as in the case of the reconnaissance machine.

CHAPTER XII DETAILS OF FUSELAGE CONSTRUCTION

Classification of types. While there are a number of methods adopted in building up the fuselage structure, the common type is the ”wire truss” in which wood compression members are used in connection with steel wire or cable tension members. Four wooden ”longerons” or ”longitudinals” run the entire length of the body and are bent to its general outline. The longitudinals are spaced at the correct distance by wood compression members, which in turn are held in place by wire cross bracing. This method of trussing forms a very strong and light structure, although rather complicated, and difficult to build. The cross-section is rectangular, although in many cases the body is converted into a circular or elliptical section by the use of light wood formers fastened to the main frame.

Another well known type is the ”Monocoque” body, first used on the Gordon-Bennett Deperdussin monoplane. This fuselage is a circular shell built up of three-ply tulip wood, thus forming a single piece body of great strength. The three-ply shell is really a veneer, the layers proceeding spirally around the body, each layer being securely glued to its neighbor. Between each layer is a scrim layer of treated silk, and another fabric layer is generally glued to the outside of the shell. The shell is very thin, the total thickness of the three layers of wood and fabric in modern machines being rather less than 1.5 millimeters (about 1/16 inch). In the original ”Deps” this was somewhat greater, 0.15 inch. Monocoque construction as a rule is heavy and expensive, but offers the great advantage of strength, perfect alignment at all times, and of offering resistance to rifle and shell fire. If the longitudinals of a truss type are struck with a bullet, or shell fragment, the entire fuselage is likely to fail, but a monocoque body may be well perforated before failure is likely to take place.

The American L. W. F. Tractor Biplane has a monocoque body in which spruce laminations are used instead of hardwood. One ply runs longitudinally while the other two layers are spiralled to the right and left respectively. Between each layer is a scrim layer of treated silk, the whole construction being covered with a final layer of fabric, several coats of waterproof compound, and four final coats of spar varnish. When used for seaplanes the wood plies are stitched together with strong wires to prevent separation due to dampness. Since spruce is used in place of hardwood, the construction is lighter than in European models, and the L. W. F. Company claim that it is lighter than the usual truss construction. An additional advantage of the monocoque construction is that the pilot is protected against splinters or penetration by the limbs of trees when making a forced landing in the brush.

Another form of monocoque construction was adopted by the French builder, Bleriot, at the beginning of the war. The fuselage of this machine was covered with papier-mache, the ash longitudinals being buried in this mixture. The papier-mache is built up with glue and silk threads. This construction is very light and strong, but is expensive and difficult to protect against moisture. The front of the fuselage is protected with a 3 millimeter steel armor plate to protect the pilot against bullets and shrapnel. The papier-mache portion of the body is not easily splintered by bullets.

A third form of monocoque, experimented upon by the author, is the steel shell type in which the three-ply wood veneer is supplanted by a thin steel shell. This outer shell is strengthened by suitable stiffener angles. With a shell thickness of 0.013 inch, the strength is equal to the strength of a wood shell and is slightly less in weight. It has the advantage of being easily and cheaply formed into shape and is absolutely proof against the influences of heat and moisture. It cannot splinter, will not catch fire and offers a maximum resistance against penetration. There is yet much experimental work to be done before the construction is perfected.

About midway between the truss fuselage and the monocoque is the veneer construction used on many of the modern German aeroplanes. In general, this may be described as being a veneer shell fastened to the conventional wood longitudinals. Stay wires are not in general use, the veneer taking the shear due to the bending movement. Six longerons are used instead of four, the two additional members being located midway on the vertical sides. Transverse wood frames take the place of the transverse stay wires used in the truss type. Examples of this type are met with in the ”Albatros de Chasse” and in the ”Gotha” bomb dropper. The single seater, ”Roland,” has a fuselage of circular section, with a true monocoque veneer construction, but German-like, reinforces the construction with a number of very small longitudinals. In this machine there are 6 layers, or plies, of wood reinforced by fabrics. The entire thickness of the wood and fabric is only 1.5 millimeters (1/16 inch).

Steel tube fuselage dates back to the beginning of the aeroplane industry. In this type the wood longitudinals of the wood truss type are replaced with thin gage steel tubes, the cross struts being also of this material. The diagonal bracing may be either of steel wire, as in the wood frames, or may be made up of inclined steel tube members that perform both the duty of the stay wires and struts. For the greatest weight-efficiency, a steel tube body should be triangular in section rather than square. A triangular section saves one longitudinal and a multitude of wire struts and connections since no transverse bracing is necessary. Connections on a steel tube fuselage are difficult to make and are heavy. They require much brazing and welding with the result that the strength is uncertain and the joint is heavy.

A very modern type of steel construction is that developed by the Sturtevant Company. The members of the Sturtevant fuselage are in the form of steel angles and channels, similar in many respects to the sections used in steel buildings and bridges. The joints are riveted and pinned as in steel structural work. The longitudinals are angles and the struts are channels. Crystallization of the steel members is prevented by the use of special pin-connected joints provided with shock absorbing washers. Owing to the simplicity of the riveted joints, there is practically no weight due to connections, and since the weight of connections is a large item in the total weight of a fuselage, the Sturtevant is a very light structure. According to G. C. Loening, engineer of the company, the fittings of a large wood fuselage weigh at least 60 pounds. This is almost entirely saved with the riveted connections.

[image]

Truss Type Fuselage of Curtiss R-4 Biplane, Showing Motor and Front Radiator Mounted in Place. It Will Be Noted That the Upper and Lower Longerons Are Channeled Out for Lightness and Hence These Members Are of the ”I” Beam or Channel Form. Propeller Flange Is Shown Projecting Through the Radiator Opening.

A novel type of wood fuselage has been described by Poulsen in ”Flight.” Eight small longitudinals are used which are held in place by three-ply wooden formers or diaphragms. Wire bracing is used in a longitudinal direction, but not transversely in the plane of the diaphragms. The cross-section is octagonal, and the completed structure is covered with fabric. For the amateur this offers many advantages since the wiring is reduced to a minimum and all of the members are small and easily bent to shape. It is fully as light as any type of body, for the connections are only thin strips of steel bolted to the diaphragms with small machine screws. No formers are needed for the deck, and the machine can be given a close approximation to the ideal stream-line form with little trouble.

Truss Type Fuselage. We will now take up the construction of the truss type of fuselage in more detail, and investigate the merits of the different types of connections used in fastening the frame together. Like every part of the aeroplane, the fuselage must either be right or wrong, there is no middle course. Fig. 23 shows a side elevation of a typical truss type fuselage built up with wood longitudinals and struts, the tension members being high tensile strength steel wire and cable. L and L' are the upper and lower longitudinals, S-S-S are the vertical struts, and T-T-T are the horizontal cross struts which run across the frame. The engine bed is the timber marked B at the front of the body. The upper wing is attached to the body through the "cabane" struts C, and the chassis connections are shown at D. The stern post E closes the rear end of the body in a knife edge and acts as a support for the rudder and the rear end of the stabilizer. F is the seat rail which carries the seats and supports the control yokes.

All cross bracing is of high tensile strength steel wire, or of high strength aviation cable, these strands taking the tensile stresses while the wood struts are in compression. In the forward portion, double stranded cables are generally used, with solid wire applied to the after portions. The longitudinals are of ash from the motor to the rear of the pilot's seat, while the rear longitudinals are generally of spruce. In some machines, however, the entire length of the longitudinals is ash. The latter arrangement makes a heavier, but stronger body. The struts are usually of spruce as this material is stiffer than ash and much lighter.

[image]

Diagram of Typical Truss Type Fuselage, Showing Principal Members in Place.

[image]

Fuselage of Hansa-Brandenburg Fighting Biplane. See Page 268. Figs. 27-28-29-30. Fuselage Details. (Truss Type)

Both the struts and longitudinals are frequently channelled out for lightness, as shown by Fig. 27, the wooden member being left rectangular in section only at the points where the connections are made with the struts and cables. The channelling-out process, if correctly followed, gives very strong stiff members with a minimum of cross-sectional area and weight. Many captured German machines, on the contrary, have solid longitudinals of rectangular section, wrapped with linen fabric. This fabric strengthens the construction and at the same time reduces the chances of splintering the wooden members in a hard landing. The fabric is glued to the wood and the entire wrapping is then given several coats of a moisture repelling varnish. In the older types of fuselage, the longitudinals were often of the "laminated" class, that is, were built up of several layers of wood glued together in a single rectangular mass. This reduced the tendency toward splitting, but was very unreliable because of the uncertainty of the glued joints when exposed to the effects of heat and moisture. Laminated longitudinals are now seldom used, particularly in the region of the motor where water and oil are certain to wreck havoc with the glued up members.

As the stresses rapidly diminish toward the tail, it is the general practice to taper down the section of the longitudinal toward the rear and to reduce the section of the struts. The longitudinals are generally kept constant in section from the motor to the rear of the pilot's seat, the taper starting at the latter point and continuing to the rear end. For example, if the longitudinal section at the motor is 1 1/4" x 1 1/2", the section at the rear will be 1" x 1", the width of the struts corresponding to this taper. While tapering is very desirable from the weight standpoint, it makes the fitting problem very difficult since each fitting must be of a different dimension unless the connections can be designed so that they are adjustable to changes in the section of the longitudinals. In one machine, the width and depth of the longitudinals are kept constant, the variation in weight and section being accomplished by increasing the depth of the channelling as the rear is approached. With this design, the same fittings can be applied from one end to the other.

[image]

Figs. 27-28-29-30. Fuselage Framing Members and Details.

Since the loading of the struts is comparatively light, they can be much reduced in section by channelling or by chamfering, as shown by Fig. 28. If the width and thickness is maintained, much of the interior material can be removed without danger of reducing the strength. Sketch (A) in Fig. 28 shows a very common method of strut reduction, the strut being of rectangular section throughout its length, but tapered in such a way that it is thickest at the center (d) and thinnest at the two ends (e). To obtain the correct relation between the center end thickness requires very careful calculation. As shown, the strut is attached to the upper and lower longitudinals by sheet steel fittings or "sockets." Sketch (B) shows a simple method, the rectangular strut being chamfered off at each of the four corners, and left full size at either end where the fittings connect it with the longitudinals. This form is not correct from a technical standpoint, but is generally good enough for lightly loaded struts, and has the advantage of being cheaply and easily constructed. In sketch (C) a channelled strut is shown, the center portion being channelled out in a manner similar to the channelling of the longitudinals. This lightening process is most commonly adopted with the large heavily loaded struts in the front portion of the fuselage, and at the points where the motor bed is suspended or where the wings and chassis are attached to the body. The black dots at the ends of the struts indicate the bolt holes for the fittings, it being permissible to drill holes in the ends of the struts but not in the longitudinal members. If the strut is large enough to resist the bending stresses at the center it will generally allow of holes being drilled near the ends without danger of strength reduction. Again, the struts are always in compression and hence the bolts may be depended upon to partly take the place of the removed material in carrying the compressive stresses.

Holes should never be drilled in the longitudinals since these members may be either in tension or compression, depending upon the angle at which the elevator flaps are set. The hole not only destroys the strength at the point at which it is drilled, but this reduction also extends to a considerable distance on either side of the hole, owing to the fibrous nature of the wood. In steel members the effect of the hole is purely local and does not usually extend much beyond the edge of the hole. Considering the wood beam as consisting of a series of parallel fibers, it will be seen that severing any one of the fibers will decrease the strength of the wood through a distance equal to the length of the cut fiber, or at least through a distance equal to the natural shear value of the resins that bind the fibers together.

Fuselage fittings are almost numberless in the variety of design. They must be very light and strong, must be applied without drilling the longerons, and should be simple and cheap to construct. They are usually made of sheet steel of from 0.20 to 0.30 point carbon, and may be either bent or pressed into shape. At the points where the struts are joined to the longitudinals, the fittings connect struts and wires in three planes, the vertical struts and fore and aft wires; the transverse wires and horizontal struts, and the top and bottom wires that lie in a horizontal plane. There are at least 6 connections at every strut, four of the connections being made to the stay wires or cables. A simple connection is therefore very hard to design.

Fig. 29 shows a typical fuselage ”panel” and the interconnected members in their usual relation. LU and LL are the top and bottom longitudinals at the right, while LU’ and LL’ are the longitudinals at the right hand side. The vertical struts SV and SV’ separate the top and bottom longitudinals, while the horizontal struts SH and SH' separate the right and left hand sides of the fuselage body. The wires w-w-w-w brace the body fore and aft in a vertical plane. The wires t-t lie in a horizontal plane, produce compression in the horizontal struts SH-SH', and stiffen the frame against side thrust. The transverse rectangle SV-SH-SV'-SH' is held in shape by the transverse stay wires W-W, this rectangle, and the stays resisting torsional stress (twisting), act against the struts composing the sides of the rectangle. In some European machines, the wires WW are eliminated, and are replaced by thin veneer panels, or short wood knee braces as shown by Fig. 30. The section shows the longitudinals L-L-L-L and the struts SV-SV'-SH-SH' braced by the veneer sheet or diaphragm D. This diaphragm is well perforated by lightening holes and effectually resists any torsional stress that may be due to motor torque, etc. Since the transverse wires W-W in Fig. 29 are rather inaccessible and difficult to adjust, the veneer diaphragm in Fig. 27 has a great advantage. In this regard it may be stated that wire bracing is not a desirable construction, and the substitution of solid veneer is a step in advance.

Wire bracing has always seemed like a makeshift to the author. The compression and tension members being of materials of widely different characteristics are not suitable in positions where a strict alignment must be maintained under different conditions of temperature and moisture. The difference in expansion between wire and the wood compression members produces alternate tightness and slackness at the joints, and as this is not a uniform variation at the different joints, the frame is always weaving in and out of line. Under the influence of moisture the wood either swells or contracts, while the wire and cable maintain their original lengths and adjustments. The result is that a frame of this kind must be given constant attention if correct alignment is desired.

The adjustment of a wire braced wood fuselage should be performed only by a skilled mechanic, as it is easily possible to strain the members beyond the elastic limit by careless or ignorant handling of the wire straining turnbuckles. In the endeavor to bring an old warped fuselage back into line it is certain that the initial tension in the wires can be made greater than the maximum working stress for which the wires were originally intended. Shrinkage of the wood also loosens the bond between the wooden members and the steel fittings unless this is continually being taken up. Some form of unit construction, such as the monocoque body, is far more desirable than the common form of wire trussed wood body.

Fuselage Fittings. In the early days of aviation the fuselage fittings on many machines were made of aluminum alloy. This metal, while light, was uncertain in regard to strength, hence the use of the alloy was gradually abandoned. At present the greater part of the fittings are stamped steel, formed out of the sheet,

[image]

Fuselage Details of De Havilland V. Single Seat Chaser. A Rotary Le Rhone Motor Is Used in a Circular Cowl. The Diagonal Bracing in the Front Section is Reinforced by Laminated Wood Plates Instead of by Wires. Dimensions in Millimeters.

and are of a uniform strength for similar designs and classes of material.

The steel best adapted for the fittings has a carbon content of from 0.20 to 0.30, with an ultimate strength of 60,000 pounds per square inch, and a 15 per cent elongation. The steel as received from the mill should be annealed before stamping or forming to avoid fracture. After the forming it can be given a strengthening heat treatment. A lower steel lying between 0.10 and 0.15 carbon is softer and can be formed without annealing before the forming process. This material is very weak, however, the tensile strength being about 40,000 pounds per square inch. Fittings made of the 0.15 carbon steel will therefore be heavier than with the 0.30 carbon steel for the same strength. The thickness of the metal will vary from 1/32" to 1/16", depending upon the load coming on the fitting.

A typical fuselage strut fitting is shown by Fig. 31-A in which L-L-L are the longerons, d is the fitting strap passing over the longerons, S and So are the vertical and horizontal struts respectively. The stay wires are fastened to ears (b) bent out of the fitting, the wires being attached through the adjustable turnbuckles (t). The struts are provided with the sheet steel ferrules marked (F). There are no bolts passing through the longitudinals L-L', the fitting being clamped to the wooden member. This is very simple and light fitting. Fig. 31-B is a similar type, so simple that further discussion is unnecessary.

Fig. 32 shows a fuselage strut fitting as used on the Standard Type H-3 Biplane. We are indebted to "Aerial Age" for this illustration. This consists of a sheet metal strap of "U" form which is bent over the longitudinal and is bolted to the vertical strut. At either side of the strut are through bolts to which bent straps attach the turnbuckles. These straps are looped around the bolts and form a clevis for the male ends of the turnbuckles.

[image]

Fig. 31. Typical Fuselage Strut Fittings.

An old form of fuselage connection used on the Nieuport monoplane is shown by Fig. 33, an example of a type in which the bolts are passed through the longeron member. This fitting is very light but objectionable because of the piercing of the longeron.

An Austrian aeroplane, the Hansa-Brandenberg, has a wood fuselage in which no stay wires are used. This fuselage is shown by Fig. 23a. Both the vertical and inclined members are wood struts. The outer covering of wood veneer makes the use of stay wires unnecessary since the sheath takes up all horizontal stresses, and hence forms a sort of plate girder construction. The German Albatros also employs a wireless veneer fuselage, the construction being shown in detail by Figs. 36 and 36a. Three longerons are located on either side of the body, the third member being placed at about the center of the vertical side. As will be seen, the veneer makes the use of wire bracing and metal connections unnecessary. The veneer also insures perfect alignment.

[image]

Fig. 32. Fuselage Strut Fittings of the Standard H-3 Training Biplane.

Wing Connections. The lower wings are attached to the lower longitudinals by a special sheet steel fitting which also generally connects to a vertical strut at this point, and to an extra heavy horizontal strut. A sheet metal clevis, or socket, on the wing spar is pinned to the fuselage half of the fitting so that the wing can be easily detached when the machine is to be dissembled. At this point a connection is also provided for the end of the inner interplane stay wires. The horizontal strut at the point of wing attachment is really a continuation of the wing spar and takes up the thrust due to the inclination of the interplane stays. In the majority of cases the horizontal thrust strut is a steel tube, with the hinged connection brazed to its outer ends. This is one of the most important and heavily loaded connections on the machine and should be designed accordingly.

[image]

Fig. 33. Fuselage Fittings of the Nieuport Monoplane.

Fig. 37 shows a typical wing to fuselage connection of the hinge type. The wing spar (G) is covered with a sheet steel ferrule (A) at its inner end. Two eye bars (B) are bolted to the wing spar, and over the ferrule, the eyes of the bar projecting beyond the end of the spar. This forms the wing half of the connecting hinge. The eyes are fastened to the fuselage hinge member (H) by means of the pin (E). This pin has a tapered end for easy entry into the joint, and is pierced with holes at the outer end for cotter pins or a similar retaining device. The fuselage hinge member (H) is brazed to the end of the steel tube strut (T). This tube runs across the fuselage from wing spar end to wing spar end.

Strut tube (T) lies on, and is fastened to, the fuselage longeron (L), and also lies between the two halves of the vertical strut (S). The vertical strut is cut out at its lower end for the receipt of the steel tube (T). A steel plate is brazed to the tube, is wrapped about the longeron (L) and is bolted to the vertical strut (S). The interplane stay (F) is attached to the pin (E) at the point of juncture of the wing spar eye and the fuselage member of the hinge. A collar (I) is brazed to the tube, and forms a means of attaching the fuselage stays (D). The drift wires (C) of the wings are attached to an eye at the end of one of the wing spar bolts. As shown, the fitting (H) is a steel forging, very carefully machined and reduced in weight. The inside wing ribs are indicated by (K), from which it will be seen that there is a gap between the end of the wings and the outside face of the fuselage.

[image]

Fig. 36. Veneer Fuselage Construction of the German ”Albatros” Speed Scout. Body Outline Is Obtained by Veneer Diaphragms and no Stay Wires Are Used.

Fig. 36-a shows the construction of the wing joint of the German Albatros machine. The fuselage is of monocoque construction which allows of a simple attachment to the outer shell. This is a very sturdy and simple connection. Fig. 38-Z is the wing attachment detail of the English London and Provincial Biplane (1916), the fuselage in this case being of the wire trussed wood type. We are indebted to ”Flight” for this illustration.

[image]

Fig. 36-a. Details of Albatros Veneer Fuselage Construction.

In some machines the interplane stay wires are attached to a lug formed from the attachment plate, but we do not consider that this construction is as good as the type in which the wire is attached directly to the wing spar pin. While the former may be easier to assemble, the attachment of the wire to the pin eliminates any eccentricity, or bending moment, due to the pull of the interplane stay. The attachment in the L. W. F. insures against any eccentricity in the stay attachment, and at the same time makes the assembly and dismounting a very simple matter.

[image]

Fig. 37. Wing Connection to Fuselage.

Chassis Member Attachment. The attachment of the chassis struts generally involves some difficulty as these members usually intersect the line of the longerons at a very awkward angle. If the wing attachment is near the same point, as it generally is, the detail is made doubly difficult. The chassis must be pin connected as in the case of the wing joint so that the chassis members can be easily and quickly removed. A detail of a chassis to body connection is shown by Fig. 39. In this figure (L) is the lower longeron, (S) is the vertical fuselage strut, and (C) is one of the chassis members. The upper end of the chassis member is enveloped in a sheet steel ferrule (D) which is bolted in place, and which is provided with a clevis at its upper end for the attachment pin (P).

A plate (E) is bolted to the fuselage strut (S) and is passed around the lower longeron (L), a hinge joint (H) being provided for attachment to the chassis ferrule through the pin (P). Ears or lugs are left at (G-G) for the attachment of the fuselage stays (B-B). On the inner side of the plate (E) are attachment lugs for the horizontal strut (H). It will be noted that the plate (E) is well provided with lightening holes so that the weight can be kept down to a minimum. The pin is tapered at the end, and is provided with cotter pin holes. The fitting in general is small, and does not produce any great degree of head resistance, the small part exposed being of good streamline form.

[image]

Fig. 38x. Wing Connection of the Albatros Reconnaissance Biplane. Fig. 38y. Wing Attachment of Albatros Fighter with Pin Joint. Fig. 38z. Wing Connection of London and Provincial Biplane.

Great care should be taken in brazing or welding these fittings, since the heat changes the structure of the metal and greatly reduces its strength. The brazing temperature varies from 1,500 to 1,700 degrees, a point well above the tempering heat of steel. Attempts have been made to heat treat the metal after the brazing operation, but with very little success, owing to the fact that the heat treating temperature is generally at or above the melting point of the brazing spelter, hence is likely to cause holes and openings in the brazed joints. With acetylene welded joints the parts can, and should be, heat treated after the welding. While this is an apparent advantage of acetylene welding, all parts cannot be successfully handled in this manner. The welding torch can only join edges, while the brazing spelter can be applied over almost any area of surface. Welding is very successful in joining thin steel tubes while in many fittings made of sheet metal, brazing is the only feasible operation.

[image]

Fig. 39. Chassis Connection.

Both methods have a common fault, in that they are unreliable. Imperfect welds and brazing are not always apparent from the outside, actual breakage of the part being necessary to determine the true nature of the joint.

FUSELAGE WEIGHTS.

Distribution of Weight. The weight of a fuselage depends upon the span of the wings, upon the seating capacity, and upon the weight and type of the power plant. The weight also varies considerably with the type of construction, that is, whether of truss, veneer, or monocoque construction. A heavily powered machine, or one carrying more than a single person, requires heavier structural members and hence weighs more than a small single seater. The amount of fuel carried also has a considerable bearing on the fuselage weight.

Probably the best method of treating this subject is to give the fuselage weights of several types of well known machines. The reader will then have at least a comparative basis for determining the approximate weight. (Truss type only.)

[image]

There are so many variables that the weight cannot be determined by any set rule or formula. Alexander Klemin in his ”Course in Aerodynamics and Airplane

Design" says that the approximate weight of a bare wood truss type fuselage is about 150 pounds for a machine having a total weight of 2,500 pounds. For small biplane and monoplane scouts weighing approximately 1,200 pounds total, the bare fuselage frame will weigh about 70 pounds. These figures are for the bare frame alone and without seats, controls, tail skids or other fittings. The weights given under the column headed "Wt. Bare" include the engine beds, tail skids, flooring, cowling and body covering, and hence exceed the "bone bare" estimate of Klemin by a considerable amount.

The all-steel fuselage of the large Sturtevant battle-plane (Model A) weighs 165 pounds inclusive of the steel engine bed. A wooden, wire braced fuselage of the same size and strength weighs well over 200 pounds, the metal fittings and wires weighing about 60 pounds alone. Ash is used in the wood example for the longerons. The struts and diagonal members in the Sturtevant metal fuselage are riveted directly to the longitudinals, without fittings or connection plates. The safety factor for air loads is 8, and for the ground loads due to taxi-ing over the ground, a safety factor of 4 is used.

After a minute comparison of the items comprising the fuselage of the Curtiss JN4-B and the Standard H-3, Klemin finds that the fuselage assembly of the Standard H-3 amounts to 13.6 per cent of the total loaded weight, and that the fuselage of the Curtiss JN4-B is 15.5 per cent of the total. Tanks, piping and controls are omitted in both cases. For machines weighing about 2,500 pounds, Dr. J. C. Hunsaker finds the body weight averaging 8.2 per cent of the total, this figure being the average taken from a number of machines.

On careful examination it will be found that the fuselage assembly (bare) amounts to a trifle less than the wing group for biplanes having a total weight of from 1,900 to 2,500 pounds. The relation between the wing weight and the fuselage weight seems to bear a closer relation than between the fuselage and total weights. We will set these different relations forth in the following table:

In the above table, the column headed "Body Assembly and Equipment" includes the body frame, controls, tanks and piping. In the fourth column, the radiator, motor, propeller, water, and exhaust pipe have been added. For the average value it will be seen that the bare fuselage is about 1.88 per cent lower than the weight of the wings. It should be noted that the wing weight given is the weight of the surfaces alone, and does not include the weight of the interplane struts, wires and fittings. The weight of the wing surfaces as above will average about 0.75 pounds per square foot.

Based on the above figures, we can obtain a rough rule for obtaining the approximate weight of the fuselage, at least accurate enough for a preliminary estimate. If A = the total area of the wings, then the total weight of the wings will be expressed by w = 0.75A. The weight (f) of the fuselage can be shown as f

PERCENTAGE OF FUSELAGE WEIGHT

Name of Plane or Investigator	Fuselage Weight as Percentage of the Total Load			Wing Weight As Percentage of Total Weight
	Body Assembly Bare	Body Assembly and Equipment	Body Assembly and Power Plant	
Curtiss JN4-B	15.50%	17.86%	43.96%	14.15%
Standard H-3	13.60%	17.70%	45.40%	14.52%
J.C. Hunsaker	8.20%	11.50%	34.30%	16.50%
Author's Experience	14.96%	17.62%	46.66%	14.60%
Average of Above	13.06%	16.17%	42.58%	14.94%

= 13.06/1494 x w = 0.65A.

Example. The area of the Standard H-4 is 542 square feet total. Find the approximate weight of the fuselage. By the formula, f = 0.65A = 0.65 x 542 = 352 pounds. The actual bare weight is 302.0 pounds. For several other machines, the actual weight is greater than the weight calculated by the formula, so that the rule can be taken as a fair average, especially for a new type that is not as refined in detail as the H-3.

SIZE OF LONGERONS

The size of the longerons, that is, the section, is influenced by many factors. As these members must resist flying loads, the leverage of elevator flaps, stresses due to control wires, landing stresses and the weight of the motor and personnel it is always advisable to itemize the loading and then prepare a diagram to obtain the stresses in the different members. This latter method is a method for a trained engineer, but an exhaustive description of the method of procedure will be found in books on the subject of "Strength of Materials." For the practical man, I give the following list of longeron dimensions so that he will have at least a guide in the selection of his material.

The length of the fuselage and power of motor are given so that the reader can obtain sizes by comparison, although this is a crude and inaccurate method. As the longerons taper from front to back, the sizes of the section are given at the motor end, and also at the tail. The size of the front members depends principally upon the weight of the motor and the passenger load, while the rear longerons carry the elevator loads and the tail skid shock. If the rudder is high above the fuselage it introduces a twisting movement that may be of considerable importance. The loads on the stabilizer, elevators and the vertical rudder are very severe when straightening out after a steep dive or in looping, and the pull on the control wires exerted by the aviator at this time greatly adds to the total stress. In the front of the fuselage, the motor exerts a steady torque (twist) in addition to the stress due to its weight, and to this must be added the gyroscopic force caused by the propeller when the machine is suddenly changed in the direction of flight. The combination of these forces acting at different times makes the calculation very difficult.

[image]

In the case of the Curtiss R-4, the front longerons taper down from the motor 1.63" x 1.25" to a point directly behind the pilot's seat, the section at the latter point being 1.25" x 1.25". From this point the rear longerons taper down to 1" x 1" at the tail. At the motor, the section is 1.63" x 1.25". The longitudinals of the Bleriot monoplane are laminated and are built up of alternate layers of spruce and ash. This is an old type of machine and this practice has since been discontinued. It will be noted that as the power is increased, the size of the front longerons is generally increased, although this is not always the case in speed machines. The Chicago Aero Works' "Star" fuselage could easily carry a 90 horsepower motor, although this size is not regularly installed.

Pusher Type Fuselage (Nacelle). Compared with the tractor biplane and the monoplane fuselage, the body of the pusher is very short and light. The latter body simply acts as a support for the motor and personnel since the tail loads are carried by the outriggers or tail booms. The motor is located at the rear end of the body and may be either of the air or water-cooled type. The accompanying figure shows a typical pusher type body, or "Nacelle" as it is sometimes called.

The advantages of the pusher type for military service are obvious. The observer or gunner can be placed immediately in the front where his vision is unobstructed, and where the angle of fire is at a maximum.

Twin Motored Fuselage. Twin motored aeroplanes generally have the power plants mounted at a point about midway between the fuselage and tips of the wings. In almost every case, the power plants are of unit construction, that is to say, consist of the motor, radiator and propeller complete on one support, only the fuel and oil tanks being mounted in the fuselage. The fuselage of the twin

[image]

Typical Pusher Body Showing Wings, and Outrigger to Tail Surfaces.

may be similar in length and general construction to that of the tractor biplane, or it may be a short "nacelle" similar to that used in the pusher type. In any case, the observer can be located in the extreme front of the body.

An interesting and unusual construction is the body of the Caproni Biplane (1916). A center nacelle carries the passengers, a pusher screw being located at the rear of the central body as in the case of the pusher biplane. On either side of the center are the motors driving the tractor screws, each motor being encased in a long tractor type fuselage that also supports the tail surfaces. The latter fuselage serves to streamline the motors and takes the place of the usual outrigger construction. There are three bodies, two tractor screws, and one pusher screw. Somewhat similar in design is the famous German "Billy Two-Tails," this machine being equipped with two tractor type bodies. A motor is located in the front of each body. Each fuselage is provided with accommodations for passengers, and is long enough to support the tail surfaces. The Caproni and the German machine are both very large machine and heavily powered.

U.S.A. Sea-Plane Specifications (1916). These government specifications cover a twin motored sea-plane with a central nacelle. The body is arranged so that the forward man (observer) can operate the forward machine gun through a horizontal arc of at least 150°, and through a vertical arc of at least 270°, with the gun at an angle of about 75° with the center line of the body. The muzzle must be forward of the propeller plane. The rear man (pilot) operates a machine gun through a vertical arc of at least 150° to the rear, and through a vertical arc of at least 180°, with the gun at an angle of about 105° with the fuselage center line. The muzzle must be to the rear of the plane of propeller rotation.

The number of stays and other important connections which extend across the plane of propeller rotation shall be reduced to a minimum. It is considered advisable to incorporate in the design of the body such a structure (in the plane and 8 inches forward of propeller plane) as will prevent a broken propeller blade from severing the main body. The system used in the construction of the cage masts used on battleships is suggested, with a number of spruce compression members in place of stay-wires. The clearance of the propeller tips from the sides of the central body shall be from 5 to 12 inches. No part of the gas tanks shall lie in the plane of propeller rotation, nor within a space 6 inches ahead of this plane.

A space extending at least 9 inches back from the rear of the observer's seat, and entirely across the body, must be left open and unoccupied in order that any desired instruments can be installed therein. In the center line of the body, a circular hole 9 inches in diameter shall be cut in the floor of the observer's cock-pit, the rear of the hole being 5 inches forward of the forward edge of the observer's seat. The flooring of the pilot's and observer's cockpits shall consist of spruce strips 1/2" x 1/2 " spaced at 1/2" intervals along the longerons. No flooring is to be placed under the seats.

The safety factor of the body and tail structure shall not be less than 2.5, the air speed being taken at 100 miles per hour with the elevator at an angle of 20° and the fixed stabilizer surface at 6°. All wire tension members not readily accessible for inspection and adjustment are to be single strand high tensile steel wire. All tension stays that are easily accessible shall be of non-flexible stranded steel cable. For turnbuckle safetying No. 20 semi-hard copper wire shall be used. All cable shall be well stretched before making up the connections. A load equal to 20 or 30 per cent of the breaking load shall be applied for a period of from two to three hours. The hard wire must undergo a bending test by bending at a right angle turn over a radius equal to the diameter of the wire, back and forth four times each way. No more than four sizes of turnbuckles shall be used on the entire aeroplane structure. The strengths and size numbers of the turnbuckles will be as follows: No. 1 = 8,000 lbs. No. 2 = 4,600 lbs. No. 3 = 2,100 lbs. No. 4 = 1,100 lbs. Controls and fittings in the vicinity of the compasses shall, as much as possible, be of non-magnetic material. All steel plate and forged fittings shall be protected against the action of salt water by baking enamel, the best standard three coat process being used. All covered wiring and turnbuckles shall be coated by at least two coats of Flexible Compound.

All steel tubing shall be thoroughly cleaned, slushed with mineral oil inside, and plugged at both ends by wood plugs impregnated with mineral oil or paraffine. All steel nuts, bolts, pins and cotter pins shall be protected by heavy nickel plating over copper. All wood members, especially faying surfaces, end grain butts, scarfs and joints, shall be protected against the access of moisture before final assembly by the best grade of varnish, or by impregnation by paraffine. All wood shall be straight grained, well seasoned, of uniform weight, and free of knots, pitch pockets, checks or cracks. Spruce to be of the very highest grade of selected straight, even grained, clear spruce. It shall be air seasoned, preferably for two years. Kiln dried wood is not acceptable.

It is highly desirable to have all bolts, pins, plate fittings and turnbuckle ends made of chrome vanadium steel (S. A. E. Specification 6.130), heat treated to obtain the best physical characteristics. All parts and fittings that must be bent shall be heat treated after all bending operations are completed, and by such a sequence of treatment as will produce the desired grain and toughness, and relieve all stresses due to the bending. This includes sheet and forged steel fittings, turnbuckle ends and bolts and pins. All steel parts and fittings submitted to stress or vibration shall be heat treated in such a manner as to produce the highest possible refinement of grain and give the greatest possible resistance to alternating and vibratory stresses. Where plate fittings are in contact with wooden members, sharp edges next to the wood shall be removed. In making up and connecting steel fittings, welding shall be used wherever possible. If impracticable to weld, and in such cases only, brazing will be used, proper heat treatment to be employed to restore strength and toughness of metal after such welding or brazing. Extreme care should be taken to avoid nicking or kinking any wire, cable or fitting. Fittings, sheet or forged, must be free from sharp corners and supplied with generous fillets.

In general the S.A.E. Standards will be acceptable, and these standards for screw threads shall be used wherever possible. U.S. Standard threads will be accepted where threaded into cast iron, cast aluminum or copper alloys. All nuts and pins must be provided with one or more positive and durable safety devices. In general, where it must be expected that a structural fitting will be disassembled a number of times during the life of the aeroplane, castellated nuts with split pins, in accordance with S.A.E. Standards, shall be used. Wherever this is not the case, pins or bolts shall be riveted in a workmanlike manner.

Seats shall be securely braced against both horizontal and vertical stresses. Arrangement and dimensions of cock-pits shall be as nearly as practicable to that indicated by the drawings (not published in this chapter). In addition, if practicable, the pilot should be provided with quick release arm rests. Sections of best grade of khaki on each side of seats, in which pockets are made, should be fastened to longerons and vertical posts in such a way as to be securely in place and yet readily detachable for inspection of structural wiring and fittings. Safety belts shall be provided for both seats and securely fastened. The belts shall safely support at any point a load of 2,000 pounds applied as in practice. Rubber shock absorbers in the safety belt system are considered to be an advantage. The quick release device shall be as indicated in drawings and shall reliably and quickly function. Seat pads shall be quickly detachable in order that they may be used as life preservers. They will be filled with Kapok or other similar material and covered with real leather to protect it against the action of salt water.

Suitable covers shall be provided over the top of the rear end of the fuselage. These must be easily removed and capable of being securely fastened in place during flight. Space shall be allowed in the body directly in the rear of the observer’s seat for the stowage of the sea anchor. When in use, the sea anchor shall be attached by suitable and convenient fastening hooks to the two points along the lower longerons, and at the junction of the two vertical struts in the rear of the front seat. The structure must be such that it will successfully withstand the stresses imposed by the sea anchor. Controls shall be of the standard Deperdussin type, installed in the rear cock-pit only. The tanks for the main supply of gasoline shall be in the fuselage and located so that the longitudinal balance will not be disturbed by the emptying of the tank during flight.

The above data is not in the exact form of the original specifications and is not complete, but gives only the specifications that affect the design of the body. These were picked out part by part from the original.

Army Specification 1003 (Speed Scout). These specifications cover the design of land machines, the extracts given here referring only to the safety factor. Body forward of the cockpit shall be designed for safety factor of 10 over static conditions, with the propeller axis horizontal. Body in rear of cockpit shall be designed to fail under loads not less than those imposed under the following conditions:

(a) Dynamic loading of 5 as the result of quick turns in pulling out of a dive. (b) Superposed on the above dynamic loading shall be the load which it is possible to impose upon the elevators, computed by the following formula: $L = 0.005AV^2$, where A is the total area of the stabilizing surface (elevators and fixed surface), and V is the horizontal high speed of the machine. The units are all in the metric system. (c) Superposed on this loading shall be the force in the control cables producing compression in the longerons.

Fuselage Covering. Disregarding the monocoque and veneer constructed types of fuselage, the most common method of covering consists of a metal shell in the forward end, and a doped linen covering for that portion of the body that lies to the rear of the rear seat. The metal sheathing, which may be of sheet steel or sheet aluminum, generally runs from the extreme front end to the rear of the pilot's cockpit. Sheet steel is more common than aluminum because of its stiffness. Military machines are usually protected in the forward portions of the fuselage by a thin armor plate of about 3 millimeters in thickness. This is a protection against rifle bullets and shrapnel fragments, but is of little avail against the heavier projectiles. Armor is nearly always omitted on speed scouts because of its weight. Bombers of the Handley-Page type are very heavily plated and this shell can resist quite large calibers.

The fabric used on the rear portion of the fuselage is of linen similar to the wing covering, and like the wing fabric is well doped with some cellulose compound to resist moisture and to produce shrinkage and tautness. On the sides and bottom the fabric is supported by very thin, light stringers attached to the fuselage struts. On the top, the face is generally curved by supporting a number of closely spaced stringers on curved wooden formers. The formers are generally arranged so that they can be easily removed for the inspection of the wire stay connections and the control leads. On some machines the top of the fuselage consists entirely of sheet metal supported on formers, while in others the metal top only extends from the motor to the rear of the rear cockpit.

CHAPTER XIII. CHASSIS CONSTRUCTION.

General Notes. The chassis or landing gear carries the weight of the aeroplane when resting on or running over the ground, and is subjected to very heavy shocks, especially when landing. It is provided with pneumatic tired wheels, an elastic shock absorbing device, and the structural members that connect the axle with the fuselage. In some forms of landing gear, the wheels are supplemented by long horizontal skids which serve to support the machine after the elastic shock absorbers are fully extended or when the wheels collapse. The skids also protect the aeroplane in cases where the wheels run into a ditch and also prevent the machine from nosing over in a bad landing. Since the skids and their structural members cause a high resistance they are now seldom used except on the larger and slower machines. In running over the ground, or in making a hard landing, part of the shock is taken up by the deflection of the tires and part by the deflection of the shock absorber. The greater the movement of the tires and absorber, the less will be the stress in the frame.

In the majority of cases, the shock absorbers consist of rubber bands or cords, these being wound over the axle and under a stationary part of the chassis members. Since rubber is capable of absorbing and dissipating a greater amount of energy per pound of weight than steel, it is the most commonly used material. Rubber causes much less rebound or ”kick” than steel springs. The principal objection to rubber is its rotting under the influence of sunlight, or when in contact with lubricating oil. The movement of the axle tube is generally constrained by a slotted guide or by a short radius rod.

The design of a suitable chassis is quite a complicated problem, for the stresses are severe, and yet the weight and resistance must be kept at a minimum. In running over rough or soft ground for the ”Get off,” the shocks and vibration must be absorbed without excessive stress in the framework, and without disturbing the balance or poise of the machine. There must be little tendency toward nosing over, and the machine must be balanced about the tread so that side gusts have little tendency in throwing the machine out of its path. It must be simple and easily repaired, and the wheels must be large enough to roll easily over moderately rough ground.

Types of Chassis. The simplest and most extensively used landing gear is

[image]

Fig 1. ”V” Type Chassis as Applied to ”Zens” Monoplane. Courtesy ”Flight.”

the ”Vee” type shown by Fig. 1, and is equally applicable to monoplanes, biplanes or triplanes. Primarily, the Vee chassis consists of two wheels, an axle, a rubber shock absorber, and two sets of Vee form struts. The chassis shown by Fig. 1-a is that of the Hansa-Brandenburg and is typical of biplane chassis. The winding of the rubber cord and the arrangement of the chassis struts are clearly shown. The two struts are connected at the bottom by a metal fitting, and the rubber is wound over the axle and under this fitting. No guiding device is used for the axle, the machine being freely suspended by the chord. The struts are made as nearly streamline form as possible.

[image]

Fig 1a. ”V” Type Chassis Used on Hansa-Brandenberg Biplane.

Fig. 2 is a front view of a typical Vee chassis, and Fig. 3 is side view of the same device, the same reference letters being used in each view. The vertical struts C run from the fuselage at F to the connecting axle guide plate G. The wheels W-W are connected with the steel tube axle A, and the struts are braced against side thrust by the cross-tube D and the stay wire braces B-B. In Fig. 3 the metal fitting G is provided with the guiding slot S for the axle A. The elastic rubber cord absorber passes over the axle and is fastened to the plate G by the studs I. Fig. 4 is a side view of the chassis of the Lawson trainer, which like many other primary training machines, uses a front pilot wheel to guard against nosing over. The rear two wheels (W) are elastically supported between the Vee struts C and F, while the front wheel X is attached to the fuselage by the vertical strut E, and to the rear wheel frame by the tube G. It will be noted that the front wheel is smaller than the rear main wheels, as this wheel carries but little load. The tail skid T is hinged to the fuselage and is provided with elastic cord at the upper end so that the shock is reduced when the tail strikes the ground. Fig. 5 shown directly above the Lawson trainer, is the complete assembly of the Hansa-Brandenburg already described. The tail skid of the Hansa-Brandenburg is indicated by T.

The metal shod ash skid stick is hinged to the lower face of the fuselage, and at the upper end is attached to a stationary fuselage member through four turns

[image]

Figs. 2-3. Typical ”V” Chassis With Axle Guide.

of elastic cord. When the skid strikes an obstacle the rubber gives and allows the tail to move in relation to the ground. By this arrangement the greater part of the device is enclosed within the fuselage and, hence, produces little head resistance.

[image]

Fig 4. (Below). Lawson Training Tractor Biplane. Fig. 5 (Above). Hansa-Brandenburg Fighting Biplane Showing Chassis and Tail Skid (t).

Fig. 7 is the skid chassis of the Farman biplane which shows clearly the arrangement of the skids and the shock absorbing suspension. A metal bridge is attached to the axle, and a series of short rubber bands are used in connecting the axle bridge, and the bridge on the skid. A triangular tubular radius rod is attached to the axle and hinged to the skid. This restrains the travel of the axle in a fore and aft direction. Another form of skid shock absorber is given by Fig. 8, in which the rubber rings pass over a spool on the axle. The guiding links or radius rods on the inside of the skids regulate the axle travel. In general, the use of a radius rod is not desirable as it transmits a percentage of the shock to the machine.

[image]

Fig. 7. (Left). Farman Skid Type Chassis. Fig. 8. Another Type of Skid Chassis in Which the Axle Is Guided by a Radius Rod or Lever.

[image]

Fig. 9. Chassis Details of the Nieuport Monoplane. This Has a Central Skid and Uses an Automobile Type Steel Spring Instead of Rubber Cord. Fig. 10 Is a Detail of the Nieuport Spring. (At Right.)

Fig. 9 is an older form of Nieuport monoplane chassis, a steel cross spring being used in place of the usual rubber bands. This is simple, but comparatively heavy, and is subject to frequent spring breakage. To guard against spring failure, a long ash skid is placed under the axle. The spring system is connected with the body by three sets of oval steel struts. An old type of Curtiss chassis is given by Fig. 11. This has been widely used by amateurs and exhibition flyers, but requires a fairly smooth landing ground as there are no shock absorbers. The only shock absorption is that due to the deflection of the tires. The extreme forward position of the front wheel effectually prevents any tendency toward nosing over when landing.

[image]

Fig. 11. An Old Type of Curtiss Exhibition Chassis With Three Wheels.

[image]

Fig. 12 (Left). Standard H-3 Shock Absorber. Fig. 13. (Right). Rubber Cord on Axle.

A Standard H-3 shock absorbing system is given by Fig. 12. This has a bracket or hanger attached to the axle over which the elastic cord is wrapped. The cord is wrapped in continuous turns between the axle hanger and the bottom of the Vee support members. As shown, the upper streamlined bar is the axle, while the lower is the cross bar brace which serves to hold the lower ends of the U's. I am indebted to "Aerial Age" for this cut. In order to guide the axle in a straight line in its up and down movement, two radius links are attached between the axle and the front vertical strut. One decided advantage of the "Standard construction" is that the cords are wound without crossing the strands, thus reducing cutting and wear between the cord turns. Fig. 13 is a variation of Fig. 12, the cord being wound directly around spools on the axle and the lower stationary cross tube. The axle is guided by a slot in the guide plate at the right, while end motion is controlled by a radius link. Fig. 14 is the double wheel arrangement of a large "Twin" bombing plane. Two wheels are placed directly under each of the motor units so that a portion of the load is communicated to the chassis by tubes. Diagonal tubes transmit the body load to the chassis.

Folding Chassis. Owing to the great relative resistance of the chassis it has

[image]

Fig. 14. Chassis for Twin Motored Biplane of Bombing Type.

been suggested by many designers to provide a folding frame which will automatically fold up into the body after the machine has left the ground. This would be a decided advantage but the gear is complicated and probably not altogether reliable.

Height of Chassis. The height of the chassis is made as small as possible with a sufficient clearance for the propeller tips. It is usual to have the tips of the propeller blades clear the ground by from 10 to 12 inches when the aeroplane is standing with the body in a horizontal position. Any smaller clearance is almost certain to result in broken blades when landing at a sharp angle or when running through high grass. If the chassis is excessively high the resistance will be high and the machine is also likely to be top heavy.

[image]

Figs. 15-16. Methods of Calculating Wheel Position on Two Wheel Chassis. This Is an Important Item in the Design of an Aeroplane.

Location of Wheels. The exact location of the wheels, in a fore and aft direction, is of the greatest importance. If they are too far ahead of the center of gravity, too much weight will be placed on the tail skid and excessive running will be required to get the tail off the ground. If the wheels are too far back, the machine will be likely to nose over when landing or running over the ground. In any case, the wheels must be well ahead of the center of gravity so that the weight will resist a forward overturning moment. In the majority of orthogonal biplanes, in which the leading edges of the upper and lower wings are on the same vertical line, the center of the wheel is from 3 to 6 inches back of the leading edges. In staggered biplanes the wheel center is from 6 inches to one foot in front of the lower leading edge. This difference is caused by the fact that the center of gravity is nearer the leading edge of a staggered wing than with the Orthogonal type, and hence the wheels must be further forward.

Fig 15 (upper diagram) shows the conditions when the machine is running over the ground with the body horizontal. The vertical line a-a passing through the center of gravity C G is a distance N from the center of the wheel. The weight acting down has a tendency to pull the tail down, this moment being equal to the weight of the machine multiplied by the distance N, or W x N. The elevator flap M exerts a lifting force Ky which acts through the lever arm L, and opposes the moment due to the weight. The force K must be equal to K = WN/L. The distance I is the distance of the wheel center line from the entering edge of the wing. The weight on the tail skid S when the machine is resting on the ground will be equal to S = WN/M, and this may range anywhere from 40 to 200 pounds, according to the size of the aeroplane.

Fig. 16 illustrates a principle of wheel location advanced by Capt. Byron Q. Jones, and published in "Aviation and Aeronautical Engineers," Nov. 16, 1916. The body is shown in a horizontal position with the propeller axis X-X horizontal. The center of gravity is at G on X-X, the weight acting down as at P with the line prolonged meeting the ground line at B. A line E-E is a line drawn tangent to the wheels and the tail skid at D, the angle of this line with the ground determining the maximum angle of incidence. E-E is the ground line when the machine is at rest. For the best conditions, Capt. Jones finds that the line connecting the point of tangency C, and the center of gravity at G, should make an angle of 13 degrees and 10 minutes with the vertical GB dropped through the center of gravity. With the line GA drawn perpendicular to the resting line E-E, the angle BGA should be 10 degrees as nearly as possible. This is for a two-wheel Vee chassis, but with a third front wheel as with the training of type the angle CGB can be made less. Capt. Jones has found that with the wheels in the above location there will be no tendency to nose over even with very poor landings, and this method has been applied to the training machines at the San Diego Signal Corps aviation school. If the angle BGA is greater than 10 degrees it is difficult to "taxi" the machine on the ground, this tending to make the machine spin or turn into the wind. Capt. Jones claims that a two-wheel chassis arranged according to these rules is superior to the three-wheel type for training purposes since the tendency toward spinning is less.

The location of the tail skid S should be such that the elevator and rudder surfaces are well off the ground with the skid fully deflected, and yet the skids must be low enough to permit of the maximum angle of incidence or an angle of EXX = 10 degrees. To a certain extent, the maximum angle of incidence determines the chassis height. If the angle EXX is made greater than the greatest angle of incidence, the wings can be used as air brakes in bringing the machine to a quick stop after landing.

The track, or the distance between the centers of the wheels measured along the axle, must be about 1/7 or 0.15 of the span of the lower wing. This makes the track vary from 5 to 7 feet on the usual types, and as high as 15 feet on the large bombing planes. The track must be great enough to prevent overturning when making a landing on soft ground or with a cross wind. If the track is excessive, there will be a heavy spinning moment in cases where one wheel strikes a depression or soft spot in the ground.

Shock Absorbers. The axle movement allowed by the elastic shock absorbers and guiding appliances averages from 5 to 6 inches. The greater the movement, the less will be the stresses induced by a given drop, but in practice the movement is generally limited by considerations of chassis height and propeller clearance. It can be proved that a movement of 5 inches will produce a maximum stress equal to 8.6 times the weight of the machine under conditions of a one-foot drop, while with an absorber movement of 6 inches the stress is reduced to 7.5 times the weight. This calculation takes the tire deflection into consideration. With the absorber movement limited to one inch, the stress may be as high as 35 times the weight of the machine.

$F=W\ (2 + 2.77/x)$ where W = weight of machine in pounds, F = the stress produced by the fall, and x = the absorber movement in inches.

Landing Gear Wheels. The wheels are generally of the tangent laced wire spoke type, and are enclosed with discs to reduce the resistance. They must have very wide hubs to resist the heavy end stresses caused by landing sidewise. The length of the hub should be at least twice the diameter of the tire and a greater width, say three times the tire diameter, is preferable. The narrow hubs used on motorcycle wheels are not safe against side blows, although they may be capable of withstanding the vertical load. The wheels are rated according to the outside diameter over the tire, and by the diameter of the tire casing. A 26” x 4” wheel signifies that the outside diameter is 26 inches with a casing diameter of 4 inches.

[image]

The 26 x 4 tires are used on the majority of training machines of the two-wheel type, while a 20 x 4 wheel is used for the front wheel of the three-wheel trainer. Two larger sizes, 30 x 4 and 34 x 4, have also been used to some extent, particularly on the Ackerman spring wheels.

CHAPTER XIV. ESTIMATION OF WEIGHT.

Effect of Weight. Weight is an all important consideration and is most difficult to estimate unless one has accurate data on existing machines of the same type. The total weight in flying order depends upon the useful load to be carried, and upon the weight of the power plant. The weight of the latter varies both with the useful load and with the speed, climb, and duration of flight. The type of aeroplane determines the relative head resistance which again reflects back to the weight of the power plant.

The only reason for the existence of an aeroplane is to carry a certain useful load for a given distance, and this useful load is the basis of our weight calculations. The basic useful load consists of the passengers and cargo, although in some specifications the live load may be construed as including the weight of the fuel, oil and instruments, and in the case of military aeroplanes, the weight of the armament, armor, ammunition, wireless and cameras. For comparison, the elements constituting the live load should always be specified.

For a given horsepower, speed and climb, it is obvious that the dead or structural weight should be at a minimum for a maximum live load capacity. The dead load carried in present aeroplanes will be undoubtedly reduced in the future by the adoption of lighter and stronger materials, better methods of bracing, and by reductions in the weight of the power plant. Just as the automobile industry developed light and powerful materials of construction, so will the aeroplane designer develop more suitable materials for the aircraft. While the present power plant has been refined to a remarkable extent when compared with the older types, it is still far from the lowest possible limit. At present the complete power unit—the motor, radiator, propeller, water, etc.—will weigh from 2 to 5 pounds per horsepower.

With a given aeroplane, the performance is determined by the total weight and power. The duration and flight range can be increased by increasing the fuel weight at the expense of the passenger or cargo weight. The power available for climbing is the excess of the total power of the motor over the power required for horizontal flight. Since the power for horizontal flight depends principally upon the weight, it is at once evident that the weight is a regulating factor in the climbing speed. In fact the climbing speed may be almost directly determined from the weight carried per horsepower at normal flight speed. A fast climbing scout may weigh from 8 to 12 pounds per horsepower, while the large low climbing machine will weigh from 16 to 20 pounds per horsepower, the respective climbing speeds being approximately 1,200 and 350 feet per minute.

Fuel Efficiency and Weight. The efficiency of the motor, or its fuel consumption for a given output, has a very marked effect upon the total weight of the aeroplane. Under certain conditions a very light motor with a high fuel consumption will often contribute more to the total weight than a heavier but more economical motor. In short flights, up to 3 hours, the very light rotating cylinder motor with its high fuel consumption probably gives the least total weight, but for longer flights the more efficient and heavier water-cooled type is preferable. For flights of over three hours the fuel weight is a considerable percentage of the total weight. The proper motor for any machine must be selected by computing the weight of the fuel and oil required for a given duration and then adding this to the total weight of the engine and its cooling system.

Distribution of Weight. Practically the only way to predict the weight of a proposed machine is to compare it with a similar existing type. After the ratio of the useful load to the total load has been determined, the useful load of the proposed machine can be divided by the ratio factor to obtain the total weight. It should be noted in this regard that if the proposed machine is much larger than the nearest existing example, a liberal allowance must be made to compensate for the increase in the proportional weight of the structural members. There have been many mathematical formulas advanced for predicting the weight, but these are very inaccurate in the majority of cases.

As a rough estimate, based on a number of successful machines, the weight of the actual aeroplane structure without power-plant, live load, fuel, oil, or tanks, is very nearly 32 per cent (0.32) of the total weight. The remaining 68 per cent is divided up among the power-plant, fuel and live load. Thus, the aeroplane structure proper of a machine weighing 2000 pounds total will be 2000 x 0.32 = 640 pounds. Taking the weight of the power plant, tanks and piping at 28 per cent, the total dead load of the bare machine without fuel or oil will be 60 per cent of the total. With a training aeroplane built for a 6-hour flight, the fuel and oil will approximate 16 per cent, so that the total percentage possible for the crew and cargo will be 24 per cent. With a given live load, the total load can now be calculated by dividing the live load by its percentage. Using the above value, for example, the total weight in order of flight with a live load of 720 pounds becomes: W = 720/0.24 = 3000 pounds.

In government specifications the total weight of the pilot and passenger are taken at 330 pounds, or 165 pounds per man. Gasoline and oil are for a 4-hour flight. A safer average figure will be 170 pounds per man, and a fuel allowance of 6 hours. The floats of a seaplane or flying boat bring the percentage of the dead load much higher than with the land type of chassis.

The following table will give an idea as to the weight distribution expressed both in pounds, and as a percentage of the total weight. It covers a wide range of types, varying from the training types Curtiss JN-4B and the Standard H-3, to the Handley-Page Giant bomber and the Nieuport speed scout. The average values found by Hunsaker for a number of machines weighing in the neighborhood of 2500 pounds is given in the fourth column. Under each heading are the actual weights and the percentages of the total weight for each item. Items marked (*) include both gasoline and oil. Mark (C) is the power plant complete, and (@) includes radiator.

Weight Per Horsepower. As already explained, the weight carried per horsepower varies with the type of machine. When the total weight is determined for any aeroplane, the power requirements can be calculated by dividing the total weight by the weight per horsepower ratio. A fair value for a training or exhibition machine is from 18 to 20 pounds per horsepower, while for a very high speed machine, such as a chaser, the weight will be taken at 10 pounds per horsepower. For two-seater fighters 16 to 18 pounds is fair practice. For a comparison of the horsepower-weight ratios used on different well-known machines see tables in Chapter II. Thus, if our total weight is found to be 2400 pounds as determined from the above table, and if this is a training machine, the horsepower will be: 2400/20 = 120 horsepower. Using the same total weight, but powered for two-seater fighter conditions, the power will be increased to 2400/16= 150 horsepower. As a scout the power will be increased still further to 2400/10=240 horsepower.

[image]

As a problem in solving the weight and horsepower from the data, we will assume that we are to design a two-seater fighter with a total useful load of 1200 pounds. This load consists of the following items: Personnel (2) = 330 pounds; gas and oil = 500 pounds; guns and ammunition = 370 pounds. The nearest example that we have to this live load is that of the Standard H-3, which carries 744 pounds and in which the percentage of live load is 28.1 per cent. As our machine will be somewhat larger, we will not be far from the truth if we take the percentage as 0.27 instead of 0.281. The total weight, in flying order, will now be 1200/0.27 = 4440 pounds. At 16 pounds per horsepower the motor will be: 4440/16=277 horsepower.

An empirical formula for a high-speed scout was set forth in ”Aviation and Aeronautical Engineering” by D. W. Douglas. This is based on the horsepower unit. A unit wing loading of 8.45 pounds per square foot, and a low speed of 55 miles per hour was assumed. The wing section chosen was the U.S.A.-1. In the formula, H = horsepower:

- Power plant weight = 3 H.
- Chassis weight = 0.7 H.
- Tail weight = 0.25 H.
- Fuel for 2.25 hours = 1.4 H.
- Military load = 250 pounds.
- Tanks and piping = 0.42 H.

- Fuselage weight = 1.84 H.
- Wing weight = 1 lb. sq. ft.
- Propeller = 2.8/H.
- (Total) = (7.61 H + 2.5/H + 250)/7.45 = Weight of aeroplane fully loaded in the order of flight.

Weight of Wings. The weight of the wings depends upon the span, very small machines having wings that weigh only 0.38 pounds per square foot, while the wings of very large machines may run as high as 1.1 pounds per square foot. For average size biplanes from 0.75 to 0.80 pounds per square foot would probably be safe—that is, for areas ranging from 450 to 550 square feet. The weight of the upper wing of the Nieuport is 0.815 pounds per square foot, while the lower wing (short chord) is 0.646 pounds per square foot. The wings of the Standard H-3 trainer will average 0.77 pounds per square foot, the lower wing and center section being heavier than the upper wing. The wings of the Curtiss JN-4B will average 0.75 pounds per square foot. These weights do not include the interplane wires or struts, nor the fittings. The total weight of the interplane struts of the JN-4B, the Aviatic, and machines of similar size will average from 28 to 30 pounds. The ailerons will weigh about 12 pounds each.

Weight of Motors. There is a considerable difference in the weight of air-cooled and water-cooled motors. The water, water piping, radiators and jackets of the water-cooled motors adds considerably to the weight of the complete power plant. The mountings are heavier for the water-cooled motors, and because of the tandem arrangement of the cylinders, the crankshaft and crankcase weigh more. In taking the bare weight of the power plant all of the accessories must be included. In the following table, the ”bare engine” includes the carbureter, magneto, and necessary integral accessories, but does not include the jacket water, mounting, radiator, oil in base, water piping, nor controls. Water-cooled motors are marked by (W) and air-cooled by (A). Rotary air-cooled are (RA), and gallons (G).

WEIGHTS OF AERONAUTICAL MOTORS.

The bare radiator will weigh from 0.48 to 0.56 pounds per horsepower, the average being safe at 0.52. The water contained in the radiator will average 0.35 pounds per horsepower. The weights of the piping and the water contained therein will be computed separately. The circular sheet metal cowl used over the rotary cylinder air-cooled motor is equal to twice the square root of the motor weight, according to Barnwell. Propeller weight varies considerably with the diameter, pitch, etc., but a safe rule will give the weight as $2.8 \sqrt{H}$ where H = horsepower. The tanks will weigh from 0.75 to 1.2 pounds per gallon of contents, or approximately 1/5 the weight of the contents when completely filled.

Chassis and Wheel Weight. The chassis of a two-wheel trainer will weigh about 90 pounds complete, although there are chassis of training machines that weigh as much as 140 pounds. The chassis of speed scouts will be from 22 to 40 pounds complete. Tail skids can be taken at from 6 to 8 pounds.

Tangent wire wheels complete with tires are about as follows: 26 x 4 = 21 pounds; 26 x 5 = 28 pounds; 26 x 3 = 14 pounds. Ackerman spring spoke wheels are estimated as follows: 20 x 4 = 17.5 pounds; 26 x 3 = 22 pounds; 26 x 4 = 32 pounds; 30 x 4 = 35 pounds; 34 x 4 = 45 pounds.

Military Loads. A 20-mile wireless outfit devised by Capt. Culver weighed 40 pounds with storage batteries, while the 120-mile outfit weighed 60 pounds with a 180-watt generator. The 140-mile U.S.A. mule-back wireless of 1912 weighs 45 pounds. The ”Blimp” specifications allow 250 pounds.

The Lewis gun as mounted on the ”11” Nieuport weighs 110 pounds, including mount, gun and ammunition. Lewis gun bare is 26 pounds. The Davis 6-pounder, Mark IV, weighs 103 pounds with mounting but without ammunition, while the same make of 3-inch 12-pounder weighs 238 pounds under the same conditions.

[image]

Controls and Instruments. The Deperdussin type controls used on the Curtiss JN-4B weigh 16 pounds per control, while those installed in the Standard H-3 weigh about 13 pounds. An average of 15 pounds per control is safe. An instrument board for the aviators' cock-pit, fully equipped, weighs from 20 to 24 pounds. The front, or students' instrument board will average 10 pounds. Pyrene extinguisher and brackets = 7 pounds; Speaking tube = 3 pounds; Oil pressure line and gage = 3 pounds; Side pockets = 3 pounds; Tool kit = 10 pounds.

Control Surfaces. The rudder, stabilizer, fin, and elevator can be made so that the weight will not exceed 0.60 to 0.65 pounds per square foot.

General Notes on Weight. Before starting on the weight estimates of the machine the reader should carefully examine the tables in Chapter II which give the weights, and general characteristics of a number of modern machines.

Weights and Wing Area. When the weight of the machine is once determined, the next step will be to determine the wing area. For speed scouts or very large heavy duty machines the choice of a wing section must be very carefully considered. For the speed scout several wings giving a minimum high speed resistance should be examined, such as the Eiffel 37 or the U. S. A-1 or U.S.A.-6. For the low-speed aeroplane to be designed for great lift, a number of sections such as the U.S.A.-4 or the R.A.F.-3 should be tried for a number of speeds and angles. For training machines a wing of the ”All around” type such as the R.A.F.-6 should be adopted, the structural characteristics in the case of a trainer having an important bearing on the subject. If W = weight of the machine in pounds, V = low speed in miles per hour, A = total area in square feet, and Ky=lift coefficient, then the area becomes $A=W/KyV^2$. Compensation must be made for biplane interference for aspect ratio, and stagger as previously explained. For an ordinary training machine with the usual gap/chord ratio, and aspect ratio, the correction factor of 0.85 may be safely employed.

Example. We will take the case of an aeroplane carrying a personnel load of 340 pounds, oil and gasoline 370 pounds, and baggage amounting to 190 pounds, instruments 100 pounds. Total live load will be 1000 pounds. Taking the live load percentage as 0.30, the total load will be 1000/0.30 = 3333 pounds. If the low speed is 50 miles per hour, and the maximum Ky of the chosen wing is 0.003 at this speed, the area will be $A = W/KyV^2 = 3333/0.003 \times (50 \times 50) = 444$ square feet. Since this is a biplane with a correction factor of 0.85, the corrected area will be: 444/0.85 = 523 square feet. The unit loading, or weight per square foot will be: 3333/523 = 6.36 pounds. The corrected area includes the ailerons and the part of the lower wing occupied by the body.

Empirical Formula for Loading. After investigating a large number of practical biplanes, the author has developed an expression for determining the approximate unit loading. When this is found, the approximate area can be found by dividing the total weight by the unit loading. This gives an idea as to the area used in practice.

It was found that the unit loading increased with the velocity at nearly a uniform rate. This gave an average straight line formula that agreed very closely with 128 examples. If V = Maximum velocity in miles per hour, and w = weight per square foot, then the unit loading becomes:

$w = 0.065V - 0.25$ for the average case. For high speed scouts this gives a result that is a trifle low, the formula for a fast machine being more nearly $w = 0.65V - 0.15$, for speeds over 100 miles per hour.

A two-seat machine of average size weighs 2500 pounds, and has a maximum speed of 90 miles per hour. Find the approximate unit loading and area. The loading becomes: $w = 0.065V - 0.25 = (0.065 \times 90) - 0.25 = 5.6$ pounds per square foot. The approximate area will be: 2500/5.60 = 446 square feet.

If the above machine had a speed of 110 miles per hour, the formula would be changed for the high-speed type machine, and the loading would become:

$w = 0.065V - 0.15 = (0.065 \times 110) - 0.15 = 7.00$ pounds per square foot. The required area will be: 2500/7.0 = 372 square feet. When the unit load is also determined in this way it is a very simple matter to choose the wing section from Ky = w/V^2.

Area From Live Load and Speed. By a combination of empirical formula we can approximate the area directly. For the average size machine, w = 0.065V - 0.25. And the total weight W = U/0.32 where U is the useful or live load. Since A = W/w, then A = U/(0.65V - 0.25) x 0.32 = U/0.021V - 0.08.

Thus if an aeroplane travels at 90 miles per hour and has carried a useful load of 800 pounds (including gas and oil), the approximate area is: A = U/0.021.V = 0.08 = 800/(0.021 x 90) - 0.08 = 442 square feet. This assumes that the useful load is 0.32 of the total load and that the speed is less than 100 miles per hour.

CHAPTER XV. BALANCE AND STABILITY.

Elements of Stability. When we balance a board on a fulcrum so that it stands in a perfectly horizontal position, the board is said to be ”In equilibrium,” or is supported at its ”Center of gravity.” There is only one point at which a body will balance, and this point is at the center of gravity or ”C. G.” In an aeroplane, the combined mass of the body, motor, wings, fuel, chassis, tail and live load has a center of gravity or a balancing point at which the lift must be applied if the machine is to rest in equilibrium. When the center of lift (or center of pressure) does not pass through the center of gravity of the aeroplane, some other force must be applied to overcome the unbalanced condition. When the machine is unbalanced in a fore and aft direction with the tail low, a force must be applied by the elevator flaps that is opposite and equal to the moment of the unbalanced forces. An aeroplane is stable when it is balanced in such a way that it returns to a state of equilibrium after meeting with a disturbance.

When disturbed, a stable body does not usually return instantly to its position of equilibrium, but reaches it after a series of decreasing oscillations. The heavier the body, and the more compact its form, the longer will it oscillate about its fulcrum before coming to rest. By arranging broad surfaces at the ends of the oscillating body, a portion of the energy will be expended in creating air currents, and the motion will be readily ”damped out.” If the damping effect is so great that the body does not swing back after once reaching the position of equilibrium, the body is said to be ”dead beat,” or ”dynamically stable.” There is a great difference between the static forces that tend to return the body to a position of equilibrium and the dynamic retarding forces that tend to damp out the oscillations. Usually, a body with excessive static stability is far from being stable in a true sense, since such a body tends to oscillate longer, and more violently, than one in which the static restoring forces are not so strongly marked. A body may be statically but not dynamically stable, but a dynamically stable body must of necessity be statically stable.

Static stability in calm air is determined by the location of the center of gravity, the center of lift, the center of propeller thrust, the center of area of the surfaces, and the center of the forward resistance. The forces acting through these centers are: (1) The weight; (2) The lifting force; (3) The propeller thrust; (4) The resistance. The weight and lift are vertical forces equal and opposite in direction. The thrust and resistance are horizontal forces, also equal and opposite in direction. When all of these forces intersect at a common point, they will completely neutralize one another and the body will be in equilibrium.

Dynamic stability is attained by the use of large damping surfaces such as the stabilizer surface, fins, and the elevator. These act to kill the oscillations set up by the static righting couples or forces. Without suitable damping surfaces the machine would soon be out of control in gusty weather since successive wind gusts will act to increase the oscillations of the righting forces until the machine will turn completely over. On the other hand, an aeroplane can be too stable and therefore difficult to steer or control in gusts because of its tendency toward changing its attitude with every gust in order to restore its equilibrium. A machine should only be partially stable, and the majority of pilots are firmly set against any form of mechanical or inherent control. No matter how simple the method, mechanical control always introduces a certain amount of mechanism that may go wrong. The question of stability has already been solved to a sufficient extent.

A disturbance that simply changes the direction of travel is not considered an unstable force since it normally does not tend to endanger the machine. Nearly any machine, equipped with any possible form of control apparatus, tends to change its direction when being righted.

Axes of Stability. An aeroplane has six degrees of freedom or motion. Three are of translation or straight line motion, and three are of rotation about rectangular axes. It can travel forward in a straight line, rise and fall in a vertical plane, or skid sidewise. When it rolls from side to side about the fore and aft axis (X axis) it is laterally unstable. When pitching up and down in a fore and aft direction, and around an axis parallel with the length of the wings (Y axis), the machine is said to be longitudinally unstable. When swinging or ”Yawing” from right to left about a vertical axis (Z axis) it is unstable in ”Yaw.”

Rolling is resisted by the ailerons, pitching by the elevators and stabilizer, and yawing by the vertical directional rudder. Lateral oscillation are damped out by the wing surfaces and by vertical surfaces or ”Fins.” Longitudinal oscillations are damped mostly by the stabilizer and elevator surfaces. Directional or yawing vibrations are corrected by the damping action of the vertical tail fin, vertical rudder and the sides of the body, the latter also serving to damp out longitudinal vibrations. On an absolutely calm day, the pilot can shut off the motor and glide down without touching the controls if the machine is longitudinally stable. The glide generally starts with a few pitching oscillations, but these gradually are damped out by the tail as soon as the machine picks up its natural gliding angle and speed, and from this point it will continue without oscillating.

The Spiral and Nose Dive. There are two forms of instability that have not yet been fully corrected, and both are highly dangerous. One of these is known as the ”spiral dive” or nose spin, and the other as the straight nose dive. The aeroplane in a spiral nose dive rotates rapidly about a vertical axis during the dive. Spiral instability resulting from lateral instability, can be minimized by decreasing the area of the vertical rudder and by the proper placing of fins so that there is not so great an excess of vertical area to the rear of the C. G.

The covered-in body acts as a fin and will be productive of spiral instability if the area is not properly distributed. In the majority of cases the rear of the body is equivalent to a large fin placed to the rear of the C. G. A fin above the G. G. tends to reduce all spiralling.

Stability and Speed. An aeroplane in straight horizontal flight must be driven at such an angle, and such a speed, that the weight is just sustained. To be inherently stable the machine must always tend to increase its speed by diving should the power be cut off in any way. An aeroplane that does not tend to increase its speed in this way, ”Stalls” or becomes out of control. Any machine that will automatically pick up its gliding angle after the propeller thrust has ceased is at least partially inherently stable, and if it does not possess this degree of stability, other forms of stability are practically worthless. The machine having the smallest, flattest gliding angle is naturally safest in cases of power failure, and hence the gliding angle is somewhat related to the subject of stability.

[image]

A Spanish Aeroplane Using a Peculiar Form of Upper Fin. These Fins Also Perform the Duty of Vertical Rudders as Well as Acting as Stabilizers.

The longitudinal stability decreases with a decrease in the speed, the fore and aft vibrations becoming more rapid due to the decreased effect of the tail surfaces, and to the reduction of wing lift. Instability at low speeds is common to all aeroplanes, whether inherently stable or not, and at a certain critical speed the machine becomes absolutely unstable in a dynamic sense. If a machine is to be stable at low speeds, it must not fly at too great an angle of incidence at these speeds, and it should have a very large tail surface acting at a considerable distance from the wings. Hunsaker states that the lowest speed should not require more than 80 per cent of the total lift possible.

Inertia or Flywheel Effect. The principal weights should be concentrated as nearly as possible at the center of gravity. Weights placed at extreme outer positions, as at the wing tips, or far ahead of the wings, tend to maintain oscillations by virtue of their flywheel effect. The measure of this inertia or flywheelage is known as the "Moment of Inertia" and is the sum of the products of all the masses by the squares of their distances from the center of gravity. A great amount of inertia must be met by a large damping surface or control area if the vibrations are to be damped out in a given time. In twin-motored aeroplanes the motors should be kept as close to the body as the propellers will permit.

Wind Gusts and Speed. A machine flying at high speed is less affected by wind gusts or variations in density than a slow machine, since the disturbing currents are a smaller percentage of the total speed. In addition, a high speed results in smaller stresses due to the gusts.

Gyroscopic Instability. The motor gyroscopic forces do not affect the stability of a machine to any great extent, and in twin motored aeroplanes the gyroscopic action of the propellers is almost entirely neutralized. At one time the gyroscopic torque was blamed for every form of instability, but on investigation it was found that the practical effect was negligible.

Instability Due Power Plant. The power plant affects stability in a number of ways. The thrust of the propeller may cause a fore and aft moment if the center line of thrust does not pass through the center of resistance. This causes the machine to be held head up, or head down, according to whether the line of thrust is below or above the C. G. If the propeller thrust tends to hold the head up in normal flight, the machine will tend to dive, and assume its normal gliding velocity with the power off, hence this is a condition of stability. With the effect of the thrust neutral, or with the thrust passing through the center of resistance, the machine will not tend to maintain the speed, and hence it is likely to stall unless immediately corrected by the pilot. With the line of thrust above the C. G., the stall effect is still further increased since with this arrangement there is a very decided tendency for the machine to nose up and increase the angle of incidence when the power is cut off.

The slip stream of the propeller has a very decided effect on the tail surfaces, these being much more effective when the propeller slip stream passes over them. With lifting tails, or tails that normally carry a part of the load, the stoppage of the slip stream decreases the lift of the tail and consequently tends to stall

[image]

Steel Elevator and Rudder Construction Used on a European Machine. The Elevators Also Act as Stabilizers, the Entire Surface Turning About the Tube Spar.

the machine. Non-lifting tails should be arranged so that the slip stream strikes down on the upper surface. This tends to force the tail down, and the head up in normal flight, and when the power ceases the tail will be relieved and there will be an automatic tendency toward diving and increase in speed. On a twin aeroplane, a similar effect is obtained by making the upper tips of both propellers turn inwardly. The air is thus thrown down on the tail.

With a single motor, the torque tends to turn the aeroplane in a direction opposite to the rotation of the propeller. Lateral stability is thus interfered with when the motor is cut off or reduced in speed. With right-hand propeller rotation, for example, the machine will be turned toward the left, forcing the left tip down. To maintain a horizontal attitude, the left aileron must be held down by an amount just sufficient to overcome the torque. In some machines one wing tip is given a permanent increase in incidence so that the down seeking tip is given permanent additional lift.

Lateral Stability. When an aeroplane is turned sharply in a horizontal plane, or ”Yaws,” the outer and faster moving wing tip receives the greater lift, and a lateral rolling moment is produced about the fore and aft axis. In the opposite condition, a lateral rolling moment tends to yaw or to throw the aeroplane off a straight course. Below a certain critical speed, the lateral or rolling oscillations increase in amplitude, with a strong tendency to side slip, skid or spiral. The tail fin or rudder retards the tail velocity in a side slip, and thus turns the slipping or skidding machine into a vertical spiral or spinning nose dive. This spin increases the angle of bank and hence the side slip. This in turn increases the turning or yawing velocity, and the spiral starts. This tendency toward a spiral dive can be corrected by a vertical fin placed forward, and above the center of gravity, or by raising the wing tips. An upper fin of this type will give a force that tends to break up the bank when side slip starts and thus will prevent spinning.

At normal speeds the rolling is damped down by the wing surfaces, and can be further controlled by the application of the ailerons. At the lower critical speed when the machine is stalled, one wing tip has no more lift than the other, and hence the damping effect of the wings and the action of the ailerons becomes negligible.

[image]

Sperry Gyroscopic Control System for Automatic Stability. The Gyroscopic Control at the Left Controls the Movements of the Electric Servo-Motor at the Extreme Right. This Motor Operates the Control Surfaces Through the Pulley Shown. A Small Electric Generator Between the Servo-Motor and Gyroscope Provides the Current and Is Driven by a Small Wind Propeller.

Dutch Roll. In "Dutch Roll," the rolling is accompanied by an alternate yawing from right to left. This is aggravated by a fin placed high above the C. G., and hence corrections for spiral dive conflict with corrections for Dutch roll. The rolling is accompanied by some side slip, and the motion is stable providing that there is sufficient fin in the rear and not an excessive amount above the C. G.

Degree of Stability. Excessive stability is dangerous unless the control surfaces are powerful enough to overcome the stable tendency. Since a stable machine always seeks to face the relative wind, it becomes difficult to handle in gusty weather, as it is continually changing its course to meet periodic disturbances. This is aggravated by a high degree of static stability, and may be positively dangerous when landing in windy weather.

Control Surfaces. A non-lifting tail must give no lift when at a zero angle of incidence. It must be symmetrical in section so that equal values of lift are given by equal positive and negative angles of incidence. Square edged, flat surfaces are not desirable because of their great resistance. A double cambered surface is suitable for such controls as the stabilizer, elevator and rudder. It has a low resistance, permits of strong internal spars, and is symmetrical about the line of the chord. Some tails are provided with a cambered top and a flat bottom surface so that the down wash of the wings is neutralized. Under ordinary conditions this would be an unsymmetrical lifting surface, but when properly adapted to the wings the lifting effect is completely neutralized by the down wash.

The curvature of the section should be such that the movement of the center of pressure is as small as possible. With a small movement of the center of pressure, the surface can be accurately balanced and hinged on the center of pressure line. It is desirable to have the maximum thickness of section at, or near to the C. P., so that a deep spar can be used for the support of the hinge system. Usually the movement of the control surfaces is limited to an angle of 30 degrees on either side of the center line, as the lift of all surfaces start to decrease after this point is reached. The surface movement should be limited by the maximum lift angle of the section in any case, since an accident will be bound to occur if they are allowed movement beyond the angle of maximum lift.

In locating the control surfaces, careful attention should be paid to the surrounding air conditions so that they will not be unduly affected by the wash-down of the wings or body. The effectiveness of the tail surfaces is very much reduced by bringing them close to the wings, and the lift is always reduced by the wash of a covered fuselage.

The wash-down effect of the wings on the tail is proportional to the chord and not to the span, and for this reason an increase in span does not always necessitate an increase in the length of the body. An adequate damping effect requires a large surface at the end of a long lever arm.

Balancing the Aeroplane. Figs. 1 to 6 show the principles involved in the balancing of the aeroplane. In Fig. 1 a number of weights 1’-2’-3’ and 5M are supported on a beam, the load being balanced on the fulcrum point M. The load 2’ being directly over the fulcrum, has no influence on the balance, but load 1’ at the left tends to turn the mass in a left-hand direction, while 3’ and 5M tend to give it a right-hand rotation. This turning tendency depends upon the weights of the bodies and their distance from the fulcrum. The turning tendency or ”Moment” is measured by the product of the weight and the distance from the fulcrum. If weight 1’ should be 10 pounds, and its distance A’ from the fulcrum should be 20 inches, then it would cause a left-hand moment of 10 x 20 = 200 inch pounds. If the system is to be in balance, then the left-hand moment of 1’ should be equal to the sum of the moments of 3’ and 5M. Thus: 1’ x A = (3’ x B) + (5M x C’).

[image]

Figs. 1-6. Methods of Balancing an Aeroplane About Center of Lift.

The application of this principle as applied to a monoplane is shown by Fig. 4, in which X-X is the center of pressure or lift. The center of lift corresponds to the fulcrum in Fig. 1, and the weights of the aeroplane masses and their distance from the center of lift are shown by the same letter as in Fig. 1. The engine 1’ is at the right of the C. P. by the distance A, while the fuel tank 2 is placed on the C. P. in the same way that the weight 2’ in Fig. 1 is placed directly over the fulcrum. By placing the tank in this position, the balance is not affected by the emptying of the fuel since it exerts no moment. The chassis G acting through the distance E is in the same direction as the engine load. The body 5 with its center of gravity at M acts through the distance C, while the weight of the pilot 3 exerts a right-hand moment with the lever arm length B. If the moments of all these weights are not in equilibrium, an additional force must be exerted by the tail V.

Fig. 2 shows an additional weight 4' that corresponds to the weight of the passenger 4 in Fig. 5. This tends to increase the right turning moment unless the fulcrum is moved toward the new load. In Fig. 2 the fulcrum M remains at the same point as in Fig. 1, hence the system requires a new force P' acting up at the end of the beam. If the load was in equilibrium before the addition of 4', then the force P' must be such that P' x T' = 4" x D'. In the equivalent Fig. 5, the center of gravity has moved from its former position at S to the new position at R, the extent of the motion being indicated by U. To hold this in equilibrium, an upward force P must be exerted by the elevator at Y, the lever arm being equal to (T + U).

Fig. 6 shows the single-seater, but under a new condition, the center of pressure having moved back from X-X to Z. To hold the aeroplane in equilibrium, a downward force must be provided by the tail V which will cause a right-hand moment equal to the product of the entire weight and the distance U. For every shift in the center of pressure, there must be a corresponding moment provided by the elevator surface. The condition is shown by the simple loaded beam of Fig. 3. In this case the fulcrum has been moved from M to N, a distance equal to the center of pressure movement in Fig. 6. This requires a downward force P' to maintain equilibrium.

Center of Pressure Calculation. Fig. 7 is a diagram showing the method of calculating the center of gravity. The reference line R is shown below the elevators and is drawn parallel to the center of pressure line W-W, the latter line being assumed to pass through the center of gravity. The line R may be located at any convenient point, as at the propeller flange or elsewhere, but for clearness in illustration it is located to the rear of the aeroplane. The weight of each item is multiplied by the distance of its center of gravity from the line R, these products are added, and the sum is then divided by the total weight of the machine. The result of this division gives the distance of the center of gravity from the line R. Thus, if the center of gravity of the body (11) is located at (10), then the product of the body weight multiplied by the distance B will give the moment of the body about the line R. The weight of the motor (2) multiplied by the distance F gives the moment of the motor about R, and so on through the list of items.

[image]

Center Of Gravity Table

The distance of the center of gravity (or center of pressure) from the reference line R is given by H + K. This gives the numerical value 219350/1375 = 1596 inches. Thus if we measure 159.6 inches from R toward the wings we will have located the center of gravity. The location of the C. G. can be changed by shifting the weights of the motor, passenger, or other easily moved items. In any case, the C. G. should lie near the center of pressure.

Tail Lever Arms. The effective damping moment exerted by the fixed stabilizer surface (12) will be the product of its area by the distance (I), measured from the center of pressure of the wing to the center of pressure of the stabilizer. The lever arm of the elevator is the distance (H) measured from the centers of pressure as before.

[image]

Fig. 7. Method of Determining the Center of Gravity of an Aeroplane.

Resultant Forces and Moments in Flight. The aeroplane is in equilibrium when all of the forces pass through a common center, as shown by Fig. 8. In this figure the lift (L), the weight (W), the line of propeller thrust (T), and the resistance (R) all pass through the center of gravity shown by the black dot C. G. There are no moments and hence no correction is needed from the elevator (T). In Fig. 9, the thrust and resistance pass through the center of gravity as before, but the center of lift (L) does not pass through the center of gravity, the distance between the two being indicated by (n). This causes a moment, the length of the lever arm (n) being effective in giving a right-hand rotation to the body. If horizontal flight is to be had this must be resisted by the upward elevator force (E).

In Fig. 10, the lift passes through the center of gravity, but the line of resistance lies below it by the amount (m). The thrust (T) tends to rotate the machine in a left-handed direction. The elevator must exert a downward force (e) to resist the moment caused by (m). This is a bad disposition of forces, as the machine would tend to stall or tail-dive should the propeller thrust cease for even an instant. The stability of Figs. 8 and 9 would not be affected by the propeller thrust, as it passes through the C. G. in both cases. In Fig. 11, the center line of thrust is below the line of resistance (R), so that the thrust tends to hold the nose up. Should the motor fail in this case, the nose would drop and the machine would start on its gliding angle and pick up speed.

In Fig. 12 none of the forces intersect at a common point, the lift and weight forming a right-handed couple, while the thrust (T) and the resistance (R) form a left-handed couple that opposes the couple set up by the weight and lift forces. If the thrust-resistance couple can be made equal to the lift-weight couple, the aeroplane will be in equilibrium and will need no assistance from the elevator. As the weights in the aeroplane are all located at different heights, it is necessary to obtain the center of gravity of all the loads in a vertical plane as well as horizontally. Thus in Fig. 13 the line C. G. is the center of gravity of the engine weight (1), the wing weight (2), the pilot's weight (3), the chassis weight (4), the fuselage weight (5), and the fuel tank weight (6). The line C. G. is the effective center of all these loads, and is calculated by taking the products of the weights by the distance from a reference line such as R-R. The center of resistance is the effective center of all the resistance producing items such as the wings, body, struts, chassis, etc.

[image]

Figs. 8-15. Forces Affecting the Longitudinal Stability of an Aeroplane.

A suggestion of the method employed in obtaining the center of resistance is shown by Fig. 14, the center line of resistance R-R being the resultant of the wing resistance (D), the body resistance (B), and the chassis resistance (C). It will be noted that the wing resistance of biplane wings (W-W') does not lay midway between the wings but rather closer to the upper wing, as shown by (E). This is due to the upper wing performing the greater part of the lift. In locating the center of resistance, the resistance forces are treated exactly like the weights in the C. G. determination. Each force is multiplied by its distance from a horizontal reference line, and the sum of the products is divided by the total resistance. As shown, the center of resistance R-R passes through the center of gravity C. G. The center of pressure line X-X also contains the center of resistance.

A staggered biplane cell is shown by Fig. 15, the center of pressure of the upper and lower wings being connected by the line X-X as before. The center of resistance of the pair is shown at (D), where it is closer to the upper wing than to the lower. A vertical line Y-Y dropped through the center of resistance gives the location of the center of lift. As shown, the center of lift is brought forward by the stagger until it is a distance (g) in front of the leading edge of the lower wing. The center of lift and the center of resistance both lie on a line connecting the center of pressure of the upper and lower wings.

Calculation of Control Surfaces. It is almost impossible to give a hard and fast rule for the calculation of the control surfaces. The area of the ailerons and tail surfaces depends upon the degree of stability of the main wings, upon the moment of inertia of the complete machine, and upon the turning moments. If the wings are swept back or set with a stagger-decalage arrangement, they will require less tail than an orthogonal cell. All of these quantities have to be worked out differently for every individual case.

Aileron Calculations. The ailerons may be used only on the upper wing (2 ailerons), or they may be used on both the upper and lower wings. When only two are used on the upper wing it is usually the practice to have considerable overhang. When the wings are of equal length either two or four ailerons may be used. Roughly, the ailerons are about one-quarter of the wing span in length. With a long span, a given aileron area will be more effective because of its greater lever arm.

If a = area of ailerons, and A = total wing area in square feet, with S = wing span in feet, the aileron area becomes: a = 3.2A/S. It should be borne in mind that this applies only to an aeroplane having two ailerons on the upper wing, since a four-aileron type usually has about 50 per cent more aileron area for the same wing area and wing span. For, example, let the wing span be 40 feet and the area of the wings be 440 square feet, then the aileron area will be: a = 3.2A/S = 3.2 x 440/40 = 35.2 square feet. If four ailerons were employed, two on the upper and two on the lower wing, the area would be increased to 1.5 x 35.2 = 52.8 square feet. As an example in the sizes of ailerons, the following table will be of interest:

[image]

Aileron Sizes Table

In cases where the upper and lower spans are not equal, take the average span—that is, one-half the sum of the two spans.

Stabilizer and Elevator Calculations. These surfaces should properly be calculated from the values of the upsetting couples and moments of inertia, but a rough rule can be given that will approximate the area. If a' = combined area of stabilizer and elevator in square feet; L = distance from C. P. of wings to the C. P. of tail surface; A = Area of wings in square feet, and C = chord of wings in feet, then:

a' = 0.51AC/L. Assuming our area as 430 square feet, the chord as 5.7 feet, and the lever arm as 20 feet, then:

a' = 0.51AC/L = 0.51 x 430 x 5.7/20 = 62.5 square feet, the combined area of the elevators and stabilizer. The relation between the elevator and stabilizer areas is not a fixed quantity, but machines having a stabilizer about 20 per cent greater than the elevator give good results. In the example just given, the elevator area will be: 62.5/22 = 28.41 square feet, where 2.2 is the constant obtained from the ratio of sizes. The area of the stabilizer is obtained from: 28.41 x 1.2 = 34.1 square feet.

Negative Stabilizers. A considerable amount of inherent longitudinal stability is obtained by placing the stabilizing surface at a slight negative angle with the wings. This angle generally varies from -2° to -6°. At small angles of wing incidence the negative angle of the tail will be at a maximum, and acting down will oppose further diving and tend to head the machine up. At large wing angles, the tail will be depressed so far that the tail angle will become positive instead of negative, and thus the lift on the tail will oppose the wings and will force the machine to a smaller angle of incidence. The negative angle can thus be adjusted to give longitudinal stability within the ordinary range of flight angles.

Stabilizer Shapes and Aspect Ratio. Stabilizers have been built in a great number of different shapes, semicircular, triangular, elliptical, and of rectangular wing form. Measured at the rear hinged joint, the span or width of the stabilizer is about 1/3 the wing span for speed scouts, and about 1/4 the wing span for the larger machines. Nearly all modern machines have non-lifting tails, or tails so modified that they are nearly non-lifting. Since flat plates give the greatest lift with a small aspect ratio, and hence are most effective when running over the ground at low speeds, the stabilizers and elevators are of comparatively low aspect. In general, an aspect ratio of 3 is a good value for the stabilizer. Vertical rudders generally have an aspect ratio of 1, and hence are even more effective per unit area than the stabilizers. This is particularly necessary in ground running.

[image]

Aileron Control Diagram of Curtiss JN4-B.

[image]

Elevator Control Diagram of Curtiss JN4-B.

Vertical Rudders. The calculation of the vertical rudders must take the moment of inertia and yawing moments into effect, and this is rather a complicated calculation for the beginner. As an approximation, the area of the rudder can be taken from 9 to 12 square feet for machines of about 40 feet span, and from 5 to 8 square feet for speed scouts.

[image]

Stick Control Used on the Caudron Biplane. Wing Warp Is Used Instead of Ailerons. Back and Forth Movement Actuates Elevator.

[image]

German Stick Control With Double Grips. A. Latch on the Side of the Stick Acts on a Sector So That the Lever Can Be Held at Any Point. It Is Released by the Pressure of the Knees.

Wing Stability. Under wing sections, the subject of the center of pressure movement has already been dealt with. The variation of the center of pressure with the angle of incidence tends to destroy longitudinal stability since the center of pressure does not at all times pass through the center of gravity. On some wings, the camber is such that the variation in the position of the center of pressure is very little, and hence these are known as stable wings. A reflex curve in the trailing edge of a wing reduces the center of pressure movement, and swept back wings are also used as an aid in securing longitudinal stability. Introducing stagger and decalage into a biplane pair can be made to produce almost perfect static longitudinal stability. It should be noted that stability obtained by wing and camber arrangements is static only, and requires damping surfaces to obtain dynamic stability.

[image]

Form of Control Used on the Nieuport Monoplane.

Manual Controls. In flight, the aviator has three control surfaces to operate, the ailerons, elevator, and rudder. In the usual form of machine the ailerons and elevator are operated by a single lever or control column, while the rudder is connected with a foot bar. In the smaller machines ”Stick Control” is generally used, the ailerons and elevator being moved through a simple lever or ”Joy Stick” which is pivoted at its lower end to the floor. The Deperdussin or ”Dep” control is standard with the larger machines and consists of an inverted "U" form yoke on which is mounted the wheel for operating the ailerons.

Stick Control. With the stick pivoted at the bottom, a forward movement of the lever causes the machine to descend while a backward movement or pull toward the pilot causes the aeroplane to head up or ascend. The stick is connected with the elevators with crossed wires, so that the flaps move in an opposite direction to the "Stick." Moving the stick from side to side operates the ailerons.

[image]

Standard Stick Control and Movements Used in the U.S.A.

Deperdussin Control. A "U" shaped yoke, either of bent wood or steel tube, is pivoted the bearers at the sides of the fuselage. Wires are attached to the bottom of the yoke so that its back and forth movement is communicated to the elevator flaps. On the top, and in the center of the yoke, is pivoted a hand wheel of the automobile steering type. This is provided with a pulley and is connected with the aileron flaps in such a way that turning the wheel toward the high wing tip causes it to descend. Pushing the yoke forward and away from the aviator causes the machine to descend, while a reverse movement raises the nose. The "Dep" control is reliable and powerful but is bulky and heavy, and requires a wide body in order to allow room for the pilot.

[image]

Foot Rudder Bar Used in the Standard H-3. Courtesy "Aerial Age."

Rudder Control. Foot bar control for the rudder is standard with both the stick and Dep controls. The foot bar is connected with the rudder in such a way that the aeroplane turns opposite to the movement of the foot bar in the manner of a boat. That is, pushing the right end of the bar forward causes the machine to turn toward the right.

[image]

Automatic Control System (Sperry) Installed in Fuselage of Curtiss Tractor Biplane.

CHAPTER XVI. HEAD RESISTANCE CALCULATIONS.

Effect of Resistance. Resistance to the forward motion of an aeroplane can be divided into two classes, (1) The resistance or drag due to the lift of the wings, and (2) The useless or ”Parasitic” resistance due to the body, chassis and other structural parts of the machine. The total resistance is the sum of the wing drag and the parasitic resistance. Since every pound of resistance calls for a definite amount of power, it is of the greatest importance to reduce this loss to the lowest possible amount. The adoption of an efficient wing section means little if there is a high resistance body and a tangle of useless struts and wires exposed to the air stream. The resistance has a much greater effect on the power than the weight.

Weight and Resistance. We have seen that the average modern wing section will lift about 16 times the value of the horizontal drag, that is, an addition of 16 pounds will be equal to 1 pound of head resistance. If, by unnecessary resistance, we should increase the drag by 10 pounds, we might as well gain the benefit of 10 x 16 = 160 pounds of useful load. The higher the lift-drag efficiency of the wing, the greater will be the proportional loss by parasitic resistance.

Gliding Angle. The gliding angle, or the inclination of the path of descent when the machine is operating without power, is determined by the weight and the total head resistance. With a constant weight the angle is greatest when the resistance is highest. Aside from considerations of power, the gliding angle is of the greatest importance from the standpoint of safety. The less the resistance, and the flatter the angle of descent, the greater the landing radius.

Numerically this angle can be expressed by: Glide = W/R, where W = the weight of the aeroplane, and R = total resistance. Thus if the weight is 2500 pounds and the head resistance is 500 pounds, the rate of glide will be: 2500/500 = 5. This means that the machine will travel forward 5 feet for every foot that it falls vertically. If the resistance could be decreased to 100 pounds, the rate of glide would be extended to 2500/100 = 25, or the aeroplane would travel 25 feet horizontally for every foot of descent. This will give an idea as to the value of low resistance.

Resistance and Speed. The parasitic resistance of a body in uniform air varies as the square of the velocity at ordinary flight speeds. Comparing speeds of 40 and 100 miles per hour, the ratio will be as 40° is to 100° = 1600: 10,000 = 6.25, that is, the resistance at 100 miles per hour will be 6.25 times as great as at 40 miles per hour.

The above remarks apply only to bodies making constant angle with the air stream. Wings and lifting surfaces make varying angles at different speeds and hence do not show the same rate of increase. In carrying a constant load, the angle of the aeroplane wing is decreased as the speed increases and up to a certain point the resistance actually decreases with an increase in the speed. The wing resistance is greatest at extremely low speeds and at very high speeds. As the total resistance is made up of the sum of the wing and parasitic resistance at the different speeds, it does not vary according to any fixed law. The only true knowledge of the conditions existing through the range of flight speeds is obtained by drawing a curve in which the sums of the drag and head resistance are taken at intervals.

Resistance and Power. The power consumed in overcoming parasitic resistance increases at a higher rate than the resistance, or as the cube of the speed. Thus if the speed is increased from 40 to 100 miles per hour, the power will be increased 15.63 times. This can be shown by the following: Let V = velocity in miles per hour, H = Horsepower, K= Resistance coefficient of a body, A = Total area of presentation, and R = resistance in pounds. Then H = RV/375. Since $R = KAV^2$, then $H = KAV^2 \text{ x } V/375 = KAV^3/375$.

Resistance and Altitude. The resistance decreases with a reduction in the density of the air at constant speed. In practice, the resistance of an aeroplane is not in direct proportion to a decrease in the density as the speed must be increased at high altitudes in order to obtain the lift. The following example given by Capt. Green will show the actual relations.

Taking an altitude of 10,000 feet above sea level where the density is 0.74 of that at sea level, the resistance at equal speeds will be practically in proportion to the densities. In order to gain sustentation at the higher altitude, the speed must be increased, and hence the true resistance will be far from that calculated by the relative densities. Assume a sea level speed of 100 ft./sec., a weight of 3000 pounds, a lift-drag ratio of L/D = 15, and a body resistance of 40 pounds at sea level.

Because of the change in density at 10,000 feet, the flying speed will be increased from 100 feet per second to 350 feet per second in order to obtain sustentation. With sea level density this increase in speed (3.5 times) would increase the body resistance 3.5 x 3.5 = 12.25 times, making the total resistance 12.25 x 40 = 490 pounds. Since the density at the higher altitude is only 0.74 of that at sea level, this will be reduced by 0.26, or 0.26 x 490 = 364 pounds. Thus, the final practical result is that the sea level resistance of the body (40 pounds) is increased 9.1 times because of the speed increase necessary for sustentation. Since the wing angle and hence the liftdrag ratio would remain constant under both conditions, the wing drag would be constant at both altitudes, or 3000/15 = 200 pounds. The total sea level resistance at 100 feet per second is 200 + 40 = 240 pounds, while the total resistance at 10,000 feet becomes 364 + 200 = 564 pounds.

The speed varies as the square root of the change in density percentage. If V = velocity at sea level, v = velocity at a higher level, and d = percentage of the sea level density at the higher altitude, then v = V/√D. When the velocity at the high altitude is thus determined, the resistance can be easily obtained by the method given in Capt. Green's article. The following table gives the percentage of densities referred to sea level density.

Altitude Feet	Density Percent	Altitude Feet	Density Percent
Sea-level	1.00	7,500	0.78
1,000	.97	10,000	.74
2,000	.95	12,500	.66
3,000	.91	15,000	.61
5,000	.85	20,000	.52

If the velocity at sea level is 100 miles per hour, the velocity at 20,000 feet will be 100/0.72 = 139 miles per hour, where 0.72 is the square root of the density percentage, or the square root of 0.52 = .72 at 20,000 feet.

Total Parasitic Resistance. Aside from the drag of the wings, the resistance of the structural parts, body, tail and chassis depends upon the size and type of aeroplane. A speed scout has less resistance than a larger machine because of the small amount of exposed bracing, although the relative resistance of the body is much greater. The type of engine also has a great influence on the parasitic resistance. The following gives the approximate distribution of a modern fighting aeroplane:

Body	62 percent
Landing gear	16 ”
Tail, fin, rudder	7 ”
Struts, wires, etc.	15 ”

The body resistance is by far the greatest item. A great part of the body resistance can be attributed to the motor cooling system, since in either case it is diverted from the true streamline form in order to accommodate the radiator, or the rotary motor cowl. The body resistance is also influenced by the necessity of accommodating a given cargo or passenger-carrying capacity, and by the distance of the tail surfaces from the wings. A body is not a streamline form when its length greatly exceeds 6 diameters.

Calculation of Total Resistance. The nearest approach that we can make to the actual head resistance by means of a formula is to adopt an expression in the form of $R = KV^2$ where K is a factor depending upon the size and type of machine. The true method would be to go over the planes and sum up the individual resistance of all the exposed parts. The parts lying in the propeller slip stream should be increased by the increased velocity of the slip stream. The parasitic resistance of biplanes weighing about 1800 pounds will average about, $R = 0.036V^2$ where V = velocity in miles per hour. Biplanes averaging 2500 pounds give $R = 0.048V^2$. Machines of the training or 2-seater type weigh from 1800 to 2500 pounds, and have an average head resistance distribution as follows:

Body, radiators, shields	35.5 percent.
Tail surface and bracing	14.9 ”
Landing gear	17.2 ”
Interplane struts, wires and fittings	23.6 ”
Ailerons, aileron bracing, etc.	8.8 ”

The averages in the above table differ greatly from the values given for the high speed fighting machine, principally because of the large control surfaces used in training machines, and the difference in the size of the motors.

With the wing drag being equal to $D = Kx\ AV^2$, and the total parasitic resistance equal to $R = KV^2$, the total resistance can be expressed by $Rt = KxAV^2 + KV^2$, where K = coefficient of parasitic resistance for different types and sizes of machines. The value of K for training machines will average 0.036, for machines weighing about 2500 pounds K = 0.048. Scouts and small machines will be safe at K = 0.028. The wing drag coefficient Kx varies with the angle of incidence and hence with the speed. For example, we will assume that the wing drag (Kx) of a scout biplane at 100 miles per hour is 0.00015, that the area is 200 square feet, and that the parasitic resistance coefficient is K = 0.028. The total resistance becomes: $R = (0.00015 \times 200 \times 100 \times 100) + 0.028 \times 100 \times 100 = 300 + 280 = 580$ pounds. The formula in this case would be $R = KxAV^2 + 0.028V^2$.

Strut Resistance. The struts are of as nearly streamline form as possible. In practice the resistance must be compromised with strength, and for this reason the struts having the least resistance are not always applicable to the practical aeroplane. From the best results published by the N. P. L. the resistance was about

12.8 pounds per 100 feet strut at 60 miles per hour. The width of the strut is 1 inch. A rectangular strut under the same conditions gave a resistance of 104.4 pounds per 100 feet. A safe value would be 25 pounds per 100 feet at 60 miles per hour. If a wider strut is used, the resistance must be increased in proportion. With a greater speed, the resistance must be increased in proportion to the squares of the velocity. When the struts are inclined with the wind, the resistance is much decreased, and this is one advantage of a heavy stagger in a biplane.

The "Fineness ratio" or the ratio of the width to the depth of the section has a great effect on the resistance. With the depth equal to twice the width measured across the stream, a certain strut section gave a resistance of 24.8 pounds per 100 feet, while with a ratio of 3.5 the resistance was reduced to 11.4 pounds per hundred feet. Beyond this ratio the change is not as great, for with a ratio of 4.6 the resistance only dropped to 11.2 pounds.

Radiator Resistance. For the exact calculation of the radiator resistance it is first necessary to know the motor power and the fuel consumption since the radiator area, and hence the resistance, depends upon the size of the motor and the amount of heat transmitted to the jacket water. An aeronautic motor may be considered to lose as much through the water jackets as is developed in useful power, so that on this basis we should allow about 1.6 square feet of radiation surface per horsepower. This figure is arrived at by J. C. Hunsaker and assumes that the wind speed is 50 miles per hour (73 feet per second). The most severe cooling condition is met with in climbing at low speed, and it is here assumed that 50 miles per hour will represent the lowest speed that would be maintained for any length of time with the motor full out. For a racing aeroplane that will not climb for any length of time, one-half of the surface given above will be sufficient, and if the radiator is placed in the propeller slip stream it can be made relatively still smaller as the increased propeller slip at rapid rates of climb partially offsets the additional heating.

In the above calculations, Hunsaker does not take any particular type of radiator into consideration, merely assuming a smooth cooling surface. The Rome–Turney Company states that they allow 1.08 square feet of cooling surface per horsepower for honeycomb radiators, and 0.85 square feet for the helical tube type. The surface referred to means the actual surface measured all over the tubes and cells, and does not refer to the front area nor the exterior dimensions of the radiator. While a radiator may be made 25 percent smaller when placed in the slipstream, the resistance is increased by about 25 per cent, with a very small saving in weight, hence the total saving is small, if any. Side mounted radiators have a lower cooling effect per square foot than those placed in any other position, owing to the fact that the air must pass through a greater length of tube than where the broad side faces the wind.

In the radiator section tested by Hunsaker, there were about 64 square feet of cooling surface per square foot of front face area, but for absolute assurance on this point one should determine the ratio for the particular type of radiator that is to be used. The Auto Radiator Manufacturing Corporation, makers of the ”Flexo” copper core radiators, have published some field tests made under practical conditions and for different types and methods of mounting. The four classes of radiators described are: (1) Front Type, in which the radiator is mounted in the end of the fuselage; (2) Side Type, mounted on the sides of the body; (3) Overhead Type, mounted above the fuselage and near the top plane; (4) Over-Engine Type, placed above and connected directly to the motor, as in the Standard H-3.

The following table gives the effectiveness of the different mountings in terms of the frontal area required per horsepower and the cooling surface, the area being in square inches (Front face area of radiator). Area in wind of type (3) is half the calculated frontal area since one core lies behind the other: Taking the value of the Rome–Turney honeycomb radiator as 60 square feet of cooling surface per horsepower, the frontal area per horsepower will be 0.0169 square feet, assuming that the radiator is approximately 6 inches thick. This amounts to 2.43 square inches of frontal area per horsepower.

Example. Find the approximate frontal area of a Rome-Turney type honeycomb radiator used with a motor giving 100 brake-horsepower. Find Resistance at 50 miles per hour (73 feet per second).

Class of Mounting	Square Inches Per H.P.	Cooling Surface Per H.P Square Inch
Front Type	4.00	117.00
Side Type	7.20	104.00
Overhead Type	2.70	112.00
Over-Engine Type	5.00	121.00

Solution. Area = A = 0.0169 HP = 0.0169 x 100 = 1.69 square feet. The honeycomb portion of surface for a square radiator of the above area will measure 16.2” x 16.2”. Allowing a 1-inch water passage or frame all around the core, the side of the completed square radiator will measure 16.2” + 1” = 18.2”. The diameter of a circular radiator core of the same 1.69 x 144 area will be 17.4 inches, since D = 1.69x144/0.7854. Adding the water passage, the overall diameter becomes 17.4 + 1 + 1 = 19.4 inches. The round honeycomb front radiator used on the 100 horsepower Curtiss Baby Scout measures 20 inches. Hunaker found the resistance of a honeycomb radiator to be $R=0.000814\ AV^2$, there being 4 honeycomb cells per square inch. A = area of radiator in square feet, and V = velocity in feet per second. Adopting, for example, a speed of 73 feet per second, and an area equivalent to a 19.4-inch diameter circular radiator as above, the total resistance becomes:

$R = 0.000814\ AV^2 = 0.000814 \times 3.1 \times (73 \times 73) = 13.32$ pounds, at 50 M. P. H. where A = 3.1 square feet.

Resistance of Chassis. Disc wheels (Enclosed spokes) have a resistance of about one-half that of open-wire wheels. The N. P. L. and Eiffel have agreed that the resistance of a wheel approximating 26” x 4” has a resistance of 1.7 pounds at 60 miles per hour (Disc type). For any other speed, the wheel resistance will be $R = 1.7\ V^2/3600$, where V = speed in miles per hour. We must also take into consideration the axle, chassis struts, wiring, shock absorbers, etc. The itemization of the chassis resistance, as given by the N.P.L. for the B.E.-2 biplane is as follows (60 miles per hour):

Wheels 2(a)1.75 pounds	3.5 pounds
Axle	2.0 ”
Chassis struts and connections	1.1 ”
Total chassis resistance(3)60 MPH.	6.6 pounds

At any other speed, the resistance for the complete chassis can be given by the formula $R = 6.6V^2/3600$. This allowance will be ample, as the B. E.-2 is an old type and is equipped with skids.

Interplane Resistance. The interplane struts and wires are difficult to estimate by an approximate formula, the only exact way being to figure up each item separately from a preliminary drawing. The resistance varies with the form of the strut or wire section, the length, and the thickness. The fact that some of the struts lie in the propeller slipstream, and some outside of it, makes the calculation doubly difficult. The only recourse that we have at present is to analyze the conditions on the B. E.-2. With struts approximating true streamline form, a great percentage of the total resistance is skin friction, and as before explained, this item varies at a lesser rate than the square of the speed.

[image]

According to a number of experiments on full size biplanes averaging 1900 pounds, it has been found that the interplane resistance (Struts, wires and fittings) amounts to about 24 per cent of the total parasitic head resistance of the entire machine, the drag of wings not being included. The maximum observed gave 29 per cent and the minimum 15 per cent. The resistance of the interplane bracing of speed scouts will be considerably less in proportion, as there are fewer exposed struts and cables on this type, the resistance probably averaging 15 per cent of the total head resistance. Based on these figures the resistance of the interplane bracing can be expressed by the following formula, in which I = resistance of interplane bracing in pounds, and V = translational speed in miles per hour:

$I = 0.009\ V^2$ (For two-place biplanes weighing 1900 pounds).

$I = 0.0054V^2$ (For biplane speed scouts or racing type biplanes).

Strut Resistance. The above estimate includes wiring, strut fittings, etc., complete, and also takes the effect of the slipstream into consideration. A more accurate estimate can be made on the basis of strut length. To obtain this unit value we have recourse to the B. E.-2 tests. The translational speed in 60 miles per hour (88 feet per second) and the slipstream is taken at 25 feet per second. This gives a total velocity in the slipstream of 113 feet per second. The struts are 1% inches wide, and vary in length from 3’ 0” to 6’ 0”. In the slipstream the increased velocity increases the resistance of the items by 64 per cent.

Total running length = 110’–0”. Total resistance = 10.81 pounds. The resistance per foot = 10.81/110 = 0.099 pounds.

Resistance of Wire and Cable. In this estimate we will take the resistance given in the B. E.-2 tests, since values are given in the slipstream as well as for the outer portions. In the translational stream there is 240’ 0” of cable, 70’ 0” of No. 12 solid wire, and 52 turnbuckles, the total giving a resistance of 38.10 pounds. In the slipstream there is 50’ 0” of cable and 30’ 0” of solid wire with a resistance of 11.00 pounds. The total wire and cable resistance for the wings is therefore 49.10 pounds. The resistance of the wire and cable combined is 0.127 pounds per running foot.

Summary of Interplane Resistance. The total interplane resistance includes the struts, wires, cables and turnbuckles, a portion of which are in the slipstream. Since the total head resistance of the entire machine (B.E.-2) is 140 pounds at 60 M. P. H., and the interplane resistance = 10.81 + 49.10= 59.91 pounds, the relation of the interplane resistance to the total resistance is 43 per cent. This is much higher than the average (24 per cent), but the B.E.-2 is an old type of machine and the number of struts and wires were much greater than with modern aeroplanes.

Control Surface Resistance. The resistance of the control surfaces is a variable quantity, since so much depends upon the arrangement and form. Another variation occurring among machines of the same make and type is due to the various angles of the surfaces during flight, or at least during the time that they are used in correcting the attitude of the machine. With the elevator flaps or ailerons depressed to their fullest extent, the drag is many times that with the surfaces in "neutral," and as a general thing the controls are depressed at the time when the power demand is the greatest—that is, on landing, flying slow, or in "getting off."

Ailerons "in neutral" can be considered as being an integral part of the wings when they are hinged to the wing spar. In the older types of Curtiss machines the ailerons were hinged midway between the planes and the resistance was always in existence, whether the ailerons were in neutral or not. Wing warping, in general, can be assumed as in the case where the wings and ailerons are combined. With ailerons built into the wings, the resistance of the ailerons, and their wires and fittings, can be taken as being about 4 per cent of the total head resistance. With the aileron located between the two wings, the resistance may run as high as 20 per cent of the total.

Like the ailerons, the elevator surfaces and rudder are variable in attitude and therefore give a varying resistance. In neutral attitude the complete tail, consisting of the rudder, stabilizer, elevator, fin and bracing, will average about 15 per cent of the total resistance, it being understood that a non-lifting stabilizer is fitted. With lifting tails the resistance will be increased in proportion to the load carried by the stabilizer. In regard to the tail resistance it should be noted that these surfaces are in the slipstream and are calculated accordingly, although the velocity of the slipstream is somewhat reduced at the point where it encounters the tail surfaces. The total tail resistance of the B. E.-2 is given as 3.3 pounds.

Resistance of Seaplane Floats. The usual type of seaplane with double floats may be considered as having about 12 per cent higher resistance than a similar land machine. Some forms of floats have less resistance than others, owing to their better streamline form, but the above figure will be on the safe side for the average pontoon. Basing our formula on a 12 per cent increase on the total head resistance, the formula for the floats and bracing will become: $Rt = 0.00436V^2$ where R1 = resistance of floats and fittings.

Body Resistance. This item is probably the most difficult of any to compute, owing to the great variety of forms, the difference in the engine mounting, and the disposition of the fittings and connections. The resistance of the pilot's and passenger's heads, wind shields, and propeller arrangement all tend to increase the difficulty of obtaining a correct value. Aeroplanes with rotary air-cooled motors, or with large front radiators have a higher resistance than those arranged with other types of motors or radiator arrangements. Probably the item having the greatest influence on the resistance of the fuselage is the ratio of the length to the depth, or the "fineness ratio." In tractor monoplanes and biplanes, of the single propeller type, the body is in the slipstream, and compensation must be made for this factor.

If it were not for the motor and radiator, the tractor fuselage could be made in true dirigible streamline form, and would therefore present less resistance than the present forms of ”practical” bodies. The necessity of placing the tail surfaces at a fixed distance from the wings also involves the use of a body that is longer in proportion than a true streamline form, and this factor alone introduces an excessive head resistance. The ideal ratio of depth to length would seem to range from 1 to 5.5 or 1 to 6. The fineness ratio of the average two-seat tractor is considerably greater than this, ranging from 1 to 7.5 or 8.5. A single-seat machine of the speed-scout type can be made much shorter and has more nearly the ideal proportions.

The only possible way of disposing of this problem is to compare the results of wind tunnel tests made on different types of bodies, and even with this data at hand a liberal allowance should be made because of the influence of the connections and other accessories. Eiffel, the N. P. L., and the Massachusetts Institute of Technology have made a number of experiments with scale models of existing aeroplane bodies. It is from these tests that we must estimate our body resistance, hence a table of the results is attached, the approximate outlines being shown by the figures.

As in calculating the resistance of other parts, the resistance of the body can be expressed by $R = KxAV^2$, where Kx = coefficient of the body form, A = Cross-sectional area of body in square feet (Area of presentation), and V = velocity in miles per hour. The area A is obtained by multiplying the body depth by the width. The ”area of presentation” of a body 2’ 6” wide and 3’ 0” deep will be 2.5 x 3 = 7.5 square feet.

The experimental data does not give a very ready comparison between the different types, as the bodies not only vary in shape and size, but are also shown with different equipment. Some have tail planes and some have not; two are shown with the heads of the pilot and passenger projecting above the fuselage, while the remainder have either a simple cock-pit opening or are entirely closed. The presence of the propeller in two cases may have a great deal to do with raising the value of the experimental results. The propeller was stationary during the tests, but it was noted that the resistance was considerably less when the propeller was allowed to run as a windmill, driving the motor. This latter condition would correspond to the resistance in gliding with the motor cut off. In all cases, except the Deperdussin, the bodies are covered with fabric, and the sagging of the cloth in flight will probably result in higher resistance than would be indicated by the solid wood or metal model used in the tests. The pusher type bodies give less resistance than the tractors, but the additional resistance of the outriggers and tail bracing will probably bring the total far above the tractor body.

In the accompanying body chart are shown 7 representative bodies: (a) Deperdussin Monocoque Monoplane Body, a single-seater; (b) N. P. L.-5 Tractor Biplane Body, single-seater; (c) B. F.-36 Dirigible Form, without propeller or cock-pit openings; (d) B. E.-3. Two-Place Tractor Body, with passenger and pilot; (e) Curtiss JN Type Tractor Body, with passengers, chassis and tail; (f) Farman Pusher type, with motor, propeller and exposed passengers; (g) N. P. L. Pusher Body, bare. Body (a) was tested with a 1/5 scale model at a wind tunnel speed of 28 meters per second, the resistance of the model being 0.377 kilograms (0.83 pounds). Body (d) in model form was 1/16 scale and was tested at 20.5 miles per hour, at which speed the resistance was 0.0165 pounds. Model (e) was 1/12 scale and was tested at 30 miles per hour. These varying test speeds, it will be seen, do not allow of a very accurate means of comparison. The resistance of model (e) was 0.1365 pounds at the specified wind-tunnel air speed.

[image]

The speeds given in the above table are simply translational speeds, and are not corrected for slipstream velocity. With a slipstream of 25 per cent, increase the body resistance by 40 per cent. It would be safe to add an additional 10 per cent to make up for projecting fittings, baggy fabric, and scale variations.

Since a body of approximately streamline form has a considerable percentage of skin friction, scale corrections for size and velocity are even of more importance than with wing sections. No wind-tunnel experiments can determine the resistance exactly because of the uncertainty of the scale factor. The resistance as given in the table is also affected by the proximity of the wing and tail surfaces, and by projections emanating from the motor compartment. It will be noted that the dirigible form B.F.-36 is markedly better than any of the others, being almost of perfect streamline form. The nearest approximation to the ideal form is N.P.L.-5, which has easy curves, low resistance, and is fairly symmetrical about the center line. Because of their small size, the pusher bodies or ”nacelles” have a small total resistance, but the value of Kx is high.

[image]

Chart Showing Forms of 7 Typical Aeroplane Fuselage

Problem. Find the resistance of a Curtiss Tractor Type JN body with a breadth of 2’ 6” and a depth of 3’ 3”, the speed being 90 miles per hour. The slipstream is assumed to be 25 per cent, with an additional 10 per cent for added fabric loss, etc.

[image]

Typical Stream Line Strut Construction.

Solution. The cross-sectional area = 2' 6" x 3' 3" = A = 8.13 square feet. The velocity of translation is 90 M. P. H., or V^2 = 8100. The value of the resistance coefficient is taken from the table, Ko-0.00273. The total resistance R = $KxAV^2$ = 0.00273 x 8.13 x 8100 = 178.2 pounds. Since a slipstream of 25 per cent increases the resistance by 40 per cent, the resistance in the slipstream is 1782 x 1.4 = 249.48 pounds. The addition of the 10 per cent for extra friction makes the total resistance = 249.48 x 1.1 = 274.43 pounds. The resistance of this body, used with "twin" motors, would be 178.2 x 1.1 = 196.02, but as a tractor with the body in the slipstream, the resistance would be equal to 274.43 pounds as calculated above.

CHAPTER XVII. POWER CALCULATIONS.

Power Units. Power is the rate of doing work. If a force of 10 pounds is applied to a body moving at the rate of 300 feet per minute, the power will be expressed by 10 x 300 = 3000 foot-pounds per minute. As the figures obtained by the foot and pound units are usually inconveniently large, the "Horsepower" unit has been adopted. A horsepower is a unit that represents work done at the rate of 33,000 foot-pounds per minute, or 550 foot-pounds per second. Thus if a certain aeroplane offers a resistance of 200 pounds, and flies at the rate of 6000 feet per minute, then the work done per minute will be equal to 200 x 6000 = 1,200,000 foot-pounds. Since there are 33,000 foot-pounds of work per minute for each horsepower, the horsepower will be: 1200000/33000 = 36.3.

As aeroplane speeds are usually given in terms of miles per hour, it will be convenient to convert the foot-minute unit into the mile per hour unit. If H = horsepower, R = resistance of aeroplane, and V = miles per hour, then H = RV/375, the theoretical horsepower, without loss. If an aeroplane flies at 100 miles per hour and requires a propeller thrust of 300 pounds, then the horsepower becomes:

H = RV/375 = 300 x 100/375 = 80 horsepower. This is the actual power required to drive the machine, but is not the engine power, as the engine must also supply the losses due to the propeller. The propeller losses are generally expressed as a percentage of the total power supplied. The percentage of useful power is known as the ”Efficiency.”

The efficiency of the average aeroplane propeller will vary from 0.70 to 0.80. If e = propeller efficiency expressed as a decimal, the motor horsepower becomes: $H = RV/375e$. To obtain the motor horsepower, divide the theoretical horsepower by the efficiency. Using the complete formula for the solution of an example in which the flight speed is 100 M. P. H., the resistance 225 pounds and the efficiency 0.75, we have:

$H = RV/375e = 225 \times 100/375 \times 0.75 = 80$ horsepower.

Power Distribution. Since power depends upon the total resistance to be overcome, part of the power will be used for driving the lifting surfaces and a part for overcoming the parasitic resistance. The power required for driving the wings depends upon the angle of incidence, since the drag varies with every angle. The wing power varies with every flight speed, owing to the changes in angle made necessary to support the constant load. The power for the wings will be least at the speed and angle that corresponds to the greatest lift-drag ratio. Owing to the low value of the L/D at very small and very large angles, the power requirements will be excessive at extremely low and high speeds.

As the parasitic resistance increases as the square of the speed, the power for overcoming this resistance will vary as the cube of the speed. It is the parasitic resistance that really limits the higher speeds of the aeroplane, since it increases very rapidly at velocities of over 60 miles per hour.

The total power at any speed is the sum of the wing power and power required for the parasitic resistance. Owing to variations in the wing drag and resistance at every point within the flight range, it is exceedingly difficult to directly calculate the total power at any particular speed. The wing drag and the resistance should be calculated for every speed, and then laid out by a graph or curve. The minimum propeller thrust, or the minimum total resistance, occurs approximately at the speed where the body resistance and wing drag are equal. The minimum horsepower occurs at a low speed, but not the lowest speed, and this will differ with every machine.

[image]

Fig. 1. Power Chart of Bleriot Monoplane, With Outline of Wing Section. The Results Were Taken From Full Size Tests Made by the English Government.

Fig. 1 is a set of performance curves drawn from the results of tests on a full size Bleriot monoplane. At the bottom the horizontal row of figures gives the horizontal speed in feet per second. The first column to the left is the horsepower, and the second column is the resistance or drag in pounds. The four curves represent respectively the body resistance, wing or "plane" resistance, horsepower, and total resistance. The horizontal line "AV" shows the available horsepower. It will be noted that the body resistance increases steadily from 9 pounds at 50 feet per second, to 180 pounds at 100 feet per second. The wing resistance, on the other hand, decreases from 350 pounds at 56 feet per second to a minimum of 130 pounds at 83 feet per second. It will be noted that the angles of incidence are marked along the wing-drag curve by small circles. The incidence is 6° at 75 feet per second, and 4° at a little less than 85 feet per second.

The available horsepower "AV" is 42. This is shown as a straight line, although in the majority of cases it is slightly curved owing to variations in power at the higher speeds, and to variations in the propeller efficiency. At 90 feet per second the actual horsepower curve crosses the line of available horsepower "AV." Beyond this point horizontal flight is no longer possible, as the power requirements would exceed the available horsepower. It will be noted that the lowest total resistance occurs near the point where the body and wing resistance curves intersect, or in other words, where the body and wing resistance are equal. The minimum horsepower takes place at 63 feet per second, or at a point nearly 1/3 between the lowest flight speed and the highest speed attained by the available horsepower in horizontal flight (90 ft/sec).

The actual range of flight speeds is limited to points between the intersection of the "Horsepower required" curve, and the "Available horsepower" curve. By increasing the propeller efficiency, or by increasing the power of the motor, the available horsepower line is raised and the flight range increased.

Horsepower For Climbing. Up to the present we have only considered horizontal flight. The power available for climbing is the difference between the power required to maintain horizontal flight at any speed, and the actual horsepower that can be delivered by the propeller. Thus, if the actual power delivered by a motor through the propeller is 85 horsepower, and the power required for horizontal flight at that speed is 45, then we have: 85−45= 40 horsepower available for climbing. Since the difference between the driving power and the power required for horizontal flight is less at extremely low and high speeds, it is evident that we will have a minimum climbing reserve at the high and low speeds. Consulting the power curve for the Bleriot monoplane, we see that the power required at 56 feet per second is 40 horsepower, and at 85 feet per second it is 38 horsepower. At the low speed we have a climbing reserve of 44−40 = 4 H. P., and at the higher speed 44−38 = 6 H. P. The maximum available horsepower "AV" is 44 horsepower. The minimum horizontal power required is found at 63 feet per second, the climbing reserve at this point being 44−28 = 16 horsepower. At 55 feet per second, and at 90, we would not be able to climb, as we would only have sufficient power to maintain horizontal flight.

If W = total weight of aeroplane, c = climbing speed, and H = horsepower reserve for climbing, then the climbing speed with a constant air density will be expressed by: $c = 33000H/W$. Assuming that the weight of the Bleriot monoplane is 800 pounds, and that we are to climb at the speed of the greatest power reserve (16 horsepower), our rate of climb is:

$c = 33000H/w = 33000 \times 16/800 = 660$ feet per minute. It should be understood that this is the velocity at the beginning of the climb. After prolonged climbing the rate falls off because of diminishing power and increasing speed. Much depends upon the engine performance at the higher altitudes, so that the reserve power for climb usually diminishes as the machine rises, and hence the rate of climb diminishes in proportion.

The following table taken from actual flying tests will show how the rate of climb decreases with the altitude. These machines were equipped with 150 H. P. Hispano-Suisa motors. It will be noted that the S. P. A. D. and the Bleriot hold their rate of climb constant up to 7800 feet altitude, which is a feat that is undoubtedly performed by varying the compression of the engine.

Besides increasing the power, the rate of climb can also be increased by decreasing the weight of the aeroplane.

[image]

Maximum Altitude. The maximum altitude to which a machine can ascend is known as its ”Ceiling.” This again depends on both the aeroplane and the motor, but principally on the latter. It has been noted that machines having the greatest rate of climb also have the greatest ceiling. Thus the ceiling of a fast climbing scout is higher than that of a larger and slower machine. Based on this principle, a writer in ”Flight” has developed the following equation for ceiling, which, of course, assumes a uniform decrease in density. Let H = maximum altitude, h = the altitude at any time t after the start of the climb, and a = the altitude after a time equal to twice the time t, then:

$H = h / (2 - a/h)$

Approximate values of h and a may be had

from the following table, which are the results of a test on a certain aeroplane:

Time (Minutes)

0.0 2.5 5.0 7.5 10.0 12.5 15.0 17.5 20.0 22.5

Altitude (Feet)

0.03300 6150 8730 10760 12610 14190 15530 16650 17600

If we assume that the height is 10760 feet after the first 10 minutes, and that the altitude after twice this time (20 minutes) is 16650 feet, then the maximum ceiling attained will be:

$H = h / (2 - a/h) = 10760 / 2 - 16650/10760 = 23{,}770$ feet. The use of this formula requires that the climb be known for certain time intervals before the ceiling.

Gliding Angle. The gliding angle of the wings alone is equal to the lift-drag ratio at the given angle. The best or ”Flattest gliding angle” is, of course, the best lift-drag ratio of the wing—say on the average about 1 in 16. The gliding angle of the complete machine is considerably less than this, owing to the resistance of the body and structural parts. This generally reduces the actual angle to less than 12, and in most cases between 6 and 8. Expressed in terms of degrees, $\tan ø = R/W$ where R = head resistance and W = weight in pounds.

Fig. 2 is a diagram giving the gliding force diagram. The plane descends along the gliding path AC, making the angle of incidence (ø). When in horizontal flight, the lift is along OL and the weight is OW. When descending on the gliding path the lift maintains the same relation with the wing, but the relative angle of the weight is altered. The weight now acts along OG. The drag is represented by OD, with the propeller thrust OP equal and opposite to it. With the weight constant, the lift OL is decreased by the angle so that the total life = $L = W \cos ø$. The action of the weight W produces the propelling component OP that gives forward velocity. The line AB is the horizontal ground line. If the total lift-drag ratio is 8, then the gliding angle will be 1 in 8, or measured in degrees, $\tan ø = R/W = 1/8 = 0.125$. From a trigonometric table it will be found that this tangent corresponds to an angle of 7° – 10’. It should be noted that R is the total resistance and not the wing-drag.

[image]

Fig. 2. Gliding Angle Diagram Showing Component of Gravity That Causes Forward Motion. The Gliding Angle Depends Upon the Ratio of the Resistance to the Weight.

Complete Power Calculations. Knowing the total weight and the desired speed, we must determine the wing section and area before we start on the actual power calculations. This can either be determined by empirical rules in the case of a preliminary investigation, or by actual calculation by means of the lift coefficients after the approximate values are known. Sustaining a given weight, we can vary the angle, area, wing section, or the speed, the choice of these items being regulated principally by the power. Given a small area and a great angle of incidence, we can support the load, but the power consumption will be excessive because of the low value of the L/D ratio at high angles. If small area is desired, a large value of Ky due to a high lift-wing section is preferable to a low lift wing at high angles. In general, the area should be so arranged that the wing is at the angle of the maximum lift-drag ratio at the rated speed. A low angle means a smaller motor, less fuel, and hence a lighter machine. This selection involves considerable difficulty, and a number of wing sections and areas must be tried by the trial and error method until the most economical combination is discovered.

[image]

Graphical Gliding Diagrams of Several Aeroplanes Recorded in British Army Contest of 1912.

The first consideration being the total weight, we must first estimate this from the required live load. This can be estimated from previous examples of nearly the same type. Say that our required live load is 660 pounds, and that a live load factor of 0.30 is used. The total weight now becomes 660/0.30=2200 pounds. To make a preliminary estimate of the area we must find the load per square foot. An empirical formula for biplane loading reads: w = 0.065V - 0.25 where V = maximum speed in M. P. H., and w = load per square foot. If we assume a maximum speed of 90 M. P. H. for our machine, the unit loading is w = (0.065 x 90) - 0.25 = 5.6 pounds per square foot. The approximate area can now be found from 2200/5.6 = 393 square feet. (Call 390.) The minimum speed is about 48 per cent of the maximum, or 43 M. P. H. We can now choose one or more wing sections that will come approximately to our requirements by the use of the basic formula, $Ky = w/V^2$.

At high speed, Ky = 5.6/(90 x 90) = 0.000691. At low speed, Ky = 5.6/(40 x 40) = 0.003030. We must choose the most economical wing between these limits of lift, and on reference to our wing section tables we find:

[image]

It would seem from the above that the chosen area is a little too large, as the majority of the L/D ratios at high speed are poor, the best being 11.00 of the U.S.A.-1. The angles are small, being negative in most cases at high speed. While the lift-drag of the R.A.F-3 is very good at low speed, it is very poor at high, hence the area for this section should be reduced to increase the loading. The R.A.F.-6 and the U.S.A.-1 show up the best, for they are both near the maximum lift at low speed and have fair L/D ratios at high speed. It will be seen that for the best results there should be a series of power curves drawn for the various wings and areas. This method is too complicated and tedious to take up here, and so we will use U.S.A.-1, which does not really show up so bad at this stage. Both the R.A.F.-6 and the U.S.A.-1 have been used extensively on machines of the size and type under consideration. While we require Ky = 0.003030, and U.S.A-1 gives 0.003165, we will not attempt to utilize this excess, as it will be remembered that we should not assume the maximum lift for reasons of stability.

The wing-drag at high speed will be 2200/11.0 = 200 pounds, and at low speed it will be: 2200/10.4 = 211 pounds. Since the maximum L/D is 17.8 at 3°, where Ky is 0.00133, the least drag will be: 2200/17.8 = 124 pounds. This least drag will occur at V = V5.6/000133 = 65 M. P. H.

The wing drag for each speed must now be divided by the correction factor 0.85, which converts the monoplane values of drag into biplane values. Since this is practically constant it does not affect the relative values of Kx in comparing wings, but it should be used in final results. For this type of machine we will take the total parasitic resistance as $r = 0.036V^2$. At 90 M.P.H., r = 0.036 x 90 x 90 = 291.6 pounds. At 65 M. P. H., the resistance is: 0.036 x 65 x 65 = 152.1. At the extreme low speed of 43 M. P.H. we have r - 0.036x43 x 43 = 66.56 pounds. The total resistance (R) is equal to the sum of the wing-drag and the parasitic resistance. At 90 M. P. H. the total resistance becomes 200 + 291.6 = 491.6 pounds. At 65 M.P.H. the total is 124 + 152.1 = 176.1, and at 43 M.P.H. it is 211 + 66.56 = 277.56 pounds. The horsepower is computed from H = RV/375e, and at 90 M. P. H. this is : H = 491.6 x 90/375 x 0.80 = 147.5 H. P. where 0.80 is the assumed propeller efficiency. At 65 M. P. H. the horsepower drops to H = 176.1 x 65/375 x 0.8 = 38.1 H. P., assuming the same efficiency. In the same way the H. P. at 43 M. P. H. r is 39.8.

A table and power chart should be worked out for a number of sections and areas according to the following table. The calculations should be computed at intervals of 5 M. P. H., at least the lower speeds. Wing drag is not corrected for biplane interference:

[image]

Weight and Power. The weight lifted per horsepower varies in the different types of aeroplanes, this difference lying principally in the reserve allowed for climbing and horizontal speed. A speed scout may carry as little as 8 pounds per horsepower, while a slow two-seater may exceed 20 pounds per horsepower. A rough estimate of the horsepower required may be had by dividing the total weight by the weight per horsepower ratio for that particular type. Thus if the unit H. P. loading is 16 pounds and the total weight is 3200, then the horsepower will equal 3200/16 = 200 horsepower. Assuming that the live load w' is 0.32 of the total weight W, then W = w'/0.32. If m = lbs. per H.P., then H = W/m or H = w'/0.32m. Taking the case of a training machine where m = 20, and the live load is 640 pounds, the approximate horsepower will be: H = w'/0.32m = 640/0.32 x 20 = 100 horsepower. A speed scout carrying 320 pounds useful load, with m = 10, will require H = 320/0.32 x 10 = 100 horsepower.

CHAPTER XVIII. PROPELLERS.

Principles and Use of Propellers. A propeller converts the energy of the engine into the thrust required to overcome the resistance of the aeroplane. To maintain flight the thrust, or force exerted by the propeller, must always equal the total resistance of the aeroplane. A total resistance of 400 pounds requires a propeller thrust of 400, and as the resistance varies with the speed, the engine revolutions must be altered correspondingly. The propeller is the most complicated and least understood element of the aeroplane, and we can but touch only on the most elementary features. The inclined blades of the propeller throw back an airstream, the reaction of which produces the thrust. The blades can also be considered as aerofoils moving in a circular path, the lift of the aerofoils corresponding to the thrust of the propeller. The reactions in any case are quite complicated and require the use of higher mathematics for a full understanding.

Pitch and Velocity. When in action the propeller rotates, and at the same time advances along a straight line parallel to its axis. As a result, the tips of the propeller blades describe a curve known as "Helix" or screw-thread curve. The action is very similar to that of a screw being turned in a nut. For clearness in explanation we will call the velocity in the aeroplane path the "Translational velocity," and the speed of the tips in their circular path as the "Rotational velocity." When a screw works in a rigid nut it advances a distance equal to the "Pitch" in each revolution, the pitch of a single threaded screw being equal to the distance between the threads. Since the propeller or "Air screw" works in a fluid, there is some slip and the actual advance does not correspond to the "Pitch" of the propeller blades. The effective pitch is the distance traveled by the propeller in one revolution. The actual pitch or the angle of the blades must be greater than the angle of the effective helix by the amount of slip.

If N = Revolutions per minute, P = effective pitch in feet and V = translational velocity in miles per hour, then $V = NP/88$. With an effective pitch of 5 feet, and 1200 revolutions per minute, the translational velocity of the aeroplane will be: $V = 1200 \times 5/88 = 68.2$ miles per hour.

[image]

Excelsior Propeller, an Example of American Propeller Construction. This Propeller Is Built Up of Laminations of Ash.

The actual pitch of the blades would be from 15 to 25 per cent greater than the effective pitch because of the slip. To have thrust we must have slip. With the translational velocity equal to the blade-pitch velocity, there is no airstream accelerated by the blades, and consequently there is no thrust due to reaction. The air thrown to the rear of a propeller moves at a greater speed than the translation when thrust is developed, and this stream is known as the "slipstream." The difference between the translational and slipstream velocity is the slip.

The angle of the blade face determines the pitch. The greater the angle of the blade with the plane of propeller rotation, the greater is the pitch. This angle is measured from the chord of the working face of the table, or from that side faced to the rear of the blade. In the majority of cases the working face is flat. The front face is always heavily cambered like a wing section, with the greatest thickness about one-third the chord from the entering edge. As in the case of the wing, the camber is of the greatest importance.

A uniform pitch propeller has a varying blade angle, smallest at the tip and increasing toward the hub. With a uniform pitch propeller, every part of the blade travels through the same forward distance in one revolution, hence it is necessary to increase the angle toward the hub as the innermost portions travel a smaller distance around the circle of rotation. Theoretically, the angle at the exact center would be 90 degrees. The blade angles at the different points in the length of a uniform pitch propeller are obtained as follows: Draw a right angle triangle in which the altitude is made equal to the pitch, and the base is equal to 3.1416 times the propeller diameter. The angle made by the hypotenuse with the base is the blade angle at the tip. Divide the base into any number of equal spaces and connect the division points with the upper angle. The angles made by these lines with the base are the angles of the different blade sections.

Blade Form. The blade may be either straight-sided or curved. In the latter case the most deeply curved edge is generally the entering edge, and the maximum width is about one-third from the tip. Much care is exercised in arranging the outline so that the center of pressure will not be located in an eccentric position and thus harmfully distort the blade when loaded. If this is not attended to, the pitch will vary according to the load. In one make of propeller the blade is purposely made flexible so that the pitch will accommodate itself correctly to different flight speeds and conditions. This, however, is carefully laid out so that the flexure is proportional throughout the blade to the changes in the load.

[image]

The Lang Propeller, Having Straight Edges, Slightly Tapering Toward the Tips. The Tips Are Sheathed With Thin Copper for Protection Against Spray. This Outline Is Often Known as the ”Normale.” Type From the French Propeller First Using This Outline.

[image]

A ”Paragon” Propeller With a Curved Leading Edge. The Maximum Width Is About One-Third the Blade Length from the Tip and §o. Toward the Tip So That It Is Very Narrow at the Outer End. The Steel Propeller Flange Is Shown in Place on the Hub.

Propeller Diameter. The largest propellers are the most efficient. The propeller should be as large as can be safely swung on the aeroplane. Large, slow revolution propellers are far superior to the small high speed type. It is more economical to accelerate a large mass of air slowly with a large diameter than to speed up a small mass to a high velocity. The diameter used on any aeroplane depends upon the power plant, propeller clearance, height of chassis and many other considerations. Approximately the diameter varies from about 1/3 the span on small speed scouts, to 1/5 or 1/6 of the span on the larger machines.

Air Flow. The greater part of the air is taken in through the tips, and is then expelled to the rear. This condition prevails until the blade angle is above 45 degrees, and from this point the flow is outward. Owing to the great angles at the hub, there is little thrust given by the inner third of the blade, the air in this region being simply churned up in a directionless mass of eddies. At the tips the angle is small and the velocity high, which results in about 80 per cent of the useful work being performed by the outer third of the blade. In some aeroplanes a spinner cap is placed around the hub to reduce the churning loss and to streamline the hub. The blade section is very thick at the hub for structural reasons.

The ”Disc area” of a propeller is the area of the circle swept out by the blades. It is the pressure over this area that gives the thrust, and in some methods of calculation the thrust is based on the mean pressure per square foot of disc area. The pressure is not uniformly distributed over the disc, being many times greater at the outer circumference than at the hub. The average pressure per square foot depends upon the blade section and angle. Because of the great intensity of pressure at the circumference, the effective stream is in the form of a hollow tube.

Number of Blades. For training, and ordinary work, two-bladed propellers are preferable, but for large motors where the swing is limited, three or four blades are often used. A multiple-bladed propeller absorbs more horsepower with a given diameter than the two-blade type. In general, a four-bladed propeller revolving slowly may be considered more efficient than the two-blade revolving rapidly. Where the swing and clearance are small, a small four-blade may give better results than a larger and faster two-blade. A three-blade often shows marked superiority over a two-blade even when of smaller diameter, and the hub of the three-blade is much stronger than the four-blade, although neither the three or four is as strong as the two-blade type.

Effects of Altitude. At high altitudes the density is less, and consequently the thrust is less with a given number of revolutions per minute. The thrust can be maintained either by increasing the speed, or by increasing the pitch. For correct service at high altitudes the propeller should undoubtedly be of the variable pitch type, in which the pitch can be controlled manually, or by some automatic means such as proportional blade flexure.

Effects of Pitch. Driven at a constant speed, both the thrust and horsepower increase with the pitch up to a certain limiting angle.

For a given horsepower the static thrust depends both on the diameter and the pitch. If the pitch is increased the diameter must be decreased in proportion to maintain a constant speed. As the pitch is regulated by the translational speed and revolutions, the static thrust of a high speed machine is very small. As the translational speed increases, the pitch relative to the wind is less, and consequently the thrust will pick up until a certain limiting speed is reached.

Thrust and Horsepower. The calculation for thrust and power are very complicated, but the primary conditions can be given by the following: Let V = the pitch velocity in feet per minute, T = thrust in pounds, and H = horsepower, then H = TV/33000E from which T = 33000HE/V, the efficiency being designated by E. Since the pitch velocity is NP, where N = revs. per minute and P = pitch in feet, then T = 33000HE/PN. Assuming a 5-foot pitch, 1200 revs., the efficiency = 0.75, and the horsepower 100, the thrust will be:

T = 33000 x 100 x 0.75/5 x 1200 = 412.5 pounds. The pitch in this case is the blade pitch, and the great uncertainty lies in selecting a proper value for E. This may vary from 0.70 to 0.85. The diameter is also an unknown factor in this primitive equation.

Materials and Construction. The woods used for propeller construction are spruce, ash, mahogany, birch, white oak, walnut, and maple. Up to 50 H. P. spruce is suitable, as it is light, and strong enough for this power. In Europe walnut and mahogany are the most commonly used, although they are very expensive. Birch is very strong and comparatively light for its strength, and can be used successfully up to 125 horsepower. Ash is strong, light and fibrous, but has the objectionable feature of warping and cannot withstand moisture. Maple is too heavy for its strength. White oak, quarter-sawed, is the best of propeller woods and is used with the very largest engines. It is strong for its weight and is hard, but is very difficult to work and glue. For tropical climates, Southern poplar is frequently used as it has the property of resisting heat and humidity.

One-inch boards are rough dressed to 7/8 inch and then finished down to 13/16 or 3/4 inch. After a thorough tooth planing to roughen the surface for the glue, they are thoroughly coated with hot hide glue, piled together in blocks of from 5 to 10 laminations, and then thoroughly squeezed for 18 hours in a press or by clamps until the glue has thoroughly set. Only the best of hide glue is used, applied at a temperature of 140°F. and at a room temperature of 100°. The glue must never be hotter, nor the boards cooler than the temperatures stated. The propeller after being roughed out is left to dry for ten days so that all of the glue stresses are adjusted. If less time is taken, the propeller will warp out of shape. The propeller is worked down within a small fraction of the finished size and is again allowed to rest. After a few days it is finished down to size by hand, is scraped, and tested for pitch, tracking and hub dimensions.

The finish is glossy, and may be accomplished by several coats of spar varnish or by repeated applications of hot boiled linseed oil well rubbed in, finishing with three or four coats of wax polish. There should be at least 5 applications of linseed oil, the third coat being sandpapered with No. 0 paper. The wood should be scraped to dimension and must not be touched with sandpaper until at least two coats of varnish or oil have been applied.

The wood must be absolutely clear and straight grained, and without discolorations. The boards must be piled so that the edge of the grain is on the face of the blades, and the direction of the annular rings must be alternated in the adjacent boards.

[image]

[image]

Plan and Side Elevation of the S.P.A.D. Speed Scout. Courtesy "Aerial Age".

CHAPTER XIX. OPERATION AND TRAINING.

Self-Training. In the early days of aviation, there were few schools, and these were so expensive to attend that the majority of the aeronautical enthusiasts taught themselves to fly on home-made machines. While this was a heroic method, it had the advantage of giving the student perfect confidence in himself, and if his funds were sufficient to outlast the crashes, it resulted in a finished and thorough flyer. In general, this process may be described as consisting of two hours of practice followed by a week or more of repairing.

The present-day beginner has many advantages. He has the choice of many excellent schools that charge a reasonable tuition, and where the risk of injury is small. He has access to the valuable notes published in the aeronautical magazines, and the privilege of consulting with experienced aviators. The stability and reliability of the planes and the motors have also been improved to a remarkable degree, and the student no longer has to contend with a doubtful aeroplane construction nor with the whims of a poorly-constructed motor.

Training Methods. In the majority of American schools, the instructor accompanies the student in the first flights. The controls are "Dual," or interconnected, so that the instructors' controls act in unison with those of the student, thus giving the latter an accurate knowledge of the movements necessary for each flight condition. After the first few flights the instructor can relax his controls at times so that the student can take charge. This continues until the student has shown the ability to handle the machine alone under ordinary conditions and is then ready for his first "Solo" or flight alone. The first solo is a critical period in his training, for when once in flight he is beyond all human aid.

At the navy training school at Pensacola, the student is first taken for a ride with one of the instructors without giving him access to the controls. This is simply to give the student an experience in the sensation of flight. After this he is taken for a series of short flights on a dual control machine, the instructor gradually allowing him to take charge to a greater and greater extent as he develops the "Air feel." During this time the intricacies of the maneuvers are also gradually increased, so that after about ten hours of this sort of work he is allowed to take his first solo. It has been found that the average student will require from 10 to 20 hours of dual control instruction before he is fit to fly alone. When his work has proven satisfactory he is then allowed to fly in rough weather, execute spirals, and attempt high altitude and long distance flying.

Some instructors believe in showing what can be performed in the air from the very beginning. During the first dual flights, the pilot indulges in dives, vertical banks, side slip, or even looping. After an experience of this sort, the student is far more collected and easy during the following instructions in simple straight flying. If this preliminary stunt flying has a very material effect on the nerve of the student it may be taken for granted that he is not adapted for the work and can be weeded out without further loss of time. If he is of the right type, this ”rough stuff” has a beneficial influence on his work during the succeeding lessons. During this time numerous landings are made, for it must be understood that this is one of the most difficult features of flying. With 15 minute lessons, at least 6 landings should be made per lesson.

A second method of instruction, and to the author’s mind the most desirable, is by means of the ”Penguin” or ”Roller.” This is a low-powered machine with very small wings—so small that it cannot raise itself from the ground. By running the penguin over the ground, the student learns how to manage his engine and to steer with his feet. In this way he obtains a certain delicacy of touch without endangering either himself or an expensive machine. After he has progressed satisfactorily on this machine he graduates to a faster penguin or else to a very slow aeroplane with which he can actually leave the ground. Since the second penguin, or the slow aeroplane are much faster than the first machine, the student finds that the sensitiveness of the rudder and controls are greatly increased. They require more careful handling than in the first instance, and the slightest mistake or delay will send the machine skidding. The aeroplanes used at this stage are very low-powered, and are capable of rising only a few feet from the ground, but they give the student an opportunity of learning the aileron and tail controls in comparative safety. The same result can be obtained with a standard aeroplane by a permanent set in the throttle control, and by adjusting the stabilizer surface. The beginner is allowed to work only during calm weather, as the low speed and small lifting capacity is likely to cause an accident if the machine is caught by a side or following gust. He only learns how to get the machine off the ground, to keep the tail up and hold it in a straight line for a few seconds.

The man taught by the penguin method is alone when he first leaves the ground, and hence is generally more self-reliant than one who has been ”Spoon fed.” His experience in handling the controls has made his movements instinctive, so that when he first actually flies he is in a better position to analyze the new problems before him. It is a better and cheaper method for the school as the breakage is less expensive and allows the unfit students be weeded out before they cause damage to themselves or to the school property.

Ground Instruction. Before attempting flight, the student should be thoroughly versed in the principles an constructional details of the aeroplane and the aeronautic motor. He should know how to take down, time and repair every type of motor with which he is likely to come into contact. He should be able to tell at a glance whether the machine is rigged or trued up properly, and have a general knowledge of the underlying principles of aerodynamics. The study of these subjects is the function of the ground school. At this school the student should learn the assembling and adjusting of the aeroplane structure and its balance.

Types Suitable for Pilots. There is a great diversity of opinion as to the type of man best suited for flying. In this country the government requirements regarding age and physical condition are very exacting, while in Europe it has been found that physical condition is not an index to a man's ability as a pilot. Many of the best French pilots were in such bad shape as to be rejected by the other branches of the army. Our men are well under 30 years of age, while in European service there are many excellent pilots well over 40. It is almost impossible to tell from external appearances whether a man can become a good pilot.

In general he must be more intelligent and better educated than the average infantryman. He should not be subject to an attack of ”Nerves,” nor become easily rattled, for such a man courts disaster in flying. Many exhibition flyers of reputation have proved absolute failures in military service. A knowledge of mechanics will be of great benefit and has been the salvation of many a pilot in active service. Automobile or motorcycle experience is particularly valuable. Recklessness, or a dare-devil sort of a disposition, are farthest from being qualifications for an aviator. Such a man should not be permitted to fly, for he is not only a constant menace to himself but to everyone else concerned.

Learning to Fly Alone. It is with the greatest hesitancy that the author enters into a ”Ground course” of flight instruction. I can, however, list the principal things to avoid and some of the things to do, but this will never take the place of actual field instruction and experience. The first and last thing to remember is to ”Proceed slowly and with caution.” Never try a new stunt until you are absolutely sure that you have thoroughly mastered the preliminary steps in straight flying. Over-confidence at the beginning is almost as bad as no confidence at all, and the greatest difficulty met with by instructors during the first solo flights is to keep the student from imitating the maneuvers of the more experienced flyers. Spend plenty of time rolling or ”Grass-cutting” before attempting to leave the ground. Be sure that you can handle the rudder with accuracy, and at fairly high speeds before attempting to lift. A few days spent in sitting in the machine (motor dead), and acquainting yourself with the controls is excellent practice and certainly is not a loss of time. With the machine in the hangar, move the controls for imaginary turns, dips and other maneuvers so that the resistance, reach and limit of control movement will come more naturally when the machine is moving.

During the ground rolling period, the elevator or stabilizer should be set so that it is impossible to leave the ground, and the motor should be adjusted so that it cannot develop its full thrust. This will provide against an accidental lift. Be easy and gentle in handling the controls, for they work easily, and have powerful effect at high speeds. The desperate fervor with which the beginner generally yanks at the "joystick" is generally the very reason for his accidents. Do not start off at full speed without first getting used to the effect of the controls. Learn to find the location of the various devices so that you can reach them without looking or without fumbling.

The First Straight. By adjusting the stabilizer and elevators so that the latter has a greater degree of freedom, and by changing the motor so that it can be run at a slightly higher speed, we are in a position to attempt our first flight. Be careful that the adjustment will limit the climb of the machine, and choose only the calmest of weather. It should be remembered that the aeroplane will get off the ground at a lower speed than that required for full flight at higher altitudes, this being due to the cushioning effect between the wings and the earth. A machine traveling at a speed capable of sustaining flight at a few feet above the earth will cause it to stall when it is high enough to lose this compression. The adjustment should be such that the machine cannot rise above this "Cushion," and in this condition it is fairly safe for the beginner.

In making the first runs under the new conditions of adjustment, the student should learn to manipulate the elevators so that they will hold the tail up in the correct position, that is, with the chord of the wings nearly horizontal. Do not allow the tail skid to drag over the ground further than necessary. At this point the student should be strapped in the seat by a quick-detachable safety belt.

Now comes the test. Get under full headway with the tail well up, taking care to run against the breeze. The speed increases rapidly, then the motion and jar seem softer, and the motor ceases to roar so loudly. There is now a very distinct change in the note of the motor. You are off. At this point a very peculiar illusion takes place, for your elevation of a few feet seems about a thousand times greater than it really is. With this impression the student usually tries to correct matter by a sudden forward push on the control lever causing fine dive and a smash. It must be borne in mind that only the slightest movement of the controls should be made, and if this does not prove sufficient after a moment or so, advance them still further but very gently. Sudden movements must be avoided. At first the "Hops" should not extend over a hundred yards or so until the student is sure of his controls. Little by little they can be increased in length and height. He should practice for some time before attempting a flight of more than a mile. By this time, the student will have learned that the landing is by far the most difficult feature in flying, and he should practice this incessantly before trying flights in windy weather.

The machine should be headed directly into the wind, both in getting off and in landing, especially in the latter case, as a sudden following gust will tend to stall a machine or upset it. With a head wind, the lift is maintained at a low speed and hence is an aid in a safe landing. When flying in still air there is little if any use for the ailerons, but in gusts the student will need their aid in maintaining lateral balance. After the rudder and elevator controls have been well learned the effect of the ailerons can be tried. Gusty or squally weather must be avoided at this point in the training, and no turns should yet be attempted.

When the student attains heights greater than a few feet he should take great care in obtaining a sufficient ground speed before trying to get off, for if lifted before the full flying speed is attained it is likely to stall. Fast climbing at sharp angles is dangerous unless a sufficient ground speed has been attained. Sustentation is due to forward speed, and this must not be forgotten. The quickest climb for getting over trees and other obstructions is obtained by gaining full speed on the ground before the climb begins, as the power of the engine is aided by the momentum of the machine.

In landing in small fields it is necessary to bring the machine to rest as soon as possible, and this stopping distance depends to a great extent upon the attitude of the machine when it first touches the ground. If it is landed so that the chassis wheels and tail skid strike the ground simultaneously, the incidence is so great that the wings act as air brakes. On landing, the angle in any case should be quickly increased past the angle of maximum lift. The lift is much reduced and the drag is increased by quickly pulling the control toward the aviator. This also reduces the tendency toward nosing over.

A normal landing in a large field can be affected by first starting down at the normal gliding angle, and when from twenty to thirty feet above the ground the elevator control is pulled back so that the machine will describe a curve tangent to the ground. In student's practice the curve should not be exactly tangent to the ground, but tangent to a level two or three feet above the ground. The machine is now losing speed, and to prevent settling the elevator should be pulled back a trifle. The speed continues to decrease until it settles down through the small remaining distance with the elevator full back. The points of support should strike simultaneously. It is difficult for the beginner to make this sort of a landing, as there always seems to be an uncontrollable desire to jam the machine down on the ground. If a puff of wind happens to strike the machine when a few feet off, the student becomes rattled by the suddenly increased elevation and jams her down doubly hard.

Wind Flying. The nature of wind at low altitudes is determined to a great extent by the contour of the ground. Eddies are caused by trees, embankments, fences, small hills, etc., which tend to disturb the equilibrium or change the course of the aeroplane. As the altitude increases, the effects of these obstructions are less pronounced, until at from 2000 to 3000 feet the effect is practically negligible. Winds that may be ”Bumpy” near the ground are fairly regular when 3000 feet is attained. At the higher altitudes the velocity increases, and if the machine is flying against the wind the progress will naturally be much slower at the higher altitudes. When starting in a strong wind it is advisable to attain an altitude of at least 300 to 400 feet before turning. Turning in with the wind carries the possibility of a drop or stall.

A short gust striking the machine, head on, tends to retard the velocity in regard to the earth, but in reality increases the relative air speed and thus causes the machine to climb momentarily. A prolonged head gust may produce a stall unless corrected by the elevator or met with by reserve power. A rear gust reduces the relative wind velocity and tends to make the machine stall, although there are a few cases where the gust velocity has been great enough to cause a precipitate drop. The higher the speed, the less the danger from rear gusts.

The gusts are much more pronounced with low winds, say winds of about 5 to 15 miles per hour, and hence it is usually more tricky to fly in a wind of this velocity than with a higher wind. It is not the speed of the wind so much as it is its variation from the average velocity. One should start to work on a ”bump” at the moment it first starts to appear.

When flying with the wind, the total speed in regard to the earth is the sum of the wind speed and the aeroplane speed. When flying against it is the difference between the aeroplane and air speeds. Thus, if the air speed of the aeroplane is 60 miles per hour, the speed in regard to the ground will be 75 miles per hour with a following wind of 15 miles per hour, and 45 miles per hour when flying against a 15-mile wind. The speed when flying across the wind would be represented by the diagonal of a parallelogram, one side of which represents the aeroplane speed, and the other side the wind speed. The angle of the diagonal is the angle at which the machine must be pointed. When viewed from the ground, an aeroplane in a cross wind appears to fly sideways.

Turning. After the beginner is able to maintain longitudinal and lateral balance on straight away flights, he next attempts turns. At first, the turns must be of great radius. As the radius is gradually shortened, the effects of centrifugal force become greater, increasing the tendency toward skidding or outward side slip. To prevent skidding, the outer wing tip must be raised so that the lift will oppose the centrifugal force. The shorter the turn, and the faster it is made, the greater will be the banking angle. Should the bank be too steep, the gravitational force will pull the machine down, and inwardly in a direction parallel to the wings. This is known as an ”Inner side slip.” The banking may be performed by the natural banking tendency of the aeroplane or may be assisted by depressing the aileron on the outer wing tip. Unless the speed is well up to normal, the machine will be likely to stall and drop on a turn, as the head resistance is much greater under these conditions. For safety one should take a short downward glide before starting the turn, so that the speed will surely be sufficient to carry it around the turn. A turn should never be attempted when climbing unless one has a great reserve power. The combined effects of the turning resistance, and absorption of energy due to the climb, will be almost certain to stall the machine. There are banking indicators on the market which will prove of great service. These operate on the pendulum principle and indicate graphically whether the aeroplane is being held at the correct angle of bank.

Proper Flight Speed. An aeroplane should always be provided with an air speed meter, giving the speed of the machine in relation to the air. When flying with the wind the pilot is likely to be confused by the tremendous ground speed at which his machine is flying. While the machine may be moved at a fast clip in regard to the earth, it may be really near the stalling speed. This error is particularly dangerous when one turns in with the direction of the wind, after flying against it for some time. The sudden increase in the earth speed, when fully in with the wind, always creates a sudden desire to throttle down at the very time when the relative air speed has already been greatly reduced by the turn. Stalling due to this cause has resulted in many accidents, and the beginner should always attain an altitude of a least 500 feet before he tries turning in with a strong wind. An accurate speed indicator eliminates this danger to a great extent, but it should be proved that the instrument itself is accurate before too much reliance is placed on it.

Before the advent of the indicator, pilots were compelled to estimate the speed by the sense of feel, some depending upon the feel of the wind pressure on their faces, and others by the relative resistance offered to the movement of the control surfaces. The sense of ”Air feel” developed by the late Lincoln Beachey was marvelous, for without instruments he would repeatedly climb nearly into a stall when only 50 feet from the ground, and then recover with his chassis nearly dragging in the weeds.

Gliding (Fr. Vol Plan). ”Gliding” is a descent along an inclined path without power, and is possible with any aeroplane. By suitably inclining the wings with the horizontal, gravity is made to produce a forward propelling component that moves the machine forward at the expense of a loss in altitude. The angle of the gliding path made with the horizontal is known as the ”Gliding angle,” and indicates the efficiency of the aeroplane, for with machines having very low head resistance the angle is very "flat," and more nearly approaches the horizontal. The best or flattest gliding angle is an inherent feature of the aeroplane design, and this cannot be exceeded by any effort on the part of the pilot. It is generally expressed in terms of the ratio of the descent to the forward distance traveled, thus a gliding angle of 10 means that the aeroplane travels 10 feet horizontally for every foot of descent. Any angle steeper than the flattest angle can be produced by pushing forward on the elevator controls, thus depressing the elevator tips.

A very flat gliding angle is a most important feature from the standpoint of safety, as it determines the extent of the area within which a landing can be made with a dead engine. If the gliding angle is taken as 12, and the height is 2000 feet, then the radius of the circular area in which a landing is possible is $2000 \times 12 = 24000$ feet, and the diameter is twice this or 48,000 feet, so that we can land anywhere within a distance of over 9 miles. If the best gliding angle of the machine were only 10, this will be reduced to $2000 \times 10 = 20000$ feet, hence our chance of choosing a safe landing space would be cut down in proportion. The best gliding angle corresponds to a certain speed and wing angle, and must be determined by experiment, but in many machines the adjustment of the weight is such that the machine automatically picks up the best glide as soon as the motor is cut off, and needs but little correction by the elevators. Such a machine is dived slightly when the motor is cut out, and then after a few oscillations settles down and travels steadily along the proper gliding path. In trying to improve this performance, the speed indicator and incidence indicator should be carefully watched so that neither the stalling angle nor the stalling speed are approached. The best glide angle corresponds to the best flight speed and will be increased if the incidence is much below or above the incidence for the most economical flight speed.

Vertical Nose Dive. When the aeroplane is diving vertically, nose down, the center of pressure movement in some machines may oppose the elevators, thus making it difficult to straighten out into the horizontal. If pulling full back on the elevator control does not remedy matters, the control should then be quickly reversed so that there is a momentary tendency to throw the machine over on its back. This breaks up the lock, and when accomplished, the controls should be again pulled back to bring the machine into the horizontal with the elevators in the original straightening out position. The momentum swings the machine out and against the locking position, thus aiding the controls in overcoming the moment of the C. P.

Tail Spin (Spinning Nose Dive). Spinning is due to side slipping or stalling, and sooner or later every pilot gets into this position either through accident or intention. If an accident, it may be due to the design of the aeroplane through an

[image]

Typical Gliding Angle Diagram Showing Path Inclination of Deperdussin Monoplane.

improper distribution of the vertical surfaces, or again it may be caused by very steep banking without an equivalent rate of turning. Incorrect manipulation of the ailerons when the machine is near stalling speed, or when gliding in a spiral of gradually decreasing radius, also causes this result. At any rate, the side slip and stall are the final cause of spin. In ”Stunt flying,” where a spin is desired, one of the quickest methods of getting a spin is to pull the controls all the way back and push the rudder hard over in the desired direction of spin with the motor shut off. Another way to get a spin with lots of ”Pep” in it, is pull the stick clear back with the motor on, and climb until the machine is stalled, then rudder over hard with the controls still held back. The aeroplane will now fall over on its side in the direction of the rudder, and assisted by the motor which has again cut in after the peak of the climb, will give all the spin that any critic could ask for. After the stall occurs, the motor should be throttled down for it is likely to strain the plane or even break it.

There are several ways of coming out of the spin. Probably the best way, and the one that causes the least loss of altitude, is to keep the controls pulled back all the way, and rudder in the opposite direction to the spin (Motor cut out). The rudder will stop the spin, and the elevator will cause the plane to level out of the dive simultaneously, but the controls should be put into neutral as soon as leveled out or there will be another spin started in the opposite direction. A very common method used by exhibition flyers is first put the controls into neutral, and rudder opposite to the spin until it stops turning and it is then put into a nose dive. The straight nose dive can then be easily corrected by pulling back on the controls until it levels out. This latter method develops an excessive speed and requires a high altitude.

When the aeroplane is overbanked at normal speed, and the turn is not correspondingly rapid, the plane will slip down sideways into an ”Inside side slip.” The strong upward wind against the side of the body will turn the nose into a dive, the nose drops, and the tail will then start to swing around in a circle larger than the circle described by the nose—the dive continuing. When much below the normal flight speed, or near the stalling point, the inner ailerons are not as effective when making a sharp turn for their velocity is much reduced. When fully depressed, the inner ailerons give very little lift toward righting the machine but add to the drag and tend to spin the machine around with the inner tips acting as a center of rotation. The outer ailerons are very effective and because of the high speed of these tips, there is a strong banking tendency that eventually will result in side slip and a spin if the pilot is not experienced. Either the spin due to overbanking, or that due to low speed may be straightened out according to instructions already given.

When a turn is attempted at low speed near the ground, the student generally fails to bank up sufficiently through fear of striking the ground with the lower wing tip, and therefore gets into an outward side slip. In the frantic effort to keep the low wing up and off the ground he depresses the low aileron to the full, thus increasing the drag on the low side and starting the spin. Very much to his surprise he finds that this actually drops the low tip further instead of raising it as the outer tip is now speeding around at a tremendous clip, and the outer lift is increasing the bank against his will. Given time, and altitude, the plane will bank up until it stands on end, and in any event a bad side slip results, and the fun is on. If near the ground as assumed, either the side slip or the resulting nose dive will soon terminate matters. The moral to be derived from this experience is to keep up to speed in making a turn, to maintain a safe altitude, and in case the speed should fall off, to depress the **outer aileron**. The outer aileron will resist the spin if depressed, as the drag acts against the spin, and the bank thus obtained will act against the outer side slip, without destroying the velocity of the machine as a whole. In turning at stalling speed, the aileron effects are reversed, and as soon as straightened out the engine should be opened up so that the speed will be increased and the landing made as easy as possible.

If the fin and rudder surface is not sufficient for the machine, little is gained by turning the rudder to an angle greater than 15°, and in such cases it is much more effective when held parallel to the wind. If correction has been started before the spin has developed great rapidity, the rudder can first be turned to check the rotation and then turned back parallel to the wind. It is always best to shut off the engine when getting out of a tail spin, especially if the engine rotation is in the direction of the spin, since the motor torque aids the spin and acts against the controls. In case of a smash there is no danger from fire with the engine cut out.

Stunt Flying. When the student has had 20 hours or more of solo flying, and is capable of performing the ordinary maneuvers with confidence and accuracy, he is in a position to undertake stunt flying under the directions of a good instructor in a dual control machine. This tremendously increases the confidence of the student if gone about in the right way, and in his after flying experience enables him to get out of tight places that would otherwise often prove impossible. There is no doubt but what stunt flying has decreased the percentage of accidents when properly taught, and that Pegoud's original stunt of looping the loop has been one of the greatest steps in the advancements of aeronautics that we have had, if only for the fact that it taught the flyer that there was no flying attitude so bad but what there was a solution for it.

Flying Upside Down. With the machine on its back, then wings are very inefficient, and it is impossible to maintain horizontal flight in this position, and the machine is also very unstable. It should really be called gliding instead of flying since the aeroplane constantly loses altitude along an inclined gliding path. The distance that a machine can be glided in this way depends upon the skill of the pilot, and it will also be found that upside down flight with a large dihedral is more difficult than with straight wings. The upside down flight begins with a glide to gain speed, the path being about 20° with the horizontal, and this speed gain is imperative since it requires both the power of the motor and the momentum of the machine to overcome the sharp climb for the turnover.

[image]

Upside Down Glide Diagram, Showing Successive Positions of Aeroplane.

After sufficient speed has been attained, the controls are pulled back for a climb at about a 60° angle, as between (A) and (C), this maneuver being best performed with the gliding path (C-D) against the wind. With the control pulled back at (A), the rudder is thrown over sharply in the desired direction of the turnover, and this will turn the machine over as indicated by at (B), the machine finally getting on its back at the peak of the climb (C). With the machine on its back, reverse rudder to stop the overturning, and when the wings are horizontal, the rudder should be put in neutral to hold it in this position. At (C) the motor is shut off, and the glide continued to (D) where it is leveled out by a backward pull on the controls. This should always be performed at an altitude well over 2000 feet.

[image]

Looping Diagram Showing Successive Positions of Machine.

Looping. This is probably the easiest of all stunts outside of the spiral glide. It starts with about a 20° glide as at (A) to increase the velocity (Motor on), and at the beginning of the loop at (B), the control lever is pulled back slowly. The controls must be pulled back faster and faster as the plane approaches the top of the loop, a steady pull producing nearly the correct effect because of the decreasing elevator resistance as the machine reaches the top of the loop at (C). At the top, the lever should be clear back and must be held in this position until at the bottom (D) where the machine leaves the loop along the inclined path (D-E) At (D), the stick is pushed slowly forward to neutral, gradually bring the machine into the horizontal. The loops must always be made when flying into the wind, and the faster they are made the better, for there is less strain on the frame and speed also prevents the motor from cutting out at the top of the loop.

[image]

A Few Straight Loops and Backward Reverse Loops Performed by Niles.

[image]

Photograph of Night Looping by Charles Niles. The Machine was Provided with Railroad Flares which Left the Trace or Path of the Aeroplane on the the Dry Plate.

Immelmann Turn. This maneuver was originated by the German flyer Immelmann, and is much used in combat by both the Allied and German armies, for it subjects the enemy to a maximum field of fire and enables the machine to make a quick getaway with a single seat machine. With the enemy machine at (X), and with our machine provided with two machine guns, it will be seen that the enemy is under the fire of either the rigid front gun or the pivoted cock-pit guns through nearly three-quarters of the twisting loop. The pivoted gun which fires over the top wing is the most effective as it can reach the enemy machine (X) at (A), (B), (D) and (E), the only blind spots occurring during the climb from (B) to (D) as indicated by the partly rolled over position at (C).

It begins with the usual power glide (Motor on) at (A) in order to gain speed, and at the beginning of the 60° at (B) the elevator controls are pulled back and the rudder given a quick turn to the extreme position in the direction of the desired turnover. The rudder action turns the machine over on its back at the peak of the climb at (D) without the use of ailerons. At the top (D), the rudder is thrown to the opposite direction to stop the roll over and is then brought back

[image]

Successive Positions in Immelmann Turn, Enemy Machine Either Being at Y or X.

to neutral to hold the machine flat on its back. The elevator controls are held back until the machine comes out of the reverse loop extending from (D) to (E) and until it leaves on the horizontal at (F). As the object is to get away quick, the finish along (E-F) should be made with the wind, and preferably should be started across wind. Motor should be throttled down from (D) to (E) to prevent coming out with excessive speed.

[image]

Positions in "Turn Over," the Machine Continuing to Rotate in the Same Direction from B to D.

The Roll-Over. The start of this stunt is exactly like the start of the upside down glide or the Immelmann, while the finish is a sort of reversed Immelmann, the machine being straightened out without going around a loop. When at the top of the turnover climb, the rudder is not reversed and straightened out as in the Immelmann, but a little rudder is kept on so as to continue the turnover and bring the plane out on the horizontal. The rudder action is assisted by a slight application of the aileron while the elevator control is pushed forward after the machine leaves the peak of the climb. I am indebted to Lieutenant Charles W. Keene for suggestions on the Immelmann and roll over, and to the late Lieutenant R. C. Saufly of the U. S. Navy for other items on training.

[image]

Flying Upside Down With a Bleriot Monoplane. The Plane is Far Too Low to Recover Its Normal Position, and as a Result, the Glide Ended Fatally.

CHAPTER XX. AERONAUTICAL MOTORS.

[image]

An Aeroplane Equipped with the Light Boat Hull Shown, in this Figure is Known as a ”Flying Boat”. It Differs from the ”Seaplane,” as the Floats or Pontoons of the Latter Do Not Enclose the Passenger and Pilot.

General Notes. It is assumed that the reader understands the principles of the automobile motor and its accessories, for a minute description of gas-engine principles does not fall within the scope of this book. If more information is desired on this subject, the reader is referred to the author’s ”Practical Handbook of Gas, Oil and Steam Engines.” Only those features peculiar to aeronautic motors will be discussed in this chapter.

Aeronautic Requirements. The principal requirements of an aeronautic motor are light weight, low oil and fuel consumption, reliability and compactness. The outline as viewed from the shaft end is also very important, for the motor must be mounted in a narrow streamline body. The compression pressures are much higher than those employed on auto motors, and the speed is generally lower. With one or two exceptions the four-stroke cycle has been universally adopted.

Aeronautic service is a severe test for the motor. From the start to the finish of a flight, the aeroplane motor is on a steady grind, loaded at least to 75 per cent of its rated power. The foundations are light and yielding and the air density varies rapidly with changes in the altitude. As the fuel and oil require an expenditure of power for their support, the fuel consumption becomes of great importance, especially in long flights. Because of the heavy normal load the lubricating system must be as nearly perfect as it is possible to make it.

A motor car runs normally at from 10 to 25 per cent of its rated horsepower, while the aero motor may develop as high as 75 per cent to 100 per cent for hours at a time. A car engine of 672 cubic inches displacement is rated at 65 horsepower, while the same size aero engine has a rating of 154. On the basis of normal output, this ratio is about 7 to 1, and taking the weight of the aero motor as one-half that of the auto type, the true output ratio becomes 14 to 1. Up to the time of a complete overhaul (50 hours), and at 100 miles per hour, the average distance traveled by the aero motor is 5000 miles. The equivalent motor car mileage is 25,000, and the duration is about 1000 hours. This suggests the necessity for improved materials of construction. Even on the present aeronautic motors the fiber stress in the crank-shaft ranges from 120,000 to 140,000 pounds per square inch against the 80,000-pound stress used in auto shafts. The crank case of an aeronautic motor must be particularly rigid to withstand the stresses due to the light mounting, and this demands a higher grade metal than that ordinarily used with automobiles. Unlike the car engine, quality comes first and price is a secondary consideration.

Cooling Systems. Both the air and water cooling system is used, the former for light fast aeroplanes such as speed scouts, and the latter for the larger and more heavily powered machines. Even in some types of speed scouts the air-cooled motor has been displaced by the water-cooled, owing to the fact that the air-cooler cannot be built satisfactorily for outputs much greater than 110 horsepower. By increasing the revolutions of the stationary water-cooled type an increase in power may be had with the same cylinders, but in the case of the rotary air-cooled type the speed is limited by the centrifugal forces acting on the cylinders.

[image]

A 6-Cylinder Hall-Scott Motor Installed in a Martin Biplane.

While the weight of the radiator, water and piping increase the weight of the water-cooled motor very considerably, the total weight is not excessive. When the fuel is considered, the total weight is below that of the rotary when long flights are attempted. The radiator and water add complication and are a source of danger. The radiators increase the head resistance and add very considerably to the maintenance cost.

[image]

A Motor Installation in a Pusher Type Biplane, Showing the Motor at the Rear and the Double Radiator Sections Over the Body.

Each type of cooling has its limitations, and it is hoped that an improvement in cooling may be had in the near future. This system should primarily reduce the size and resistance of the power plant, and if possible the weight, although the latter is a secondary consideration. At present the cooling system prevents even an approach to the true streamline form of the body.

Propeller Speed. For the best results, the propeller speed should not exceed 1200 revolutions per minute, and for structural reasons this is generally limited to 1500 R. P. M. This at once puts a limiting value on the output of a given size engine unless a gear down arrangement is used. It should be understood, between certain limits, that the power output increases roughly as the speed. With direct drive arrangements in which the propeller is mounted directly on the end of the engine shaft, the motor revs. are necessarily the propeller revs., and the only way of increasing the speed is by increasing the length of the stroke or by gearing down. An increase in stroke adds rapidly to the weight by increasing the cylinder length, length of connecting rod, length of crank throws, etc.

Horsepower Rating. At present there are many methods of calculating the horsepower of gasoline engines. Formula applying to auto or boat motors does not apply to flight conditions, for the aero motor is essentially a high compression type and has a greater output per unit of displacement. It is not practical to give the rated horsepower as the maximum output possible under ideal conditions, for this would give no idea as to the practical capabilities except by long tedious calculation. The brake horsepower would give no overload capacity at a fixed propeller speed, and the conditions are entirely different from those regulating the rating of auto motors. The latter can be forced up to the wrecking speed, or many times the normal automobile speed of 30 miles per hour.

As aero engines are generally well kept up, and well tuned at all times, the rated horsepower may be taken from 15 to 20 per cent below that of the maximum brake horsepower. In geared-down motors, the gear efficiency is still to be considered. The question of the quality of the mixture, and barometric pressure, also enter into the problem whether the power is rated on the maximum obtained with a rich mixture, or is calculated from the output at the maximum efficiency. A writer in ”Aviation” suggests that the rated horsepower be taken as 95 per cent of the power developed at a point midway between the maximum output, and the output at the greatest efficiency. Barometric pressure to be 30 inches and the revolutions 1200.

Owing to the great diversity in the bore-stroke ratio, a power formula must include the bore and stroke. This makes the S.A.E. formula for auto motors impossible. A formula is proposed by a writer in ”Aviation.” The writer has checked this up with the published performance of several well-known aeronautical motors.

$H = B^2SNR/12{,}500$ Where B = bore in inches, S = stroke in inches, N = number of cylinders, R = Crankshaft revolutions per minute, and H = rated horsepower. This applies only to the four-stroke cycle type.

Power and Altitude. The power drops off rapidly with an increase in altitude unless corrections are made for compression and mixture. With constant volume, the decreased density causes decreased compression. As the weight of air taken in per stroke is reduced, this also reduces the amount of fuel that can be burned per stroke. By holding the compression constant through adjustment of the clearance or valve motion, a fairly constant output can be had through a wide range of altitudes.

A compression of 115 pounds per square inch (commonly used) is difficult to handle with a light construction, but this pressure must be obtained if the output is to be kept within practical limits. Engines having a compression ratio of as high as 6 are running satisfactorily at sea level, this ratio giving a mean effective working pressure of 134 pounds per square inch. With this ratio the engine cannot be used with full open throttle at sea level for more than 10 or 15 minutes without causing damage to the shaft, bearing and valves. At about 10,000 feet the compression is normal.

At great altitudes carburetion has become a great problem, and as aerial battles have already taken place at elevations of 20,000 feet, it is quite possible that future motors will be equipped with some device that will force a measured fuel charge into the cylinders. The air necessary for the combustion will also have to be pumped in by some means.

Weight Per Horsepower. The weight per horsepower of the engine is a very loose term since so much depends upon the equipment included in the weight. As many as 20 items may be considered as being in the doubtful list, and among these are the radiator water, piping, mounting, propeller hub, oil in sump, wiring, self-starter, etc. The only true unit weight is that obtained by taking the plant complete (ready to run), with the cooling system, gasoline for an hour's flight, and the oil. The weight of the bare engine signifies nothing. The weights of the various items used on well known motors are given in a table under the chapter "Weight Calculations." While the bare weight of a certain engine may be very low per brake horsepower, an excessive fuel consumption will often run the effective weight up and over that of a type in which the bare weight is far greater. The weight of the engine per horsepower, including the magneto and carbureter, will run from 2.2 to 5.0 pounds, according to the type.

[image]

Two Examples of Cowls Used Over Rotary Cylinder Motors (Air Cooled).

Fuel Consumption. The fuel consumption of water-cooled motors varies from 0.48 to 0.65 pounds per horsepower hour, an average of 0.6 being safe. The fuel consumption of a rotary air-cooled motor will range from 0.6 to 0.75. The oil consumption varies from 0.18 gallons per horsepower in the air-cooled type to 0.035 with the water-cooled stationary motor.

Radiators. Owing to extremes in the temperature of the air at different altitudes, the radiating surface should be divided into sections so that a constant cooling effect can be obtained by varying the effective surface of the radiator. The temperature can also be controlled by an automatically regulated by-pass which short circuits a part of the radiator water at low temperatures. Constant water temperature has much to do with the efficiency and general operation of the motor, and there will be only one temperature at which the best results can be obtained.

[image]

Typical Radiators. A) Side or Top Type.

[image]

Typical Radiators. (B) Front Type.

Hunsaker finds that 0.83 square feet of actual cooling surface per horsepower is correct at 60 M. P. H., while others give a value of about 100 square foot under similar conditions. The front or projected area varies with the thickness of the radiator, the thicknesses varying from 2 to 5 inches. The Livingston radiator gives a cooling surface of 50 square inches per square inch of front surface. The total cooling effect depends upon the speed, the location in regard to the slipstream, and the position on the body. A radiator maker should always be consulted when making the final calculations. See Chapter XVI.

Fuel Tanks and Piping. The fuel tanks may be of copper, aluminum or tin-coated steel, and all joints should be welded or riveted. Never depend upon solder, as such joints soon open through the vibration of the engine. Gasoline should not come into contact with steel, nor the zinc used on galvanized iron. Splash plates are provided to keep the fluid from surging back and forth while in flight. All gas should be supplied to the engine through a filter or strainer placed in the main gas line. The valves in the fuel lines should be provided with stopcocks, so arranged that they can be closed from the pilot's seat.

In general, the carbureters should be fed by gravity from an overhead service tank, this tank being supplied from the main reservoir by air pressure or a gasoline pump. The air can be compressed by a pump on the engine or by a paddle driven pump operated by the airstream, and as a rule the latter is preferable, as it can be operated with the aeroplane gliding and with the engine dead. Air pressure systems are likely to fail through leaks, while with a good gasoline pump conditions are much more positive. The gravity service tank should be located so that it will feed correctly with the aeroplane tilted at least 30 degrees from the horizontal.

[image]

[image]

Two Views of the ”Monosoupape” Gnome Rotary Cylinder Motor. This Motor Has 9 Cylinders Arranged Radially Around the Crankshaft and Develops 100 Horsepower. The Cylinders Are Air Cooled.

The gasoline piping should be at least 5/16 inch inside diameter, and should be most securely connected and supported against vibration. To guard against crystallization at the point of attachment, special flexible rubber hose is generally used. This must be hose made specially for this purpose, as ordinary rubber hose is soon dissolved or rotted by gasoline and oil. Air pockets must be avoided at every point in the fuel and oil system.

[image]

Hall-Scott ”Big Six” Aeronautical Motor of the Vertical Water-cooled Type. 125 Horsepower.

Rotating Cylinder Motors. The first rotating cylinder motor in use was the American Adams-Farwell, a type that was soon followed by the better known French ”Gnome.” Other motors of this type are the Clerget, LeRhone, Gyro and Obereusel. They are all of the air-cooled type—cooled partly by the revolution of the cylinders about the crank-shaft, and partly by the propeller slipstream. While the pistons slide through the cylinder bore, the rotating cylinder motor is not truly a reciprocating type, as the pistons do not move back and forth in regard to the crank shaft. The cylinders revolve about the crank shaft as a center, while the pistons and connecting rods revolve about the crank pin, the difference in the pivot point causing relative, but not actual, reciprocation.

[image]

Hall-Scott 4-Cylinder Vertical Water-cooled Motor. 80-90 Horsepower.

The original Gnome motor drew in the charge through an inlet valve in the piston head. The gas passed from the mixer, through the hollow crank-shaft, and then into the crank-case. The exhaust valve was in the cylinder head. This valve arrangement was not entirely satisfactory, and the company developed the ”Monosoupape” or ”Single valve” type. The 100 H. P. Monosoupape Gnome has 9 cylinders, 4.3” x 5.9”. The total weight is 272 pounds and the unit weight is 2.72 pounds per horsepower. It operates on the four-stroke cycle principle. The gas consumption is 12 gals. per hour, and it uses 2.4 gals. of castor oil. The cylinders and cooling fins are machined from a solid steel forging, weighing 88 pounds. The finished cylinder weighs 5.5 pounds after machining. The walls are very thin, probably about 1/16 inch, but they stand up well under service conditions.

[image]

Sturtevant ”V” Type 8-Cylinder Water Cooled Aeronautical Motor. This Motor Is Provided With a Reduction Gear Shown at the Rear of the Crankcase.

Assuming the piston to be on the compression stroke, the ignition will occur from 15° to 20° before the top dead center. Moving down on the working stroke, and at 85° from top dead center, the exhaust valve begins to open, and the exhaust continues until the piston returns to the upper dead center. With the valve still open, pure air now begins to enter through the exhaust valve and continues to flow until the valve closes at 65° below the bottom center. Still descending, the piston forms a partial vacuum in the cylinder, until at 2° before the lower center the piston opens the ports and a very rich mixture is drawn in from the crank case. This rich mixture is diluted to the proper density by the air already in the cylinder, and forms a combustible gas. The upward movement of the piston on the compression stroke closes the ports and compression begins. The mixture enters the crank case through a hollow shaft, with the fuel jets near the crank throws. A timed fuel pump injects the fuel at the proper intervals.

[image]

Dusenberg 4-Cylinder Vertical Water Cooled Motor With Reduction Gear. Four Valves Are Used Per Cylinder. Note Peculiar Valve Motion.

Curtiss Motors. The Curtiss motors are of the water-cooled ”V” type, with 6 to 8 cylinders per row. These are probably the best known motors in America and are the result of years of development, as Curtiss was the first to manufacture aero motors on a practical scale.

[image]

Curtiss Type OX-5 Eight Cylinder Aeroplane Motor

Hall-Scott Motors. These motors are made by one of the pioneer aeronautical motor builders, and have met with great favor. They are of the vertical water-cooled type, and with the exception of minor details and weight are very similar in external appearance to the automobile motor. Four and 6-cylinder types are built.

Sturtevant Motors. These are of the ”V” water-cooled type, and are provided with or without a reducing gear. At least one model is provided with lined aluminum cylinders.

Dusenberg Motor. This is a four-cylinder, water-cooled, vertical motor with a very peculiar valve motion. The valves are operated by long levers extending from the camshaft. Two inlet, and two exhaust valves, are used per cylinder. The motor is generally furnished with a reducing gear.

Roberts Motor. This is a solitary example of the two-stroke cycle type, and has been used for many years. It is simple and compact, and is noteworthy for the simplicity of its oiling system. The oil is mixed with the gasoline, and is fed through the carbureter. This is one of the many advantages of a two-stroke cycle motor.

Table of Aeronautical Motors. The following table will give an idea as to the general dimensions of American aeronautical motors:

[image]

The Liberty Motor. The necessity of speed and quantity in the production of aeronautical motors after the declaration of war caused the Government to seriously consider the design of a highly standardized motor. This idea was further developed in a conference with representatives of the French and British missions on May 28, 1917, and was then submitted in the form of sketches at a joint meeting of our allies, the Aircraft Production Board, and the Joint Army and Navy Technical Board. The speed with which the work was pushed is remarkable, for on July 3rd, the first model of the eight cylinder type was delivered to the Bureau of Standards. Work was then concentrated on the 12 cylinder model, and one of the experimental engines passed the 50 hour test August 25, 1917.

It is of the ”V” type with the cylinder blocks at an angle of 45 degrees instead of 60 degrees as in the majority of 12 cylinder ”V” motors. This makes the motor much narrower and more suitable for installation in the fuselage, and in this respect is similar to the arrangement of the old Packard aviation motor. It has the additional advantages of strengthening the crank case. The bore and stroke is 5” x 7” as in the Hall-Scott models A-5 and A-7. The cylinders combine the leading features of the German Mercedes, the English Rolls-Royce, Lorraine-Dietrich, and Isotta-Fraschini. Steel cylinder walls are used with pressed steel water jackets, the latter being applied by means of a method developed by the Packard Company. The valve cages are drop forgings, welded to the cylinder heads.

The camshaft and valve gear are above the cylinder head as in the Mercedes, but the lubrication of the parts was improved upon by the Packard Company.

The crankshaft follows standard 12 cylinder practice except as to the oiling system, the latter following German practice rather closely. The first system used one pump to keep the crankcase empty delivering the oil to an outside reservoir. A second pump took the oil from the reservoir and delivered it to the main crankshaft bearings under pressure. The overflow from the main bearings traveled out over the face of the crank throw cheeks to a ”Scupper,” which collected the excess for crank pin lubrication. In the present system, a similar general method is followed except that the pressure oil is not only fed to the main crankshaft bearings, but also through holes in the crank cheeks to the crank pins instead of by the former scupper feed.

A special Zenith carburetor is used, that is particularly adapted to the Liberty motor. A Delco ignition system of special form is installed to meet the peculiar cylinder block angle of 45 degrees. This ignition is of the electric generator type and magnetos are not used.

Several American records have been broken by the new motor, and it is reported to have given very satisfactory service, but full details of the performance are difficult to obtain owing to the strict censorship maintained in regard to things aeronautic. The motor is particularly well adapted to heavy bombing and reconnaissance type machines, or for heavy duty. It is reported that the use of the motor has been discontinued on speed scouts, although further developments along this line may not have been reported.

The following gives the principal characteristics of the Liberty motor, issued by the National Advisory Committee for Aeronautics.

Year (Model)	Horse-power	Weight Pounds	Weight Per H. P.	Gasoline H. P. Hour
1917	400	801	2.00	0.50
1918	432	808	1.90	0.48
1918	450	825	1.80	0.46

The motors listed are all 12 cylinder models, and the output and unit weights are based on a crank-shaft speed of 1800 R. P. M. The 5” x 7” bore and stroke give an output of 37.5 horsepower per cylinder in the latest model. In 1917, the Liberty motor was 65 per cent more powerful, and 28 per cent lighter, than the average stock motor in service during that year.

CHAPTER XXI. GLOSSARY OF AERONAUTICAL WORDS.

In the following list are the most common of the aeronautical words and phrases. Many of these words are of French origin, and in such cases are marked ”Fr.” In cases of English words, the French equivalents follow in parentheses. When a French word or term is given it is in italics, unless it is in common use in this country. Words marked (*) are the revisions adopted by the National Advisory Board of Aeronautics at Washington, D. C., and include the term ”Airplane,” which was intended to supplant the more common ”Aeroplane.” These revisions have not met with universal adoption, for the older words are too well established to admit of change.

A

ABSOLUTE UNITS. Units given in terms of mass. For expression in terms of pounds (Gravitational units) they must be multiplied by some factor involving the value of gravitation. Thus, to convert units of mass into pounds, the mass must be multiplied by the value of gravitation, 32.16 being the average figure taken for this quantity. To convert the absolute lift factors given by the N.P.L. into pounds per square foot per mile per hour, multiply the absolute value by O.005IV^2.

ABSOLUTE ZERO. The temperature at which heat ceases to exist. This is 461 degrees below the Fahrenheit zero, or 273 degrees below the Centigrade zero.

ACCELERATE. To increase in speed.

***ACIER* (Fr.)** Steel.

AERODONETICS. A word originated by Lanchester to denote the science of stability.

AEROCURVE. See AEROFOIL.

AEROFOIL.* A thin wing-like structure designed to obtain lift by the reaction of moving air upon its surfaces.

AERODYNAMICS. A science investigating the forces produced by a stream of air acting upon a surface.

AERODYNAMIC RESISTANCE. The resistance caused by turbulence or eddies.

AERODROME. A flying field. This word was also used by Langley to describe an aeroplane.

AEROSTAT. A lighter than air machine.

AEROSTATICS. The science of lighter than air machines, or devices sustained by flotation.

AEROPLANE. (Fr. L'Avion.) A heavier than air craft sustained by fixed wing surfaces driven through the air at the same velocity as the body of the machine. Auxiliary surfaces are provided for stabilizing, steering, and for producing changes in the altitude. The landing gear may be suitable for either land or water, although in the latter case it is generally known as a "Seaplane." The Committee equivalent is "Airplane."

AILERON.* A movable auxiliary surface used in maintaining lateral balance.

***AILE* (Fr.)** Wing.

AIRBOAT. An aeroplane provided with a light boat hull in which the pilot and passenger are enclosed.

AIRCRAFT.* Any form of craft designed for the navigation of the air. This includes aeroplanes, balloons, dirigibles, helicopters, ornithopters, etc.

AIRPLANE.* See aeroplane.

AIRSHIP. A lighter than air craft provided with means of propulsion.

AIR-SCREW. See PROPELLER.

ALTIMETER.* An instrument used for determining the height of aircraft above the earth.

ALTITUDE. Height of aircraft above sea level—generally given in feet.

AMPHIBIAN. An aeroplane equipped with landing gear for both land and water.

ANEMOMETER.* An instrument for measuring the velocity of the wind.

ANGLE OF INCIDENCE. The angle made by a surface or body with an air stream. In the case of curved wings, the angle is measured from the chord of the curve.

ANGLE OF ATTACK.* See Angle of Incidence.

ANGLE OF ENTRY. The angle made with the chord of a wing section by a line drawn tangent to the upper curved face, and at the front edge.

ANGLE OF TRAIL. The angle made by a line drawn tangent to the upper surface at the trailing edge.

ANEMOGRAPH. An instrument used for graphically recording the velocity of air currents.

APTEROID ASPECT. A wing is in apteroid aspect when the narrow edge is toward the wind.

***ARETIER ARRIERE* (Fr.)** See Trailing Edge.

***ARETIER AVANT* (Fr.)** See Leading Edge.

***ARBRE* (Fr.)** Shaft.

ASPECT RATIO.* The ratio of the wing span to the chord (length divided by width).

***ATTERRISSAGE* (Fr.)** Landing Gear.

***ATTACHES* (Fr.)** Fastenings.

AUXILIARY SURFACE. A surface used for stability or for the control of the aeroplane.

AVIAPHONE. An electric system of communication between the passenger and pilot.

***AVION* (Fr.)** See Aeroplane.

AXIS OF PITCH. The axis taken parallel to the length of the wings, and through the center of gravity. This is sometimes called the ”Y” axis.

AXIS OF ROLL. An axis passing fore and aft parallel to the center line of the propeller. This axis is sometimes called the ”X” axis.

AXIS OF YAW. A vertical axis, passing through the center of gravity, around which the machine swings when being steered in a horizontal direction under the action of the rudder. This is the ”Z” axis.

B

BALSA WOOD. A very light wood obtained from South America. It is lighter than cork.

BALLOON.* A form of aircraft of the lighter than air type comprising a gas bag and car. It is not provided with a power plant, and depends upon the buoyancy of the gas for its sustentation. A balloon restrained from free flight by means of a cable is known as a ”Captive balloon.” A kite balloon is an elongated form of captive balloon, fitted with a tail to keep it headed into the wind, and is inclined at an angle so that the wind aids in increasing the lift of the gas.

BALLONET.* A small air balloon within the main gas bag of a balloon or dirigible used for controlling the ascent or descent, and for keeping the fabric of the outer envelope taut when the pressure of the gas is reduced. The ballonet is kept inflated with air at the required pressure, the air being controlled by a valve or by regulating the speed of the blower.

BANK.* To incline the wings laterally when making a turn so that a portion of the lift force will be opposed to the centrifugal force.

BAROGRAPH.* (Fr. *Barographe*.) An instrument used for recording pressure variations in the atmosphere. The paper charts on which the records are made are used for determining the altitude of aircraft.

BAROMETER. An instrument used for measuring variations in the atmospheric pressure, but is not provided with a recording mechanism as in the case of the barograph.

BEAUME. A scale of density or a hydrometer unit used in measuring the density of fluids. On the Beaume scale water is 10.00, while on the ”Specific gravity” scale water is 1.00. The Beaume scale is generally used for gasoline and oils.

BENDING-MOMENT. The moment or ”Leverage” that tends to bend a beam.

***BEQUILLE* (Fr.)** Tail Skid.

***BERCEAU de MOTEUR* (Fr.)** Engine Bed.

BIAS LAID FABRIC. Fabric laid on the wing structure with the seams at an angle with the ribs.

***BIPLACE* (Fr.)** Two Seater.

BIPLANE.* (Fr. *Biplan*.) An aeroplane with two superposed lifting surfaces.

BODY. See FUSELAGE.

BODY RAILS. See LONGERONS.

***BOIS* (Fr.)** Wood.

***BOIS CREUS* (Fr.)** Hollow wood construction.

BOMBER. An aeroplane used for bombing operations.

BOOM. The fore and aft beams running from the wings to the tail in a pusher type biplane.

***BORD de ATTACQUE* (Fr.)** Entering or leading edge.

***BORD de SORTIE* (Fr.)** Trailing edge.

BLADE, PROPELLER. (Fr. *Pale-Helice.*)

BOULON **(Fr.)** Bolt.

BOUSSOLE **(Fr.)** Compass.

BRAS de AILE **(Fr.)** Wing Spar.

BREVET **(Fr.)** Flying permit or license.

BRAKES, AIR. Small adjustable flaps used in increasing the head resistance during a landing, thus decreasing the speed.

BURBLE POINT. The angle at which the lift of a wing section reaches a maximum.

BUOYANCY. The static force due to a difference in density. The difference in density between the gas in a balloon envelope and the outside air determines the sustaining or buoyant force of a balloon.

BUS. A slow fairly stable aeroplane used in training schools.

C

CABLE. (Fr. *Cable.*) A wire rope built up of a number of small strands.

CABRE'. *** (Fr.)** A flying attitude in which the angle of incidence is larger than normal with the tail well down.

CAMBER.* The convexity, or rise of a lifting surface, measured from the chord of the curve. It is usually given as the ratio of the maximum height of the curve to the length of the chord. Top camber refers to the upper surface, and bottom camber to the lower surface.

CABANE **(Fr.)** The center struts rising from the top of the body to the upper wing, or the short struts used for the bracing of the overhanging portions of a biplane wing. Usually cabane denotes the center cell struts.

CANARD **(Fr.)** A machine in which the elevator and stabilizer are in front. The canard type flies "Tail first."

CAPOT **(Fr.)** Cowl or motor hood.

CAPTIVE BALLOON.* See Balloon.

CAPACITY.* The lifting capacity is the maximum flying load of an aircraft. The carrying capacity (live load) is the excess of the lifting capacity over the dead weight of the aeroplane, the latter including the structure, power plant and essential accessories.

CARLINGUE **(Fr.)** Cock-pit.

CATA-HEDRAL. A negative dihedral, or wing arrangement, where the wing tips are lower than the center portion.

CATAPULT. A device for launching an aeroplane from the deck of a ship or other limited space. The first Wright machines were launched with a catapult.

CELL. (Fr. *Cellule.*) The space included between adjacent struts of a biplane. The space between the center struts is the "Center Cell."

CEILING. The maximum altitude to which an aeroplane can ascend.

CEINTURE de SURETE **(Fr.)** Safety Belt.

CENTER OF PRESSURE (C. P.)* The point of application of the resultant of all aerodynamic forces on an aeroplane wing. If the wing is supported at the center of pressure it will be in equilibrium.

CENTER OF GRAVITY. The point at which an aeroplane will balance when freely suspended.

CENTER OF BUOYANCY.* The point at which the resultant of all the buoyant forces act.

CHARNIERE **(Fr.)** Hinge.

CHASSIS. The landing wheels and their frame. This is also called the "Landing gear" in English, or the "Train de Atterrissage" in French. The chassis carries the load when resting on the ground or when running over the surface.

CHORD.* This has two meanings. The chord is the width of a wing or its shortest dimension. The chord is also the straight line drawn across the leading and trailing edges of a wing section.

CHASER. (Fr. *Avion de Chasse.*) A small, fast machine used in scouting or fighting. This type is also known as a "Speed scout."

CHARA-A-BANC **(Fr.)** A two seater aeroplane in which the pilot and passenger are seated side by side.

***CLOCHE* (Fr.)** A type of control column used on the old Type XI Bleriot.

COCK-PIT. The part of the body occupied by the pilot or passenger. The openings in the body cut for entrance and exit are the ”Cock-pit Openings.”

***COMMANDES A PONT* (Fr.)** Control bridge or Deperdussin yoke.

***COMPTE TOURS* (Fr.)** Tachometer or speed indicator.

COMPONENTS. The individual forces that make up a total resultant force.

CONTROLS.* (Fr. *Commandes*.) The complete system used for steering, elevating, balancing, and speed regulation. When controls are operated by hand they are known as ”Manual Controls.”

CONTROL BRIDGE. (Fr. *Commandes A Pont*.) The ”U” shaped lever used with the Deperdussin control system. Sometimes known as the ”Yoke.”

CONTROL STICK. (Fr. *Manche A Balai*.) A simple control lever capable of being moved in four directions for elevation, depression and lateral balance.

CONTROL SURFACES. The adjustable surfaces used for directing and balancing aircraft. On an aeroplane these are represented by the rudder, elevator, and ailerons.

***CONTREPLAQUE* (Fr.)** Three-ply wood.

***CORDE* (Fr.)** Cord or wire.

***CORD A PIANO* (Fr.)** Piano or solid hard wire.

CORD WINDING. (Fr. *Transfil*.) A winding wrapped around wooden struts to prevent splintering or complete fracture.

***COSSE* (Fr.)** Thimble for cable connections.

***COUSS IN* (Fr.)** Cushion.

COVERING, WING. (Fr. *Entoilage*.) The fabric used in covering the wing structure.

CRITICAL ANGLE.* The angle of attack or incidence at which the lift is a maximum.

COWL. (Fr. *Capot*.) The metal cover surrounding a rotary cylinder motor.

***CROISILLONS* (Fr.)** Bracing wires.

D

DAMPING. The reduction of oscillation or vibration by the resistance of the stabilizing surfaces.

DEAD LOAD. The weight of the structure, power plant, and essential accessories.

DEAD WATER. The wake directly in the rear of a moving body or surface.

***De CHASSE* (Fr.)** See CHASER.

DECALAGE.* The difference in the angle of incidence between the upper and lower wings of a biplane.

DEMOISELLE TYPE. A small monoplane type developed by Santos Dumont.

DENSITY. The specific weight, or the weight per cubic foot.

***DIEDRE* (Fr.)** Dihedral angle.

***DERIVE* (Fr.)** Fin.

DIHEDRAL ANGLE. (Fr. *Diedre*.) When the tips of the wing are higher than at the center, the two wing halves form an angle. The included angle between the two halves, taken above the surface, is known as the ”Dihedral angle.”

DIPPING FRONT EDGE. A wing section in which the leading edge is well bent down below the rest of the lower surface.

DIRIGIBLE.* A lighter than air craft in which sustentation is provided by a gas bag. It differs from a balloon in having a power plant, and is thus capable of flying in any desired direction regardless of the wind.

DISC AREA OF PROPELLER.* The total area of the disc swept out by the propeller tips.

DISCONTINUITY. Interruption in direction, or breaks in stream line flow. A body causing eddies or turbulence causes ”Discontinuous flow.” The surface separating the eddies and the continuous stream is called a ”Surface of Discontinuity.”

DISPLACEMENT. The volume or space occupied by a floating body.

DOUBLE CAMBER. A wing section in which both the top and bottom surfaces are given a convex camber or curvature.

DOPE. **(Fr.** ***Enduit.*****)** A solution used for protecting and stretching the wing fabric.

DRAG. The resistance offered to the forward motion of a surface or body moving through the air. As defined by the Advisory Committee this is the total resistance offered by the craft and includes both the resistance of the wings and body. This conception is confusing, hence the author has considered drag as being the forward resistance of the wings alone. The resistance of the structure is simply called the ”Head resistance,” and the sum of the resistances is the ”Total resistance.” This nomenclature was in existence before the Advisory Board proposed their definition.

DRIFT. As defined by the Advisory Board, the drift is the horizontal resistance offered by the wings alone. This is confusing since previous works defined ”Drift” as the amount by which an aircraft was driven out of its normal path by wind gusts. According to usage, ”Drift” is the sidewise deviation from the normal flight path.

DRAG WIRES. The bracing wires used for resisting the drag stresses set up in the wing.

DRIFT INDICATOR. An instrument for indicating the amount by which an aircraft is blown out of its path by side winds.

DUAL CONTROL. A double system of control that can be operated both by the pilot and passenger.

DUTCH ROLL. A combined side roll and fore and aft pitch. The machine rolls from side to side in combination with an up and down motion of the nose.

DYNAMIC PRESSURE. The pressure due to the impact of an air stream.

E

ECCENTRIC LOAD. A load acting to one side of the center line of a beam or strut.

ECOLE **(Fr.)** School.

ECROU **(Fr.)** Nut.

EDDY. An irregularly moving mass of air caused by the breaking up of a continuous air stream, or by ”Discontinuity.”

EFFICIENCY. The efficiency of a lifting surface is generally expressed by the ratio of the lift to the drag, or the ”Lift-drag ratio.” The efficiency of a propeller is the ratio of the work usefully applied to the air stream in regard to the power supplied to the propeller.

ELEVATOR.* The hinged horizontal tail surface used for maintaining longitudinal equilibrium and for ascent or descent.

EMPENNAGE **(Fr.)** The group of tail surfaces, including the elevator and stabilizer.

ENDUIT **(Fr.)** Dope.

ENGINE ROTATION. According to the Advisory Board, an engine is turning in right-hand rotation when the output shaft stub is turning anti-clockwise.

ENGINE BEARERS (BED). (Fr. *Berceau du Moteur*). The timbers or fuselage members upon which the engine is fastened.

ENGINE SPIDER or BRACKET. (Fr. *Arraignee Support de Moteur.*) A perforated metal support for a rotary cylinder motor.

ENTERING EDGE. (Fr. *Bord D’Attaque or Aretier Avant.*) The front edge, or air engaging edge, of an aerofoil or lifting surface. It is also called the ”Leading Edge.”

ENTOILAGE **(Fr.)** Wing fabric or covering.

ENVELOPE. The gas bag of a balloon or dirigible.

ESSIEU **(Fr.)** Axle.

ENVERGURE **(Fr.)** Wing span.

EXPANDING PITCH. A system in which the pitch increases or ”expands” towards the tips of the propeller.

F

FABRIC, WING. (Fr. *Entoilage.*) The cloth used for covering the wing and control surface structures.

FAIRING. (Fr. *Fusele.*) Wood coverings used to streamline steel struts or other structural members.

FERRULES. Sheet steel caps used for the ends of the interplane Struts.

FIN. (Fr. *Derive*.) A fixed vertical stabilizing surface used for damping out horizontal vibration and oscillations.

FINENESS RATIO. The ratio of the maximum length to the width of a streamline body.

FITTINGS. (Fr. *Ferrures, Godets*.) The metal parts used for making connections between the structural parts of an aeroplane.

FIXED TAIL. (See STABILIZER.)

FLACCID BLADE PROPELLER. A propeller having a cloth covered frame work on which the fabric is free to adjust itself to the air pressure.

FLAPS, ELEVATOR. (Fr. *Volets de Profondeur*.) See ELEVATOR.

FLEXIBLE SHAFT. (Fr. *Transmission flexible*.) Used for tachometer drive.

FLOORING. (Fr. *Plancher*.)

***FLASQUE D'HELICE* (Fr.)** Propeller flange.

FOOT LEVER. (Fr. *Palomnier*.) The foot lever generally used to operate the rudder.

FORMERS. Supports used in giving a certain outline to the fuselage. The formers are attached to the fuselage frame and in turn support small stringers on which the fabric is fastened.

FRICTIONAL WAKE. The following current of air in the rear of a moving body or surface. Because of the friction, a portion of the air is drawn in the direction of the motion.

FUSELAGE. A structure, usually enclosed, which contains and streamlines the power plant, passengers, fuel, etc. Sometimes called the "Body."

FUSELAGE BIPLANE. See TRACTOR BIPLANE.

FUSIFORM. Of streamline form.

G

GAP. The vertical distance between leading edges of the superposed planes of the biplane or triplane.

GLIDING. (Fr. *Vol Plan*.) With an aeroplane the weight of the machine can be made to provide a forward component that will allow the machine to descend slowly (without power) along an inclined line. This line is known as the ”Gliding Path.”

GLIDING ANGLE. The angle made by the gliding path with the horizontal is known as the gliding angle. This may be expressed in degrees or in the units of horizontal distance traveled per foot of fall.

GLIDER. A small form of aeroplane without a power plant, which is capable of gliding down from an elevation in the manner of an aeroplane. With a proper direction and velocity of wind it can be made to hold a constant altitude and can be made to hover over one spot continuously.

***GOUVERNAIL* (Fr.)** Rudder.

GUY WIRE. A bracing wire.

H

HARD WIRE. A solid tempered wire of high tensile strength used for aeroplane bracing systems.

H.T. WIRE. Another expression for hard or high tensile strength wire.

HEAD RESISTANCE. The resistance of the structural parts of an aircraft. In an aeroplane, the head resistance is the sum of the resistances of the body, stays, struts, chassis, tail, rudder, elevators, etc.; in fact, this includes everything with the exception of the wing drag.

HELICOPTER. A type of direct lift machine in which sustentation is performed by vertical air screws or propellers.

HELIX. A geometrical curve formed by the combined advance and revolution of a point.

***HELICE* (Fr.)** Propeller or screw.

***HELICE TRACTIVE* (Fr.)** Tractor propeller.

HYDROAEROPLANE. See SEAPLANE.

HOLLOW WOOD CONSTRUCTION. (Fr. *Bois Creus.*)

HOOD OF ENGINE. (Fr. *Capot.*)

HYDROMETER. An instrument for measuring the density of liquids.

I

ICTHYOID. Fish or stream lined shape.

INCLINED PLANE. A plane inclined to the wind stream so that the energy of the air stream is broken up into the two components of lift and drag.

INCLINOMETER. An instrument used for determining the angle of the flight path.

INCIDENCE. See ANGLE OF INCIDENCE.

INCIDENCE, NEGATIVE. The angle formed with the air stream when front edge of the lifting surface dips below the apparent flight path.

INHERENT STABILITY. Stability due to some fixed arrangement of the main or auxiliary surfaces. A machine that requires mechanism or moving parts for its stability is automatically but not inherently stable.

INTERFERENCE. The crowding of the airstream in the gap of a biplane or triplane causes the surfaces to ”Interfere,” and results in a loss of lift.

J

JOY STICK. See CONTROL STICK.

***JAMB de FORCE* (Fr.)** Bracing strut.

***JANTE* (Fr.)** Rim of wheel.

K

KITE BALLOON. See BALLOON.

KILOMETER. French metric unit of distance. One kilometer equals O.621 statute mile or O.5396 nautical mile.

KILOGRAM. Metric unit of weight. One kilogram equals 2.205 Avoir. pounds.

KNOCKOUT HUB. An aeroplane chassis wheel hub provided with removable bronze bushings.

KEEL PLANE AREA.* The total effective side area of an aeroplane which tends to prevent skidding or side slipping.

L

LATERAL STABILITY. Stability about the fore and aft axis.

L'AVION **(Fr.)** Aeroplane.

LAMINATED. Built up in a series of layers.

LEEWAY.* The angular deviation from a given course due to cross currents of wind.

LEADING EDGE. See ENTERING EDGE.

LIFT. The vertical component of the forces produced on an aerofoil by an air current.

LIFT COEFFICIENT. The lift per unit of area at a unit velocity (Ky). The American lift coefficient is the lift in pounds per square foot at one mile per hour.

LIFT CAPACITY. See CAPACITY.

LIVE LOAD. The live load generally includes the passengers, pilot, fuel, oil, instruments, and portable baggage, although in some cases the instruments are included in the dead load. The live load is the difference between the total lift and the dead load.

LOADING (UNIT). The unit loading is the load carried per square foot of wing surface, or is equal to the total weight divided by the area.

LONGERONS. The principal fore and aft structural members of the fuselage.

LONGITUDINALS. See LONGERONS.

LONGITUDINAL STABILITY. Stability in a fore and aft direction about the ”Y” axis.

M

MASS. The quantity of matter. Is equal to the weight in pounds divided by the gravitation, or generally to the weight divided by 32.16.

MANDRIN de BOIS **(Fr.)** Wood spar.

MAROUFLAGE **(Fr.)** Strut taping with fabric bands.

MANCHE A BALAI **(Fr.)** Control stick.

MANETTE **(Fr.)** Throttle.

MAR, MONTANT **(Fr.)** Interplane struts.

METACENTER.* The point of intersection of a straight vertical line passing through the center of gravity of the displaced fluid or gas, and the line that formerly was a vertical through the center of gravity before the body was tipped from its position of equilibrium. There is a different metacenter for each position of a floating body.

MONOPLANE. (Fr. *Monoplan*.) A type of aeroplane with a single wing surface.

MONOCOQUE BODY (Fr.) A body built up in tubular form out of three-ply wood, thus virtually forming a single piece body.

MONOPLACE **(Fr.)** Single seater.

MONOSOUPAPE **(Fr.)** Single valve Gnome motor.

MONTGOLFIER **(Fr.)** Hot air balloon.

MULTIPLANE. An aeroplane having the main lifting surface divided into a number of parts.

N

NACELLE. The body or fuselage of an aeroplane or dirigible. It generally signifies a dirigible body. The short fuselage of a pusher type is often called the nacelle.

NATURAL STABILITY. See INHERENT STABILITY.

NEGATIVE AILERONS. Ailerons making a negative angle with the wind when in normal flight. The negative incidence of the ailerons is decreased on the low side and increased on the high side so that the high side is pushed down. This decreases the drag on the lower, inner wing in making a turn, and therefore does not tend to stall the machine.

***NERVURES* (Fr.)** Wing ribs.

NORMAL PLANE. A flat plane placed with its surface at right angles to the air stream.

NORMAL PRESSURE. The pressure at right angles to the surface of a plane.

NON-LIFTING TAIL. A stabilizing surface arranged so that it carries no load in normal flight.

NOSING. The member used for the entering edge of the wing.

NOSE. The front end of the aeroplane.

NUT. (Fr. *Ecru.*)

O

***OBLITEUR RINGS* (Fr.)** The special piston rings used on the Gnome motor.

ORTHOPTER. Any type of wing flapping machine.

ORNITHOPTER. A wing flapping machine that imitates bird flight.

ORTHOGONAL BIPLANE. A biplane with the upper and lower leading edges in line.

OSMOSIS. The transfer of hydrogen or other gas through a balloon envelope by a molecular process. This must not be confused with leakage due to holes.

OUTRIGGER. See Boom.

O.W.L. TYPE. A type of machine adapted for use over ”Water and Land.”

P

PANCAKE. A straight vertical drop due to stalling.

PATH OF FLIGHT. The path of the center of gravity of an aircraft in reference to the air.

PALONNIER **(Fr.)** Foot bar or lever.

PANELS. The wing sections included between adjacent struts.

PATIN, PATINNAGE **(Fr.)** Skids.

PARASOL TYPE. A monoplane in which the wing is located above the body.

PENGUIN. A training machine which cannot leave the ground.

PERSONNEL. Pilot and passengers.

PETROL. An English term for gasoline.

PHILLIP’S ENTRY. See DIPPING FRONT EDGE.

PILOT. The operator of aircraft.

PILOT BALLOONS. Small balloons sent up to determine the direction of the wind.

PITCH. The forward distance traveled through by one revolution of the propeller.

PITCHING. A fore and aft oscillation, first heading up and then diving.

PISCIFORM. Fish form.

PIQUE, VOL **(Fr.)** Dive.

PLAFOND **(Fr.)** ”Ceiling” or maximum altitude obtainable.

PLAN CENTRAL **(Fr.)** Center panel.

PLANCHER **(Fr.)** Flooring.

PLAN FIXE de QUEUE **(Fr.)** Stabilizer surface.

PLAN de DERIVE **(Fr.)** Stabilizing fin.

PITOT TUBE. An instrument for measuring the velocity of an air current.

PONTOON. Seaplane floats.

POIGNEE **(Fr.)** Handle.

POMPE **(Fr.)** Pump.

POMPE A PRESSION **(Fr.)** Pressure pump.

POULIE **(Fr.)** Pulley.

PROPELLER. (Fr. *Helice.*) A device used in converting the energy of a motor into the energy required for the propulsion of an aircraft. It consists of two or more rotating blades which are inclined in regard to the relative wind, and hence they act as rotary aeroplanes in creating a tractive force.

PROPELLER ROTATION. The direction of rotation is determined when standing in the slip stream.

PNEU **(Fr.)** Pneumatic tire.

PTERYGOID ASPECT. A wing flying with the long edge to the wind is said to be in ”Pterygoid Aspect.”

PUSHER TYPE. An aeroplane with the propeller in the rear of the wings.

PYLON. A marking post on an aeroplane course.

P

RACE OF A PROPELLER. The air stream thrown by the propeller.

RADIAL MOTOR. A motor with the cylinders arranged in radial lines around the crankcase.

RAKED TIPS. The tips are arranged at an angle with the wing so that the span of the trailing edge is greater than that of the leading edge.

RAYONS **(Fr.)** Spokes.

REFLEX CURVE. An aerofoil in which the trailing edge is given an upward turn.

REMOUS **(Fr.)** A downward current of air.

RESERVOIR **(Fr.)** Tank.

RESERVOIR SOUS PRESSION **(Fr.)** Pressure tank.

RESULTANT. The total force resulting from the application of a number of forces.

RETREAT. Back swept wings with the tips to the rear of the wing center.

RIBS. The fabric forming member of the wing structure.

RUDDER, VERTICAL. A control surface used for steering in a horizontal plane.

ROLL. Oscillation about the fore and aft axis.

S

SCREW. (Fr. *Helice.*) See PROPELLER.

SEAPLANE.* An aeroplane equipped with floats or pontoons for landing on water.

SCOUT TYPE. See CHASER.

SERVICE TANK. The fuel tank feeding directly into the carburetors.

SET BACK WINGS. A type of wing in which the leading edge is inclined backward as in the Mann biplane. The trailing edge is straight.

SHOCK ABSORBERS. An elastic device on the chassis or landing gear that absorbs vibration by allowing a limited axle movement.

SIDE SLIP.* Sliding down sideways, and toward the center of a turn. This is due to an excessive angle of bank.

SIEGE **(Fr.)** Seat.

SIMILITUDE, LAWS OF. The drag or resistance of a small aerodynamic body does not increase in direct proportion with the area and speed. The laws governing the relation between a model and a full size machine are known as the laws of "Similitude."

SKIDS.* (Fr. *Patin, Pattinage.*) Long wood or metal runners attached to the chassis to prevent the ”nosing over” of a machine when landing, or to prevent it from dropping into holes or ditches on rough ground. It also acts when the wheels collapse.

SKID CURTAINS. Vertical side curtains or surfaces provided to reduce the skidding action on turns or to prevent side slip.

SKIDDING.* Sliding sideways away from the center of the turn. It is due to insufficient banking on a turn.

SKIN FRICTION. The resistance caused by the friction of the air along a surface.

SLIP.* Applied to propeller action, the slip is the difference between the actual advance of an aircraft and the theoretical advance calculated from the product of the mean pitch and the revolutions per minute. When the propeller is held stationary, the slip is said to be 100 percent.

SLIP STREAM. The wind stream thrown by a propeller.

SOARING FLIGHT.* The sustentation of a wing surface due to wind currents and without the expenditure of other power. Soaring flight is performed by gulls, buzzards and vultures, but no practical machine has yet been built that will fly continuously without the aid of power.

SPAN. (Fr. *Envergure.*) The length or longest dimension of a wing, generally taken at right angles to the wind stream.

SPAR. (Fr. *Bras D’Aile.*) The main wing beams that transmit the lift to the body.

SPOKES. (Fr. *Rayon.*)

SPREAD.* See SPAN.

STABILITY.* The property of an aircraft that causes it to return to a condition of equilibrium after meeting with a disturbance in flight.

STAGGER.* The advance of the leading edge of the upper wing over that of the lower wing.

STABILIZER.* (Fr. *Stabilisateur.*) A horizontal tail surface (fixed) used for damping out oscillations and for promoting longitudinal stability.

STALLING.* The condition of an aeroplane that has lost the speed necessary for steerage way or control.

STALLING ANGLE. See CRITICAL ANGLE.

STEERING WHEEL. (Fr. *Volant*.)

STATOSCOPE.* An instrument for detecting a small rate of ascent or descent. Used principally with balloons.

STAY WIRE. (Fr. *Tendeur*.) A wire or cable used as a tie to hold members together, or to give stiffness to a structure.

STEP.* A break in the form of a float or flying boat bottom.

STREAMLINE. A form of body that sets up no turbulence or eddies in passing through air or liquid.

STRUT.* **(Fr. *Mar, Montant*.)** A compression member used in separating the upper and lower wings of a biplane, or the longerons of the fuselage.

SWEEP BACK. See RETREAT.

T

TACHOMETER. (Fr. *Compte Tours*.) An instrument for directly indicating the revolutions per minute.

TAIL.* **(Fr. *Queue*.)** The rear part of an aircraft to which usually are attached the rudder, stabilizer, and elevator.

TAIL SKID. (Fr. *Bequille*.) A flexibly attached rod which holds the tail surfaces off the ground, and breaks the landing shocks on the tail structure.

TAIL BOOM. See BOOM.

TAIL DIVE. A very dangerous backward dive.

TAIL SPIN. A condition in which the tail revolves about a vertical line passing through the center of gravity.

TANDEM PLANES. A form of aeroplane in which the wings are placed one after another.

TAUBE. An old type of German or Austrian aeroplane with back swept wing tips.

TAXI. To run along the ground.

THIMBLE. (Fr. *Cosse.*) An oval grooved metal fitting used for the protection of a cable loop at the point of attachment.

THREE-PLY. (Fr. *Contreplaque.*) A wood sheet composed of three layers of wood glued together, the line of grain crossing at each joint.

THRUST. The propulsive force exerted by a propeller.

THRUST DEDUCTION.* The reduction of thrust due to a reduction of pressure under the stern of the aircraft.

***TIRANT* (Fr.)** Bracing tubes.

TORQUE. The turning force or moment exerted by the motor.

***TOILE* (Fr.)** Linen.

TORQUE WARP. The amount of warp, or permanent set in the ailerons necessary to overcome the torque or twisting effect of the motor. In some machines the torque is overcome by changing the angle of incidence at the wing tips.

TRACTOR BIPLANE. A type of aeroplane in which the propeller is placed in front of the wings so that it pulls the machine along.

TRAILING EDGE. The edge of a wing at which the air stream leaves the surface.

***TRAIN D'ATTERRISSAGE* (Fr.)** Landing gear.

***TRANSFIL* (Fr.)** Cord winding on the struts.

TRIPLANE. (Fr. *Triplan.*) An aeroplane with three superposed wings.

TURBULENCE. The eddies or discontinuity caused by a body or surface passing through the air.

U

USEFUL WEIGHT. The difference between the total lift and the dead load. This comprises the pilot and passenger, the weight of the fuel, baggage and instruments.

UNIT LOADING. The weight per square foot of main wing surface.

V

***VOL PLANE* (Fr.)** See GLIDE.

***VOL PIQUE* (Fr.)** See DIVE.

***VOLANT* (Fr.)** Steering wheel.

***VERNIS* (Fr.)** Varnish.

***VRIL* (Fr.)** Spinning nose dive.

***VOLETS de PROFONDEUR* (Fr.)** Elevator flaps.

W

WARP CONTROL.* Lateral control obtained by twisting the wing tips.

WASHOUT. Decreased camber or incidence toward the wing tips.

WEATHER-COCK STABILITY. Stability in the line of travel, or with the relative wind, so that the machine always tends to head into the wind.

WHALE TYPE. A speed type biplane in which the body entirely fills the gap between the upper and lower wings.

WHIRLING TABLE. A testing device in which a model wing or body is placed at the end of a revolving arm.

WINGS.* (Fr. *Aile.*) The main supporting surfaces of an aeroplane.

WORKING FACE. The face of a propeller blade lying next to the slip stream.

WAKE GAIN.* Due to skin friction and eddies, a moving aircraft drags a certain amount of the surrounding air with it. This reduces the effective resistance of the hull and increases the effective pitch of a pusher propeller since the latter acts on a forward moving mass of air. This is ”Wake gain.”

[image]

Launching with Catapult from Deck of Battleship

[image]

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