MILITARY AEROPLANES

AN EXPLANATORY CONSIDERATION OF THEIR CHARACTERISTICS, PERFORMANCES, CONSTRUCTION, MAINTENANCE AND OPERATION, FOR THE USE OF AVIATORS

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PREFACE TO SECOND, THIRD AND FOURTH EDITIONS

Although great strides have been made in the application of military aeroplanes to problems of strategy and tactics, actual war lessons show that the principles of design, construction, and flying remain the same. Many important improvements in details, however, are given great impetus by the exacting and inspiring rivalry of war.

The object of this book, in assisting military aviators to acquire a more intimate knowledge of their machines, appears to be attained, in that at the military and naval aviation schools of several nations it has been adopted.

These new editions are corrected, more conveniently re-arranged and somewhat enlarged.

Boston, June, 1917.

PREFACE

That military or naval aviators should desire to acquire a sound knowledge and just appreciation of the machines to which, day after day, they entrust their lives, is but natural. And at the suggestion of the officers of the Signal Corps Aviation Section, the writer has gathered together some information acquired in practical experience, into the form of a text-book for flyers.

Based, in its composition, on questions asked and information sought by military aviators, and written practically on the field, at the largest aviation center in this country, with unusual facilities for inspection, test, flying and discussion of aeroplanes — every effort has been made in this work to permit this practical atmosphere to permeate its pages.

It is to be noted that enlargement on or repetition of any matter contained in the author's previous work, "Monoplanes and Biplanes," has been avoided. There is presented here a new text-book, limited to the practical consideration of Military Aeroplanes in a manner particularly applicable on an aviation field, and containing knowledge that every aviator should have.

Occasion is taken to point out that the considerations of flying, stability, airworthiness and performances, are based on experiences of the author himself, in acting as observer, noting aeroplane movements, reading instruments and taking observations, in flight (a specialty to which the writer has devoted scores of hours in the air), particularly in the extensive experimental flying on the Signal Corps aeroplanes designed by him and piloted by Lieut. T. DeWitt Milling. To the latter, the author wishes to express appreciation of much valuable co-operation and assistance; and he is also indebted to Capt. Townsend F. Dodd, Lieut. Walter R. Taliaferro, George Hallett, and Oscar A. Brindley, expert aviator, for many valuable suggestions and assistance in proof reading, and to Capt. Arthur S. Cowan, in command, for every encouragement in this work.

Opportunity cannot too often be taken by aeronautical engineers to recognize and pay tribute to the great work of the Aerodynamical Laboratories, and in particular to the labors of the eminent French engineer, Gustav Eiffel, whose exhaustive tests and their splendid presentation form a basis for accurately predicting performances that one cannot help but marvel at. This work, and the reports of the British Advisory Committee, have been freely consulted, and reference frequently made to information they contain.

Coronado, Cal., May, 1915.

MILITARY AEROPLANES

CHAPTER I.

INTRODUCTION

Although Aviation is a new field of human endeavor, its application to the art of warfare is already becoming a specialty. Only recently has it been appreciated, that military requirements have a most vital and important influence on many features of aeroplanes — not only in the art of using them in military operations, but in their fundamental design and construction.

It is planned, therefore, to give particular attention here to the military aeroplane, as we find it today — emerged from a crude state of invention and development into a more or less finished product, which, in the greatest war of history, has gloriously demonstrated its strategical and tactical importance.

It is no longer necessary to speculate on the uses of aeroplanes in warfare. What has actually been accomplished in directing artillery fire, in reconnaissance, in dispatch-carrying, and in offensive work has opened a new phase of warfare, as significant as it is surprising.

The technique of the use of aeroplanes in strategy and tactics, is decidedly a subject for the military expert, but the general design and construction of aeroplanes to accomplish certain definite purposes, and their operation and maintenance in the field, are subjects that may properly be considered here.

In addition to expert ability in their operation, it is found that a sound and practical knowledge of the design and construction of aeroplanes is exceedingly helpful to the military aviator.

A full consideration, therefore, is given to elementary theory and practice applied in aviation, and the information used is primarily designed to be of definite service, in the field, where many unforeseen difficulties constantly arise.

Before taking up the determination of its elements, it is necessary, clearly, to distinguish the aeroplane from other craft designed to navigate the air.

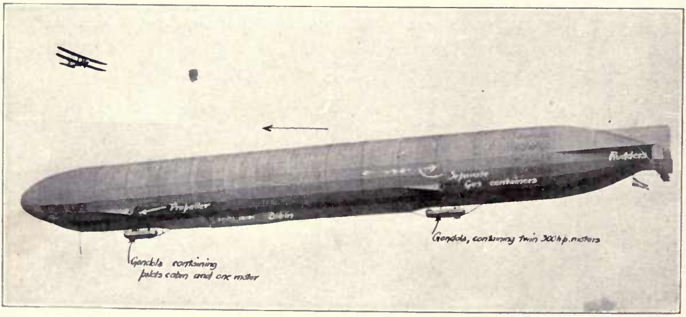
Aircraft may be divided into the following classes:

1. AIRSHIPS OR DIRIGIBLE BALLOONS.

The "airship," is distinctly a lighter-than-air machine, consisting of a balloon or gasbag, containing a gas — hydrogen for example — lighter than air, which by displacement of an equal volume of air, gives a flotation, the magnitude of which is determined by the kind of gas, the size of gas container, and atmospheric conditions. The ordinary free balloon is, in short, nothing more than a harnessed "bubble," and the dirigible, or airship, is a balloon of elongated shape, fitted with steering apparatus and propelling mechanism.

Airships are constructed mainly in three different types, the **"Rigid,"** the **"Semi-Rigid"** and the **"Flexible or Non-Rigid."** These designations refer, entirely, to the manner of combination of gas container and framework carrying the weights of engines, etc. A flexible gas container, held in shape only by the pressure of gas within and to which the load is hung, characterizes the "Non-Rigid" system. A gas container, held in shape by gas pressure, with an additional stiffening keel to which the weights are attached, is descriptive of the "Semi-Rigid." Whereas, in the "Rigid" system, a stiff, braced frame-work or hull, carrying directly the motors and loads, is formed to contain within it numerous separate, drum-shaped gas containers instead of balloons. The stiff frame provides, in itself, that necessary rigidity of hull, which interior gas pressure on the envelope provides in the other types.

The Zeppelin airship was the first successful development of the rigid system.



A Zeppelin "Rigid" airship and above it an aeroplane. The airship can float at rest but an aeroplane must acquire speed in order to fly.

2. FLYING MACHINES.

The Aeroplane — In distinction to the airship, supported in the air by a buoyant gas, the aeroplane is supported by an upward wind pressure, generated by its own speed through the air. This lifting pressure is obtained on specially formed wing surfaces, which are set at an inclined angle, and forced through the air at the required speed by an air propeller. Suitable auxiliary surfaces and rudders are used to preserve the equilibrium of the craft and to enable the pilot to steer it.

The Helicopter — Air propellers are similar in character to marine screw propellers, and not only are they made use of to push or pull an aeroplane, but it has been proposed, in operating them on a vertical axis, to use their thrust directly, in lifting loads. This type of flying machine is called the "Helicopter" or "direct lift" machine, and does not involve the principle of lift from the inclined arched plane, used in the aeroplane.

The Ornithopter — Nature's flying machines — the birds — are neither screw propelled aeroplanes nor helicopters. They derive their support from the wind pressure on their outstretched wings precisely as does the aeroplane, but for propulsion, the bird flaps its wings in a rowing, weaving motion, which gives a forward push. When an aeroplane glides, it resembles in character the soaring of a bird, with wings outstretched, but attempts to derive propulsion from a reciprocating movement of wings, have not been successful, as yet. Machines of this type are called "Ornithopters" or "Flapping-wing" Machines.

Although little has been accomplished with them, the possibilities of the helicopter and ornithopter have by no means been fully investigated, and whether or not a combination of "direct lift" and aeroplane, often called the "gyroplane," has any future, is still a subject for study.

Airships, on the other hand, are very highly developed, and although they are difficult to handle and very expensive, they are looked upon as "battleships" of the air. Their design and construction are full of interesting, and difficult, engineering problems, and it is planned to give them consideration elsewhere.

In this connection it is important to point out, that the oft-stated "principle," that aeroplanes are limited in size, due to a proportionally greater increase in weight as the size is increased, is a fallacy, and, as a matter of fact, recent work on large-sized machines, appears to demonstrate, that in proportion to the weight of the machine, as the size increases, a greater excess load can be carried. (In later chapters this feature will be further investigated.) Aeroplane "battleships" are, by no means, an impossibility. The consideration of large-size aircraft, therefore, becomes merely an efficiency comparison of the lift by gas bag and the lift by air pressure on planes. If the dirigible balloon lifts more "live load," per pound head resistance, at the same speed than does an aeroplane, the dirigible is apt to survive.

Of the various kinds of aircraft, only one type of flying machine is to be considered here, primarily, because we find the aeroplane, at present, the most successful, the most economical and the best developed means of navigating the air.

CHAPTER II.

TYPES OF AEROPLANES

At the present time the early inventive stage in the development of the aeroplane is gradually but perceptibly giving way to a state of more precise engineering. And, in this step in its progress, aviation is but following the course taken by almost every other art and science. Any classification of aeroplanes, therefore, is subject to modification as newer craft are developed, and old ones rendered obsolete. But the general principles of the machines do not change as rapidly as do their concrete interpretations.

The principle of sustentation of an aeroplane from the upward push of air flowing past it, has been stated, and, in the following chapters, will be analyzed. The support being derived from the free air, an aeroplane is readily subject to loss of balance, due to air disturbances, gusts, convection currents, etc. It follows, therefore, that many features designed to overcome loss of balance, are used on aeroplanes. Organs are also introduced to give the pilot control over the craft within definite limits.

An aeroplane consists, therefore, of lift-generating surfaces attached to a frame carrying motor, fuel, pilot and equipment, and in combination with devices to balance and steer the craft.

Flying freely, in the air, an aeroplane has three axes of rotation.

1. It may ascend or descend, by virtue of changes in its longitudinal path. The nosing up and nosing down of an aeroplane is termed "pitching," as in boats.

2. An aeroplane, in flight, may change its direction of travel. This is termed "yawing," as in boats.

3. In addition to these, an aeroplane can tip over to either side, on a transverse axis, and this movement is termed "banking" or "rolling." In making turns, it is necessary to "bank" up an aeroplane, sidewise, sufficiently to overcome the centrifugal force, and prevent skidding. This "banking" is obtained by manipulating the lateral control.

The locomotive driver, is steered by the tracks, and has to give his attention, only to the control of the speed of his engine; an automobile driver, controls his motor, also, but in addition must steer his machine; whereas the aeroplane pilot both steers and operates his engine, and in addition must give his best attention, continually, to balancing the machine, fore and aft and side to side.

Like every science, Aviation has a language of its own, and a method is used here of expressing this language in photographs. Study of the explanatory caption and of the photographs themselves, therefore, is equal in importance to the reading of the text.

The types of aeroplanes considered here are typical ones of distinct features, and a more detailed discussion of their merits will be found in later chapters.

THE "TRACTOR" AND THE "PUSHER"

An aeroplane, that is pulled through the air by a propeller situated at the front of the machine, is called a **"tractor."**

On the other hand if the propeller is back of the main lifting planes, the machine is called a **"pusher."** These terms are very expressive and very widely used.

The single propeller "tractor" is the most widely used type now, but the "pusher" type, particularly for gun-carrying, has still a "raison-d'etre."

The term "biplane" refers to an aeroplane with wings, superimposed, and "monoplane" to a single deck type of plane.

THE CONTROLS.

Since there are three axes about which an aeroplane may rotate, it follows that three controlling organs are required:

1. The "elevator," for pitching;
2. The "rudder," for steering or "yawing;"
3. The "lateral" or "rolling" control.

The principle of the air force derived from an inclined plane, is used in all of these controls. The "elevator" is inclined up or down, to lift or depress the tail of the machine. The rudder is turned so as to permit the wind to blow on it, to one side or the other, whereas the lateral control consists, merely, in giving a difference in angle to the two sides of the wings, causing one side to lift more than the other.

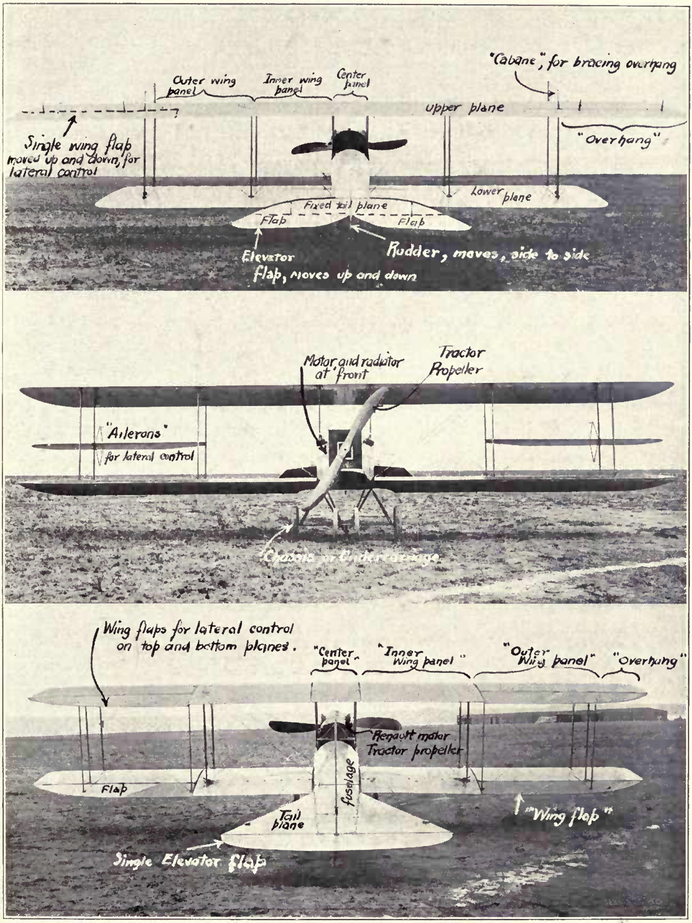
There are three general means of lateral control:

1. "Ailerons," or separate small planes, on either side independent of the main lifting surface;

2. "Wing flaps," or portions cut out of the main surface and hinged thereto;

3. "Warping," which consists in twisting the main lifting surface, so as to get a greater angle of inclination to the wind on one side and less on the other.

In the construction of rudders and elevators, the necessary change in angle to alter the wind pressure, is accomplished either by pivoting the entire surface, or by turning a flap hinged to a fixed surface in front of it.



Above — Rear view of tractor, with overhang wings, and wing flaps for lateral control.
Center — Front view of tractor with ailerons.
Below — Rear view of tractor with equal planes, and lateral control flaps on both upper and lower planes.

The combination of fixed tail plane and movable flap is often termed a "flap and fin" elevator.

THE TRACTOR BIPLANE.

The form of aeroplane that at present approaches the nearest to a standardized type is the Tractor Biplane.

The main lifting surface, as may be seen from the photographs, consists of two super-imposed planes, with their widest dimension across the flight path.

The main planes are attached to a long, fish-shaped body, termed the "fuselage," which, in effect, is the backbone of the machine, since it carries the motor and propeller at the front and the seats near the center, while at the extreme rear are mounted the rudder and elevator.

The use of an enclosed fuselage in a tractor type is almost universal, and greatly increases the efficiency of a machine, by reduction of head resistance in the wind. The disposition of the seats in the body gives excellent protection to the aviators. It will be noticed that two seating arrangements are shown — "tandem," one ahead of the other, and "side by side." The former is good for military scouting, and the latter possibly for training.

In the types of tractor biplanes shown, the chassis is mounted to the body, as is also the center section of the wings. By taking the outer wings off, this type is readily made transportable by road.

The distinction between a double flap and single flap elevator is shown in the illustrations, and there is also shown the difference between ailerons and flaps for lateral control.

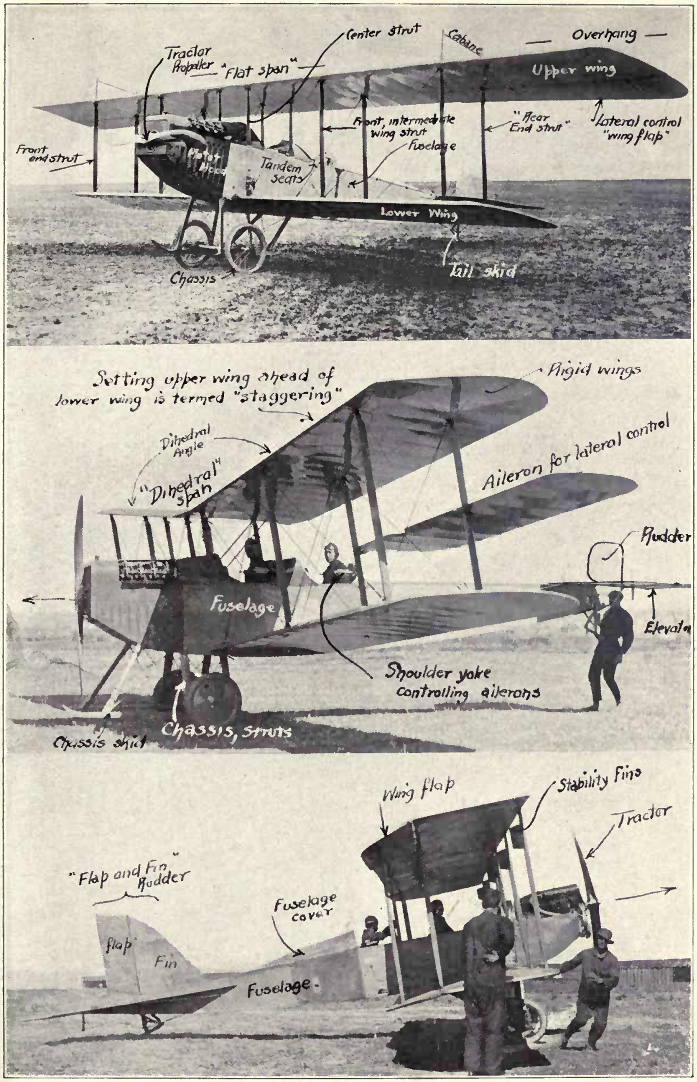
In the photograph of the biplane tractors in flight, several details show up clearly, — particularly, angles of view of the pilot, whose vision is interfered with by the lower plane.

PUSHER BIPLANES.

The older types of machines, particularly the early Wright and Curtiss, were pusher types — the Wright, however, had two propellers and the Curtiss only one. These types were open-bodied, entirely unprotected, and with the motor to the side of or behind the aviator.

A few years of development, led to the adoption of either a nacelle — short fuselage, protecting seats and motor only, — or a fuselage. In using a fuselage on a "pusher" machine, it becomes necessary either to mount a propeller at the extreme rear "torpedo" fashion, to mount a propeller on either side, or to have a propeller running on a large bearing around the fuselage. In "pusher" flying boats the propeller tips just clear the boat.

The earliest Wright machine had the elevator in front, so that to ascend the elevator was turned up, thus lifting up the nose, and vice versa; whereas, when it was later changed to the rear, for reasons of stability, to ascend it became necessary to turn the elevator the opposite way, thereby pressing down the tail. This distinguishes "front elevator" and "rear elevator."

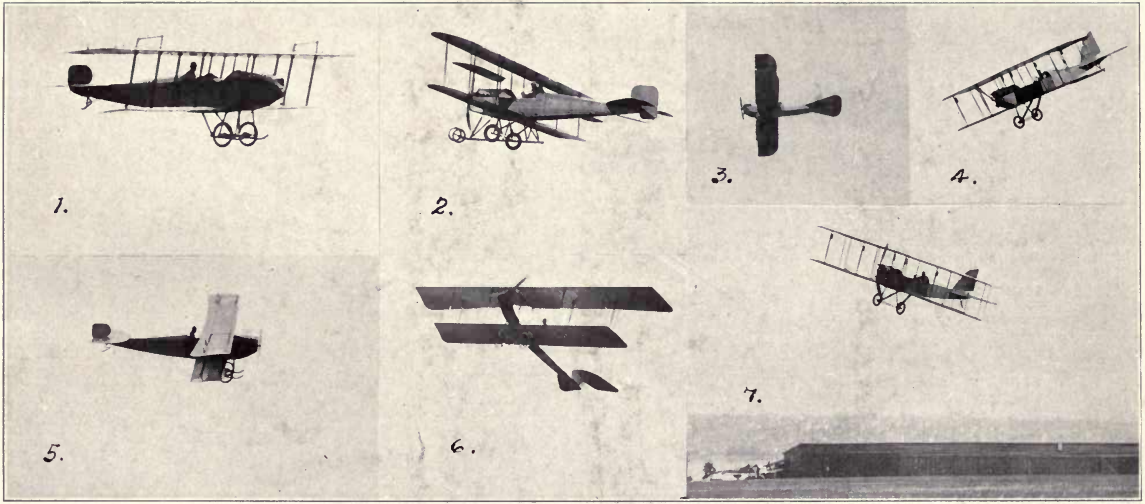


MILITARY TRACTORS

Above — Tractor with stagger, overhang, wing flaps and flat span.

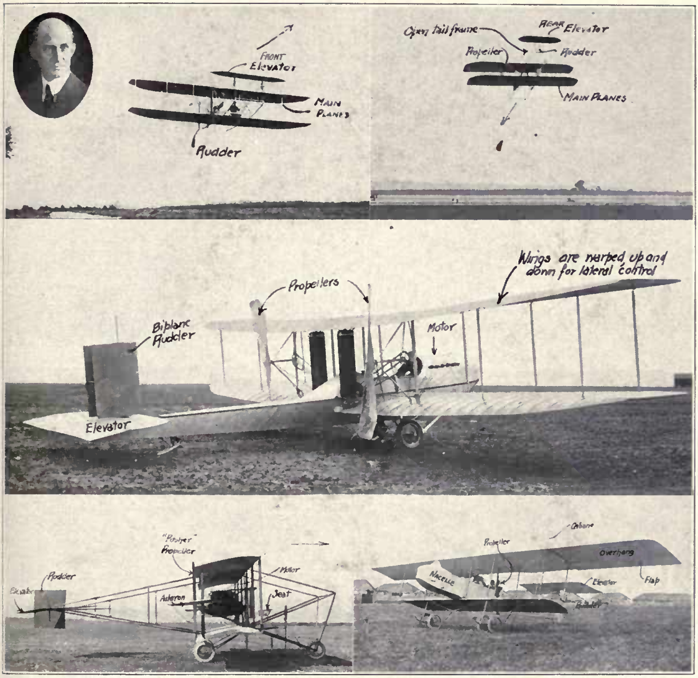
Center — Tractor with ailerons and dihedral span. The rudder has no fixed surface in front of it, and being hinged so as to balance the air pressures, it is called a "balanced" rudder.

Below — Tractor with double flaps, high rudder and fins for directional stability.



TRACTORS IN FLIGHT

1. Curtiss Tractor, tandem seat, flying at speed, "tail high." 2. Martin tractor, side by side seat, note ailerons. 3. Signal Corps tractor, gliding with motor shut off. 4. Same, coming down, on right spiral turn. 5. A Curtiss tractor banking on a turn. 6. Same, flying at climbing angle, "Cabre." 7. Signal Corps tractor, banked for a left turn.



"PUSHER" BIPLANES

Above—Left—Wilbur Wright, the inventor, and the early type of Wright double pusher biplane, with elevator out in front. Right—Double screw pusher Wright biplane, of later pattern, elevator in rear.

Center — Twin screw, pusher fuselage biplane, with engine in front.

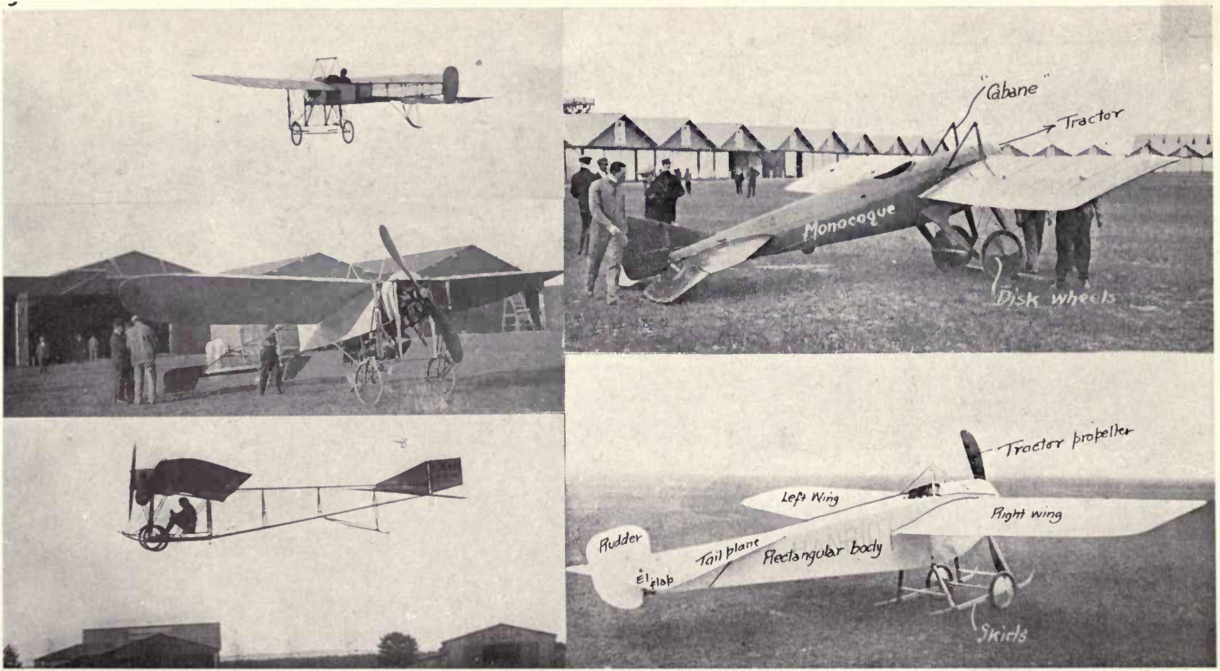
Bottom — Left — Early Curtiss open body, pusher — one screw, three wheel chassis, rudders in rear. Right — Farman pusher biplane with nacelle or enclosed body.

A "fuselage" encloses motor seats, etc., but in addition serves as the main structural unit of a machine, whereas a "nacelle" serves merely for wind protection, since a separate frame carries the rudders.

The term "empennages" refers to the tail surfaces of a machine, whether they be "balanced" or "flap and fin."

The term "fin" largely replaces the term "keel." It will be noted that the early Wright machines have no fins or keels in the empennages.

The side surfaces of an enclosed fuselage are virtually keels.



MONOPLANES

Above—"Bleriot" tractor, partly covered fuselage, and "divided" elevator.

Below—"Train" open bodied tractor, with seat below wings for observation.

Above—"Deperdussin" racing monoplane, body consisting of a wooden shell, called "monocoque," formed to reduce air resistance.

Below—"Hanriot" monoplane, similar to the "Nieuport."

MONOPLANES.

It has often been the custom, distinctly to separate biplanes and monoplanes, as different types. This is hardly justified, since the only distinguishing feature is the use of a single deck, "king post" type of truss to carry the air pressure lifting load, in the monoplane, and a double deck, "Pratt" type truss, in the biplane. Biplane surfaces, do interfere slightly with each other, but in tractors the disposition of motor, wings, body, rudders and even chassis, is identical, whether biplane or monoplane.

A further misconception, in this connection, is that the monoplane is faster than the biplane. The more recent speed scout biplanes have proved the fallacy of this, and, in later chapters, it will be found that biplane and monoplane are both similar aeroplanes, differing primarily in wing surface bracing.

Several monoplane photographs are given on the opposite page.

Monoplanes, like biplanes, may be tractors, pushers, open-bodied, or have two propellers. Several European firms construct a body and chassis, complete with rudders, to which either monoplane or biplane wings may be mounted.

In general, the biplane carries more load, and the monoplane is simpler in construction. But even these differences are fast disappearing.

A distinct advantage of the tractor monoplane over the tractor biplane, is found when the wings of the monoplane are raised slightly above the body, thereby enabling the pilot to look under them and to have a free and unobstructed view.

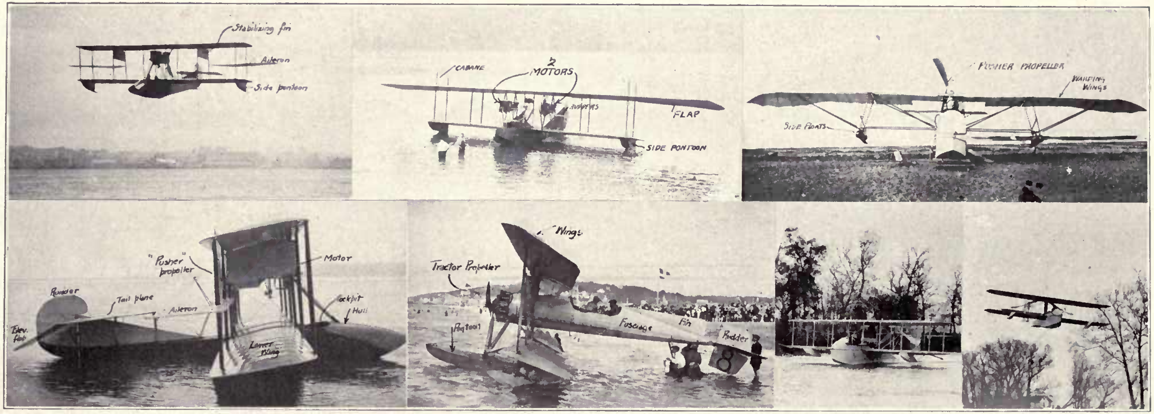
AEROBOATS OR FLYING BOATS.

For the purpose of starting from and alighting on water, aeroplanes of tractor, pusher, or any type are readily modified.

Merely adding pontoons to a tractor, in place of wheels, gives the hydro-aeroplane; and the construction of aeroplanes, fitted to receive either wheels or pontoons, as circumstances require, has developed considerably. Craft of this kind are called "convertibles."

But in order to obtain greater sea-worthiness and better co-ordination in design, a special type of aeroplane has been developed, suitable only for over-water work. The keynote in its design is found in its treatment as a boat with wings, rather than an aeroplane with floats. The aeroboat, or flying boat, therefore, is primarily characterized by a staunch, boat-like body, around which the rest of the aeroplane is built. The photographs show several different types.

For further discussion of aeroboats and hydro-aeroplanes reference is made to the chapter specially devoted thereto.



MARINE AEROPLANES

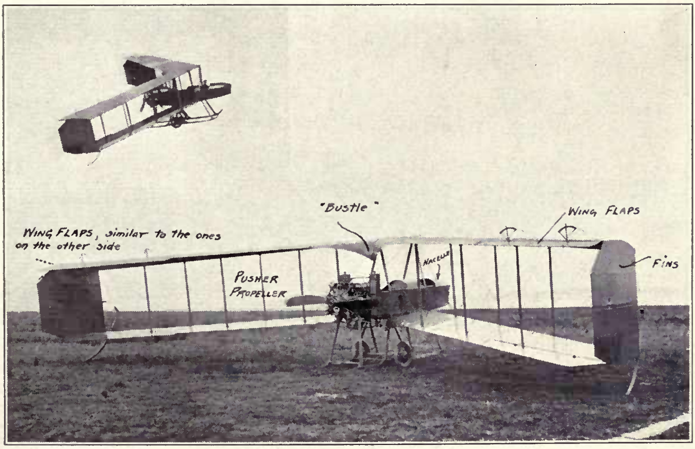
From left to right—top—A flying boat (the Curtiss pusher biplane with ailerons, boat hull and side pontoons). The "America" (the huge craft built to cross the Atlantic. Note the two separate engines). A monoplane aeroboat—(the Loening pusher monoplane, warping wings, boat hull, side pontoons). From left to right—bottom. Side view of Curtiss Flying Boat—A single pontoon hydro-aeroplane (the Breguet tractor biplane, mounted on floats instead of wheels). Views of the Wright aeroboat (two propellers, short boat hull, but with rudders carried on tail frame.)

THE "DUNNE" AEROPLANE.

In the preceding types, the auxiliary organs for pitching and yawing are separated from the main planes and are distinct. In the Dunne aeroplane, there is only one set of controlling organs, and due to the peculiar shape and construction of the machine, the control of yawing, pitching and rolling is combined and governed, only, by the double wing flaps. As may be seen from the illustrations, the main planes are set in a "retreating" position. Their position in plan, and their angle setting, give inherent stability characteristics, which will be taken up in a later chapter.

The "Dunne" principle of a retreating plane is used, though in a modified way, in the German aeroplanes, called "Pfeilfliegers" or "Arrowplanes," but the customary fuselage and rudders are retained. The German "Taubes" are monoplanes with pigeon-like retreating wings. (See p. 170.)

It may be stated here, that the "retreating" planes have much the same effect as a dihedral angle, on lateral stability, but are not so sensitive to side puffs. The effect on pitching stability, obtained on the Dunne, by the negative incidence at the tips, can be had, though in a lesser degree, on the more ordinary types of aeroplanes, by a negative setting of the tail planes. While "inherent" stability is descriptive of that obtained by the construction of the aeroplane itself, in shape,



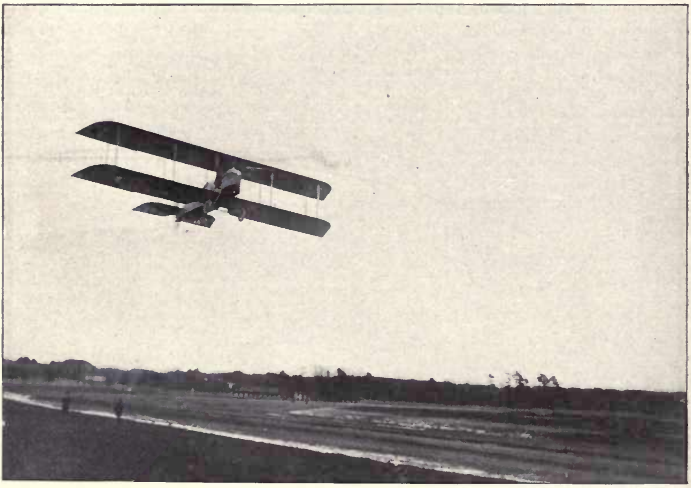
THE U. S. ARMY DUNNE TYPE BIPLANE

The changing wing section and reducing angle of incidence are clearly seen.

The bustle is used to deflect the air sideways. The wing flaps on upper and lower planes, are the only means of control. To ascend all flaps are turned up, and to descend they are all turned down. Inverse movement rolls the machine laterally, causing it to turn.

wing setting, balance and fin disposition, a clear distinction is drawn between stability of this type and that obtained by adding to any aeroplane an auxiliary mechanism, designed to be actuated by movements of the aeroplane, and automatically operating the controls, for proper corrective effect. Such a mechanism is virtually an automatic pilot, and is often termed, a stabilizer. "Automatic" stability may be obtained, by use of a mechanism of this nature, on an aeroplane that is inherently lacking in stability.

There are many other types of aeroplanes, but their general features resemble those described, and the art moves too quickly to give them all consideration. A general idea, of the various types, having been given, a more detailed study of the aeroplane may be taken up.



STURTEVANT MILITARY TRACTOR

A load-lifting type, built almost entirely of steel construction.

CHAPTER III.

PRIMARILY FOR REFERENCE

As much as possible, mathematics are avoided in the technical parts of this work. Where formulae are of real help, however, in stating clearly the relation between quantities, they are used and fully explained.

In a field like this one, so eminently practical in its nature, common-sense is of much greater benefit than abstruse scientific knowledge. There is justification for decrying the vast amount of complicated mathematics that have been built up on fundamental assumptions which the practical air pilot knows are wholly erroneous, but in doing so, let us not forget that scientists and the laboratories have contributed a great and valuable share, in advancing the aeroplane's efficiency.

It is praiseworthy in presenting a subject, to simplify it, and to avoid a too technical impression, but where this is at the expense of a clear and full understanding, it is inadvisable.

Aeroplanes, as machines, naturally involve many scientific elements, and it is certainly best, at the outset, to realize this and to acquire a working conception of what they are.

1. It is necessary to know the simpler types of equations and why they are so handy.

2. The elements used in solving triangles, such as sines and cosines of angles, should be familiarized, and a logarithm table is sometimes very convenient.

3. Mechanics dealing with momentum, inertia, accelerations, centrifugal force, and gyroscopic force, should, at least, be understood, and a comprehensive review should be made of Elasticity, Stress and Strain, and Fluid Motion.

4. A clear conception of Work, Energy, Power and Power Efficiency, is of fundamental importance.

5. Graphical representations, composition and resolution of forces, are constantly of use.

6. Various modes of representing variations of quantities on charts, serve as the basis of recording air pressure results, and should be fully appreciated.

7. The relative values and conversion factors of different systems of units, are most useful, and areas, volumes, etc., are frequently called for.

Recalling these elements is made simpler, if a brief summary of the features particularly applicable to this study be given.

FORMULAE.

To attempt to present a study of flight without any formulae would make it necessary to express relations between quantities in long paragraphs of words, that could more readily be stated in simple equations.

There is nothing mysterious about an equation.

It is merely a sentence tersely expressed.

Thus, if it was desired to state the rule that the quantity **A** multiplied by twice the quantity **B** is equal to **C**, the formula representing this would be,

$$A \times 2B = C$$

Each letter or symbol in a formula represents some factor that is substituted when its value is known. If $A = 16$ and $B = 4$, then $C = 128$, since, the rule interpreted, reads,

$$16 \times 8 = 128$$

Besides equations, other relations may be represented by formulae. Thus, the sign "$\propto$," signifying "varies as," would permit the statement that "wind pressure varies as the square of the velocity of the wind," to be expressed

$$P \propto V^2$$

Equations are of two kinds, **derived** and **empirical.** A derived equation is susceptible of proof, by use of mathematical processes based on proven assumptions.

An empirical equation is neither derived nor proven. It is merely a statement of the results of experiment, regardless of mathematical proof.

In many branches of engineering, empirical formulae are constantly used, and in Aviation, the lack of a satisfactory basic theory of air flow makes empirical formulae based on experiment, most necessary.

Empirical formulae are really experimental averages. As an example: The theory of long columns, has not as yet permitted of the mathematical derivation of a satisfactory set of formulae for the stresses. Very extensive experiments have been conducted therefore, on the loads necessary to deflect and break such columns. Grouping these experimental results together it is found that if **1/d** denotes the length ratio of a certain column, and **p,** the stress per square inch of cross section, the average of the experiments, may be expressed as

$$p = 32{,}000 - 277\ 1/d$$

This is strictly an empirical formula. The engineer is interested in its practical application, not in its derivation, and when a column of this type is to be designed, for any value or **1/d** he can find the value of **p.**

Formulae of empirical nature are fundamental in a study of Aviation.

It is often found necessary, particularly in an experimental field, to introduce numerical constants, to balance the two sides of an equation. It may be known, for example, that the horse-power of a propeller varies as the cube of the revolutions and the fifth power of the diameter, but we could not express this relation as an equation, capable of solution, until a numerical factor is found which gives a value to the h. p. (horse-power) for any r. p. m. (revolution per minute) or diameter, that agrees with the experimental results.

Thus the relation could be written,

$$\text{H. P.} = k\, N^3\, D^5$$

but unless $k = 1$, the equation cannot be solved until a value of **k** is found. Since the equation is empirical, it becomes necessary, actually to try many propellers, until an average is found. As a matter of fact, **k,** in the above formulae, has been determined by experiment to be 0.54 when certain units are used. The formula becomes,

$$\text{H. P.} = 0.54\, N^3\, D^5,$$

and is capable of simple arithmetical solution by substituting values for the letters. A term like **k** is called a "constant."

The majority of formulae for air pressures involve "constants," and the great advance in designing during the past two years may be traced directly to the determinations by the aerodynamic laboratories, of better values of these constants, for use in empirical formulae.

SOLVING TRIANGLES.

Every triangle has six parts, three sides and three angles, and if we know any three (including a side) the triangle may be solved — that is the other sides and angles may be determined.

Triangles may be solved in two ways:

1. By trigonometry.
2. By graphical methods.

In aviation work only the simplest trigonometry is used, and about the only functions of angles used are the sine, the cosine and the tangent. It is well to recall, here, that **"sine"** and **"cosine"** are merely numerical ratios, representing the fractions that certain sides of a triangle are to the hypothenuse.

The accompanying chart shows what these functions are, and also gives formulae for solving the triangles.

In later chapters it will be found that in the representation and solution of forces, in the determination of angles of incidence, glides and climbs, and in stress determinations, many occasions arise for solution of simple triangles.

But in aeroplane work great accuracy of computation is not necessary, so that a simpler way of solving triangles may, at times, be used, i. e., the graphical method. This consists merely in a mechanical process of laying off on a sheet of paper the known angles, by a

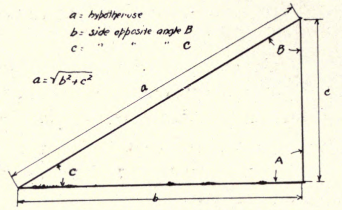
Mathematical Signs

- $>$ greater than
- $<$ less than
- $\propto$ varies as
- $::$ equals in proportion
- $\therefore$ therefore
- $^\circ$ degrees arc
- $'$ minute (also feet in drawings)
- $''$ second (also inches " ")
- g acceleration due to gravity
- π (pi) = 3.1416
- $\measuredangle$ Angle
- $\sqrt[n]{\ }$ nth root
- sin - sine
- tan - tangent
- cos - cosine
- $\perp$ - perpendicular, or "normal" to
- $\parallel$ - parallel to

Right Angle Triangle

a : hypothenuse
b = side opposite angle B
c : " " " C

$a = \sqrt{b^2 + c^2}$



Angle A = 90° $\therefore$ Angles B + C = 90°

Formulae

$\sin B = \frac{b}{a}$, $\cos B = \frac{c}{a}$, $\tan B = \frac{b}{c}$

$a = \frac{c}{\cos B}$ $\quad b = a \cos C$ $\quad c = a \sin C$

Graphical Solution of a triangle —

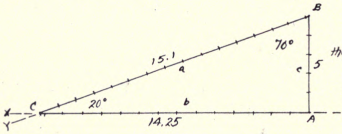
Given, angle B = 70°, side c = 5 units, A = rt. ∠

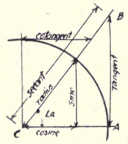
find, angle C, and sides a and b

First construct line AB, ⊥ to AX, any base line; then, at B, lay off angle of 70°, with a protractor. Project line BY Where BY, intersects AX, is situated the point C

Reading with protractor, it is found that angle C = 20°

Measuring with scale chosen, it is found, that a = 15.1 and b = 14.25





Trigonometrical Functions of an arc

$\sin^2 a + \cos^2 a = 1$

$\tan a = \frac{\sin a}{\cos a}$

$\cot a = \frac{\cos a}{\sin a}$

$\tan a = \frac{1}{\cot a}$

$\sec a = \frac{1}{\cos a}$

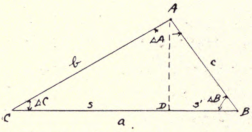
$\sec^2 a = 1 + \tan^2 a$

In determining the sign of functions, + or − it is merely necessary to recall, that

1.- All distances estimated upward, like AB, are positive, and distances estimated downwards are negative.

2.- All distances estimated toward the right, as CA are regarded as positive, and distances estimated to the left are negative.

Oblique-angled Triangles



To solve oblique triangles, three rules need to be referred to

1.- The sides of a plane triangle are proportionate to the sines of their opposite angles
Thus -
$a : b :: \sin A : \sin B$.

2.- When only two sides and an included angle are given the relation used is of the type
$c+b : c-b :: \tan \frac{1}{2}(C+B) : \tan \frac{1}{2}(C-B)$

3.- When only three sides are given, the perpendicular AD is drawn, dividing side "a," into s and s'
Then -
$s+s' : b+c :: b-c' : s-s'$
which readily permits the angles to be found.
For example,
$\cos C = \frac{s}{b}$ and $\cos B = \frac{s'}{c}$

VARIOUS MATHEMATICAL SIGNS — FORMULAE FOR AND GRAPHICAL SOLUTION OF TRIANGLES — AND FUNCTIONS OF ARCS protractor, and the sides to some convenient measurement scale. By closing the triangle, all that is necessary in order to determine the other sides or angles, is to measure them off. At first sight, this seems to lack the value of preciseness, but if a large enough scale is used, it is surprising how quickly and correctly, triangles may be solved in this way.

In aeroplane studies the use of logarithms is rarely justified excepting possibly in propeller determinations, where formulae involving, for example, the fifth power of the diameter, D^5, are used.

It may be recalled that a logarithm is merely the exponent, like five in the above, to which it is necessary to raise **10**, in order to produce the given number.

It will suffice to give here, the method of determining powers of numbers. For example, in determining D^5, a laborious calculation is avoided by looking up the log of D, multiplying it by five, and finding the number corresponding to the log represented by this quotient.

The occasion will rarely arise where logs have to be used, or even trigonometry, if graphical methods are pursued.

MECHANICS.

Mechanics is the most logical of sciences — the causes and effects are so evident. It is often defined as the science that treats of the action of forces upon bodies. And anything that concerns the action of air forces on aeroplane wings and bodies, is of vital importance here. It is almost needless to recall, that as long as the propeller is pulling or pushing, or the aeroplane gliding, it is storing up **momentum,** which is defined as the product of the mass **m** by the velocity **v** at any instant; whereas, **inertia** is that property of a body by virtue of which it tends to continue in whatever state it happens to be, until acted upon by some other force.

Velocity and Acceleration.

Acceleration of a particle is the amount of increase or decrease of its velocity in a unit of time. In other words, while the velocity is rate of motion, acceleration is rate of change by velocity.

A force is equal to a mass multiplied by its acceleration, because it is universally agreed that a force be measured by its effect in changing the velocity of a particle. When we measure weights in pounds, we actually measure the force of the earth's attraction, which is equal to the mass of the body times the acceleration of gravity, **g,** which increases the velocity of a particle 32 feet per second every second.

Therefore $w = m \times g$. So that when the mass of a particle is considered, it must be recalled that it is equal to what we call the "weight" divided by acceleration of gravity or

$$m = \frac{w}{g}$$

A body falling freely under the action of the constant pull of the earth, disregarding the retarding effects of air resistance, is an example of uniformly accelerated motion. It must not be forgotten that in a vacuum all bodies, whether a feather or a piece of lead, fall at the same speed. Air resistance, alone affects rate of fall, in free air.

It is useful to recall, that a falling body attains a velocity **v** in feet per second, falling a distance **h** feet, represented by

$$v = \sqrt{2 g h}$$

where g = 32 feet per second per second.

Rotary Motion and Centrifugal Force

In a circular orbit of radius **r** a particle making in revolutions per second, covers in each revolution the circumference, $2 \pi r$, so that its velocity in feet per second

$$v = 2 \pi r n$$

The numerical value of this velocity is solved by the above equation, easily enough, but the particle swingng in a circle is constantly changing the direction of its velocity. This change in **v**, involves an acceleration, and since the particle has mass, it follows that a force is introduced, which is constantly making or trying to make the particle hold its circular path. This is the **centripetal** force.

The force acting from without and tending to make a particle take a curved path is called centripetal force, and is the opposite to centrifugal force.

Since this acceleration towards the center of the circle is equal to v^2/r, it follows that

$$\text{Centrifugal force } F = m \times \frac{v^2}{r} = \frac{w\, v^2}{g\, r}$$

where **w** is the weight in pounds, **v** is speed in feet per second, **r** is the radius of the orbit in feet and **F** is the force.

The Pendulum

What applies to the speed with which weights fall, applies also to the simple pendulum. No matter what the weight of the pendulum, it is the length of arm 1 alone, that governs the period of oscillation. This period,

$$p = 2 \pi \sqrt{1/g}$$

Moment of Inertia.

Inertia has been defined, but "Moment of Inertia" must be considered when we come to rotary motion.

Moment of inertia is the quantity obtained by multiplying the mass of each particle of a body by the square of its distance from the axis. Whether a propeller, a flywheel, or a wing spar, every object has a "moment of inertia" I, about any axis. It would be a laborious computation to find **I** for various shaped bodies. Fortunately it has been done for us, and values are given later in a table. **I** is expressed in pounds × feet squared (lbs. ft.^{2}).

Angular Velocity

The "radian" is often used as the measure of a distance along the circumference of a circle. There are 2 π or 6.28 radians, covered in one revolution of a circle. So that one revolution per second, r. p. s., equals 2 π radians per second.

If **w** is called the rotational or angular velocity of a particle, and **n** the r.p.m., then,

$$w = 2\,\pi\,n$$

It has been indicated that acceleration of a rotating particle, due to change in direction, gives rise to centrifugal force.

But the rotational velocity of a particle, may increase or decrease. This is called angular acceleration and is a rate of change of angular velocity, called **s.**

Torque.

In linear accelerations, we have Forces, while in rotational acceleration, forces are also to be considered, but instead they are called Torques.

Torque, **T,** also equals mass × acceleration, but in its case mass is the moment of inertia and acceleration is angular.

$$\therefore T = I \times s \times \frac{1}{32}$$

where **T** is in pounds weight × feet and **s** in radians per second per second.

The Gyroscope

Linear motion and rotating motion have been considered. The axis upon which a body is rotating can be moved in a linear motion.

In addition the axis of a rotating body may change its direction continually. This brings us to the gyroscope.

An unbalanced force is of course necessary to change the direction of linear motion of a particle.

In the same way an unbalanced force is necessary to change the direction of the axis of a rotating body. When a wheel is set rotating, the direction of the axle tends to remain unaltered, as long as no unbalanced external force acts upon it. But when an unbalanced force is applied suddenly enough the axle's fixed position in space gives rise to a curious phenomenon, not only resisting movement by this force, but actually causing the axle to move in a direction at right angles to the applied force. It is unnecessary here to take up the relation of this phenomenon to the earth's rotation or the derived formulae, representing it.

An example of gyroscopic force, however, may be given. If a bicycle wheel is held out in front of one, by one end of its axle, and set rotating clockwise as viewed by the holder, when the axle is pointed down the tendency is for it to swing around and point to the left, and any effort to point the axle upward, meets a pronounced resistance, the axle at the same time turning sharply to the right.

The effect of this phenomenon on the aeroplane's stability is taken up later. In steadying ships or monorail cars, or in stability devices for aeroplanes, the movement at right angles to the direction of the applied force of a sensitive "gyro" is made use of.

Elasticity — Stress and Strain.

The phenomena which are associated with the distortion of bodies due to stresses are excessively complicated, and one has but to think of the many familiar properties of brittle substances, like glass or chalk, elastic ones like spring steel or rubber, and plastic ones like clay or wax, to realize that this is in itself a formidable study, much too extensive to be given anything but a meagre consideration here. The importance of the study of Resistance of Materials, to aviation, cannot be overestimated, since in the design of the aeroplane proper, this is the branch of engineering that solves the fundamental problem — to build light and yet strong.

This necessary combination is one that truly represents a criterion of the excellence of an aeroplane, as a structural engineering unit, and although it often does not, nevertheless, the aeroplane should involve the most refined, advanced and expert, structural features that engineering development has made possible. It has been a great detriment to aviation that so many of its devotees have failed to realize that the very best material obtainable, and the most ingenious and perfect construction, is still hardly good enough to bear the strains properly.

Of all the great variety of solid substances, having almost every imaginable degree of elasticity, softness, hardness and brittleness, we are concerned in later chapters, only with the behavior under stress of those which are used as materials of construction, such as steel, aluminum, brass, linen, spruce, ash, glues, paints and rubber.

Of the three classes of substances, **solids, fluids and gases,** let it be recalled, that an "elastic" solid, like spring-steel, can withstand a stress which tends to change its shape for an indefinite length of time, whereas a "plastic" solid, like wax, does not recover from strain when the stress ceases to act. One must qualify the above, however, since the best spring steel never completely recovers from distortion, and even wax is slightly elastic. A fluid is a substance which at rest has no power definitely to resist a stress, and when at rest it is always pressing, normally, on the sides of the vessel containing it. A gas is a matter with no independent shape, adjusting itself to take the form of the vessel in which it is confined, and tending to diffuse and expand indefinitely.

Substances are of two kinds — **grained** and **ungrained.** Glass and water are examples of ungrained substances, while wood, steel, and practically all materials of construction, have a grained structure. The grain in steel is well marked, and though often lost sight of, it is most necessary in aeroplane work, that care be taken not to put too great a stress across the grain of a steel plate.

Elasticity may properly be defined as the resisting property of a body to motion of its molecules.

Strain is the distortion of a body measured at a given point.

Stress is the force by which the molecules resist a strain at any point. Stresses are developed, and strains caused, by the application of external forces. Each stress is accompanied by its own characteristic strain.

Stresses are of five kinds — **Tension, Compression, Flexure, Torsion** and those induced by **Fluid pressure.** They are illustrated on an accompanying cut.

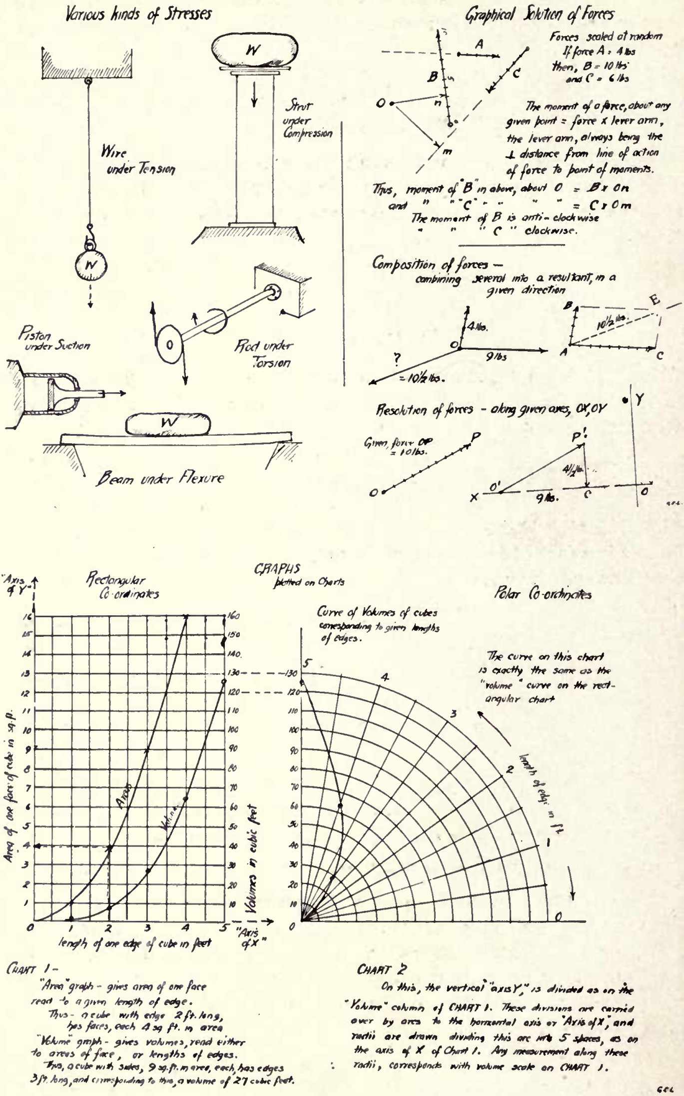
It is a fact of fundamental importance in the theory of elasticity, that however irregularly a body may be distorted, any small portion of the body suffers that simple kind of distortion which changes a circle into an ellipse, the change of shape consisting essentially of an increase or decrease of linear dimensions in three mutually perpendicular directions, sometimes accompanied by a slight rotation of the small parts of a body.

The stress on a body is usually represented as pounds per square inch, or the force in pounds acting on a one-inch square part of the body. The total force **P** on a body, divided by area **A,** of its cross-section gives this unit stress which is called "intensity of stress." The strain **l** accompanying this is not represented in actual inches or units of total deflection **d,** but is given as a fraction of the span **L** of the piece, such that strain **l** equals **d/L.**

The basic law of Resistance of Materials is that intensity of stress **p** is proportional to strain **l.** And to balance the proportion into an equation, a constant is introduced, called **E,** giving the simple rule, that

$$p = P/A = d/L \times E = 1 \times E$$

This constant **E,** is called the **"Modulus of Elasticity,"** and is of the greatest convenience in indicating what the proportion of stress in a given material is to strain. Thus, it is readily seen that steel is stronger than aluminum, when it is learned that **E** for steel is 28,000,-000 and for aluminum 1,700,000.



KINDS OF STRESSES — GRAPHICAL FORCE DIAGRAMS — CHARTS AND GRAPHS

For all materials, however, there is a limit beyond which the ratio of stress to strain or coefficient of elasticity $E = p/l$, does not hold. This region is called the **"elastic limit"** of the material, and while considerable stress can be added beyond this, the material begins to stretch out of all proportion and rapidly reaches the breaking away point, which is called the **"ultimate resistance."**

When relieved of stress, before reaching its elastic limit, a material will return more or less to its former state, but when the stress has exceeded the elastic limit the material takes a permanent set. The forces necessary to bring any material to the elastic limit, and the value of the ultimate resistance, are entirely matters of experiment, from which are derived empirical values.

Fluids and Gases.

In liquids the phenomena of surface tension, capillary action, cohesion, etc., are of but minor interest excepting in hydro-aeroplane studies. It is important to recall of liquids, however, that the pressure exerted on any part of an enclosed liquid, is transmitted undiminished in all directions (air-pressure fuel tanks). When a fluid is in motion it is being acted upon by an unbalanced force, giving it velocity and by a pressure, or in other words, it has the energy of a "velocity head" and a "pressure head." Any increase in one is at the expense of the other.

A device very widely used for the measurement of velocities of both water and air is the **Pitot tube,** which measures the velocity head $v = \sqrt{2gh}$. It consists, merely of a bent tube with a nozzle, pointing into the relative flow and measuring by means of the length of a column of liquid, the head **h,** which substituted in the above, gives the velocity **v.**

In considering liquids the losses in head in long pipe lines and the effects of expansion and contraction and of nozzles, are of interest with reference to the gasoline and radiator connections.

Buoyancy and **Specific Gravity** should be considered.

A body immersed in a liquid or a lighter gas immersed in air, is acted upon by a lifting force which equals the weight of the liquid or air displaced. In other words, the law of Floating Bodies is to the effect that a floating body will displace a volume of liquid of gas whose weight equals its own. A body immersed in pure water has a flotation of 62.4 lbs. per $ft.^3$

The **density** of a substance is its mass per unit volume, while **Specific Gravity** of a substance is its weight as compared with the weight of an equal "bulk" of pure water. So that, given the specific gravity of a substance, it is necessary to multiply by 62.4 to obtain its actual weight in pounds per cubic foot, since water weighs 62.4 lbs. per $ft.^3$ Specific gravity is sometimes referred to other substances — air for example. The specific gravity of gold is 19.26. Its weight per cubic foot is consequently 1,200 lbs. A table of weights and specific gravities is given later.

Gases are highly compressible, in distinction to water and solids, and are perfectly elastic, though in distinction to solids their elasticity is one of volume and not of form.

It must be borne in mind, with reference to gases, that the temperature remaining the same, the volume of a gas is increased exactly in the same proportion as the pressure is decreased. Or, the product of volume × pressure equals a constant quantity.

The study of **Aerodynamics** which constitutes the major part of this work, takes up the mechanics of gases, making it unnecessary to give them further consideration here.

WORK, ENERGY, POWER.

Work is said to be done when a resistance is overcome, so that movement takes place through a certain distance. The air propeller which pulls against a resistance of 200 pounds, causing the machine to which it is fixed to move 80 feet, is doing work, inasmuch as it is continually overcoming this resistance.

The unit of work is the foot-pound, which is equivalent to the work performed in moving one pound of weight through one foot of space.

Work may be done in several ways — pushing or pulling weights, or working against pressures, such as the work performed by a piston in driving a fluid of gas before it, which is equal to the intensity of pressure × area of piston × distance traversed or stroke.

In the above example, the propeller is doing 16,000 foot pounds work by overcoming a resistance of 200 pounds and moving against it 80 feet.

Work, in whatever units it is expressed, is always "resistance overcome" multiplied by "distance traversed."

Energy is distinct from work, in that it represents capacity to do work, but not the actual work done. It is expressed in the same units as work.

There are two kinds of energy — **Potential and Kinetic** — since a body when at rest may have stored up "potential energy" due to its peculiar position or condition, and when in motion, a body is capable of performing work against a retarding resistance, due to its "kinetic energy."

A reservoir full of water, capable of turning a water wheel, if released, is an example of potential energy, and another is the stored energy in storage batteries or gunpowder. The weight of the stored body × the distance through which it is capable of acting is the measure of potential energy.

Kinetic energy or **K. E.** of a body, is equal to the work which must have been done upon it to have brought it to its actual velocity from a state of rest. While potential energy is due to the acquirement of "strategical position," kinetic energy is due to the acquirement of "tactical impetus" or velocity.

Kinetic Energy = $wv^2/2g$ and is derived from the familiar relation $v = \sqrt{2gh}$ since K. E. equals the weight of the body $\times$ height from which it would have had to fall to acquire its velocity.

Finally, it becomes obvious that Energy exerted = Work done.

In referring to the amount of work done in a unit of time, it is necessary to consider **Power,** which may be defined as the rate of doing work. Whether the propeller in the above example traverses the 80 feet of distance in one second, or in one hour, the actual work done in foot pounds is the same, since time is not a dimension of work. Obviously, it would take more "power" to overcome any resistance in one second than in one hour, and to measure power it is necessary not only to consider the resistance and the distance traversed, but also the time it takes to do it.

Power, then, is the number of foot pounds per second or per minute or the number of mile-tons per year, if we choose to use such units.

The customary unit of power is the **Horse-Power.**

One horse-power equals 33,000 foot pounds per minute, or,

1 h.p. = 550 foot pounds per second.

Thus, when a weight of 5.5 pounds is moved 100 feet per second, one horse-power is exerted.

An aeroplane, with a resistance in the air of 200 lbs., requires 29 h.p. when travelling at 80 feet per second, since

$$200 \times 80 \div 550 = 29 \text{ h.p.}$$

It is interesting to note here, with reference to the possibility of man-power flight, that, for a few minutes a man can exert at the limit 200 ft. lbs. per second, and for an hour about 100 ft. lbs. per second, less than 1/5th of one horse-power.

Although much energy is generated and expended, the fact remains that the sum total of all the energy in the universe remains the same. Mechanical energy and heat are converted one into the other, the heat of the boiler, taken from fuel coming from the earth, passes into the engine and into parts which do work against various kinds of friction, until finally the sum total of the mechanical energy has returned to the earth, from whence it originally came, as heat.

The law of the Conservation of Energy is the most firmly established of the laws of mechanics, and only by the creation of an additional amount of energy in the universe, which is impossible by any known human agency, could perpetual motion be achieved, although some magnetic and atmospheric phenomena may be used very nearly to approach it.

POWER EFFICIENCY.

Any machine, in order to accomplish an amount of work in a given time, must have work put into it in proportion. Due to friction and other losses, it is always true that the power obtained from a machine is not as great as the power put into it.

Now, call **P,** the power delivered by a machine, and **P′** the power necessary to put into it, then the ratio **P/P′** will be less than unity, ordinarily; it might be equal to 1, if the machine were a perfect one with no losses but never can it exceed one.

The ratio of the power delivered by a machine and the power it used in doing so is called the Power Efficiency of the machine.

We have used above an example of an aeroplane, with a flying resistance of 200 lbs., which, when it was travelling at 80 feet per second, required 29 h.p.

If the h.p. of the engine were 50 h.p. then the efficiency would be 29/50 or 58%.

It is most important in this study clearly to understand the significance of Power Efficiency.

FORCES REPRESENTED GRAPHICALLY.

The development of a simple notion into an extensive science is well illustrated in Graphic Statics.

Based upon the elementary fact that a force can be represented by a line, — long enough to measure its magnitude to some convenient scale, and placed so as to indicate the direction in which the force acts with reference to some fixed point — there has been built up a complete science of the action of every kind of force, and in many cases simple solutions are obtained for problems that would require complicated mathematics.

For all ordinary engineering the numerical computation of the characteristics of forces has almost entirely given way to their determination by machine-like graphical methods. In later chapters the particular application of graphical methods to determine the stresses in aeroplanes will be taken up.

It will suffice here to give a general idea of how the combined effect of several forces can be determined, — **composition of forces:** and how a single force can be split up into an equivalent set of forces — **resolution of forces.**

The single force, that would have the same effect at a point as a set of several forces, is called the **Resultant.**

Referring to the diagrams, illustrating the action of forces, it is indicated that two forces of 4 and 9 lbs. are acting at a point **o.** It is desired to know what their combined effect is, so that a single force could be placed at **o** that would resist their combined action.

The mechanical process of finding their resultant consists merely in applying what is often called the "parallelogram of forces," p. 34.

Graphically, the mechanical process is as follows: Lay off **AB** parallel to the 4-lb. force, and from **A** lay off **AC** parallel to the 9-lb. force. Complete the parallelogram to **E,** and draw **AE.** Then choose some scale, such that **AB** when actually measured on the drawing measures 4 units, and **AC** 9 units. With this same scale measure **AE.** It scales about 10½ units.

Therefore, its value is 10½ pounds.

Its direction is given by the direction of **AE** so that by drawing the force through **o,** parallel to **AE,** and making it 10½ pounds long to scale, we completely determine it in direction, magnitude and point of application.

Finding the resultant of any number of forces, whether co-planar or not, consists in finding the resultant of two, then finding the resultant of this resultant and one other, and so on.

Moments are defined on the diagram as merely the forces times their perpendicular lever arms, from the point about which moments are taken. If the force is expressed in pounds and the lever arm in feet, the moment is in foot-pounds. The unit is the same as in Work, but obviously, moment expresses what could be termed the Potential Energy of the force.

Scaling lever arms of forces, from diagrams to scale, is by far the easiest and quickest way to obtain them.

Of course, if a point is in equilibrium, all the forces pulling one way are balanced by forces pulling the opposite way. In the same way **the sum of moments of all the forces will be zero.** This is a very important conception to keep in mind.

The **resolution** of forces into parts or **complements,** along given directions or axes, is indicated in the diagram, and is, briefly, a reverse application of finding the Resultant.

The intricate-looking but simply-made stress diagrams of braced frames, like bridges, are made of an elaboration of compositions and resolutions of forces.

In all this graphical work, it is best to appreciate at the outset, the necessity of learning the mode of procedure of laying off the lines like learning to run a machine and then merely keeping the scales used clear and unconfused. Successfully to determine stresses it is as unnecessary to know the theory involved, as it is for the average taxi-driver to know the theory of why certain mixtures of gasoline and air are explosive.

Charts and Graphs.

The representation of the variation of something, as a **graph** on a chart, is merely a convenient way of tabulating results. Instead of having long, cumbersome tables, giving values, at certain intervals, it is far easier to represent them on a chart.

If it is but appreciated that a graph is a table with values for all intervals between the limits indicated, its convenience becomes very evident.

Diagrams are given, as an example, of two types of co-ordinates, the Rectangular and the Polar.

Graphs are used very extensively in studying Aviation, and the power curves for Aeroplanes bid fair to become as universal as the power curves for electric railway cars, etc.

The combination of several curves on the same chart is illustrated in the diagram, and consists merely in keeping the same cross lines, but assigning to them different scales.

SEVERAL VIEWS OF STURTEVANT SEAPLANES USED IN THE U. S. NAVY

CHAPTER IV.

AIR RESISTANCES.

The Aeroplane, having been described in a general way, and an outline having been given of the ordinary conceptions of science applied to it, we can proceed with a detailed study of its various elements.

In considering the Aeroplane, three distinct features are presented:

1. The determination of the reactions of the air on the parts of the moving machine, giving rise to resistances, lifting forces and thrusts.

2. The study of the construction of the machine to withstand these forces.

3. The investigation of the stability and manner of operation of the aeroplane, under the many conditions met with.

The determination of air reaction requires, at the beginning, a clear understanding of the nature of the air and how it may be expected to act.

It is well to realize that lifting forces and thrusts are no more important than are the resistances, at the expense of which flight is obtained. And when it is found that for every ten pounds of air resistance saved there can be carried an additional load of almost one hundred pounds, the significance of low air resistance becomes apparent.

The late Edouard Nieuport, builder of the famous French monoplane, made one of the greatest single advances in aeroplane construction, in the past few years, by his practical development of aeroplanes with very low head resistance. And after the introduction of his ideas such rapid strides were made by constructors in the improvement of the aeroplane's efficiency, that load carrying capacity was almost doubled. Another lesson in the relative importance of the resistance to motion of an aeroplane, is found in the development of high-speed racing machines. It had been generally assumed that speed depended almost entirely on having added power, but the development of the Deperdussin monocoques proved that far better results could be obtained by systematic refinement and reduction in the resistances. It is needless to speculate on the speeds attainable in aeroplanes. The nature of air resistance and its increase with speed as considered in this chapter, will lead to the realization that a high speed record of 130 miles per hour is not going to stand very long.

But it is not so much in the attainment of higher speeds that we are interested in air resistances, as it is in the reduction of the power necessary to fly. While fuselage and nacelle resistances are the largest, attention must be given to the air resistance of wires, fittings, struts, wheels, etc., the cumulative effect of which is surprisingly great. **These resistances, however, are distinct from the resistance to motion of a wing that generates a lift.**

The appreciation of the resistances of different forms and shapes is of great value in the field in determining their effect on the efficiency of a machine, and also on the stability, since changes in resistances are apt to affect the center of air resistance of the machine, and consequently the equilibrium of the air forces.

Occasions constantly arise in mounting bomb-dropping apparatus, guns and other extra equipment, and in repair work, where information of this kind is of value.

The Atmosphere.

The atmosphere is an ocean, consisting of a mechanical mixture of several gases with water vapor, and even on the highest mountain we are still living at the bottom of this ocean. The atmospheric envelope has a definite extent, and at any point exerts a pressure which is given rise to by the weight of the amount of air above it. We are constantly carrying around, therefore, on our shoulders, on the roofs or buildings, everywhere, the weight of the column of air directly above. The higher up, however, the less is the weight of air, and, consequently, the less the pressure. Air being compressible this increase in pressure with decrease in altitude affects the weight of air per cubic volume. We would have quite an exact measure of height in the atmosphere, in noting the corresponding pressure, were it not that this pressure is also affected by temperature and great wave movements of the air ocean, storms and winds.

As the temperature increases the density decreases, and the volume of a pound of air increases at the same pressure.

The unit of atmospheric pressure is the mean pressure of the air at sea level, at 60° F. and is called one "atmosphere." It value is 14.7 lbs. per sq. in., and it causes the mercury in the barometer to rise 30 inches. Over one sq. ft., a pressure of one atmosphere is equivalent to a weight of 2,116 pounds.

For every 1000 feet increase in altitude the pressure decreases about ½ lb. per sq. in. At a height of 18,500 feet, atmospheric pressure is one-half of that at sea level, and at a height of 40 to 50 miles the air must be practically weightless.

At atmospheric pressure and 60° F., the weight or density of air is .081 lb. per cubic foot.

It is convenient to recall that air is about 1/800th as heavy as salt water, and 14 times heavier than hydrogen.

Nature of Air.

Since air has weight, it follows that, as a substance, it has inertia and momentum. The possibility of flight is due to the tendency of air to resist movement.

In addition to this, air is very **elastic,** but at aeroplane speeds, it may be considered, theoretically, as almost incompressible, like water.

Air is a **"continuous" medium,** each particle, naturally, tending to hold together with every other particle, and the tenuous manner in which any air disturbance influences adjacent air filaments is beautifully demonstrated in photographs of air flow.

Disturbances of the air cause up and down currents, complicated air vortices, aerial fountains, waves and pulsations, with changes in the velocity and direction of air streams; and just as water boils so will air boil, when heated. The action of the sun in boiling the air over a dry, open space, can be distinctly felt when flying.

In the consideration of air resistances, however, it is assumed that the air is uniform in flow, and at 60° F., and atmospheric pressure.

There is another very important conception, with regard to air resistance determinations. **Disregarding the effects of inertia and acceleration of an object, the air pressures are the same in action, whether the object is moved against the wind, or the wind against the object.**

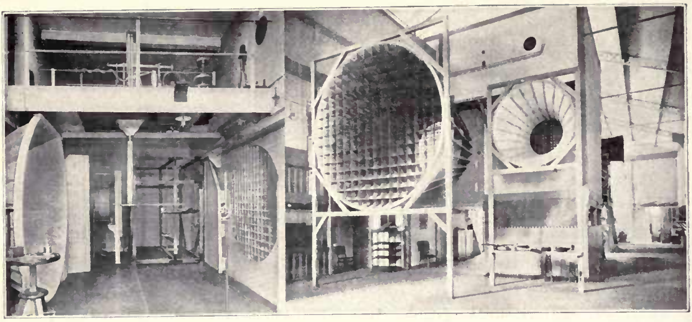
Motion through the air gives rise to two distinct kinds of resistance:

1. **Pressure,** generated by the impact of the air on an object, and

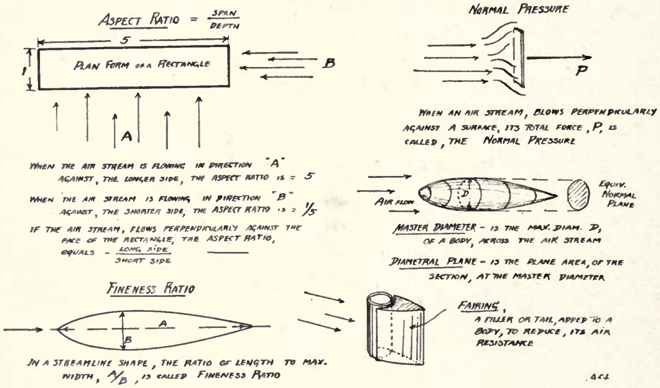
2. **Friction,** generated by the flow of the air filaments past the surface of the object.

Characteristics of Air Flow.

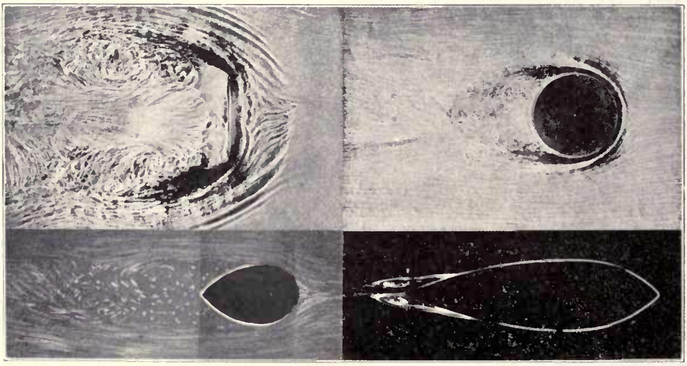
Having defined air, the manner in which it flows may be considered. Air either flows smoothly past an object in **stream lines** — continuous filaments — or it breaks up into swirls and eddies, due to too abrupt a change in flow. The accompanying photographs of air flow illustrate this.



PHOTOGRAPHS OF THE EIFFEL LABORATORY IN PARIS, SHOWING THE TESTING ROOM AND THE TWO WIND TUNNELS



DEFINITIONS



THE FLOW OF AIR
UPPER LEFT, A FLAT SURFACE — UPPER RIGHT, A SPHERE — LOWER LEFT AND RIGHT, STRUTS OF DIFFERENT FINENESS RATIO

It is apparent that a spindle or fusiform shape, gently dividing the air at the front, and gradually permitting the filaments to close together at the rear, will give a smooth flow, which amounts to the same thing as a very low resistance. It is also evident that a flat surface creates very great disturbance, and consequently high resistance.

The curve of the stream lines, necessary to prevent disrupting them, may be computed for any speed, by applying fluid dynamics. But it must be kept in mind that a form of this kind gives its low resistance, only at one particular speed, since the path of flow is affected by the speed. It is unnecessary here to take up the determinations of these forms. If the stream lines flow smoothly past an object, and close up again without eddies, it follows that the only resistance experienced is frictional.

There are many ways of determining the manner in which the air flows past an object, such as noting the directions in which light silk threads are blown, or introducing smoke or particles into the air and photographing it. Ammonium Chloride is a very convenient smoke.

Importance of Visualizing the Air.

It is of great value in aeroplane work, to become accustomed to visualize the streamline flow of air, and ability to "see the air" often solves many problems of stability and reduction in resistance, without any recourse to mathematics or measurements. Besides this, there is offered in the study of air flow by photography, a field of investigation of great promise and absorbing interest.

It is a common experience that in a wind, at the front of a flat surface, there is a dead region of air, where no wind is felt. Photographs show this air cushion clearly, and in Chapter VI this simple conception is found to hold a valuable theory.

In stability discussions, effect of following planes, interference, and propeller stream action, priceless secrets would be revealed if the air could be followed in its every movement.

Determination of Air Resistance.

The nature of the action of air on objects has been considered, but we must know in addition with what force in pounds **P,** the air pushes on an object when it passes it at velocity **V.**

Applications of Theory to determine the magnitude of air pressures, are given consideration in Chapter VI, but merely for reference, since the best measures of air resistance have been obtained by actual experiment.

Methods of measuring the resistance of the air that have been widely used, are the following:

1. Dropping surfaces from a height and measuring time of drop and pressure, used by Newton, and Eiffel in his earliest experiments.

2. The whirling arm, used by Langley, and consisting of whirling the surface at the end of a large arm around a circle of large diameter and recording the resistance automatically.

3. The moving carriage, an automobile, trolley or car, as used in the experiments of the Duc de Guiche, Canovetti, and the Zossen Electric Railway tests.

4. By blowing or drawing air through a tunnel in which the object or a model of the object is placed. This method is the most modern and convenient, and permits of a uniformity of the air current, which cannot be obtained as easily in the open.

In **wind tunnels,** the best practice is to draw the air in, through screens and channels, that straighten it out, past the experimental chamber, and thence to the fan. Practically all the great Aerodynamical Laboratories use the wind tunnel method of experiment. The prominent ones are, the Eiffel laboratory in Paris, the National Physical Laboratory in England, and the tunnel at the University of Goettingen. The speed of the wind in the Eiffel laboratory can be brought up to almost 90 miles per hour (40 metres per second), and its size permits of testing many objects such as struts, to full size, and complete models of aeroplanes to one-tenth full size. Such a magnitude permits of exceedingly valuable determinations, and the work of the laboratories is daily being applied with entire success to full-sized aeroplanes.

It must be borne in mind, however, that the air in a tunnel is confined and that all tunnel results are not perfectly adaptable to machines, unless suitable corrections are applied.

Measurements made in the laboratories consist of determining not only the magnitude, direction and position of the wind forces, but also in determining the distribution of air pressure over an object by measuring the pressures at different points.

Air Resistance varies as V^2.

It has been found by very careful and extensive experimenting that the resistance of an object in an air stream is proportional to the square of the velocity of the air.

In other words, if the velocity is doubled, it follows that the resistance will be increased four times, or if velocity is five times as great, the force on the same object would be twenty-five times as great.

There are variations from this, however, due primarily to the fact that friction resistance alone, as distinct from impact resistance, varies as $V^{1.8}$ increasing in less proportion than V^2. On very large surfaces, and particularly on dirigible balloons, of streamline shape, the frictional part of the resistance is by far the greatest, and consequently makes the total resistance increase in a proportion less than V^2.

For our purposes, however, the total resistance, of objects, including the pressures and frictions, are considered as varying with V^2.

Air Resistance varies as S.

The size of the surface area, on which the air acts, **S,** gives a magnitude of air resistance that is in direct proportion to the size. If the area of the object is doubled, the air resistance is doubled, at the same air speed.

This experimental fact is also subject to modification, since, as the size of surface increases, the pressures are somewhat greater in proportion. But we can disregard this also without serious error.

Formula for Air Resistance.

It follows, therefore, from the above, that if we call **P** the force generated by the air movement at velocity **V** against an object of area **S** in cross-section, then **P** varies as SV^2.

This at once leads to an empirical formula, for the air resistance, if we introduce **K** to represent a numerical constant, which must be determined for any particular shape by experiment.

It may be stated then, that

$$P = K\,S\,V^2$$

This is the fundamental formula of Aerodynamics.

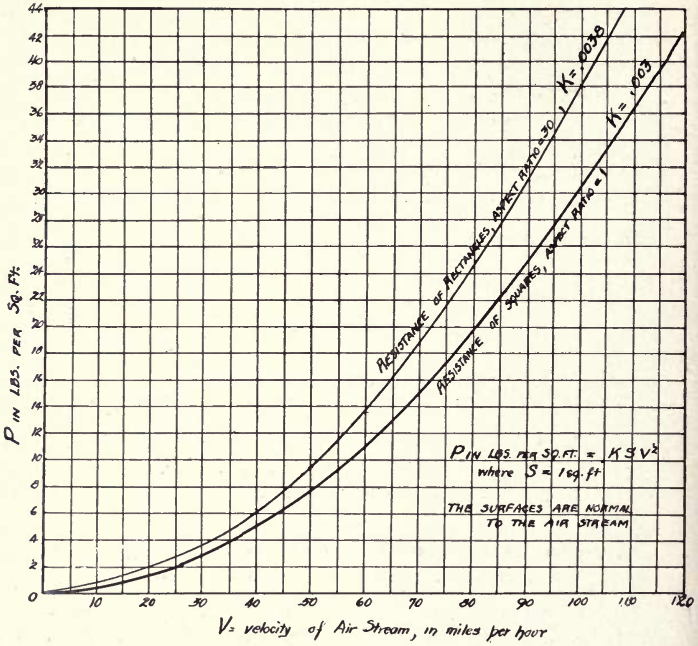
The units used will be **S** in square feet, **V** in miles per hour and **P** in pounds.

Although **P** also depends on the density of the air, sea level and 60° F., conditions are considered here and included in the value of **K.**

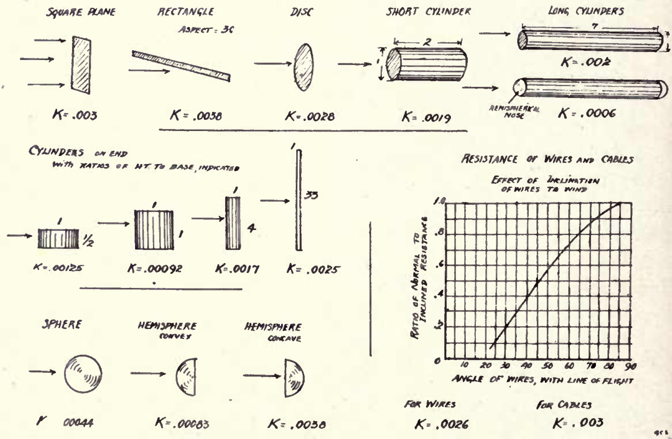
In this chapter we are interested in the air resistance of various objects and parts made use of in flying machines — and in adding to the air resistance of these parts the air force on the wings, that must be overcome to obtain the lift, we obtain the value of the total resistance to motion that is overcome by the propeller thrust.

In view of the above formula, it becomes necessary, merely, to review and average up the laboratory results, so as to obtain values of **K** for the various different objects.

The most accurate determinations of the latest experiments are made use of for this purpose and it is again emphasized that the values of **K** given, include both the impact and frictional resistances.



CURVE No. 1



THE RESISTANCE OF VARIOUS SURFACES AND BODIES

Definitions.

In Aerodynamical studies it has become customary in defining objects to use unfamiliar terms.

Aspect Ratio — is a term used to define the shape of a surface, and is the long span of the surface across the wind divided by the width.

Fineness Ratio — is a term used to define the general shape of bodies, and is obtained by dividing the fore and aft length of the body by the greatest width across the wind.

Master Diameter — is the greatest width of a body across the wind.

Fairing — is used to denote the additional "tail" or filler used to make a poorly shaped body more streamline in form, thereby reducing its resistance.

Diametral plane — is the plane, passed through a body, facing the wind perpendicularly, and cutting through at the master-diameter.

Normal plane — is another expression for diametral plane, and merely refers to the maximum cross-sectional projection of the body. It also refers to a flat surface held normal (perpendicular) to the air current.

Equivalent Normal Plane — is the size of normal flat surface, that would give the same resistance as does the body referred to.

It has been customary to refer to the air resistance of all bodies, as a percentage of the resistance of a flat square normal surface under the same conditions.

In this study, no such conception will be used, since values of **K** for each particular body are studied, and the flat square normal plane or surface is merely considered as one of several kinds of air-resisting bodies.*

Flat Surfaces,
Normal to the Air Stream.

Square Planes —

In square planes, normal to the air, the value of **K** is **.003** for surfaces up to two or three feet square, and **.0033** for very large surfaces like the sides of buildings.

It may be stated, therefore, for aeroplane usage, that **P**, the air resistance in lbs., of a square surface, **S** sq. ft., in area, at a velocity **V** miles per hour, is

$$P = .003\ S\ V^2$$

Thus, for a surface 2 feet square, at 70 miles an hour:

$$P = .003 \times 4 \times 4900$$
$$P = 58.8 \text{ pounds}$$

* Attention is invited to the author's work "Monoplanes and Biplanes," Chapt. II, where a discussion of experimental results and many values of K are given.

In curve No. 1 p. 48, the graph gives values of **P** in lbs. per sq. ft. for speeds up to 120 m. p. h. In the above example, at 70 m. p. h. the graph gives P = 14.7 lbs. per sq. ft., or 14.7 × 4 = 58.8 lbs., since S = 4 sq. ft.

Rectangles —

The aspect ratio of a square is one. Rectangles have aspect ratios above one, when presented normally to the air.

Up to an aspect of 5 or 6, **K** remains about **.003.**

An increase in the value of **K** is found for rectangles as the aspect ratio increases.

When the aspect ratio of the rectangles increases to 15, **K** becomes **.0035** and on further increasing the aspect ratio to 30, **K** = **.0038.** This is shown on the graph, p. 48.

A flat rectangle, perpendicular to the air current, with its dimension across the current, thirty times as large as its width, might be met with in rods, temporary struts, etc., and it is interesting to note how high the resistance would be.

Discs —

The shape of flat surfaces also affects their air resistance. Passing from a square plane to a round disc, reduces **K** to **.0028,** so that the air resistance of a disc 2 feet in diameter, at 60 miles per hour, is

$$P = K\,S\,V^2 = .0028 \times .7854 \times 4 \times 3600$$
$$P = 32 \text{ pounds}$$

In general rounded edges may be expected to reduce **K,** for flat surfaces.

Parallel Normal Surfaces —

Discs or flat rectangles, placed one in front of the other, interfere with each other and exhibit a most important phenomenon. When the discs are separated by more than two diameters, both receive pressure; there is a pressure on the front disc somewhat greater than on a single disc, **K** = **.0031,** and a very slight pressure on the rear disc. But with spacing less than this, the rear disc ceases to have any pressure, and instead undergoes a suction effect, which action actually pushes it toward the front disc. The forward push of the rear disc naturally reduces the total resistance of the two discs to a smaller value of **K,** making it much less than a single disc, when the rear one is 1½ diameters back of the front one. This phenomenon is given rise to by the nature of the air flow, which is illustrated in the diagram. A familiar application of this is where the racing bicycle rider follows in the wake of a motorcycle pace-maker.

Various Shaped Bodies.

Cylinders —

Passing from the disc to the cylinder, with the circular base facing the wind, the resistance is found to be less as the length of cylinder is increased, until the length becomes greater than 5 diameters, when the resistance is found to increase again. Some values of **K** are given on the chart. **K** for a cylinder 7 diameters long is **.002.**

When this cylinder is capped by hemispherical ends, the value of **K** falls to **.0006,** an interesting result.

When the cylinders are stood upon their bases various values of **K** are given. It is most important to point out that for the two cases corresponding with high aspect ratio — the cylinder with height very low in comparison to the diameter, and the long cylinder with diameter very small in proportion to height — the values of **K** are high.

Wires and cables are merely very long cylinders. Extensive experiments have been conducted on them, and values of **K** found. For smooth wires **K** = **.0026,** whereas cables are found to have considerably higher resistance with **K** = **.003.**

Thus, a machine having 200 feet of 1/8 inch cable, giving a projected area of 200/96 = 2.08 sq. ft., will have an air resistance due to the cables at 80 miles an hour of

$$\begin{aligned} P &= .003 \times 2.08 \times 6400 \\ &= 40 \text{ lbs.} \end{aligned}$$

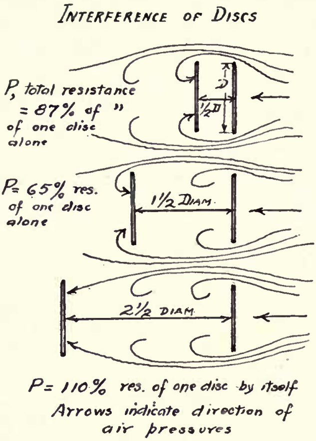
This high value immediately suggests the advisability of reduction of cable resistances. In double cables, it would prove beneficial to tape them together, so as to streamline each other. A graph is given showing the reduction in resistance due to inclining the wires i. e., staggered planes.

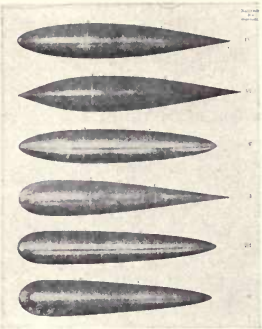
Experiments indicate that the vibration of wires does not increase their resistance.

Spheres —

The resistance of the air on spheres presents a study of interest. The sphere is the simplest geometrical form, and, as a basic one, it should long ago have served as the unit form for air resistance. Lack of agreement in the experimental results of different laboratories was only cleared up when Eiffel discovered that an increase of speed of the air above 20 miles per hour caused a change of flow, due to the flattening out of vortices back of the sphere, which reduced the resistance considerably. And that above this speed, the nature of the air resistance remained constant. **K** = **.00044,** for a sphere, at speeds above 20 miles per hour, whereas at very low speeds **K** becomes **.001.** In having a smoother flow at the higher speeds, less lbs. of air are put in motion, which means that the resistance is less. This action of air, in tending to smoother flow with speed increase, is important to bear in mind.

For a **hemisphere, convex** side to the wind, **K** = **.00083,** and when turned so as to present the **concave** side to the wind, **K** increases to **.0038.**

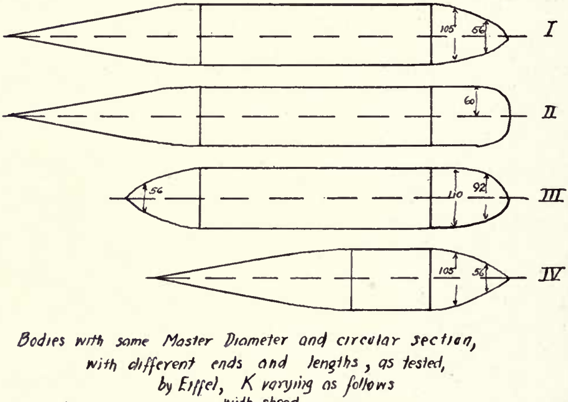


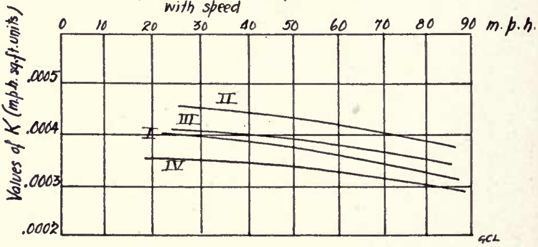


The bodies are placed in the order of their least resistances.

For the top one K = .00012

For the lower one K = .0002





TOP LEFT — INTERFERENCE OF FOLLOWING DISCS — TOP RIGHT, THE BODIES TESTED AT GOETTINGEN — BELOW, BODIES TESTED BY EIFFEL.

Streamline Shapes—

In this class may be included bodies of fusi-form or streamline form, shaped for least resistance. Their application to the design of tanks, fuselages, nacelles, hoods, etc., is of fundamental importance.

In a most interesting set of experiments, conducted by M. Eiffel, on streamline shapes, illustrated in the diagrams and chart on p. 52, the bodies consist of a nose, a cylindrical central portion, and a tail. The results of the experiments show that:

1. The blunter the nose, the greater the resistance.

2. The shorter the central cylindrical portion is, for the same nose and tail, the lower the resistance.

3. The effect of shortening up the tail is not very great, although slightly increasing the resistance.

In each case, however, measurements made at speeds up to 90 miles an hour showed that the resistance does not vary as $\mathbf{V}^2$, the value of **K** becoming constantly less with speed increase. This is a very significant determination, and may be explained on the ground that, in bodies of this kind, the major part of the resistance at high speeds is frictional and therefore increases at much less than $\mathbf{V}^2$. In addition the effect of velocity increase is to flatten out the flow and suppress eddies.

The values of **K** for these bodies are given.

The Goettingen Laboratory conducted extensive experiments on the best shapes for dirigible balloons which it is important to consider. The models tested measured 3.75 feet long and .62 feet in diameter, giving a fineness ratio of 6. The shapes in their order of least resistance and values of **K** for 25 m. p. h. are given. At higher speeds, still lower **Ks** would be expected.

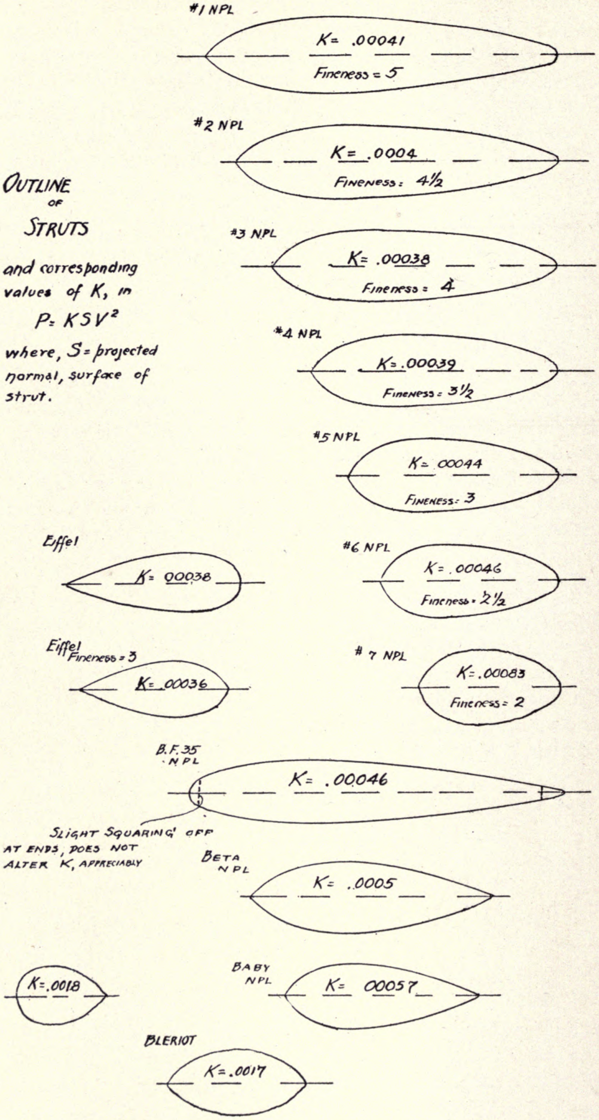
The form No. 1, having the least resistance, is, perhaps, the best form that has ever been tested in a laboratory, and at high speeds would give a resistance about 1/25th of the normal pressure on its diametral plane. It is the form used in the Parseval non-rigid dirigibles.

It is interesting to note in studying low resistance bodies, how closely they resemble the shapes of fishes, and of birds, measurements of a fast swimming fish showing an almost exact resemblance to this Parseval shape.

As a general rule, the best streamline body is the one having a fineness ratio of 6 and with the master diameter about 40% back of the nose, both nose and tail being fairly well pointed.

Struts—

The application of fineness ratios, and shapes of least resistance, to improvement in the form of struts, has in many instances tremendously improved the performance of aeroplanes.



THE RESISTANCE OF SEVERAL STRUTS OF DIFFERENT SHAPE

In addition to the form for least resistance, however, the weight of the struts and their strength are factors that must be considered in choosing the best shapes. We will confine ourselves here, however, to a study of the resistance of various shapes.

A group of strut sections are given and **K** for each one. It is to be noted that the effect of yawing is greatly to increase these resistances by presenting the strut sidewise to the air, and it will be necessary later to consider the amount of this increase.

Inclining the strut to the vertical, as in staggered planes, has the effect of increasing the length of section in the air stream, and, consequently, the resistance does not decrease for streamline shapes, while for blunter shapes, inclination reduces the resistance considerably.

In struts, as in bodies, an increase of velocity is accomplished by a reduction in the value of **K,** that is more noticeable the greater the fineness ratio, i. e., the longer the section of the strut. This is again due, probably, to the preponderance of friction in the total resistance.

The results obtained in studies of strut resistance indicate the importance of having struts well made and of a uniform section. Just as in bodies, abrupt changes in contour must be avoided and attention paid to a smooth curve on either side of the central portion.

It is found, in general, that a fineness ratio of 5 to 1 is best for use, where a fin effect is desired, and where not, — the best fineness ratio is 3 to 1.

Wheels —

The air resistance of chassis wheels is a considerable item in flight. Experiments have been conducted on various-sized wheels, and the results are as follows:

28½″	diameter	by	2½″	tire,	K = .0025
24 ″	“	“	3 ″	“	K = .00265
21 ″	“	“	3 ″	“	K = .0018
18 ″	“	“	2 ″	“	K = .0021

When the wheels are covered in, it is found in almost every case that the resistance is halved, so that for the 24″ × 3″ wheel, when covered in, K = .00133. An average **K** for wheels would be **.002.**

As an example, it is desired to determine the resistance of two 26″ × 4″ wheels at 80 m. p. h.

The projected surface = 1.4 sq. ft.

$$\therefore\ P = .002 \times 1.4 \times 6400$$
$$= 18 \text{ lbs.}$$

If the wheels were covered in at this high speed, about 9 lbs. would be saved in resistance; this would permit of carrying about 60 lbs. more load on an efficient machine, or would add 10 gallons more fuel.

Fuselages and Empennages —

The resistances of the bodies of aeroplanes, and of the tail pieces, constitute the major part of the resistance, and their importance and variations, with angles of yawing and pitching, make it necessary to give them separate consideration in a later chapter.

It may, however, be pointed out that the data on streamline bodies given, is readily applied to fuselages. The laboratories, however, have studied complete aeroplane models and fuselages, and have obtained valuable results.

Summary.

The data given in this chapter enables the air resistance of various shaped bodies to be computed for any speed **V** and any size surface **S,** where **S** is the maximum cross-sectional projection of the body, perpendicular to the air stream. It is merely necessary to supply the numerical values of **K, S** (in sq. ft.), and **V** (in m. p. h.), in the formula

$$P = K S V^2$$

It is well, again to recall that the propeller of an aeroplane must give a pull or push great enough to overcome:

I. The resistance to motion of the struts, wires, body, wheels, fittings, skids, gas tanks and other attachments.

II. The dynamic resistance of the wings and rudders, called the **Drift** and generated by the same pressure that gives the **Lift.**

In this chapter the first has been considered. And a study of the second may now be taken up.

A TRACTOR AEROPLANE CLIMBING

CHAPTER V.

INCLINED SURFACES.

In order to understand the mechanics of flying it is necessary to have a sound conception of the nature of air pressure on inclined surfaces. On a plane presented to the relative air current, at an angle less than 90°, the generated air pressure instead of acting straight back is inclined above or below the line of flow of the air.

Before discussing this, however, a few unfamiliar terms need to be defined.

Span is the dimension of a surface across the air stream.

Leading edge, is the first edge of the surface upon which the air impinges, whereas, **trailing edge,** is the rear edge of the surface.

Chord, is the dimension between the leading edge and the trailing edge of a surface. It is the depth of surface along the air stream.

Surfaces are of two kinds—**flat** in section and **curved** in section.

Camber, is the rise of the curved contour of an arched surface, above the chord line.

It follows from the above that for any inclined surface,

$$\textbf{Aspect Ratio} = \frac{\textbf{Span}}{\textbf{Chord}}$$

The explanatory diagrams on p. 60, are referred to, and it is seen that any inclined surface, is one in which the chord is inclined to the line of flow of the air.

This angle of inclination of the chord to the air stream is termed **angle of incidence.**

If the leading edge of a surface is presented to the air, above the trailing edge, the angle of incidence is said to be positive. And when the surface is inclined negatively to the air flow, it is meant that the air impinges on the top face of the surface, since the leading edge is below the trailing edge.

Lift and Drift.

The air acting on a surface presented to it with a positive angle of incidence generates a pressure, the line of action of which is pointed upwards and at the same time somewhat backwards. As the incidence of the surface is varied, of course, the inclination of this force above the horizontal is varied. But the important conception to grasp is, that the effect of inclining the surface below 90°, is to cause the total air pressure to assume an inclined position, with respect to the axis of flow of the air.

If the inclination is such that the total pressure points upward and backward, a study of the resolution of forces teaches that the vertical portion, or component, is equivalent to a force acting vertically upwards, capable of lifting weights, whereas the horizontal component of the same total air pressure is a resistance to motion.

It follows that in order to obtain this lifting component the horizontal one must be overcome, the two together corresponding to the resultant total pressure on the inclined surface.

Lift is the vertical component, called **L.**

Drift is the horizontal component, called **D.**

The resolution of the air pressure on an inclined surface into **Lift** and **Drift,** is the fundamental process in the mechanics of the aeroplane.

Drift is a drag or resistance to motion which is overcome by the thrust of the propeller, and at the expense of which a total inclined pressure is generated on the aeroplane surfaces, the vertical component of which is sufficient to support the weight.

Since Drift is a function of the pressure necessary to lift the weight, it now becomes apparent why Drift was classified as distinct from the head resistances of the various parts of a machine. The latter are due solely to their form and the speed of travel, and they exert no effect on the lifting power itself.

Consideration of this resolution into Lift and Drift, at once indicates that the characteristics to be sought for in a surface are great lift with a very small drift, so that for a minimum expenditure of power a maximum load carrying capacity is obtained.

The ratio of lifting power, **L,** to drift **D,** is a function widely used in considering the efficiency of surfaces, and the higher the value of **L/D** the greater is the weight that can be carried per pound of resistance.

It is well again to emphasize, that total resistance to motion is composed of two distinct items.

1. The air resistances of the various parts of a machine, such as struts, wires, wheels, bodies, etc.

2. Drift (in which is included the head resistance and frictional resistance proper of the wings alone, at the particular angle at which they are presented).

Flat Planes.

It is necessary to draw a distinction between planes that have a flat cross-section, and surfaces that have a curved cross-section, because the variations of the air pressures in magnitude, position, and dirction are quite distinct.

Let $\mathbf{P}_{90}$ represent the normal pressure on a surface set at 90° to the air stream and determined as explained in Chapter IV, pp. 49-50. And let $\mathbf{P}_a$ represent the total pressure on the surface when it is set at an angle of incidence **A** to the air stream.

It would be possible to express the variation of $\mathbf{P}_a$, with changes in the angle of incidence **a,** as a percentage of $\mathbf{P}_{90} = \mathbf{K\,S\,V}^2$. This would necessitate determining the ratio $\mathbf{P}_a/\mathbf{P}_{90}$, which is called the "ratio of inclined to normal pressure." Then

$$\mathbf{P}_a = \mathbf{P}_a/\mathbf{P}_{90}\,\mathbf{K\,S\,V}^2$$

where **K** is chosen for the particular aspect ratio used (see p. 50). This is the system ordinarily employed, but for our purposes it is considerably more convenient to return to the conception of having values of **K** tabulated for each separate item. So that we may call $\mathbf{K}_a$ the value of the constant in the expression

$$\mathbf{P}_a = \mathbf{K}_a\,\mathbf{S\,V}^2$$

and proceed to investigate the values of $\mathbf{K}_a$ for different angles of incidence, on the various surfaces. Thus, if we desire to determine the total pressure on a surface set at an angle of incidence, a = 6°, our system of notation becomes quite clear, in stating

$$P_6 = K_6\,S\,V^2$$

Lift and Drift.

It is a fundamental fact of aerodynamics, capable of proof, that, in **flat planes, $\mathbf{P}_a$ is always perpendicular to the chord.** This simplifies the consideration of inclined pressures on flat planes, since at any angle of incidence we know the direction in which the air pressure acts. Thus, a flat plane, set at an incidence of 10°, is acted upon by an air force, the line of action of which is pointed 80° above the direction that would be taken by the normal pressure.

This uniformity in the direction of $\mathbf{P}_a$, with reference to flat planes, enables us to obtain very simple rules for finding the Lift and Drift of flat sections.

Obviously from the resolution of forces

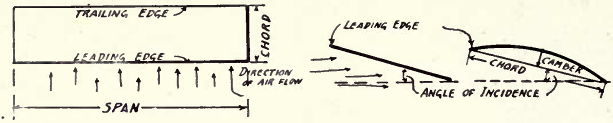
$$\textbf{Lift} = \mathbf{P}_a \textbf{ cosine a,} = \mathbf{K}_a\,\mathbf{S\,V}^2 \textbf{ cos a}$$

$$\textbf{Drift} = \mathbf{P}_a \textbf{ sine a,} = \mathbf{K}_a\,\mathbf{S\,V}^2 \textbf{ sin a}$$

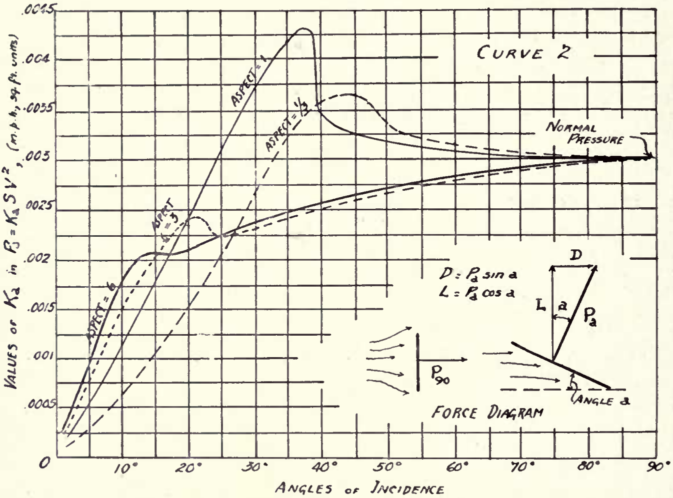
In addition, the **Lift-Drift ratio,** L/D = **cotangent a.**

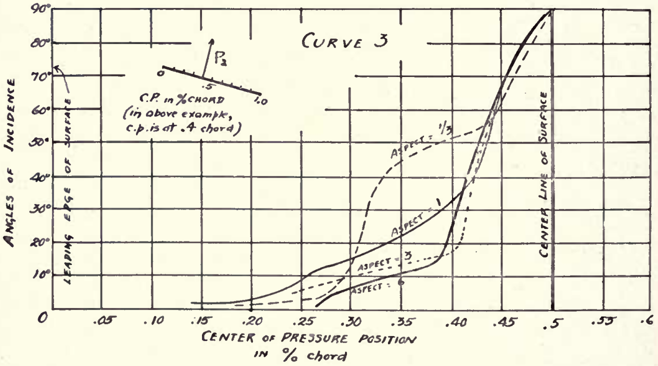
To determine the magnitude of the forces on flat planes, therefore, it is merely necessary to know the appropriate value of $\mathbf{K}_a$, as determined by mathematics or experiment. *

* In the author's work "Monoplanes and Biplanes," many relations for Pa are considered, in Chapter III.



DEFINITIONS





The definitions for flat and curved sections, given on p. 57, are shown at the top of the page.

Curve 2 shows the variation of Ka, for aspects of 1/3, 1, 3, and 6.

Curve 3 shows the c. p. movement for the various aspect ratios.

The variations of $\mathbf{P_a}$ are affected by Aspect Ratio, and a very remarkable distinction between squares and rectangles in the manner in which $\mathbf{P_a}$ varies as the incidence is changed was discovered by Eiffel. At angles in the neighborhood of 40°, on square planes, $\mathbf{P_a}$ was found to have values very much greater than $\mathbf{P_{90}}$.

Values of K_a for several different aspect ratios are given in Curve No. 2, p. 60.

It will be seen from this graph, that an increase of aspect ratio above 1 is accompanied by increases of $\mathbf{P_a}$, at low angles. But there is a general falling off of this at 15° to 20°, as the aspect ratio is increased. For efficiency, at low angles, on flat planes it is advisable therefore, to use the higher aspect ratios.

In all cases, S is the plan area of the surface.

Center of Pressure.

Although the direction and magnitude of forces on flat surfaces have been considered, these forces are not fully defined until determinations are obtained of their point of application.

The nature of the air reactions on a surface consists of a series of small impact pressures and friction rubs all over the surface; but their total effect can be represented graphically by a single force, in the resultant direction, and applied at a point about which all pressures balance.

This center of balance of air reactions is termed the "center of pressure," and if we draw thru it a force proportional to $\mathbf{P_a}$, and in direction normal to the surface, we have completely defined the air reaction on that particular flat plane.

On flat surfaces it is indicated by **Curve 3** that, as the incidence is decreased, the center of pressure moves forward until at 0°, it is very near the front edge, and at 90° it is at the center of surface.

The representation of position of center of pressure, **c. p.**, as a percentage of the chord, is a convenient one that has become quite standard.

Example.

A typical example of the use of the data given for flat planes may prove of interest.

An aileron, flat in section, measuring 2 ft. chord by 12 ft. span (aspect $12 \div 2 = 6$), is pivoted 4 inches back of the leading edge. The aileron is moved to an incidence of 10° and the air speed is 60 miles per hour.

It is desired to find the corrective force on the balance of the machine represented by the lifting force of the aileron, at 10° incidence.

$$\text{Lift, } L = K_a S V^2 \cos a.$$

From the chart we find that for a plane with aspect ratio of 6,

$$K_a = .00175,$$

and $\text{Cos } 10° = .985$, $S = 24$ sq. ft., $V^2 = 3600$, so that

$$L = .00175 \times 24 \times 3600 \times .985$$
$$= 149 \text{ lbs.}$$

In addition it is desired to know the moment of the total pressure P_a, about the pivot, at 10° incidence.

From the graph it is found that

$$\text{c. p. position} = .33 \text{ chord} = .33 \times 24$$
$$= 8 \text{ inches from leading edge.}$$

It follows, therefore, that the lever arm of the total pressure P_a about the pivot is 4 inches.

$$P_a = K_a S V^2 = .00175 \times 24 \times 3600 = 151 \text{ lbs.}$$

Therefore, the moment about the pivot is,

$$= 151 \times 1/3$$
$$= 50 \text{ foot lbs.,}$$

which would enable the pounds pull on a control mechanism to be determined, and leverages suitably arranged.

Curved Surfaces.

Although the general characteristics of the action of air on flat planes had been known more or less accurately for some time, the nature of air reaction on curved surfaces was not well appreciated until the pioneer work of Lilienthal and the Wrights disclosed it.

Lilienthal discovered that, at low angles, surfaces slightly cambered gave very much more lift and less drift, than did flat planes, at the same incidence, and that the resultant total pressure was not necessarily perpendicular to the chord, as on flat surfaces. In fact, he found that at certain low angles of incidence the total pressure on a curved surface was leaning considerably in front of the normal to the chord line, which meant that a smaller proportion of this total pressure was drift, and a greater portion was lift.

It is upon this discovery that the first practical demonstration of the possibility of flight may be said to have originated, and succeeding generations are justified in hailing Otto Lilienthal, in view of his classic experiments, as the discoverer of modern flight.

The Wrights, in their gliding experiments, discovered that the center of pressure on an arched surface of Lilienthal type, did not change its position, in the same way as the c. p. on a flat plane, but that instead of moving steadily forward as the incidence was diminished the c. p. on the curved plane ceased to move forward at about 10°-15°, and retrograded, moving rapidly past the center of surface, towards the trailing edge as the angle grew smaller. This feature rendered Lilienthal's measurements somewhat inaccurate, but the corrections, readily applied, were used to make the old results applicable to the modern aeroplane.

K_L and K_D

Since the total pressure on the curved surface, which we will call **P_i**, is not necessarily perpendicular to the chord line its resolution by trigonometry into Lift and Drift is not possible unless we know its inclination with respect to the chord line. But, since this necessitates knowing its components, it becomes, at once, more convenient to study curved surfaces directly from measurements and data on Lift and Drift.

This is done throughout the study of curved surfaces and aerofoils (aeroplane sections), and in the laboratories it is customary to measure the vertical and horizontal forces on curved surfaces. The resultant of these determines P_i, in magnitude and direction. But since we are rarely concerned with P_i, where data is already available on L and D, its consideration is not so important.

To define L and D, it is most convenient to consider that

$$\mathbf{L} = \mathbf{K_L\, S\, V^2}$$
$$\mathbf{D} = \mathbf{K_D\, S\, V^2}$$

and information on curved surfaces resolves itself into a study of the values of $\mathbf{K_L}$ and $\mathbf{K_D}$ for the various angles and shapes.

In this chapter, the simplest geometrical curved sections only are considered, as it is desired merely to bring out the main distinctions between flat and cambered sections.

The standard practice is adopted of referring to the camber of curved sections, as a fraction or percentage of the chord.

Forces on Cambered Planes.

The resolution of **P** into **L** and **D** is fully indicated in the diagrams on p. 64. The angle of incidence of the chord with the air stream is called **i.** But, since in cambered planes **P_i** is not necessarily normal to the chord, it follows that the angle between **P_i** and **L** is not necessarily equal to the angle of incidence **i,** as it is on flat sections. This angle of the resultant with the vertical is called **r,** and from the construction of the triangle of forces it is apparent that **tan r = drift/lift,** and the ratio of **L/D = cotangent r.**

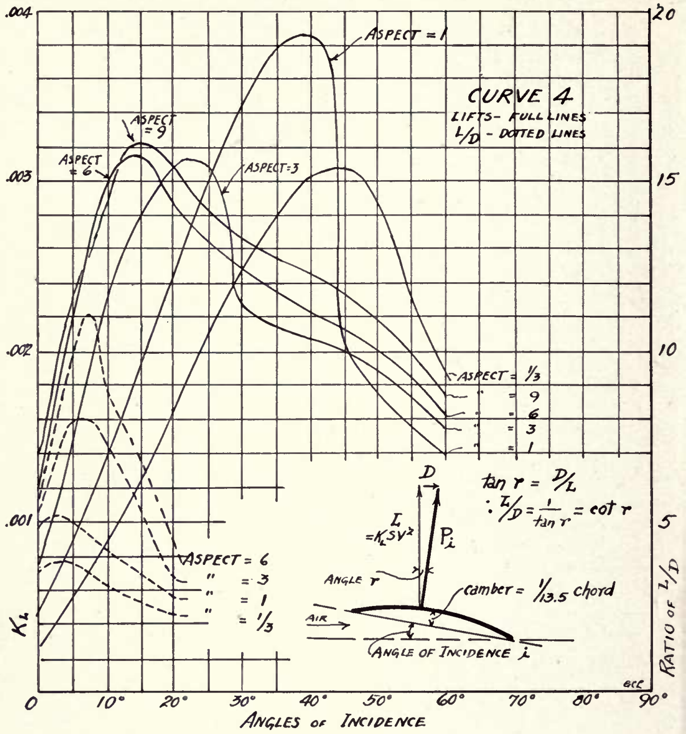
The nature and determination of **"Lilienthal's Tangential"** is not considered necessary in this study, although it is frequently dwelt upon in elementary aerodynamic treatises. *

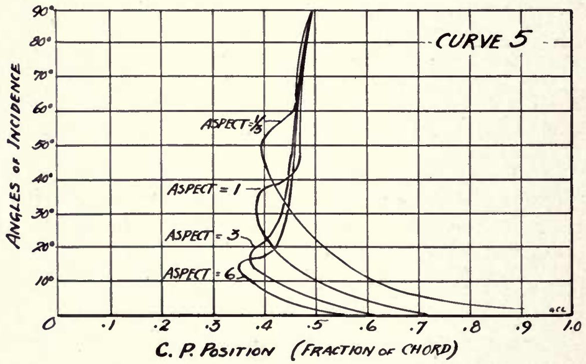
Influence of Aspect Ratio.

The manner in which a change in Aspect Ratio affects the forces on circular arcs is shown in the charts on p. 64. It is found that not only the magnitude of **L** and **D,** but the movements of the center of pressure are influenced very much as on flat sections. For a circu-

* See "Monoplanes and Biplanes" Chapt. IV, p. 47.

To find D at any angle, divide values of L by corresponding values of L/D.





Curve 4 shows coefficients Lift and Ratios of L/D for changes in aspect ratio, of a circular arc.

Curve 5 shows the c. p. movements for the same surfaces.

lar arc in which the camber is 1/13.5 of the chord (an average camber for good efficiency), the values of L and L/D steadily increase as the aspect ratio is increased from 1/3 to 6. The difference between aspects of 6 and 9, however, is not very marked, and it is indicated from these results that there is not much gained by increasing the aspect of an aeroplane wing above 6. With reference to the total pressure P_i, it is found for cambered planes as it was for flat ones, that when the aspect ratio is 1 (a square), P_i rises to a value more than once and a half times the normal pressure P_{90} at an angle of about 40°.

The center of pressure chart shows that as the aspect is increased the reversal of movement at low angles becomes sharper, and the angle at which this reversal takes place falls from 45° for aspect 1/3 to 13° for aspect 6.

Effect of Depth of Curvature.

Alterations in the camber, i. e., in the depth of curvature of circular arcs, greatly affect the magnitude of L and L/D, and the movement of the c. p. In the charts, on p. 66 there are plotted, the curves, showing the values of K_L and L/D for arcs of 1/27 and 1/7 camber, with an aspect of 6, which are to be compared with the curve for a 1/13.5 camber, aspect 6.

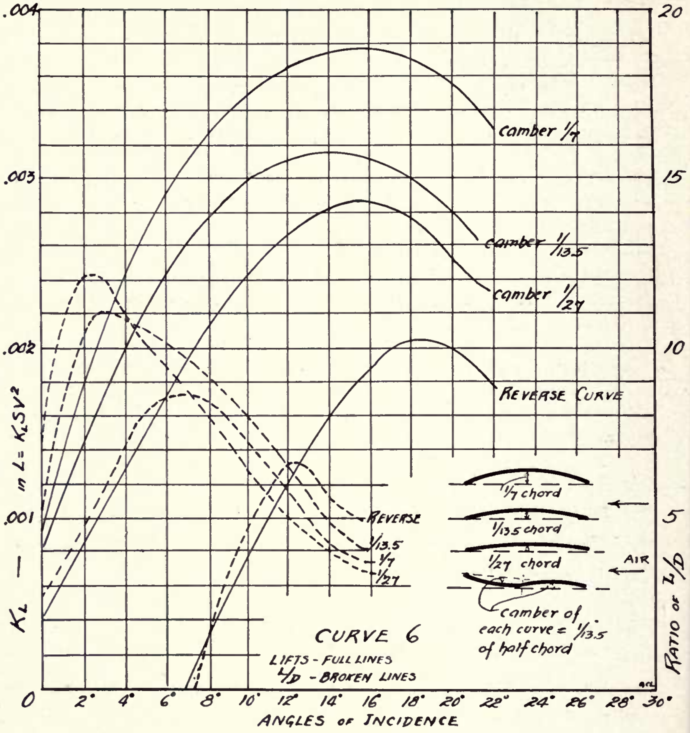
It will be noted that the magnitude of L increases with the increase of camber, but the ratio of L/D is decreased by camber increase and the point of maximum L/D varied. This indicates that deeply cambered sections would prove to be inefficient wings for aeroplanes.

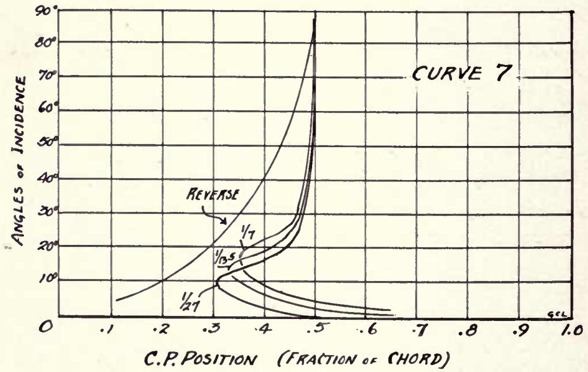
For the smaller camber, the c. p. movement is sharper, and the reversal point further forward.

The Reverse Curve.

Sections of cambered surfaces may, of course, be other than circular. Combinations of straight lines and circular arcs, parabolic curves, spirals, and the like, have characteric pressures that differ from each other, but in so small an amount that it is hardly necessary to give them separate consideration — excepting in so far as they are taken up later in studies of aeroplane wing sections.

The **reversed curve,** however, is a distinctive geometrical section, to which attention should be given. These sections, as illustrated in the diagram, have the important property that the center of pressure continues to move forward as the angle is decreased, the characteristic retrograde movement, as found on circular arcs, being apparently absent. As will be explained later, this retrograde movement tends towards instability, and although the ratio of L/D and L are very greatly reduced by a reverse curve, it becomes necessary to bear in mind that for aeroplane wing sections the loss in efficiency may be worth while, in order to gain in stability.





Curve 6, shows the coefficients for Lift, and the values of L/D, for arcs of 1/7, 1/13.5 and 1/27 camber, and the reverse curve section.

Curve 7, shows the c. p. movement for the same sections.

Aerofoils.

Only flat and the simplest geometrical sections have been considered here. In aeroplane wings, it is necessary to have spars and ribs of considerable depth, in order to obtain suitable strength and rigidity of wing. This leads to sections of surfaces in which two curvatures must be considered — the top face and the bottom face.

An aeroplane wing section is, therefore, distinct from geometrical sections, and it is customary to refer to aeroplane types of surfaces as **Aerofoils.** They are treated of fully in Chapter VII, since a knowledge of their characteristics, advantages and disadvantages enables the first essential step in the design of an aeroplane to be taken — the choice of a wing section that will give the weight-lifting, strength and speed combination desired.

Examples of the application of curved section pressures are taken up in several instances in the consideration of aerofoils, and many of them are deduced from actual practice as applied in well known types of aeroplanes.

Summary.

I. In flat surfaces.

The total pressure $\mathbf{P_a}$ is always normal to the section, and can be resolved into,

$$\textbf{Lift} = \mathbf{P_a \ Cos \ a}$$
$$\textbf{Drift} = \mathbf{P_a \ Sin \ a}$$

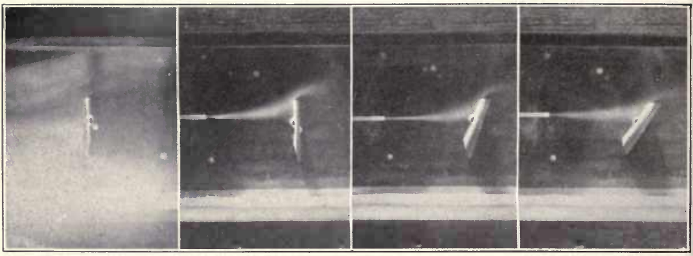
The center of pressure moves forward as the incidence is decreased.

II. In cambered surfaces.

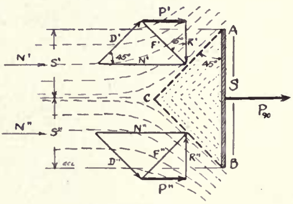
The total pressure P_i is not always normal to chord, and the pressures on a cambered plane are, therefore, more easily expressed as

$$\textbf{Lift} = \mathbf{K_L \ S \ V^2}$$
$$\textbf{Drift} = \mathbf{K_D \ S \ V^2}.$$

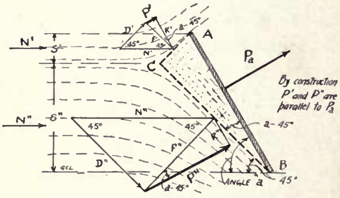
The center of pressure, on curved surfaces, moves forward up to a certain low angle where it reverses and moves rapidly to the rear (except for reverse curved surfaces).



Photographs of air flow, showing air deflections, obtained at the author's laboratory, by introducing chemical smoke into the air stream.

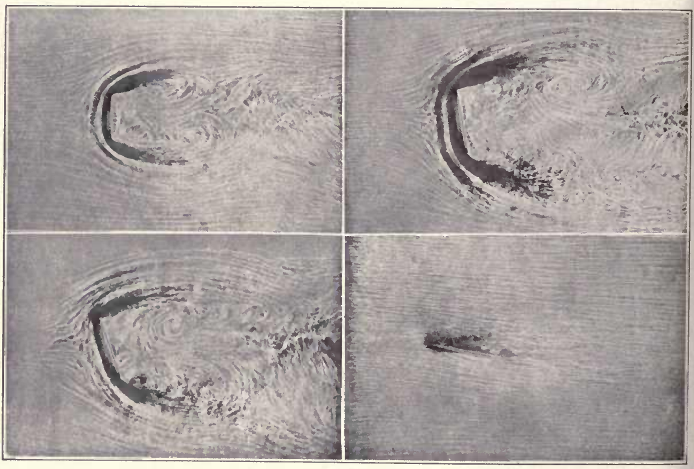


Normal Surface



Inclined Surface

DIAGRAMS OF AIR FLOW



Photographs of air flowing from left to right, on flat surfaces, made at the Koutchino laboratory. Note the general deflection of the air stream, in the lower right hand photo, where the plane is at a low angle of incidence.

CHAPTER VI.

AERODYNAMIC THEORY.

Although it is not so essential to consider the theoretical derivation of formulae for air resistances in a work of this kind, a certain interest is attached to the application of the more recent experiments on the flow of air streams to the older conception of the mechanics of the air.

An outstanding experimental fact in air stream photographic studies, that vitiates many established aerodynamic derivations, is that the air stream, when it impinges against a normal surface, divides to pass around the edges, and in doing so actually imprisons a cushion of dead air against the surface, a phenomenon constantly met with in wind effects on moving vehicles, etc. Furthermore, in dividing, the air stream acts as if separated by two physical surfaces and takes a deflection of about 45°, instead of being turned thru an angle of 90°, as assumed in older hypotheses. Many photographs of air flow, including several taken in the writer's laboratory in New York, confirm this.

The mechanics of air flow on normal surfaces, if the air is considered as deflected at 90°, may be stated as follows:

Moving air develops a pressure equal to its momentum, expending its entire energy by impact. Momentum = mass × velocity. The mass of air = **W**/g, where **W** is its total weight, and equal to the unit weight or density of air **w**, × the volume of air moved, which is equal to S V, where S is the surface in sq. ft. and V the velocity in ft. per sec.

Supplying appropriate values we get for the total resistance,

$$\begin{aligned} P_{90} &= w/g\ S\ V^2 \\ &= .0054\ S\ V^2 \end{aligned}$$

which is a formula of the form $P = K\ S\ V^2$ in which $K = .0054$.

This value of K we know by experiment is quite incorrect, and it follows that we must consider the derived result worthless.

If, however, we start with the more correct hypothesis, that the air is deflected at about 45° (depending possibly on friction effects) instead of 90,° a derivation of this form would result.

Let A B, in diagram p. 68, represent the surface of area S, in an air stream of velocity V. Let A B C represent the imprisoned cushion of air, and A C and C B the surfaces of air along which the deflected stream flows.

Let s′ and s″ represent the normal projections of A C and B C.

The total energy of the air stream, before deflection, is represented by $N' + N''$, where $N' = w/g\ s'\ V^2$ and $N'' = w/g\ s''\ V^2$.

The resolution of N′ into D′ and F′, indicates the probable state of affairs along the "deflection" plane A C. The force D′ is parallel to and vanishes with the deflected air stream, and in fact represents the stream's energy. The force F′, however, is perpendicular to the plane A C, and since its action is directed towards the surface it can be resolved into a force P′, normal to the surface, and in the same direction as P_{90} and a force R′, equal and opposite to R″, which is entirely used up in compressing the air cushion. While a greater part of the energy of the stream D′, D″, goes away with it, a portion P′, P″, of the stream's force is "deposited" on the surface,

$$P_{90} = P' + P''.$$

Analysis shows that

$$N' = w/g\ S'\ V^2 \text{ and } N'' = w/g\ S''\ V^2.$$

$$AC = BC = S \sin 45° \text{ and } s' = AC \sin 45° = S \sin^2 45° = S/2 = s'$$

$$F' = N' \sin 45°,\ F'' = N'' \sin 45°, \text{ and } P' = F' \sin 45°,\ P'' = F'' \sin 45°$$

Recalling that $\sin^2 45° = 0.5$

$$P' = w/g\ S\ 0.5\ V^2 \sin^2 45° \text{ and } P'' = w/g\ S\ 0.5\ V^2 \sin^2 45°$$

Hence using sea level and mean temperature, conditions, for w/g,

$$\begin{aligned} P_{90} &= w/g\ S\ V^2 \sin^2 45° \\ &= .0054\ S\ V^2\ 0.5 \\ &= .0027\ S\ V^2 \end{aligned}$$

which is so nearly in accord with experimental results, K = .003 as at once to lead to an appreciation of the value of considering the "air cushion, 45° deflection" characteristics of air flow, in any study of air pressures.

The experimental results on the pressures experienced by inclined planes show that at angles above 45° the change in inclination does not greatly affect the pressures. The division of the air in front of a plane inclined at angles greater than 45° is of the same character as in normal surfaces, and a similar theory when applied shows that the pressure remains constant from 90° to 45°.

Inclined Surfaces

Referring to the diagram, p. 68, the mathematics of this develops as follows:

AC = S Sin (a − 45°) and BC = S Cos (a − 45°)

∴ S′ = S Sin (a − 45°) Sin 45° and S″ = S Cos (a − 45°) Sin 45°.

The normal pressures on the projected areas, S′ and S″, may be considered as the energy of the air stream, a proportion of which is expended on surface AB as P.

Calling N′ and N″ these pressures, we have N′ = w/g S′ V^2 and N″ = w/g S″ V^2.

The force triangles show that, P = P′ + P″ and that P′ = N′ Sin (a − 45°) Sin 45° and P″ = N″ Cos (a − 45°) Sin 45°.

Supplying the values of S′, S″ and of the resulting N′ and N″, we get $P = w/g\ SV^2 \operatorname{Sin}^2 45° \operatorname{Sin}^2 (a - 45°) + w/g\ SV^2 \operatorname{Sin}^2 45° \operatorname{Cos}^2 (a - 45°)$.

Since $\operatorname{Sin}^2 + \operatorname{Cos}^2 = 1$, and $\operatorname{Sin}^2 45° = 0.5$, and supplying values of w and g there is obtained,

$$P = .0027\ SV^2$$

From 35° to 45°, the inclined flat surfaces there is a region of unsteady flow, in which for squares the pressures become much greater than the normal.

Below these angles the air flow ceases to divide along deflection planes in front of the surface, and all of the air passes under the surface. In this case the pressure would be proportional to the sine of the angle of incidence, as outlined above, in forces F′ F″ and the formula

$$P_a = K\ S\ V^2 \sin a$$

is found closely to agree with practice.

This theory, first proposed by the writer some time ago, is as rigid as any resolution into Lift and Drift. The hypotheses may be briefly summarized as the consideration of the division of the air along two deflection planes, which act like a surface on the air, and cause the energy of the air to be divided up into a force parallel to the deflected stream, which goes along with it, and a force normal to the layer of air, along which deflection takes place, which in turn is composed of a force compressing the air cushion and a force actually causing the resistance of the surface.

Proper consideration of air deflection is capable of determining c. p. position (by intersection of the deflection planes) and when applied to curved surfaces, should give most interesting results. And, it would seem, that additional measurements by the laboratories, on the angles of the deflected currents, would make the data on surfaces more complete.

It is seen, therefore, that derivations based on a more accurate hypothesis of air flow, give much more satisfactory results. In a work dealing so largely with practice it is important to point out that unless the hypothesis of the physical air flow used in any theory is correct it is far more practical to rely on observations and abandon formulae. The theory of propellers, and its lack of agreement with practice, is a field in which there is a most pressing need of a satisfactory basis for theoretical determinations.

The "Absolute" System of Units.

It has been indicated that **K,** in the formula $P = K S V^2$ is a function of w/g of air. For any body, if we introduce another constant **C,** we may write the air resistance formula in terms of density of air w, and acceleration of gravity g, as

$$P = C\, w/g\, S\, V^2$$

Since the units in which **P** is expressed depend on the units used for w and g, S and V, it follows that **C is a number independent of the system of units employed.** For this reason it is called the **absolute coefficient,** and its value is the same whether P is expressed in lbs. or grams, providing the expression of w/g is made in the proper units.

The absolute system is used by the Goettingen and the N. P. L. (British) Laboratories. It is an inconvenient system for practical field use, but for the international comparison of scientific results it is admirably adapted.

The system used in this work is

$$P \text{ (pounds)} = K\, S \text{ (sq. ft.) } V^2 \text{ (miles per hour).}$$

Therefore, to translate results in the absolute system to these units the "absolute" values must be divided by 196.

"Absolute" values $\times$ .0051 = "m. p. h., sq. ft." units

The Metric System.

The Eiffel results are expressed in metric units,

$$P \text{ (kilograms)} = K\, S \text{ (sq. meter) } V^2 \text{ (met. per sec.)}$$

so that Metric values $\times$ 8 = "absolute" values, and

Metric values $\times$ .041 = "m. p. h., sq. ft." units.

Thus for K = .0033, we would have in "absolute" units

$$P = .64\, w/g\, S\, V^2$$

and in metric units, $P = .08\, S\, V^2$.

In the consideration of these conversion factors, atmospheric pressure at sea level and ordinary temperature conditions are assumed.

Summary.

The greater part of this chapter is presented for reference, but the different systems of units and the conversion factors are of importance, and should be understood, and borne in mind.

The theory of air pressure presented, is purposely not expressed in terms of the usual theorems and laws of fluid dynamics, since it is desired to emphasize, merely, the importance of continually bearing in mind, that the resolution of air pressures, along the directions in which they act, is the correct fundamental conception of aerodynamics.

CHAPTER VII.

CHARACTERISTICS OF AEROFOILS.

The manner in which air pressures vary on flat and cambered surfaces has been considered fully enough to enable us to proceed with the study of aeroplane wings themselves. As already indicated, the necessity of having spars and ribs of considerable depth for the rigidity of an aeroplane surface, makes it necessary to use a section of a certain thickness, and consequently two curvatures — the top face and the bottom face — must be taken into consideration.

Aeroplane wing sections are ordinarily referred to as aerofoils, and the study of the various aerofoils and their characteristics is of very real importance. While a good deal of the data on air pressures has been given by way of explanation and general information, the wing characteristics referred to here are of the greatest practical significance, and are every day being put to use and verified, on the aviation fields of the military world. The connection between the characteristics of a wing section and the operation of a great war would seem remote, but when it is appreciated that superior speed and climbing ability enables a hostile aeroplane to gather information quickly and escape from attack and pursuit, primarily because of the greater efficiency of its wing section, the importance of this study becomes apparent.

The development of wing sections has been along several lines. Originally geometrical sections were made thick enough to give room for spars and then rounded at the edges. Other pioneers, after deciding on the size of spar and thickness required, adopted a certain camber for the mean center line, and then proceeded to fill out a section that would streamline the spars. Still other investigators adopted parabolic and circular curve combinations, crescent shapes, etc., and finally the great laboratories took up the matter and systematized its study. The Eiffel, N. P. L., and Goettingen results are complete enough now to give a very firm basis for aeroplane design, and to enable the effects of any changes in aerofoils to be quite accurately anticipated.

In general the features of an aeroplane wing that may be varied are:

1. Shape of Section, curvature, thickness, etc.

2. Shape in Plan, contour, aspect ratio.

In addition, the manipulations of the wing by warping or moving flap sections that are connected to it, modify the pressures, and there are further modifications of the air forces when the proximity of some other wing or body affects the air flow and interferes with the paths of the streamlines. Mutual interference of surfaces with each other is a formidable study, and is given special consideration.

The nature of air pressure on aerofoils is revealed by air-stream photographs, the most striking feature being the manner in which the rounded nose of the aerofoil in deflecting the air stream, causes the air some distance ahead to take a curvilinear path up to the aerofoil. This influence, frequently called the "phenomenon of the dipping front edge," is very pronounced for some aerofoils, and when generating an upward stream of this kind an aerofoil is virtually riding on the crest of a wave. An explanation is found here for the greater lift and less drift of aerofoils, and the section that generates the most pronounced wave with the least break in the flow is naturally the most efficient.

Another feature that it becomes more necessary to consider now, in view of the separate nature of the top face, and the bottom face, is that the total air reaction, resulting in the forces on the aerofoil, consists of pressure, both positive and negative. Positive pressure is a compressive action, while negative pressure is a suction. In previous considerations of air resistances, it has been unnecessary to draw this distinction, since we were interested, merely, in the total effect of the air reaction.

Lift by Suction on Top Face.

Careful studies of the distribution of pressure over the surface of typical aerofoils made by the great laboratories, have shown that the actual effect of the air flow at the usual flying angles is not only to generate a pressure (compression of air) on the lower face of the inclined surface, but also to cause a great suction on the upper face. Furthermore, measurements show that the value of **this suction in pounds force is about three-quarters of the total air force on the aerofoil.** In other words, the action of the air flowing past an aeroplane wing, primarily causes a partial vacuum on the top face, which tends to draw the surface up by suction. As long as this wave form suction type of flow continues, the surface is in its most favorable attitude for efficiency, but at higher angles than ordinarily employed in flying this type of flow breaks down, and a disruption of the streamlines follows, evidenced on the surface, by a great increase in resistance and fall in lift. The angle at which this change of flow occurs is called the critical angle.

While the distribution of pressure across the wing's chord is of the form indicated on p. 78, there is also good reason for investigating the manner in which the pressures on a wing vary from the center across the span to the tips. As the tip is approached the pressures reduce and the point of highest suction passes from the leading edge towards the trailing edge. The drift of the wing tips is found to increase and to be accompanied by a fall in L/D, as the tip is approached. The type of flow that produces the best L/D is found at the center of the wing, where the streamlines pass directly from front to rear. As the tips are approached, however, the streams of air begin to flow off sideways, endeavoring to escape out at the sides. Obviously, the higher the aspect ratio, the less in proportion is this sideways escape of air, and therefore the better the L/D.

General Characteristics.

Although the pressures, on the various sections differ considerably from each other, there are certain characteristic features that are common to the majority of the aerofoils.

At 0° incidence there is usually a certain lift A, and at a negative angle, anywhere from $-2°$ to $-9°$, there is a point of no lift, H (see p. 78). The manner in which the Lift and L/D curves are plotted, on a basis of angles, is the same as in Chapter V, the Lifts being defined by values of K_L in the formula, Lift = $K_L S V^2$. From A to C, on the Lift curve, is more or less of a straight line, the curve bending over at C, which point is called the point of maximum lift. From C to D, instead of continuing to increase, a critical state of flow has been reached, where further incidence increase is accompanied by a drop in the Lift. This is an interesting portion of the curve, and we will again have to refer to it when we take up the control of the aeroplane in this reversed pressure region. Where lift decreases in this way, it may be stated briefly, that the controls on an aeroplane would have to be reversed for flying in this region. To go up, it would be necessary to reduce the angle of incidence, and to descend, the elevator would have to be pulled back so as to increase the angle.

On the L/D curve from the point of F at 0°, the value of L/D increases to a maximum E, corresponding to a Lift of value B. From E to G, the L/D ratio again falls off. The ordinary regions of flight are limited to the peak region of the L/D curve.

In the study of the aeroplane, as a unit, taken up later, consideration will be given to the important relations that the maximum and minimum points of the L and L/D curves bear to each other.

Having, in a general way, considered the nature of air reaction on aerofoils, we may proceed with a study of the effect of alterations in shape and plan form and interference. The values of K_L and L/D in the curves, refer to the combined action of whatever compression or suction is generated, unless otherwise noted. It is also well to recall that L/D represents the ratio of the Lift force obtained from an aerofoil at the expense of the Drift D, a resistance that must be overcome. "Efficiency" refers to L/D, and is higher, the greater the Lift obtained for resistance overcome.

ALTERATION IN SHAPE OF SECTION.

1. Camber of Upper Face.

Increasing the camber of the top face from 1/40 to 1/6, on a form with a flat under face, shows that the maximum lift increases up to a camber 1/15 and then decreases. The ratio of L/D steadily improves up to a camber of 1/20. This camber appears the most efficient, as deeper cambers show a steady decrease in values of L/D.

On an aerofoil, having the under face arched considerably, when the camber of the upper surface is increased above 1/15, the Lift hardly varies, while the drift steadily increases with camber increase. For very thick sections, however, just as in spheres and cylinders, there is a critical flow, which, due to increases in speed, tends to smooth out and reduce resistance.

2. Camber of Lower Face.

Increasing the camber of the lower face, for a fixed upper face, shows that L/D does not vary very much, and that L increases appreciably with camber increase. Since the depth of spar is very greatly enhanced by keeping a flat underside, there is every reason for considering rather flat under surfaces as advantageous. The increased depth of spar reduces the weight of framework in the wing necessary for a given strength, and would about compensate for the lift increase obtained by camber of the lower face.

The upper face, furnishes most of the lift and variations of lower face have very little effect on the upper side.

3. Thickness and Depth at Rear.

By keeping the same mean curve of a section, and adding to the top and bottom faces at the same time, the drifts are found to remain about the same, and a decrease in lift is found as the section becomes more and more a streamline body — due to the progressive bulging out of the section, both top and bottom.

For any particular curve a thickening of the rear alone to permit of a deeper rear spar, shows a decrease in L/D with increase in thickness and a slight decrease in Lift, but this is not so very marked, and sections can be deepened at the rear with ease, thus permitting of having the front and rear spars of the same depth.

4. Bluntness and Streamlining of Nose.

Substituting a blunt for a sharp leading edge, causes the ratio of L/D to fall off, but since L remains about the same there is indicated a pronounced increase in D. Bluntness of the nose may, therefore, be considered a disadvantage. Pointing the nose of an aerofoil, to a streamline shape, designed to divide the air easier, often called a "Phillip's Entry," is frequently used. It is advantageous in decreasing the drift slightly at high speeds and low angles, but otherwise has little effect.

5. Changing Position of Maximum Ordinate.

The fraction of the chord at which the camber is the greatest is termed the position of maximum ordinate. It can readily be varied on aerofoils, and it is found that L/D increases as it is moved from the center of the surface, or .5 chord, towards the leading edge until it reaches the position of 1/3 chord, when further movement forward greatly reduces the efficiency of the section. The Lift is not affected very much at low angles by changes in the position of the maximum ordinate, but at high angles the lift of the section falls off when the greatest camber is at a point in front of 1/3 chord.

6. Reverse Curvature.

Reversing the curve of either face of an aerofoil, has a pronounced effect on the c. p. movement. The lower face of a deeply cambered aerofoil is readily made to reverse at the rear and meet the upper face. This is often done, and is distinctly beneficial.

More pronounced reverse curves in which both faces, at the rear, are turned up, have a very great influence on the air pressures. The advantageous feature of having a stationary center of pressure position for the various angles, is obtained by raising the trailing edge about .037 of chord — the curve starting from a point about .2 of chord from the trailing edge. But in doing this the maximum lift is reduced, and the range of lift restricted. There is also a speedy decrease in L/D, and, in general, this change leads to inefficiency, reducing lift by about 25% and max. L/D by about 15%.

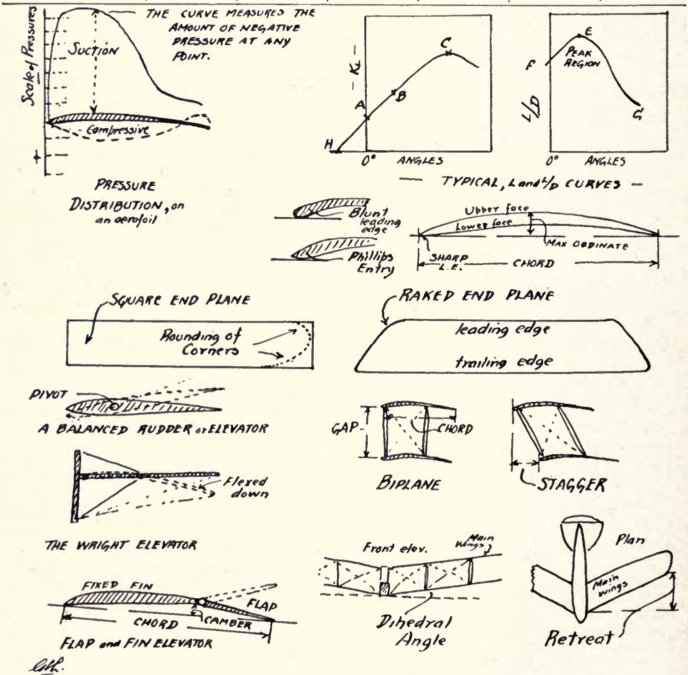
7. Warping the Aerofoil.

"Warping" an aerofoil consists in twisting it in such a way as to have the various sections presented to the air at uniformly varying angles of incidence. The section of wing remains constant, and since its characteristics for varying angles are known, the amount of pressure at the different sections could be found. In the ordinary range of warp in practice, on aeroplane wings, where one side is moved up and the other down equally at the same time, the Lift remains the same, as does also the position of the mean center of pressure, and tests show that computations on a basis of applying the ordinary data for the section to the different regions at their various angles gives correct results.

ASPECT RATIO TABLE

Values tabulated are the ratios of L and L/D at given aspect to values for an aspect of 6.

ASPECTS	ANGLES 3° L	3° L/D	6° L	6° L/D	9° L	9° L/D
2	.60	.47	.62	.54	.60	.55
3	.70	.58	.73	.64	.78	.72
4	.84	.73	.85	.77	.90	.83
5	.94	.86	.95	.90	.96	.92
6	1.00	1.00	1.00	1.00	1.00	1.00
7	1.05	1.06	1.04	1.10	1.04	1.09
8	1.08	1.09	1.08	1.16	1.08	1.15



PRESSURE DISTRIBUTION — TYPICAL CURVES — AND DEFINITIONS

ALTERATION IN PLAN FORM.

Shape of Plane.

Cutting away the trailing edge at the tips, and rounding off the ends of the plane, is often resorted to for reasons of construction and appearance. It is found that this does not appreciably affect the pressures, and cutting away the tips slightly reduces the weight of wing. On the other hand, it is found that raking the ends of a plane or that the trailing edge is of greater span than the leading edge, does appreciably affect the pressures, the Drift being considerably reduced and the ratio of L/D improved. The gain in efficiency is due undoubtedly to a better utilization of the sideways flow of air, in escaping past the edges. For the best results, where consideration is given to the strength of the wing, the ends should be raked at angles of 20° to 30°.

Aspect Ratio.

The influence of aspect ratio, on the pressures experienced by aerofoils is, of course, quite similar to its effect upon geometrical sections. It becomes quite important for us to consider this, with reference to aerofoils, in greater detail, since aeroplanes vary considerably in aspect. The "aspect" of an aeroplane is always considered as its total span ÷ by the chord of wings, the wings not being considered separately from their attachment to the body.

Although P_a on flat planes is affected by aspect, the ratio of L/D is not so affected, since it is always a function of angle of incidence **a**, as outlined in Chapter V. But on aerofoils, not only does D vary, but there is a very pronounced change in L/D.

As the aspect ratio is increased from 2 to 8, the usual limits used in practice, the maximum lift coefficient remains at about the same value, but it occurs at smaller angles of incidence as the aspect ratio is increased.

The most marked change, due to aspect ratio variation, is in the value of L/D. This is found to be due mainly to an increase in the Drift, for the smaller aspects.

The average aeroplane, has an aspect of 6, which it is found is a good value, but an increase up to 8 and 9, is justifiable, since the limit in improvement of efficiency becomes pronounced only for these higher aspects. For very flat sections of camber 1/30, or thereabouts, the ratio of L/D is found to decrease at very low angles, when the aspect is increased above 5. At higher angles, higher aspects give better efficiency as in deeper cambered planes, but it would appear that for the flatter sections, used at low angles and very high speed, on the small fast scouting aeroplanes, there is justification for limiting the aspect ratio to about 5 — a feature that is structurally very advantageous.

The most convenient way to present data on aspect ratio has been a matter of question, and a system is adopted here which, it would seem, is the most practical for the use of the engineer and the aeroplane user. The data for wing sections given, is in every case, excepting where otherwise noted, reduced and corrected to correspond to an aspect ratio of 6. In addition, accompanying this, is a table which gives the factor by which to multiply values for any other aspect ratios from 2 to 8, the aspect ratio of 6, being considered as unity (see p. 78).

For example, at 3°, the L/D of N° 36 Eiffel surface is found from the graph to be 14.7 for an aspect of 6, and the corresponding lift coefficient, K_L is .0014. It is desired to know what the values would be for an aspect of 4. From the table, we find that L/D will be 73% of the value of 14.7, which is 10.7, and the value of K_L will be 84% of .0014, which is .00118. If it is desired to know the values for angles between 3° and 6°, it is easiest to plot the values of 3°, 6°, 9° on the chart, and draw thru them curves entirely symmetrical and of the same character as the ones for the aspect of 6.

For field use, the table is put in a novel form, but one which it is thought is far handier than any hitherto published. The combined results of all the laboratories were given consideration in deriving the values given.

Effects of Speed and Scale.

In stepping from model tests to full-sized machines, the best approximation at present made appears to work out quite well in practice.

Lift values, of coefficient K_L, are applied directly without any correction.

Friction effects on Drift cause it to decrease with increase of speed, and, therefore, at speeds higher than the wind tunnel speeds, the value of L/D will be greater. The Eiffel results, however, were obtained in winds of 50 to 70 miles per hour and require no correction, and in order to bring the other results presented in accord, correction for speed has been made wherever necessary. The values given, therefore, may be applied without further correction to full-sized machines, at ordinary speeds, by supplying the values of S and V^2.

Pressures are, of course, functions of V^2 of the aeroplane, and the corrections mentioned apply only to the values of K_L and L/D tabulated. Pressures are also functions of areas, and therefore vary as the scale of the model squared. In the wind tunnels pressures are measured in pounds, let us say, and a particular pressure on an aeroplane model to 1/10 scale is found to be 1 pound, in a wind of 30 miles per hour. It is desired to know what the force on the aeroplane will be at 60 miles per hour. The observed value must be multiplied by

$$\frac{60^2}{30^2} \times 10^2, \text{or} \frac{3600}{900} \times 100 = 400 \text{ pounds.}$$

Typical Sections of Aerofoils.

Twelve aerofoil sections that represent a wide variety of actual practice are tabulated. The sections are drawn out all to the same scale, and the center of pressure graph is drawn for a distance of chord equal to that used in the drawings of the sections. This enables a rather more graphic conception to be obtained than has been possible heretofore. The values of K_L and L/D are given in groups of four sections. The graphs look complicated, but they are merely convenient methods of tabulating the results, and the curves can readily be distinguished with a little practice in reading off the values.

Among the sections given the Eiffel No. 13 bis, the one used on the Bleriot monoplanes, is a very widely adopted one, and because of its high lift and good efficiency it is one of the few of the older types of sections remaining in use. Many of the Royal Aircraft Factory biplanes, the Bristol biplane, several German and Italian aeroplanes, and the Martin biplane in this country, use a section of this type. Its most serious disadvantage is the lack of spar room, necessitating either a wide shallow and, therefore, heavy spar, or a lesser factor of safety on a well loaded wing. The efficiency at very low angles is not as good as in some of the newer types of sections, which permit of a greater range of speed though not possessing quite as good a maximum efficiency.

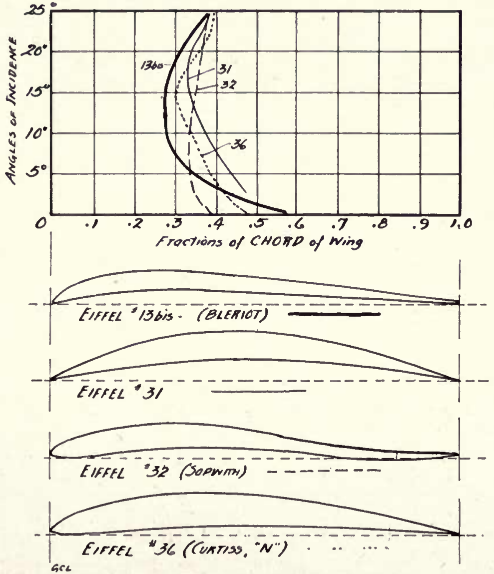
The Eiffel No. 31 section, of crescent shape, is Eiffel's most efficient all-around wing, although its maximum L/D is exceeded by many other sections. The Lift at low angles is very high, and the wing is well adapted for load-carrying aeroplanes.

No. 32 Eiffel is essentially a speed range wing, for fast speed scouts, lightly loaded and with high-powered engines. The high value of L/D at low angles is particularly favorable to high speed.

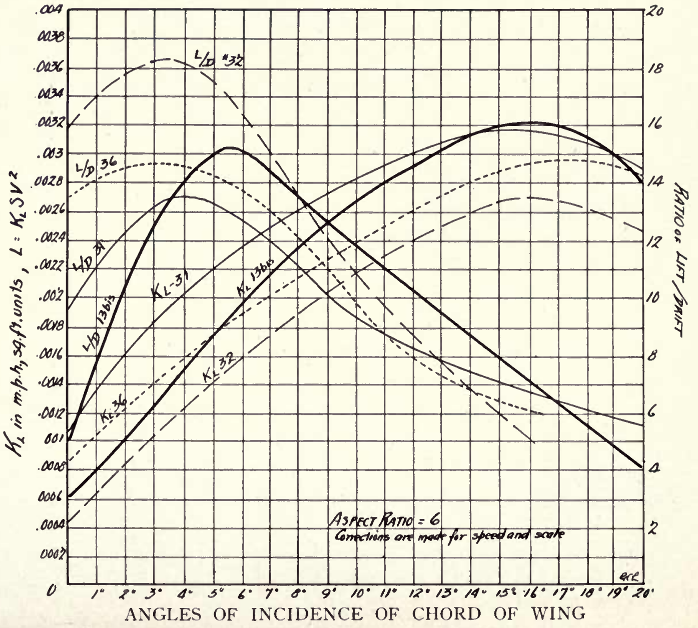
No. 36, Eiffel is used on several military machines, and is a particularly good wing for a meduim speed, military scout. The Lift is not run up very high, but the range of angles thru which a high L/D is maintained is favorable, not only to high speed, but also to climb, as will later be explained, when consideration is given to the complete aeroplane as a unit.

The Dorand wing, Eiffel No. 35, is similar to the Wright wing, and gives a very high lift, with a high L/D at angles from 3° to 6°. The small thickness of the section, however, does not make this wing very favorable from the standpoint of construction. In general, thinner wings are the more efficient, but spar room is a very necessary element, and efficiency and strength must be compromised.

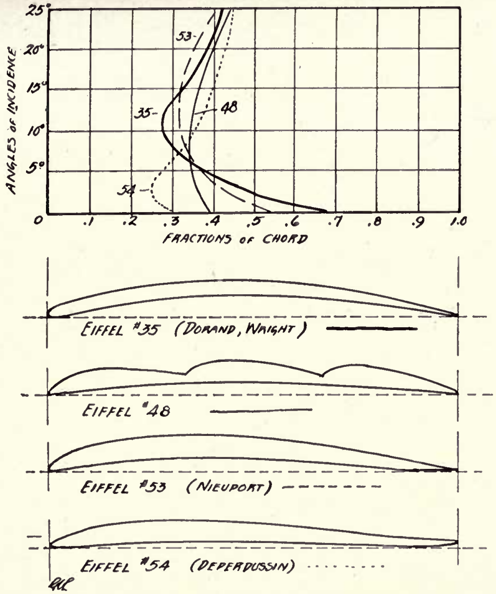
POSITION OF CENTER OF PRESSURE



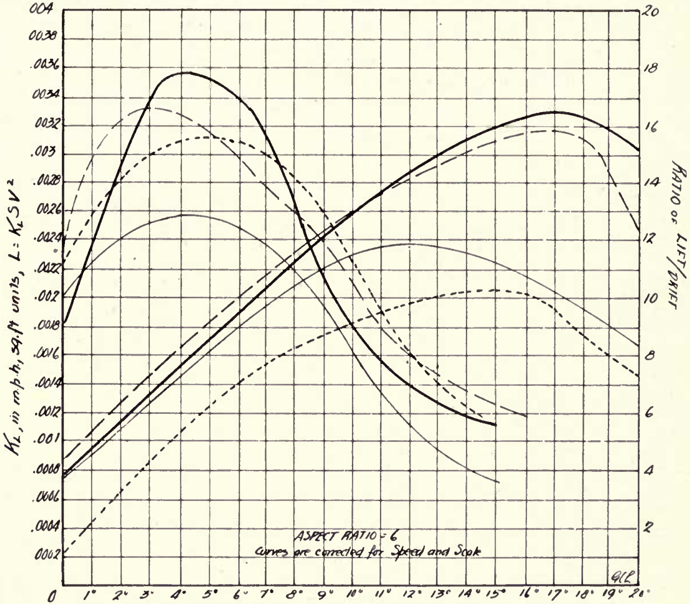
VALUES OF COEFFICIENTS FOR LIFT AND RATIO OF L/D



POSITION OF CENTER OF PRESSURE



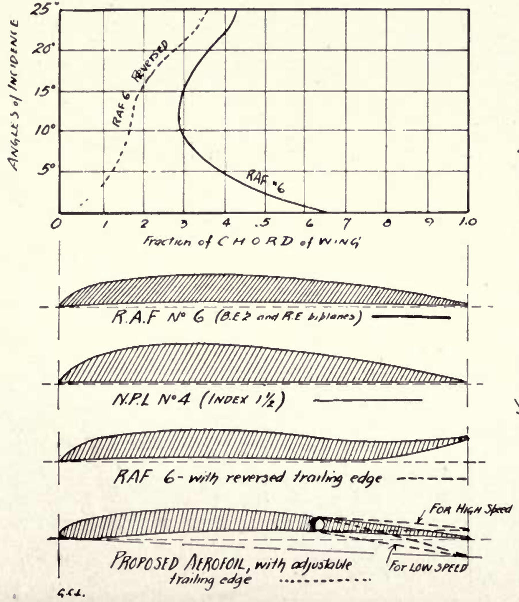
VALUES OF COEFFICIENTS FOR LIFT AND RATIO OF L/D



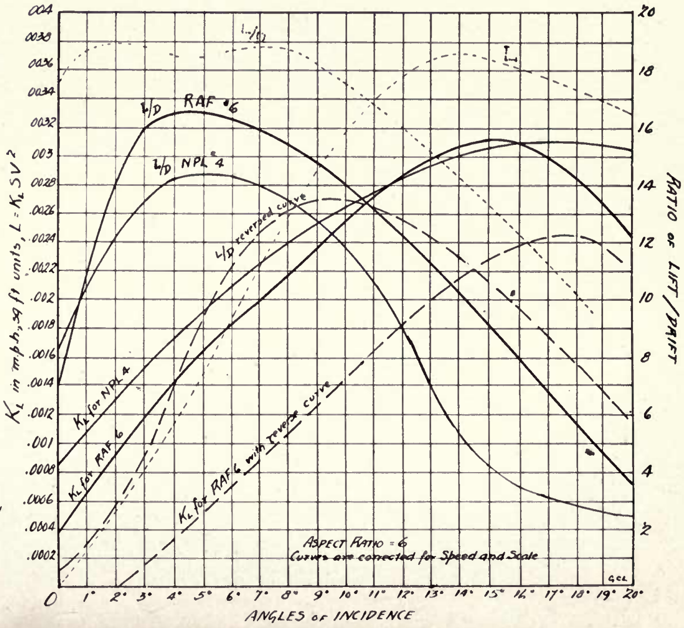
ANGLES OF INCIDENCE OF CHORD OF WING

Curves with peaks at the left are L/D, and curves with peaks at the right are for Lift.

POSITION OF CENTER OF PRESSURE



VALUES OF COEFFICIENTS FOR LIFT AND RATIO OF L/D



The Howard Wright wing, in which the contour is stepped, has been used on the White seaplanes, but its characteristics are not very advantageous, excepting in that the c. p. movement is practically stationary.

The Nieuport and Deperdussin are two standard wings, the latter designed particularly for racing aeroplanes.

R. A. F. 6 is one of the more modern sections that has become standard on British Army aeroplanes, and also used on the huge flying-boat "America." The effect of a reversal of the trailing edge on this section is shown also, and is of interest in connection with flaps on the trailing edge.

The N. P. L., No. 4 wing is a particularly deep one, in which the high Lift and fairly good L/D at angles of 3° to 6°, are advantageous for aeroplanes having a slow mean speed.

A new type of section, with a movable rear piece, is also shown, as a suggestion of improvement by the writer. The combination of low Lift and good L/D of a flatter section, at low angle, with facilities for changing to a deeply cambered surface, which would have a high Lift and also a high L/D at larger angles, could be made very greatly to extend the speed range of aeroplanes. Suggested curves of a prediction of the characteristics of a surface of this kind are indicated. It should be emphasized here, that several years ago the extent to which Lift and L/D could be varied on sections was not well known, and many investigators looked for an extension of speed range, by varying the size of the surface. The latest experiments indicate, however, that since a change in section can be made to vary the Lift and L/D, 100 per cent. or more, at different angles, much more is to be expected from a variable curvature section in extending speed range.

The Tail Planes.

The main wing surfaces determine in large measure the general characteristics of an aeroplane, but the Lift and Drift of the tail pieces or "empennages" are by no means negligible. The characteristic variations and values of L and L/D, that have been given, are sufficiently complete to enable us to determine their magnitude for these auxiliary surfaces, when it is realized that the effect of the propeller stream, on the empennages is a powerful but more or less indeterminate factor.

Where balanced rudders are used, consisting of a flat surface of a certain aspect ratio, it is merely necessary to apply the data given on p. 60. And, as is often the case, where a pivoted balanced rudder is of a more streamlined section, as illustrated on p. 78, it is proper to consider the drift slightly reduced. Elevators or ailerons, consisting of a balanced surface of constant chord, span and section, pivoted to take various angles of incidence, may be solved by the data given for their particular section.

On some aeroplanes, notably the early Wright biplanes, the elevator consisted of a normally flat plane that was quite flexible. This surface was fixed, at the leading edge, and so connected at the trailing edge that movement for control consisted of bending the ribs by moving the trailing edge up or down, thus causing the section to take various curvatures and angles. A surface of this kind is readily solved by applying the data given on p. 66, for sections of varying camber.

The more usual type of elevator, however, is the "flap and fin" type, in which movable flaps are hinged to the rear of a fixed surface. It has often been customary to consider these surfaces separately, but a moment's thought on the continuity of the air flow, shows that the proper conception is to consider a surface of this kind altogether as a single unit, which, when the flaps are in line with the fixed portion gives a flat surface of a certain aspect ratio. When the flaps are moved, there is obtained a section that is arched (though not circular), and in which the chord is a line from the trailing edge of the flaps to the leading edge of the fixed plane, with a camber depending on the amount the flap is turned. The data on curved sections given on p. 64 and 66, is then applicable, with the modification that the section being a pointed arch, instead of circular, will have a somewhat greater Drift, though the Lift may be taken as about the same.

INTERFERENCE OF AEROFOILS.

A study of the flow of the air stream about an aerofoil gives a clear indication that the streamlines are influenced and deflected quite a distance away from the surface, the rising streamline caused by the "dipping" front edge of an aerofoil being an example. In addition, the flow causes differences in pressure on an aerofoil, which, if affected, would modify the total forces on the aerofoil.

It follows that placing bodies or other aerofoils in proximity to any aerofoil will greatly affect its pressures. Interferences in flow are very interesting, and of most practical value, in their application to the aeroplane.

Biplane Effect.

When aerofoils are placed over one another, as in a biplane, there results an interference and modification of their air forces. It is customary to refer to the distance apart of the two superposed surfaces, as the **gap,** and **the ratio of gap to chord,** is used as a measure thereof.

Since the suction on the upper face, is about three times as great as the compression on the lower face, of an aerofoil, the effect of placing one over the other is greatly to reduce the Lift and efficiency of the lower plane, but only slightly to affect the upper plane. This is evident when it is borne in mind that the compression on the bottom face of the upper aerofoil and the suction on the top face of the lower aerofoil merge into and mutually reduce each other, whereas the suction on the top face of the upper aerofoil and compression on the bottom of the lower aerofoil remain unaltered. The suction being so much more important, it follows that the upper aerofoil must be much less affected. This is verified by the laboratories, and practically the entire loss due to biplane effect is found in reduction of L and L/D of the lower surface. A deduction to be drawn from this is, that flaps on the upper plane are much more effective than flaps on the lower. Also, flatter planes, in which the suction is not so great, would be less interfered with when superposed. If the combination of high camber upper plane and a very much flatter lower plane, were used, it is evident that the interference would be reduced considerably. A table of biplane reduction coefficients for an average aerofoil is given.

N. P. L. BIPLANE TABLE.

To obtain values for a biplane, multiply values for single aerofoil by factors given.

BIPLANE SPACING GAP CHORD	LIFT			LIFT/DRIFT		
	6°	8°	10°	6°	8°	10°
0.4	.61	.63	.62	.75	.81	.84
0.8	.76	.78	.77	.79	.82	.86
1.0	.81	.82	.82	.81	.84	.87
1.2	.86	.87	.86	.84	.85	.88
1.6	.89	.90	.89	.88	.89	.91

Staggering.

The position of biplane surfaces over each other is subject to variation, and the term **stagger** is used to describe the relative position referred to the vertical. For reasons of visibility, and minor considerations of construction and balance, it is sometimes convenient to stagger the upper plane ahead of the lower plane, as indicated in the sketch on p. 78. The effect of staggering, on the efficiency of the aerofoils, is again an illustration of the mutual reaction of the regions of suction and compression. When the upper plane is staggered forward, its Lift and L/D are improved, but at the same time the L/D on the lower plane is reduced. When the stagger is .44 of the chord (a practical limit), the total effect is to cause the Lift, on the biplane as a unit at angles of 5° to 10°, to be improved by about 7% to 9% with practically no effect on the L/D.

Interference of Following Planes.

The air stream deflected from the main aerofoils of an aeroplane, takes a downward course, which causes the air flow past the empennages, or any surfaces in the rear, to be affected, and causing the angles of incidence of the rear surfaces (which are always the angles of the chord with the air stream) to be less than the angles of their chords with the horizontal flight axis. This is an exceedingly important element in the balance and stability of a machine, and is taken up, more fully, in considering the entire aeroplane as a unit further on.

Dihedral and Retreat.

Attention is called to the definitions of Dihedral angle and Retreat, given graphically on p. 78. The effect of these features is considered later with reference to stability. Within the limits used in practice their effect on Lift and Drift is negligible.

Summary

From a combined consideration of Aspect Ratio, Biplane effect and staggering, a biplane at 6° of aspect 6, stagger of .44 chord and gap equal to chord, would have about 89% of the lift of a single aerofoil (81% due to biplane effect and 8% increase due to stagger) and its L/D would be 81% of that of a single aeroplane of the same aspect ratio. If this is compared with a single aerofoil of aspect 4.5, however, it is found that the Lift is practically the same, and only a slight difference is found in the efficiency. Likewise, a staggered biplane of aspect 8 and a large gap, is practically the same as a monoplane of aspect 6.

When a comparison, like the above, is made, the reference to single aerofoil means an equivalent monoplane of the same surface area as the biplane. To get the same lift with the same section and aspect, a monoplane would require less area than a biplane, by the amount of the biplane coefficient.

The data given on surfaces enables the lifting capacity and corresponding wing resistance to be determined for the various sections. Examples indicating the manner in which this data is used, and a consideration of the aeroplane as a unit, may now be taken up.

CHAPTER VIII.

CHARACTERISTICS OF THE AEROPLANE.

The surprising accuracy with which the performances of an aeroplane may be predicted from data on the lifts and resistances of its component parts, is, perhaps, the most striking indication of the great progress that has been made in Aeronautical Engineering, the past year or two. Constructors, fliers and the laboratories, have co-operated to advantage, and although many important features of the aeroplane remain to be explored, information that already has been obtained and verified, by the great work of the Laboratories, readily permits of establishing a working basis for the presentation of data of importance, relative to the aeroplane, — in a manner not only useful and intelligible to the aeroplane user, but at the same time capable of expansion as new conceptions develop.

It is proposed in this chapter to consider the aeroplane as a unit, with a view to determination of its total lifting capacity and resistances and the power necessary to fly. In a treatise on aeroplane design, the matter considered here in a few pages would of itself constitute a text book, so that the limiting scope of this work makes it necessary to confine our attention to the military "field use" features capable of leading to an intelligent solution of problems in the modification of aeroplanes and their performances, as dictated by military necessity. Flying various types of machines, with greatly varying load conditions, radius of action, atmospheric conditions, and power variations, presents a vast quantity of problems that often are solved best by the fliers themselves. That new kind of resourcefulness, in adapting themselves to many changing requirements, that is demanded of a Flying Corps, is a criterion of efficiency and may be gauged not only by skill in maintenance, but also by the knowledge that the aviators and mechanicians have of the performances that may be expected of their machines.

It must be borne in mind that a manufacturer is required to furnish data on his machine in detail, and although a few examples are given here, information on the resistances, lifts, power available, and power required to fly, under definite conditions, of particular types, should come with each machine — the manufacturer in other words, interpreting the laboratory results applied to his type, for the benefit of the user. It is clear, therefore, that the military or naval user of an aeroplane must know how to read this data and how to apply it in a practical way.

In previous chapters, consideration has been given to the resistances of bodies, and the lifting efficiency of surfaces and aerofoils — completely enough, to explain the significance of the forces generated by an air stream, and with sufficient laboratory data to make the subject matter of direct value for reference. We are now at liberty to combine these conceptions, and to give the definition of an aeroplane, (p. 11) a more technical wording — in that, **an aeroplane consists of a combination of sustaining and balancing aerofoils, with a Lift determined by the values of K_L, V and S, and with power suitably proportioned to overcome the head resistance of the structure, and the Drift of the wings, at the expense of which the Lift is obtained.**

Types of Aeroplanes.

Reference to Chap. II, gives a renewed significance to the photographs of the various types of aeroplanes, and could profitably be reconsidered with a view to fixing the relation of theory and practice. Thus, the wing section of the Curtiss Tractor, on p. 17, is none other than Aerofoil No. 36, of Eiffel, given on p. 82, and the wings of the monocoque on p. 20, have a section identical with Aerofoil No. 54, defined on p. 83. The several machines differ widely in values of the resistances of their various structural parts. Thus, the struts on the old-type Wright Aeroplanes, shown on p. 19, have something like five times the resistance of the struts on the Sturtevant tractor, p. 24, and the wheels on the Curtiss Tractor, p. 17, may be expected to have about half the resistance of the wheels on the Signal Corps tractor, shown below it, due to covering. The maze of wires and struts on the old types of pusher biplanes, are obviously more resisting than the simplified bracing and covered bodies of the later types. The difference in aspect ratio of the Bleriot, on p. 20, and the upper plane of the Farman, on p. 19, is most noticeable. And, whereas, the Curtiss Model N has two staggered planes and a dihedral angle, the Deperdussin, on p. 20, has a single surface with no dihedral. And yet if the surface section were the same, as is the case with the Bleriot, p. 20, and the Martin, p. 15, we would apply the same aerofoil data to both of them, with suitable corrections for Aspect Ratio, biplane interference and stagger. In addition, it may be noticed that the shapes of the fuselages, differ considerably, some tapering to an edge horizontally and others vertically, some square, others round, etc.

Each aeroplane, therefore, is bound to have particular characteristics of its own, for each of which the designer, if competent, had some particular object in view, towards either efficiency, stability, strength or convenience. To investigate them all would be a trespass on the domain of the aeronautical engineer. But not to appreciate what performances may be expected of any machine, is due to a lack of information, that it is the object of this work to supply.

From the standpoint of lifts, resistances and power required, the many different types all resemble each other in having a set of main supporting surfaces, auxiliary balancing surfaces, which may or may not exert lifting pressure, and certain structural resistances. In power available, there are differences of importance due to gearing of the propellers. Whereas, in characteristics of stability and operation, distinctions are most pronounced, and necessitate a full consideration later.

But whether tractors, pushers, staggered biplanes, monoplane aeroboats, etc., all aeroplanes have these characteristics in common:

I. **A Lifting Capacity,** determined by the surface characteristics, and varying with speed and inclination of the machine.

II. **A total resistance to motion,** composed of

  (a) The combined resistances of the various necessary structural parts, called **the Structural Resistance,** and varying with speed and inclination.

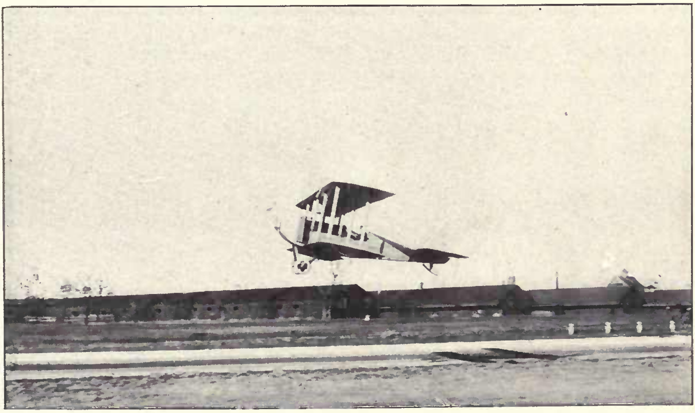
  (b) **The Drift,** which is determined solely by the Lift characteristics and is, of itself, independent of speed.

III. A certain **Power Required to fly,** varying with the speeds of the machine and its total resistances.

IV. A certain **Power Available,** due entirely to the horse-power given out by the propeller, which, in turn, for various speeds is a certain proportion of the power of the engine, and therefore must correspond to a certain fuel consumption.

Flight is impossible unless the Lifting capacity exceeds the total weight, and the Power Available is greater than the Power Required.

A study of these features enables the speed range, the glide, the climbing rate, the load-lifting capacity and the fuel consumption, to be determined in a most practical manner.



A STURTEVANT AEROPLANE RISING OFF THE GROUND

Inclination of the Aeroplane.

The variations of the pressures on surfaces has been considered for changes in the angle of incidence. It is customary in aeroplanes likewise to refer to "angle of incidence," of the supporting surfaces, in defining the attitude of the machine. And the inclination of the body to the line of flight, and the line of the propeller axis, is referred to as **the angle of incidence.** If the wing is set at 5° to the axis of the body, and the angle of incidence of the machine is 5°, it follows that the body lies parallel to the air-flow. Whereas, if this same machine were presented to the air at 10° incidence, the body axis would make an angle of 5° with the air-flow. It is of importance, now, to realize that the entire aeroplane as a unit may be presented to the air at various inclinations.

On p. 13 the three motions an aeroplane is subject to — pitching, yawing and rolling — are defined. On practically all aeroplanes the lifting planes are fixed to the body, so that a variation in angle of incidence means pitching of the machine and is considered more fully here than either yawing or rolling, because of the effect change of incidence has on the surface characteristics. Yawing slightly affects the resistances, and rolling may affect the Lift, but both are more properly considered under Stability.

The auxiliary surfaces, particularly the tail-planes, are in turn affected by the pitching of the machine, or, as we have defined it, by changes in the angle of incidence of the aeroplane. Where the machine is so balanced that the tail lifts, then as the incidence of the aeroplane is increased the lift of the tail surfaces increases. And if the tail is set to receive a downward pressure, an increase of incidence causes this to be relieved.

As will be seen later, the variation in inclination of the structure, at the different angles of incidence, gives rise to alterations in the structural air resistance, particularly of the fuselage, and in a staggered biplane an increase in the angle of incidence, increases the resistance of the struts and wires.

The Aeroplane as a combination, then, must be studied at various attitudes, and changes of inclination are expressed as changes in angle of incidence of the supporting planes. Where the special feature is involved of varying the angle of incidence as on some recent machines, inclination could be referred to the propeller axis. But it is more convenient in determining Resistances, and Lifts, to consider the chord of the wing as the base line.

Before proceeding with the study of Resistance and Power characteristics of an aeroplane, attention must be given to important features occasioned by combinations of lifting and auxiliary aerofoils, on the aeroplane frame.

Decalage, Wash-out, and Tail Interference.

The term "decalage" is used to define the difference in the angle of incidence between any two distinct aerofoils on an aeroplane. It is most often used to describe the difference between the setting of the main planes and the tail piece, and in a biplane the term is also used to denote a difference in angle of incidence between the upper surface and the lower one. Thus, on an aeroplane in which the body axis is in the line of flight with an angle of incidence of 5°, and with the chord of the elevator, inclined +2° above the body axis, the decalage of the elevator would be 3°. And in a biplane where, in order to gain slightly in efficiency, the upper surface is set at an incidence of 3°, when the lower one is at 5°, the decalage would be equal to 2°.

With reference to the decalage of the surfaces of a staggered biplane, laboratory experiments indicate that the effect of setting the upper surface at about 2° less incidence than the lower surface gives a pronounced increase in Lift and a slight gain in L/D over any other setting. This, however, is subject to modification where different wing sections are used, and a field of importance remains to be explored in the determination of the best combination of stagger, surface sections and decalage, to minimize the effect of biplane interference and improve the Lift range of the biplane as a unit.

"Wash-out" is a term used to describe the progressive reduction in the angle of incidence, from body to tip, used on some aeroplanes for reasons of stability. Thus, on an aeroplane, in which the wings are set at an angle of incidence of 7° at the body, and then steadily reduced until the angle at the tip is only 3°, there is said to be a "wash-out" of 4°. With reference to the aerodynamic characteristics of this feature, laboratory results show that the approximation of considering the entire wing, as set at an incidence, equal to the mean of the angles at the body and the tip, is quite close enough. The stability features will be given consideration later.

The air that is thrown back from the front main surfaces of an aeroplane, onto the tail, is given a most pronounced downward trend, governed by the particular angle of incidence and surface section combination used. The tail pieces, consequently, are riding in air waves generated by the sustaining surfaces, and therefore are interfered with. "Tail interference" has only recently been given proper consideration, and its importance on the functioning of a machine requires particular attention. Eiffel's experiments on this feature are particularly complete, and from them there can be drawn the general conclusion that the air, passing back from the sustaining surfaces, acquires a downward trend, dependent on their angle of incidence, which persists for some time, so that by the time this air region passes by the tail surfaces it has straightened out to only a half to one degree less than the actual angle of incidence of the sustaining planes. It becomes necessary, then, to distinguish between the apparent angle of incidence of the tail surfaces and their real angle with the direction of the airflow past them. The apparent angle is the incidence referred to the line of flight, just as for the sustaining planes, whereas the real angle at which the air attacks the sustaining planes is the one for which all calculations of pressures on the tail surfaces must be made. A few examples will aid in making this clear. Let us consider an aeroplane, at an angle of incidence of 4°, in which the body axis is parallel to the line of flight, and the tail surfaces of which have a decalage of 4°, with the sustaining surfaces. From our definition of decalage, the apparent angle of incidence of the tail surfaces would be 0°, i.e., they lie parallel to the body axis. But the air acquiring a downward trend from the main surfaces, of 4°, which gradually straightens out to 3°, as it passes the tail causes the real angle of attack of the air on the tail surfaces to be −3°. For the same case, if the tail surfaces are acted upon by the air stream, so that their real angle of incidence is 0°, it follows that the sustaining surfaces are at an angle of incidence of + 7° and the body is inclined to the air flow at + 3°. For any particular machine, it is necessary to have special data on these features furnished by the designer.

Although other features causing modification of pressures on the various aerofoils may be met with, their importance would not require special consideration here. The type of sustaining surface characterized by the "Dunne" class of aeroplanes, see p. 23, is readily solved when the laboratory data on this surface as a unit is furnished, — since the changing camber, and angle of incidence, would in no way alter the method of considering the values of L and L/D at different angles of inclination, precisely as for any other surface section. The stability features of this type, however, require special consideration.

Having acquired a working conception of the aeroplane as a unit, we may proceed with a study of its probable performances, as outlined on p. 91, and predicted from the laboratory measurements.

I. THE LIFTING CAPACITY.

The data on surface sections furnished for any machine, together with suitable corrections for biplane effect, aspect ratio, stagger, decalage, etc., is the first essential — and perhaps the most convenient way to represent this is to have curves showing the corrected values of L and L/D as applied to the particular machine, on the same chart with the data on the wing section alone, examples of which are given on pp. 82-84. The corrected curves, then, give us direct information on the actual values of K_L and L/D, to apply to the lifting surfaces as a unit, corresponding to angles of incidence of the chord of the wings to the line of flight. Since the value of the surface area

S is given for a definite machine, and also information on the weight W to be carried, we can at once supply suitable values for solving

$$W = L = K_L \, S \, V^2$$

so that we may learn at what angles the machine must be flown, for given speeds, or, conversely, how fast and how slow we could go, with a definite range of angle of incidence. Since features of stability determine a safe limit of angles, the latter problem is the one most often met with.

Thus, for an aeroplane with 335 sq. ft. of surface area, in the form of a staggered biplane, of aspect 7, and gap equal to chord, and with a wing section corresponding to Eiffel No. 53, the values of K_L and L/D corrected, would be shown, as indicated on p. 96. For this example, let us find the speed range corresponding to a range in the angle of incidence from 1° to 12°.

At the low angle 1°, we find by referring to the first chart that $K_L = .00085$. Supplying values of S and L, equal to the weight, we obtain

$$W = K_L \, S \, V^2 = 1800 = .00085 \times 335 \times V^2$$

from which it develops that,

$$V^2 = 6320, \text{ and } V = 79.5 \text{ miles per hour.}$$

In the same way, reference to the chart of aerofoil characteristics shows that at 12°, $K_L = .0027$, so that

$$L = 1800 = .0027 \times 335 \times V^2$$

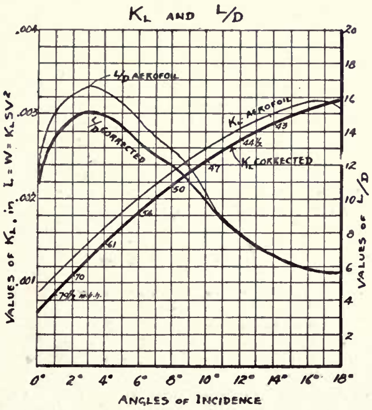
from which we obtain,

$$V = 44.6 \text{ miles per hour.}$$

Since the required lifting power and area of the wing surfaces are fixed, it is hardly necessary to emphasize that, for any inclination, there is only one speed at which horizontal flight is attained with the given load. Each angle has its particular corresponding speed, and in the above example the angle range of 1° to 12°, corresponds to a speed range of 44.6 to 79.5 miles per hour, and to none other — unless the load is changed or the surface characteristics altered.

A simple way to record this process is to write the speeds corresponding to the various angles on the curve for K_L, as has been done in the example given.

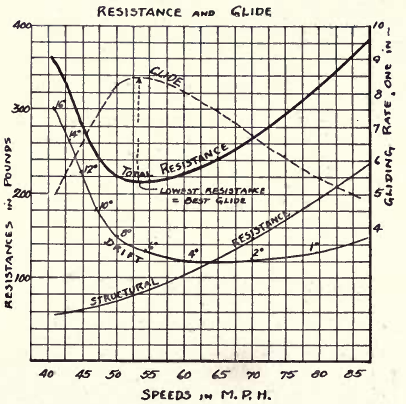
This, then, is the first step in determining the aeroplane's characteristics, i. e.: — finding the speeds required in order to lift the weight, at various angles of incidence.



LIFT AND DRIFT CHART

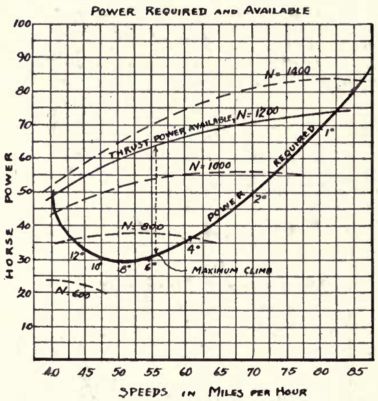
The heavy line Curves are the values of the coefficient for Lift and the ratio of Lift to Drift, that may be applied, directly to the aeroplane, used in the example. The light line curves are for the aerofoil alone (Eiffel No. 53).

Surface Area = 335 sq. ft., in the form of a staggered biplane, of aspect 7, and gap = chord. The full load weight is taken as 1800 lbs.



RESISTANCE CHART

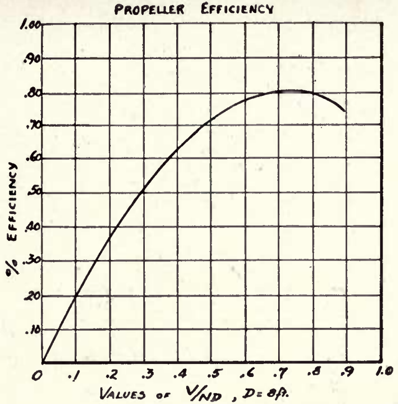
The heavy line Curve is the Total Resistance to motion of the aeroplane, and is the sum of the Drift Curve (light line) on which are indicated the angles of incidence, and the Structural Resistance (light line). On the right of the chart is a scale for reading the gliding slopes, represented by the Glide Curve (dashed line).



POWER CHART

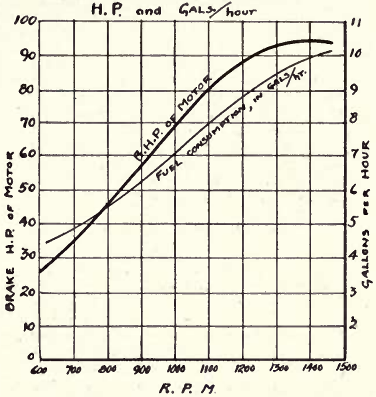
The heavy line is the Curve of Power Required for horizontal flight, at various speeds, in order to lift the 1800 lbs. weight, with the wing surface and aeroplane structure used.

The light full line is the Power Available from the propeller at 1200 r. p. m. of the engine, and the dashed lines give the power available at other motor speeds.



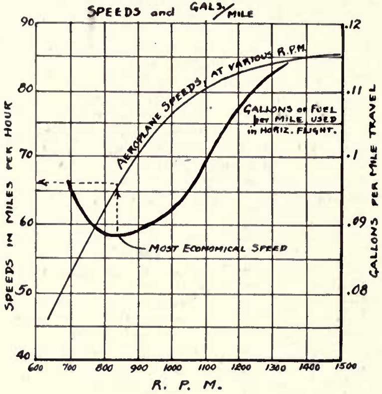
PROPELLER CHART

A typical Eiffel Propeller Efficiency chart, in which, the values of v/nd are found by taking—v, in feet per second, = speed of aeroplane in miles per hour x 1.47,—n, revolution per second of the propeller = r. p. m. div. by 60,—and d, the diameter of the propeller in feet.



ENGINE CHART

The heavy line is the Curve of horse-powers delivered by the engine, for different values of the revolutions per minute. The light line is a Curve indicating the results of tests on the amount of gasoline, consumed by the engine at various r. p. m., the scale of gallons per hour, being given on the right.



ECONOMY AND RADIUS OF ACTION

The light Curve gives horizontal speeds, at different r. p. m., obtained by plotting points where Power Available Curves cross the Power Required Curves, p. 96.

The heavy line Curve, gives the gallons of fuel consumed per mile, obtained by dividing the gals./hr., at any r. p. m., by the corresponding m. p. h. speeds. The fuel capacity of the aeroplane div. by this factor, gives the radius of action in miles.

II. TOTAL RESISTANCE TO MOTION.

As already indicated several times, the resistance overcome by the propeller consists of two distinct items: Structural Resistance and Drift.

Structural Resistance.

The air resistance of the structural parts of an aeroplane, such as the wheels, struts, wires, body, tanks, etc., all total up to a formidable value, and are conveniently and properly classed together in one item, called the "Structural Air Resistance." This term, altho a new one, is deemed so much more expressive than the older terms, "body resistance," "parasite resistance," etc., that its introduction is certainly justified. The term "parasite" is misleading, since a high drift is as much a "parasite" as an uncovered wheel.

In Chapter IV the determinations of the resistances of various shaped bodies were given consideration. For any aeroplane it is necessary to know the details of construction before a working total of the structural air resistances can be determined.

There are hardly any two types of aeroplanes with the same shape of body, so that this item, above all others, can be considered but from data given by the manufacturer. It may be of interest to note, however, that the values of K, for the nacelle of the Farman (illustrated on p. 19), has been found by Eiffel to be .0014, and K for the Deperdussin monocoque (p. 20), is .001. It has also been determined that in yawing and pitching the flat-sided fuselage has an appreciably greater resistance than a rounded one.

The resistance of the tail surfaces ordinarily should include some allowance for the drift of the tail, as determined by the particular shape and incidence used. Altho this should, perhaps, be considered in company with the wing resistances, its value is small for a well-balanced machine, and it is more convenient to include it in the structural resistance until it assumes a greater value.

Altho the process of determining the Structural Resistance consists essentially of applying information on the values of K, for the various structural items, in the formula, $P = K\,S\,V^2$, and adding up the result, we have found that a change in V for horizontal flight involves a change in the angle of incidence. This, in turn, means that at the various speeds the entire aeroplane assumes a "tail high — nose down," or "tail low — nose high" attitude. For the wheels, wires, etc., these incidence variations have but a slight effect, but the bodies, fuselages or nacelles are formed so as to give a least resistance in only one position — when the axis is in line with the wind. Any departure from this due to a change in the angle of incidence, causes an increase in their resistance. So that at angles both above and below the normal angle of incidence, the resistance of the body is higher, due to higher values of K_L.

On p. 96 a typical resistance chart is given, and on it is shown a typical curve of structural resistance. The range of incidence of 1° to 12°, used as an example already, is, as indicated, accompanied by a rise in structural resistance from 60 lbs. at 12°, to 195 lbs. at 1°, since the speeds corresponding to these angles are 44.6 and 79.5 m. p. h.

Drift.

If we refer to the first chart showing K_L and L/D, and recall that for any value of the angle of incidence the value of K_L was read, to determine speed, it is seen that we can also read at the same time the value of L/D for that particular K_L. Knowing the weight, this ratio at once gives us the Drift, since for horizontal flight,

$$\text{Drift} = \text{Weight} \div L/D.$$

It becomes clear, now, why reasons of convenience lead to plotting the values of L/D in preference to the values of K_D, to supply in $D = K_D\, S\, V^2$. Drift is always a fraction of Lift and, therefore, of the weight, but is in no other way concerned with the speed, V.

Thus, when the chart is referred to, to obtain the value of K_L for 1°, the value of L/D = 13.6 could be read at the same time, and knowing that the weight is 1800 lbs. the Drift at that angle is immediately determined as, 1800 ÷ 13.6 = 132 lbs. In the same way the Drift at 12° is found to be, 1800 ÷ 8 = 225 lbs., and the least drift at about 4° is 1800 ÷ 15 = 120 lbs. Since these determinations are made in company with the determinations of the air speeds corresponding to the various angles of incidence, we at once have obtained the values of the Drift for the various speeds — and, consequently, have solved for the second part of the Total Air Resistance. We proceed, then, to plot a curve showing the Wing Resistance, on the same chart, on which we have already plotted Structural Resistance, for different speeds.

The Total Air Resistance is the sum of these two. On a chart, curves drawn to the same cross lines are easily added graphically, by merely surmounting one value on top of the other. Thus, for 60 miles an hour speed, the value of the Wing Resistance, 120 lbs. is added by means of dividers (in actual measurement) above the point on the Structural Resistance curve, which reads 105 lbs., and this gives the total 225 lbs., graphically. **The same process is followed with other points, sufficient to establish the curve of Total Resistance to motion, which is the second characteristic to be determined.**

III. POWER REQUIRED.

In Chapter III it was recalled that power expended corresponded to the exertion of foot pounds work at a certain rate, and that one horse-power = 550 foot pounds per second.

At any speed, therefore, the lbs. Resistance × the speed in feet per second, gives the number of foot pounds per second used up by the aeroplane. Dividing this quantity by 550, will give us the Horse Power Required for horizontal flight at that particular speed.

If we call R the resistance and V the speed in miles per hour, then

$$\text{H.P.} = \frac{R \times V \times 1.47}{550}$$

since V in m. p. h. must be multiplied by 1.47, in order to express it in feet per second. Combining 1.47 ÷ 550, we get the handier relation that,

$$\text{Required H. P.} = \frac{R \times V}{375}$$

where R is the total Resistance in pounds read for any speed from the Resistance Chart, and V is the velocity in miles per hour.

A curve may then be plotted of Power Required to fly at the various speeds. This is done in the third chart, p. 96. It is to be recalled that in plotting the Drift on the resistance chart, the corresponding angles of incidence were marked on the curve.

This is also done on the Power Required Curve, the correspondence between Speeds and Angles of incidence being precisely the same as originally determined, when considering the first chart of K_L and L/D.

As examples of the manner in which to determine Power Required, let us take the machine at incidences of 12°, 6° and 1°.

From the Resistance Chart we find that at 12°, corresponding to a speed of 44½ m. p. h., the Total Resistance is 285 lbs. Therefore,

$$\text{Required H. P. at } 12^\circ = \frac{285 \times 44.5}{375} = 33.8 \text{ h. p.}$$

The same values read for 6°, give

$$\text{Required H. P. at } 6^\circ = \frac{215 \times 54}{375} = 31 \text{ h. p.}$$

And likewise for 1°, there is obtained

$$\text{Required H. P. at } 1^\circ = \frac{327 \times 79.5}{375} = 69 \text{ h. p.}$$

It is most important to note the general form of this curve, and as a "Characteristic" of the aeroplane, it is decidedly the most important one. At angles below 10° there is a noticeable rise in Power Required, because the increase in Drift is so much greater than the decrease in Structural Resistance, corresponding to a slower speed. And the pronounced increase in Power Required, at angles below 6°, is due primarily to the greater preponderance of the increase in the Structural Resistance, as the speed increases.

At angles of 10° to 6°, corresponding to speeds of about 45 to 55 m. p. h., the Power required is at its lowest value and remains very nearly the same for this particular machine. Power required curves vary greatly for different aeroplanes, both in their contour and in the angles at which the low points are located. But the rise both above and below a certain speed where the power is least, is noticeable on all power curves, and leads to the general conclusion, that high drift at low speeds and high structural resistance at high speeds, are the wasteful elements.

The establishment of all the points on the Power Required Curve, is made in the manner indicated, and we then obtain **the third characteristic of the Aeroplane — which is the determination of the horse power, required for horizontal flight, at various speeds.**

IV. POWER AVAILABLE FROM THE PROPELLER.

A certain horse power is given by the engine at various revolutions per minute, and a curve of this "Brake Horse Power," for corresponding "r. p. m.," is as necessary and as easily furnished as information on the size and weight of the engine. On p. 97, a curve for the particular motor taken as an example here is given.

But this power is not directly available, since its exertion on the air to move the aeroplane is thru the medium of an air propeller, which, unfortunately, is more or less wasteful of the power the engine gives to it.

The efficiency of the propeller, therefore, must be considered. Of all features of the aeroplane, propeller determinations from both theory and practice are exceedingly unsatisfactory. But laboratory experiments, notably Eiffel's, lately have given valuable information on a few good blades, in which the shape and section are left unaltered, and only the r. p. m. and diameter adjusted for different aeroplanes. The theory of the "similitude of propellers," which permits of passing from one machine to another with the same type of blade, is at present the only really valuable basis for propeller determinations.

Experiment shows that the old notion of "pitch," etc., on a basis of screw propeller theory is poorly founded. Whereas, the more modern notion of a propeller, consists simply in a consideration of the blade as an aerofoil at a certain angle of incidence, moved against the air in a rotating path, and in which $K_L S V^2$, would represent the Thrust, and $K_D S V^2$, the Torque.

For purposes of aeroplane design, considerations of the propeller, its loading, deflections and strength, and its Thrust and Torque characteristics, are most important. For field use the strength question requires merely that a propeller never be run at a greater r. p. m. than has been proven safe, without information from the manufacturer as to the strength of that particular propeller; and that alterations, such as metal tipping, be done by the propeller maker, unless the propeller has already been designed therefor. But, we are very vitally interested here in the suitability of various propellers, for different aeroplane performances, so as to enable us to pick out the propeller desired.

Since on any engine the power is determined from the r. p. m., by merely mounting any propeller in question on the engine and reading the r. p. m. for a given throttle, there is at once established the power used by the propeller. This is so readily and conveniently done in the field that for the present it is unnecessary to compute by extensive mathematics the power necessary to drive this propeller at a certain r. p. m. In the determination of the Power given out by the propeller in the air, however, no such convenient measurements can be made. We have recourse, therefore, to laboratory data furnished with the propeller.

This data is most conveniently given as a curve showing the Efficiency of the propeller, corresponding to values of the quantity v/nd.

The Efficiency of the propeller is merely the % of the power put into it, that is given out in Thrust Power by the propeller.

The quantity v/nd, is a convenient numerical relation, used by the laboratories to express the Efficiency of a propeller of definite shape and section for any combination of values of

(1) The velocity of the aeroplane in feet per second, v,

(2) The revolutions per second of the engine, n,

(3) The diameter of the propeller in feet, d.

The speed thru the air of the tip of the blade is determined in feet per second by the circumference = πd, and the number of times a second it covers this distance = n. The quantity $v/\pi nd$ is the actual relation between the "tip speed" of the propeller and the speed thru the air of the entire aeroplane. Let us say, briefly, that it has been "discovered" that this relation definitely determines the efficiency of any particular blade.

Our data on the engine gives us n, which is taken in this example as normally 1200 r. p. m. = 20 r. p. s. The diameter, d, in this example is 8 feet. For any speed of the aeroplane, v, therefore, we can compute v/nd, and on the Efficiency chart, p. 97, read % efficiency of the propeller. Knowing the horse power of the engine for the given value of n, we readily determine the actual horse power available from the propeller. As an example, at 60 m. p. h. speed, $v = 60 \times 1.47 = 88$ feet per second, n = 20, and d = 8, whence v/nd = .55. Reading on the first chart p. 97, we find that for v/nd = .55, propeller efficiency = 76%. On the second chart, p. 97, it is seen that at 20 revolutions per second, or rather $20 \times 60 = 1200$ r. p. m., the engine may be expected to give 88 h. p. Our propeller Power Available, therefore, is 76% of 88 = 67 h. p., and is so plotted on the Power chart for 1200 r. p. m., on p. 96.

In the same way all the other points, not only for this same curve but for values of r. p. m. = 800, 1000, etc., are plotted, **and we thus obtain the fourth characteristic — the thrust Power Available for any r. p. m., at the various speeds of the aeroplane.**

PERFORMANCES OF THE AEROPLANE.

The characteristics of the aeroplane having been determined we may proceed with determinations of the performances that may be expected of it.

The Glide or Volplane

In horizontal flight the thrust of the propeller in pounds is just slightly in excess of the total Resistance of the Aeroplane. When the motor is shut off, however, this balance between power required and power exerted ceases, and a distinctly different condition of flight results. If some other force were not introduced to overcome the total resistance, which is still about the same as in the conditions of power flight,* the aeroplane would slow down and finally fall in some dangerously unbalanced condition. Such a force can at any moment be introduced, by merely inclining the path of the machine downwards, enough to cause the gravity force, equal to the weight, to become the resultant of two forces — a Lift on the planes, less than the weight W, and a forward component of this gravity force, equal to the Total Resistance. The machine then descends, on a downward path, in which the power spent in descending the machine's weight at an inclined rate corresponding to a fall of a certain number of feet per second is equal to the power used up in overcoming the total Resistance, at the particular speed, on this downward path. The determination of the slope of this path, becomes very easy. It is merely the ratio of the Weight of the machine to the Total Resistance, at the particular angle of incidence and speed assumed on the glide. This

* It is to be noted that in a tractor, the air propeller throws back a stream of air on the body that has a speed greater than the aeroplane's speed, so that shutting off the engine slightly reduces the Total Resistance.

feature is considered again in connection with the Stability and Operation of the aeroplane.

A curve of "gliding angles" is readily plotted on the Resistance Chart, by dividing the weight by the Total Resistance at any point. Thus, at 55 m. p. h., the Total Resistance is 215 lbs. Therefore the gliding slope is 8.4 to 1. In other words, the aeroplane will travel 8.4 times as far as its vertical descent.

High Speed and Low Speed

It is apparent from a study of the Power Chart, p. 96, that the speed range is determined by the crossing points of the Power Required and Power Available curve. Thus, at 1200 r. p. m., horizontal flight is impossible due to lack of power, above 82 m. p. h., and below 41 m. p. h. The speed ranges for other r. p. m. are also indicated.

Climbing Rate

Although atmospheric conditions vitally affect the rate of climb and height attainable of any aeroplane, it is possible to determine the initial climbing rate. The climbing of a machine is due to the exertion of an extra amount of power, which raises the lbs. weight of the machine a certain number of feet per second, thereby using up a certain horse power. This excess power is directly available, if the Power Available is greater than the Power Required. And a measure of this excess power is the difference between these two curves. Thus, at 56 m. p. h., the Power Required is 32 h. p., and the corresponding Power Available at 1200 r. p. m. in actual thrust, at that speed, is 63 h.p. Therefore, we have a reserve power of 31 h. p., which can be entirely made use of in climbing the machine. Since the weight is W = 1800 lbs., the equation for climb becomes,

H. P. for climb = 1800 × climbing rate in feet per second, whence, Climbing Rate = H. P. in foot lbs. per second ÷ 1800 lbs. weight. Therefore, for this example,

$$\text{Climb in feet per minute} = \frac{31 \times 550}{1800} \times 60 = 570 \text{ f. p. m., rate.}$$

Summary

Other curves giving the economy in fuel consumption and corresponding engine speeds and aeroplane speeds, are explained on p. 97, and are of very practical value.

By the processes outlined in this chapter, the performances of an aeroplane may be predicted and recorded, with an accuracy and value that is, indeed, not only of great interest, but of real benefit to the aeroplane user.

It is seen that the characteristics of the aeroplane, from which the performances may be predicted so readily, are based on the data furnished by the laboratory tests on the aerodynamic features and the engine, so that the significance and importance of this information becomes evident.

CHAPTER IX.

STRESSES AND SAFETY FACTORS.

The nature and magnitude of the supporting and resisting pressures on aeroplanes, and their effect in determining characteristics and performances to be expected when the thrust power available and fuel consumption are known, constitute one feature of the study of the aeroplane, as outlined in Chap. IV., p. 41. We may proceed, therefore, with a consideration of the second feature — the study of the construction of the machine. And eventually, after having given attention to stability and operation, we will be at liberty to discuss the various military types of aeroplanes.

It is necessary to know the distributed loading on the aeroplane, of the air forces generated by the movement thru the air, before proper consideration can be given to the stresses and safety factors in its structure.

In gliding, the lifting forces on the wings are slightly less, and in climbing slightly greater, than in horizontal flight, but only in a small degree. When attacked by sudden puffs, the air forces are increased in various ways; banking on turns introduces extra stresses, due to the centripetal force, and in various maneuvers such as a sudden recovery from a steep dive, looping the loop, flying with full power at very high angles, etc., additional loads are imposed on the structure of the machine, which must be withstood.

Safety Factor

The ratio of the breaking strength of any structural part to the load imposed upon it, is termed the safety factor of that part. Thus, if a wire requires a tension of 3000 lbs. in order to break it, whereas the load it carries is only 300 lbs., it is said to have a safety factor of 10. In ordinary engineering practice, the load that it is considered necessary for any part to carry is taken as the maximum load that the particular part will ever have to stand, and, in designing it, a safety factor is applied to this maximum possible load. Contrary to all good engineering practice, the structural parts of an aeroplane are generally designed to have a certain "safety factor," with reference to the normal flying load, determined by the weight of the machine. The excess stress due to some additional maneuver is taken account of in the "safety factor" itself, so that in the engineering sense it is not a safety factor at all, but merely an allowance for extra stresses, induced by conditions other than ordinary horizontal flight. It is possible to estimate what the maximum possible stresses are, and to determine whether or not the aeroplane will collapse when they are imposed. And in general an aeroplane is so designed that the strength of its weakest structural part will at least be great enough to withstand a reasonable value of this maximum stress, without breakage, the real safety factor being very seldom as much as two. In most other branches of engineering a safety factor of at least ten is required. The object of a safety factor is to provide against the increased stresses of sudden impact shocks, which are difficult to estimate, and to take account of defective material and workmanship, so that, at first sight, it would seem odd that intelligent engineers should permit this general conception of "safety factor" in aeroplanes to survive, thereby apparently still further increasing the dangers of aviation. It is useless to deny this element of danger, or to attempt to excuse it, on any ground, excepting that it is a well considered compromise of opposing features.

An aeroplane, constructed with a high safety factor, on the maximum stresses to which it can be subjected, would actually prove so poor and dangerous a flyer and so difficult to land, due to its enormous weight, that ever-present dangers and limitations in its operation would far outweigh the possible dangers of its not being quite strong enough to stand some very unusual and remote maximum stress, to which in the hands of a well informed aviator it would never be subjected. The justification for building aeroplanes as light as possible, and cutting down to the limit of simplicity and necessity all the structural features, is exactly what makes a well-built aeroplane one of the most refined of engineering structures. The fact is only too often lost sight of, that increasing the strength of an aeroplane for flight, by thicker spars and struts, heavier wires, cables and larger fittings, immediately requires a landing gear much heavier in proportion, all of which results in a very much heavier machine, which for the same flying characteristics will require a more powerful engine, not only heavier in itself, but requiring more fuel, larger tanks, etc., until the final result is a machine in which the higher safety factor is largely lost by greater stresses due to the increased weight — with nothing gained. In aeroplane engineering there seems to be a remarkably nice balance between flying capacity and limitations of strength due to allowable weight of machine. And the degree in which strength has been gained by lightening up a machine, thereby improving its flying capacity, is a better criterion by which to judge of an aeroplane.

Maximum Stresses.

The greatest source of danger in flying, due to imposing great stress on the wings, is, without question, given rise to in flattening out sharply after a long dive. Modern aeroplanes have comparatively low structural and drift resistance, and when pointed earthwards the gravity force of the weight is opposed only by the air resistance of the machine, so that in diving steeply the aeroplane readily acquires a velocity through the air very much greater than its maximum high speed in horizontal flight. If, after acquiring a great speed, due to a steep dive, the aeroplane is turned, to flatten out and fly horizontally, a centripetal force must be exerted on the wings in order to make the turn. For any given radius of turn r, in feet, an aeroplane of weight w, pounds, having acquired a speed thru the air of v feet per second, will have to have exerted upon it a force equal to $wv^2/32.2\ r$ (see p. 30), in order to flatten out at this rate. As an example of the magnitude of this force, let us take the case of an aeroplane, weight loaded = 2000 lbs., which dived a few hundred feet and acquired a speed of 75 miles an hour (110 f. p. s.), and which the pilot rather quickly flattens out by turning up on an arc of radius = 100 feet — a quick recovery to be sure, but not at all unusual. The centripetal force exerted on the wings, is,

$$\frac{wv^2}{g\,r} = \frac{2000 \times 12{,}100}{32.2 \times 100} = 7520 \text{ lbs.}$$

a stress almost four times as great as the weight of the machine.

The magnitude of this force for greater speeds and sharper turns would seem enormous, but there is a definite limit, since, if this force, which makes the machine take a curved path, exceeds the maximum pressure corresponding to the angle with the highest K of the wing surfaces for the particular aeroplane speed, the aeroplane will "slip" and refuse to take this curve, since the air pressure on its wings cannot be made greater than the maximum pressure. It becomes quite easy then to determine the limiting stress. The maximum speed attainable on a glide is the one for which the air resistance becomes equal to the weight of the machine. This limits the speed of falling. A simple way to estimate it is to determine from the Resistance Chart, the minimum value of the quantity K S in $R = K\,S\,V^2$. Then supplying this same K S, and R = Weight of machine, a solution is obtained for V^2, the maximum diving speed. Thus, it is found, p. 96, that at 85 m. p. h., on the Resistance Chart, R = 365 lbs., and V^2 = 7225; it follows that K S = 365/7225 = .0505. The assumed total weight is 1800 lbs., so that

$$1800 = .0505\ V^2, \text{ and } V = \sqrt{35{,}600} = 189 \text{ miles per hour.}$$

The maximum value of K for the wing (about .003), would indicate that if the machine after diving several thousand feet vertically, could suddenly be turned up, the wings would "bite" the air with a force $K\,S\,V^2 = .003 \times 335 \times 189^2 = 35{,}650$ pounds, which is almost twenty times the weight of the machine. This is the limit that is approached, and it is clear that the lower the head resistance of a machine and the greater the surface and weight, the greater does this become. On the other hand, the greater the longitudinal moment of inertia, the more difficult does it become to flatten out sharply.

In turning, the additional force on the wing, caused by banking the machine, and required in order to hold the machine to the turn, may be determined in the same way. Other excessive stresses, such as those induced by sharp upward puffs, are not as easily evaluated, but careful observation indicates that the forces of sharp puffs, or sudden changes in wind direction, may easily give stresses three to four times the weight of the machine.

Although the stresses in the main wings are the most important ones, the other parts of the aeroplane also are subjected to great pressures. The effects of sudden maneuvers, or of gusts, in snapping the tail around, not only introduce great pressures on the tail, but subject the fuselage to severe twists. The proper proportioning of parts to resist vibration, due to variations in the engine and propeller, is almost entirely a matter of experience. And the stresses introduced by landing shocks are a separate class, requiring careful consideration and much experience, to be properly taken care of. In taxi-ing on the ground on some aeroplanes with tail skids, enormous twisting stresses are induced in the fuselage, by sharp turns, that every careful pilot avoids as much as possible, since all such stresses are unnecessarily racking and fatiguing the aeroplane structure.

The maximum stresses in an aeroplane may become very large but, in the hands of an expert pilot, they can be kept under control. Supported in the most perfect pneumatic fashion imaginable, and operated with skill and caution, an aeroplane is not likely to receive impact shocks of dangerous magnitude, and at the present time a breaking strength of 8 times the stresses due the weight, appears to compromise all opposing features properly and to give a sufficient "safety factor" for military purposes.

Kinds of Stresses.

In an aeroplane, distinction can be made between six different kinds of stresses:

(1) Lift stresses on the wings due to the lifting force equal to the weight, and carried by the main struts and wires.

(2) Drift stresses on the wings, taken account of by the interior cross-bracing of the wing.

(3) Stresses on the control surfaces, transmitted thru the frame or fuselage of the aeroplane.

(4) Stresses on various small items due to their air resistance.

(5) Stresses induced by the pull or push of the propeller and secondary effects of gyroscopic action or vibrations on the engine bed.

(6) Landing stresses on the entire machine, due to the shock of alighting. In view of the variable nature of landing fields and of air conditions near the ground, estimates of these stresses are difficult to make, and are largely a matter of experience for any particular machine.

The thrust of the propeller is the largest single air force acting at any point on the machine, and necessitates proper distribution over the frame. But it is definite in magnitude, and easily taken care of.

The consideration given stresses here, is not for the purposes of design, but rather to enable the military aviator more readily to understand the information on stresses supplied by the manufacturer. The most important stresses are occasioned by the load lifted on the wing structure.

Stresses in the Wings and Bracing.

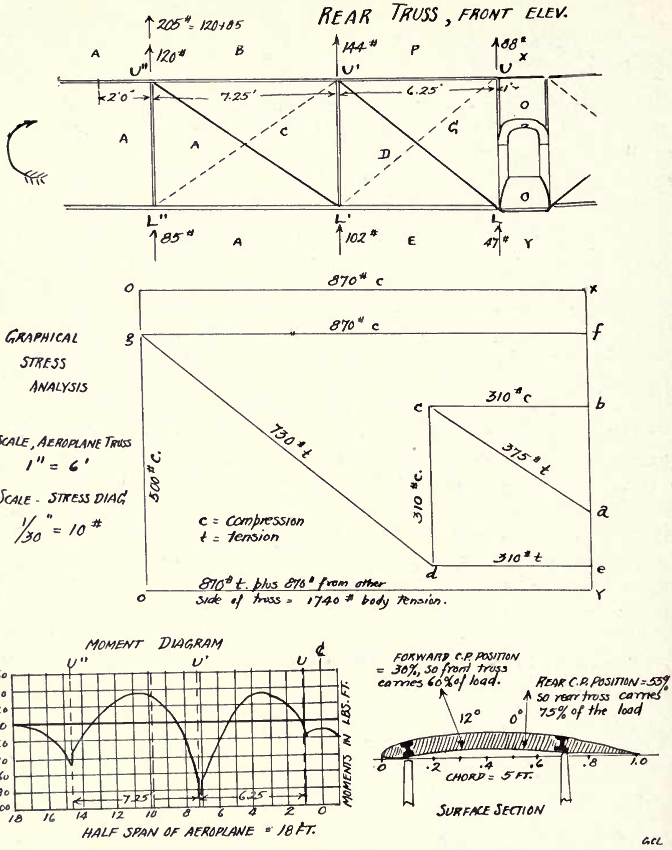
Since the consideration and method of determining the lifting stresses in the main supporting wings may be extended, readily, to other stresses in the machine, it may prove beneficial to take up an example.

The process of determining stresses consists, of

(1) Finding what proportion of the load is carried by different parts of the frame;

(2) Determining what stresses these loads induce in the members of the framework.

Since a biplane involves practically every feature requiring consideration, we may take as an example the aeroplane assumed in Chapter VIII, in which the full load weight is 1800 lbs., the surface area 335 sq. ft., chord 5 ft., gap 5 ft., and span 36 feet. Let us assume that the bracing is of the familiar strut and cross-wire type usually termed a "Pratt Truss."



STRESS ANALYSIS FOR BIPLANE TRUSS

The loads at the connecting points U, U′, U″, called panel points, are indicated on the diagram, and are due to the air load on the wings. The heavy line wires are the "flying wires," taking the stresses due to these loads; and the dashed lines in the truss diagram are the "landing wires," taking the weight of wings on landing.

In the graphical stress method, each panel point is considered in order, and for each one a closed triangle or polygon of forces is drawn. The force polygons must all close, since the point is in equilibrium.

First, a "sense" of rotation for the diagram is chosen and indicated by the arrow as clockwise, and a scale to which to lay off the forces is chosen. Then, on the truss diagram, the regions between forces are lettered A, B, C, etc., the forces considered being only the forces carrying the truss load. That is why the compression in L″U″ is not considered, since it is carried to U″ and from there over the truss. Taking the first point U″, we have the force between A and B, called ab, = 205 lbs. total, and the force of compression in U″U′, called bc and a third force, the tension in the wire ca. Thus, there are three forces at this point. The magnitude of one is known and the direction of the other two, so that a force triangle, as given on the stress diagram abc, may be drawn, such that ab = 205 lbs. to scale, bc, is parallel to U″U′, and ac is parallel to U″L′. Their point of intersection establishes the closing point of the triangle, thus determining ac and bc in lbs., merely by reading their lengths to the same scale to which ab was laid off.

Panel point L′ is now taken, the forces being taken in the same order going around the point clockwise. First, we have ac, already solved and then cd, the strut compression, the direction of which we know, so we draw cd thru c, parallel to U′L′. To obtain the rest of the polygon it is now necessary to consider ea, acting upwards at L′, which is laid off on the vertical, and then to close the polygon the other force line de, may be drawn thru e, parallel to L′L, the point d being located by the intersection of the lines of action of the two unknown forces thru e and c. Thus, with d found, cd and de are readily read to scale.

A similar process is employed for the rest of the truss.

A moment's thought on the manner in which the air force on the wings lifts the rest of the machine, will lead to the simple conception that an aeroplane is virtually a swing bridge, turned upside down, with a uniform static load of the simplest kind, equal in average intensity to 1800/335 = 5.4 lbs. per sq. ft. (a factor often termed the "loading" of the wing). The complicated stress determinations for steel bridges resulting from "live loads," such as moving locomotives of 300,000 lbs. weight, are happily in another realm, and as for the actual consideration of the aeroplane structure itself, it is well to realize that it is the simplest kind of a bridge.

For the purposes of this example reference is made to only one-half of the machine, since the other side is symmetrical, and it follows that the upper and lower wings under consideration together carry half the load.

The load actually carried by the structure is the total weight less the weight of the wings themselves, since the latter pressing down by gravity directly against the air pressure, relieve the struts and wires of having to transmit any stresses due to their weight. If the weight of the wings is taken at 240 lbs. — a reasonable figure — the load on the side of the machine we are considering equals $(1800 - 240) \div 2 = 780$ lbs. This is the distributed load over the upper and lower wings. But, due to the biplane effect (Chap. VII), the upper wing may be expected to carry a considerably greater proportion of this load. **In general, on a biplane the upper plane carries about 60% of the load and the lower plane 40%.**

From this it is indicated that the upper plane on one side, carries $780 \times .60 = 468$ lbs., whereas the corresponding lower plane carries 312 lbs.

This load is transmitted by the cloth covering to the ribs, each one of which, acting as a beam, transmits the load to the spars, which in turn are suitably braced to the body by struts and wires, so that lbs. weight in the body are carried by lbs. per sq. ft., air pressure on the outstretched wings. But, since this is distributed between the spars, of which in this case (see p. 110) there are two, it follows that separate stress determinations must be made for the front and rear truss. This at once necessitates determining what portion of the load each spar carries.

The position of the center pressure determines this readily, for if the c. p. were midway between the two spars, obviously they would each carry half the load, and if the c. p. were directly in line with a spar, the entire load on the wing would be carried by it. Since the c. p. moves, and we are here interested in the maximum stresses due to carrying the weight, the next step is to determine the max. rear position of c. p. applying the greatest load to the rear spar, and max. front position for the front spar. This is done (p. 110), and from what information we already have on the aerofoils and the aeroplane, we may recall that the former condition corresponds to a high speed and low angle of incidence, and the latter to a slow speed and high angle of incidence.

Since the data indicates that the rear spar carries a maximum of 75 % of the load at 0° incidence, it follows that the upper plane rear spar, which spans 16.5 feet, carries $(468 \times .75) \div 16.5 = 21.3$ lbs. per foot run, and the lower plane rear spar, carries $(312 \times .75) \div 15.5 = 15.1$ lbs. per foot run, — the spans being taken to include allowances for the rake and reduction of pressure of the ends of the planes, and for the body section.

Knowing the spans we can, as has been done on p. 110, indicate the load at each panel point U, U′, U″, etc. This load, which is the force carried thru the truss, results from the uniform loads on adjacent spans. For example, U′ carries half the load on span UU′ $= 21.3 \times 3.125$, plus half the load on span U′U″ $= 21.3 \times 3.625$, which together give 144 lbs. The other panel loads are obtained in the same way, and since the slopes of wires and depth of truss are outlined to scale, the graphical method explained, p. 110, is reaily made use of to determine the stresses in the members of the truss.

The tension stress on any wire, as determined in the stress diagram, may be compared directly with the breaking strength of the wire, to determine the safety factor. Thus, if L U′ indicated by dg, as having a stress of 730 lbs., consists of two 5/32″ cables each with a breaking strength of 3000 lbs., the "safety factor" is more than 8.

The strength of struts is not as readily found, since struts usually fail by bending. Only in the case where a strut is very short and thick is it possible to find its strength by multiplying the compression strength of the material in pounds per square inch by the cross-sectional area. Failure from bending makes it necessary to introduce standard engineering formulae*, which vary greatly among themselves and are largely based on experiment. Their object is merely to determine a reduced value of the allowable compressive strength of the material, to take into account the weakening due to bending. As an example, spruce, ordinarily, stands 5600 lbs. per sq. inch in direct compression, whereas one of the most practical strut formulae taking into account the average dimensions of aeroplane struts, reduces this

* These formulae and data are ordinarily furnished by the manufacturer, and if need be are readily checked by actual breakage test on a strut. A typical formula is the RAF strut formula.

$$\text{Crippling Strength} = \frac{FA}{1 + 6500\, l^2/k},$$ in which F = allowable compression stress, A = area of section l = length of strut in inches, and k = least radius of gyration.

to about 1/5th, giving 1100 lbs. per sq. in., as the ultimate strength to be expected. If U′L′ is made of spruce, with 2.3 sq. in. cross section, it may be expected to have a strength of about $2.3 \times 1100 = 2500$ lbs., and since the stress induced is 310 lbs., there is a safety factor of 8 (see p. 110).

Spars.

The stresses on the wing spars are considerably more complicated and frequently of greater importance, than stresses on other members. In almost all aeroplanes, nowadays, the upper spars are the weakest structural parts.

This is due largely to their receiving a combination of stresses which, as will be seen later, causes the spar progressively to weaken as the stresses increase, due to deflection.

The type of construction of wings, is now almost universally standardized, and consists of carrying the air pressure by means of cloth covering to light ribs running fore and aft, which are formed to give the aerofoil section desired. These ribs are carried by large beams or spars running across the wing transversely, and these spars are braced to the rest of the machine by suitable struts and wires, as already indicated. The stresses on the spars, therefore, may be divided into two items:

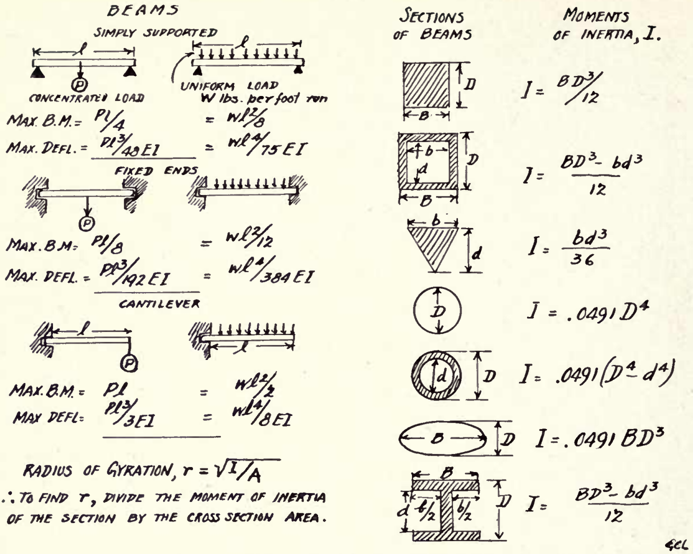
(1) The stresses due to the loading of the spar as a beam, carrying the air pressure loads transmitted by the wing covering and ribs;

(2) The stresses due to their part in the general bracing of the wing truss, as found by the stress diagram, p. 110, which indicates at once that as members of the rigid truss, the lower spars are subjected to tension and the upper spars to compression.

The result of the application of these stresses to the spar, may be taken up as follows:

(a) **Compression or Tension Stress in Spar.** — The allowable breaking load in lbs. per sq. in., for the particular material used, multiplied by the area of the cross section of the spar in sq. inches, gives the breaking strength, which, divided by the load as determined from the stress diagram, determines the factor of safety for that stress.

(b) **Bending due to the pull of wires** of the frame, attached unsymmetrically with reference to the neutral axis of the spar. This feature on some machines is of considerable magnitude, but fittings are so readily made to bring the pull of wires, etc., all together at any one point, symmetrical with the beam's center line, that they should



Bending Moments and Sections of Beams

always be demanded, so as to enable this unnecessary load on the wing to be eliminated.

(c) **Bending and Compression due to the Drift Load.** — This is an element in the rigidity of the wing, which requires that the stresses be taken care of by suitable cross bracing, etc., but as a factor in determining the strength of the spars, the drift loads are so small in proportion to the lift loads, that they are negligible, for our purposes.

(d) **Bending due to Uniform Load of air pressure on the Wing.** — This load is the principal one on a long span, and since the load may be considered as spread uniformly, along the spar, the ordinary engineering formulae for beams are directly applicable.

(e) But the bending of the spar due to the uniform air loading, introduces a certain deflection of the beam, which gives any compressive force on the spar due to the truss load a chance still further to increase the bending moment. In the inner spars of the upper wing of an aeroplane, this stress is by no means a negligible one.

The stresses on a beam, then, are first considered in the determination of the several bending moments due to the loading and these are combined and charted for convenience on a "moment diagram," an example of which is given on p. 110. The truss is laid off to scale as indicated, and the bending moment values are given in "lbs. ft." Suitable corrections are applied for the continuity of the spars, and these diagrams, furnished for each spar by the manufacturer, enable the value of the total bending moment at any point to be read.

Bending Moment.

It would prove beneficial here to consider what is meant by "bending moment," and how it is made use of in strength determinations.

In the tension on wires and the compression on struts or spars, the load stresses are taken up by members which have areas of a certain number of square inches of a certain material. It is known by experiments that the particular manner in which the material is used permits of assigning to it a certain breaking strength, called "fibre strength" or "modulus of rupture," which is most easily expressed as a certain number of "lbs. per sq. inch." The area of the member times the strength of its material per unit of area, gives the total actual force that it is reasonable to expect would break the member in question. In beams, however, the loads are not applied endwise, so that instead of having a direct push or pull, the beam is subjected to a bending.

The loads on the beam tend to make it sag and the amount of sag for any given load is determined not only by the load, but by the manner in which the beam is supported.

1. The beam may merely be resting freely on its supports, or pinned to them — in which case it is termed a "simply supported" beam.

2. The beam may be fixed at both ends and held firmly in its supports, or may be continuous over several spans — in which case it is termed a "fixed end" beam. A "cantilever" is a fixed end beam, held only at one end.

When loaded, the beam resists the bending tendencies of the load with a force which varies from that of a light string (which has practically no beam strength) to the deep plate girders of a railroad bridge, and which is determined by the shape, span, size, and material of the beam.

The mechanics of the action of a beam are very simple. The forces, and air pressure loads, have lever arms and, therefore, moments about any point of a spar that we care to consider. These can all be summed up into an equivalent force, in lbs., with a certain lever arm in feet. This moment is the "bending moment" for the particular point under consideration. On beams that are loaded uniformly, like the spars of an aeroplane, the maximum bending moment is found at the center of the beam, and decreases as the points of support are approached, with the exception that the continuity of spars over two or three spans may slightly modify this.

This maximum bending moment for any beam, loaded uniformly, is readily found by supplying values for the quantities in the accompanying simple formulae. This, then, gives us the value of the "bending moment" due to the air loading, which is the important one for the spar, but which is slightly modified by the other forces causing bending, as already indicated.

The total maximum bending moment as determined by the manufacturer and read from the diagram for the beam, is equal in its effect to the twist of a force in lbs. with a leverage in ft., giving the same lbs. ft. moment, about the center of the section of the beam, at the point considered.

Any "twist" or moment of this kind would naturally be taken up by a tension resistance on the upper side of the beam and a compression on the lower. The final test is what "the extreme fibre" of the beam will stand, since, if the beam begins to cripple on the upper or lower flange, it will progressively weaken to the breaking point.

The strength of the extreme fibre of a beam, then, expressed in lbs. per sq. inch, will give us a measure of the resisting force of the beam; and the depth of the beam from the center or neutral axis to the outer edge is the lever arm of this **"Resisting Moment" of the beam, which opposes the "Bending Moment" of the loads.**

This Resisting Moment for any beam is,

$$M = K\,I/d$$

where, K = the strength per sq. inch of the material, I = the moment of inertia of the section, and d = the distance from the neutral axis to the extreme fibre = $\frac{1}{2}$ depth of beam.

If it were desired to know what fibre stress was induced in a beam, for which I and d were known, by a bending moment M, the value of which is known, it would merely be necessary to solve for K in the above formula. So that on a spar, if to this determined fibre stress there is added the stress per sq. in., due to the compression, a value is at once obtained for the total intensity of stress in lbs. per sq. in., on the weakest extreme fibre of the beam. Comparing this value with the breaking strength of the material in lbs. per square inch gives the safety factor for the spar.

An example would serve to illustrate how the safety factor of a spar may be determined. Let us suppose that the rear spar in the span UU', (see p. 110) consists of a rectangular section beam of spruce 3 inches deep and 1 inch wide, and with a cross-sectional area of 3 sq. inches. The span l is 6 1/4 ft. and the load per foot of spar is $w = 21.3$ lbs. per foot.

We could read from the moment diagram furnished what the maximum bending moment is, account having been taken of the nature of fixing of the ends of the spar, the moments due to any unsymmetrical wire pulls, etc. For the purposes of convenient analysis, in the field, however, it is not necessary to go into these details. A sufficiently accurate conception of the bending moment in the beam is obtained by considering the ends fixed, and finding the large moment due solely to the air load on the spar per foot run. The table given shows this to be,

$$\text{B.M.} = \frac{w\,l^2}{12} = \frac{21.3 \times 6.25^2}{12} = 69.5 \text{ lbs. ft.}$$

It is desired to find what stress this bending moment induces on the outer fibre of the beam. We merely substitute, then, in the equation,

$$M = K\,I/d$$

taking care, however, to express M in lb. inches, by multiplying by 12, to correspond with the units of I and d.

For any rectangular section beam, the moment of inertia I, is $bd^3/12$, and in this case $d = 3$ inches and $d = 1$ inch, so that $I = 27/12 = 2.25$. The distance to extreme fibre from the neutral axis equals half the depth of the beam $= 1\frac{1}{2}$ inches, and solving we get

$$M = 69.5 \times 12 = K \times \frac{2.25}{1.5}, \text{ whence}$$

$$K = 555 \text{ lbs. per sq. inch.}$$

To this stress must be added that due to the compression truss load — also carried by these same fibres. From the diagram on p. 110, this is seen to be 870 lbs. and being distributed over the 3 sq. inches of cross-section of the spar, adds a stress of 290 lbs. per sq. in. to the spar.

The total fibre stress, then, is the sum = 845 lbs.

The material of the spar being spruce, which has a fibre strength of 5600 lbs. per sq. inch, it follows that the safety factor for the spar is $5600 \div 845 = 6.64$.

It is of interest to note that the continuity of spars over several spans is apt to reduce the value of the max. bending moment, but increases its value at the points of support. This is determined by the Theorem of Three Moments, which it is not necessary to consider here, but a characteristic bending moment diagram inclusive of these corrections is shown, p. 110. As indicated in this example the b. m., due to the air load on the span, gives an excellent and sufficiently intelligible indication of the magnitude of the stress in the spar.

The upper rear spar of the panel, next to the body, on a tractor biplane is almost always the weakest member of the entire structure, and is subjected to a combination of loads that are very formidable.

A study of a stress diagram, as to the distribution of loads, and the magnitude of bending moments, should always be made by a conscientious aeroplane pilot, in order to obtain an appreciation of the nature of the stresses his machine is required to withstand.

The weakening of spars by the drilling of holes, for some extra kind of fitting, should never by done, until the moment diagrams have been consulted and a rough calculation made of how much the reduction in sectional area caused by the hole, is going to weaken the spar.

The splicing and re-enforcing of spars by ferrules, etc., is taken up later, and should always be considered in the light of preserving depth of section and strength in extreme fibre.

Tightening of Wires.

A feature that results directly from a consideration of the aeroplane structure as a truss, is, that extra stresses may be induced on the members by tightening up too much on some parts, lack of proper fitting, etc. The systems of wiring on aeroplanes consist of the "**flying wires,**" indicated by full lines on p. 110, and the **"landing wires,"** indicated by the dashed lines. The stresses for the former are determined by the methods already outlined.

The stresses on landing wires are largely indeterminate, and proper strength to take landing shocks is a matter of experience. Due to the possibility of large negative air loads, the "landing wires" are usually made of practically the same strength as the "flying wires."

In addition to these, the general rigidity of the truss and resistance to drift loads, twists, etc., requires, cross wiring from front to rear of the panels. (See photographs in Chap. II.)

The entire structure, therefore, is cross wired and completely braced, although in flying only the "flying wires" should take the loads.

Nevertheless, complicated extra loads can be induced on the spars and struts and flying wires by the universal mistake of having the wires too tight. Thus, if L U′ and U L′ are both tightened up too much, L U′ before it ever receives its proper flying load, is carrying an initial load due merely to the tightening, while the spars L L′ and U U′ are perhaps already bent up and weakened before they ever receive their air load bending moments. **Buckling of spars and struts and initial stresses in wires, due to having the trusses tightened up too much, greatly fatigue the parts, introduce entirely uncalled for stresses and are apt to result in serious crippling.** Wires should never "sing" and need only be tight enough to avoid deflection of the truss when loaded.

"Follow Thru"

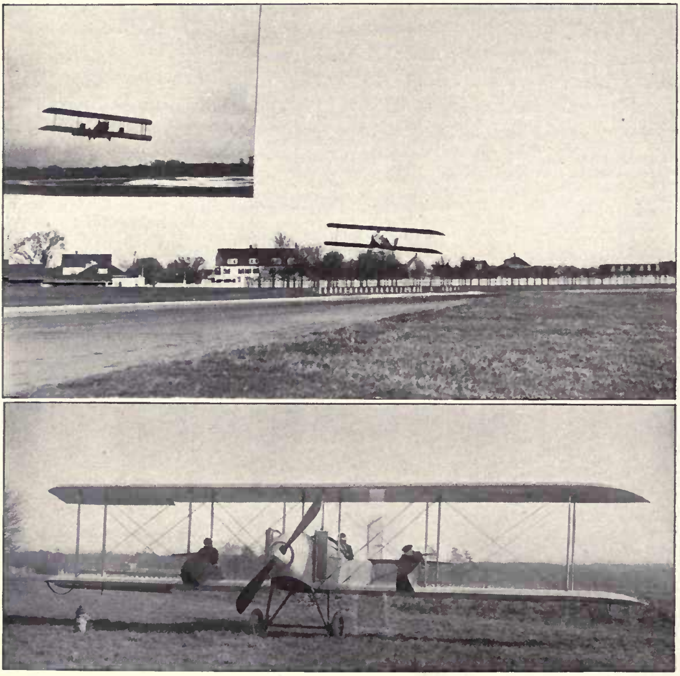
The characteristic wing sections, struts and wires, the stresses in which have been considered here, are readily distinguishable, in the photographs of aeroplanes, p. 15 and p. 17, and may conveniently be referred to. Some aeroplanes have "overhangs," others more panels than taken in the example p. 110, etc., but the general principles of finding the air loads and solving the stresses graphically are the same.

There is one very important feature, however obvious it may be on the stress diagram, that, to the unpracticed eye, is not so easy to appreciate on a full sized aeroplane, i. e., the degree in which the stresses induced in the wires, struts and spars, are carried thru the truss to their logical end, so as really to "complete" their strength. A wire may be strong enough in itself to hold the stress induced in it, but the fitting holding this wire at the base of the strut may not be properly proportioned.

On monoplanes, (see p. 20), the wing spars are subjected to a large compression, due to the truss load, and may be made strong enough. These spars, however, on either side of the body, press against the body towards each other with an enormous compression. Lack of attention in following thru these stresses so that the spars could butt directly against each other with ample compressive strength, led many constructors to provide therefor merely by permitting the spars to rest in sockets against the body — with no suitable provision across the body at this point. Many accidents are attributable to the crushing of the body by this spar compression, due solely to lack of "follow thru."

A typical example is found today in more or less serious measure on many tractor biplanes of reputable construction. Reasons of simplicity and convenience in the chassis have eliminated auxiliary safety wires from points like L′ (see diag. p. 110) to the chassis. It follows, then, that the pull of the wire L U′, and the tension in the spar L L′, are all exerted at the point L, on the body. It is customary to draw the diagrams and determine the stresses and safety factors for all the struts, wires and spars, but not always is the proper attention given to the cross member at the body, indicated in the diagram by O Y. As a matter of fact, this member carries an enormous tension — a stress of 870 lbs., from both sides of the truss — and the "following thru" of the tension in wire L U′, denoted as dg, across under the body, connecting to the wire symmetrical to L U′, on the other side of the aeroplane, is of the very greatest importance. A safety factor of at least ten should be demanded on this tension stress, and more attention paid to it. Similar instances can be cited, but the general principle is the same, and applies equally in importance to the proportioning of bolt heads, plate fittings, pins and turnbuckles to develop the full strength of the wire or cable to which they are attached. An expert can spot these flaws in construction quite readily, but the location of the "weak link" in the chain is not always so apparent to the amateur, and military aviators can profitably spend considerable effort in acquiring that "knack" that will enable them to locate lack of "follow thru," in the construction of the machines they are using.

Details of construction that bear directly on this are studied in the next Chapter.



An aeroplane with a "safety factor" of 12 throughout. The Sturtevant military tractor, in which provision is made for carrying two gun turrets.

Above — Views in flight with and without turrets.

CHAPTER X.

ASSEMBLY AND CONSTRUCTION.

Although it is difficult to give in written form all the practical information and directions desirable relative to the assembly, alignment and verification of construction of aeroplanes, a few notes are presented here, accompanied by some data on the strength of aeroplane parts, that may be of use. Structural details on aeroplanes differ greatly, but the ones chosen here as examples will serve to illustrate the mode of procedure in considering these details, and, at the same time, will be found to give many suggestions, to help in repair and maintenance work in the field — where, as already stated, resourcefulness in keeping the equipment in operation is of the greatest importance.

Aeroplanes for other purposes may become elaborate in construction and exceedingly replete in extra fittings, but for military purposes it is quite certain that the structural details will become as simple and as easy to repair as possible, with particular attention paid to having parts accessible for inspection and easy to take down or assemble. And in order to reduce the amount of stores necessary to carry around in the way of "spare parts," it should be an elementary policy of the construction department of a Flying Corps to standardize as many parts as possible, accentuating interchangeability of parts, and reducing to the minimum the different grades and thicknesses of lumber, the different sizes of wire and the thickness of steel plate used in fittings, so that a small stock of raw material may be found suitable for repairing practically any part of the machine.

Unpacking.

An aeroplane received from the manufacturer almost always has suffered from shipment or packing in one way or another, and in taking the parts out of the boxes and crates, great care should be exercised not to do any more damage.

Aeroplanes do not seem so fragile when they are all assembled, tightened up and trim, but when dis-assembled they can easily be maltreated.

One of the most serious things to watch out for is the bending or twisting of wires and cables, as they are coiled or uncoiled for convenience. Cable can readily be unravelled, and hard wire, if bent up too much, should under no circumstances be straightened, but the entire wire must be replaced. The same holds true of turnbuckles, fittings and bolts, which, in unpacking and setting up may become more or less seriously bent up or knocked out of true, and the wilful straightening

of these parts, without bringing them to the attention of someone who is competent to judge of the degree of weakness resulting from the damage is most reprehensible.

Among other things, it is the universal experience that wings or other surfaces may have suffered a few holes or rips. These should all be repaired, first by cross-stitching and then by covering with a glued patch of the same material as the wing covering — and then,

Care should be taken, never to lay tools on the planes.

Caution should be exercised, not to permit bolts or turnbuckles to fall on the ground or in the sand, with possibilities of unnecessary damage to the threads by grit. And to prevent any chance of loss or error, each part should be tagged and tied to the place to which it belongs.

Alignment, or "Trueing up."

From a consideration of the foregoing we are at once led to the study of the trueing up, or lining up, of the truss of an aeroplane, so as to obtain the proper alignment of the members, with respect to each other and to the rest of the machine.

"Trueing up" may be defined as the process by which the wings and rudders are adjusted to the body and line of thrust, so as to give the proper angle of incidence, dihedral, decalage, etc., with perfect symmetry.

Since slight errors in alignment cause marked changes in flying qualities, this subject is a particularly important one for practical field work, and it should be borne in mind that an aeroplane must be properly trued up, just like any other delicate piece of machinery, before the best results can be obtained from it.

Aeroplanes can, of course, be flown when more or less out of alignment, but tricky characteristics are apt to arise from this, and the machines will not give their best and most pleasing performances, while they may actually prove dangerous.

There are four general methods of lining up an aeroplane:

1. By level and plumb bob, in a factory or shed, with a solid floor.

2. By transit, projection of angles and levels. (The most accurate method, and of great convenience in a factory in setting up.)

3. By measurements of cross distances and wire lengths, combined with sighting.

4. By sighting alone.

Methods 1 and 2 are obviously capable of great accuracy in a factory, and should be resorted to when the aeroplane is first constructed.

Methods 3 and 4, may be used anywhere at all, on the side of a hill, if necessary, and directly concern us here in reassembling a machine for use on the field.

Types of aeroplanes differ widely among themselves, and actual instructions and measurements for lining up aeroplanes are required to be furnished in complete detail by the manufacturer.

Certain general principles of importance are involved, however, to which special attention must be given.

All bolts on fittings should be tightened before any trueing up of wires is attempted.

Turnbuckles, when assembling, should first have the barrel taken off and then be started even and turned up about 6 or 8 turns — enough to give a firm hold.

In tightening up any wires, as already indicated, the tension should not exceed that required to make the wire just taut and free of sag or vibration.

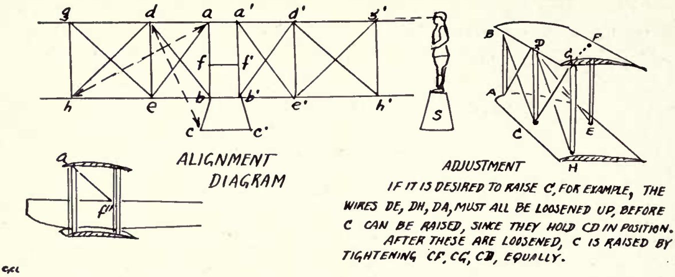
In placing bolts in fittings, or in spars, great care should be taken to see that the threads are neither worn nor burred, and that the bolts are not forced in too strongly — since they have been made to fit well and are driven home best by carefully directed, easy pressure.

Under no circumstances should wings and their parts be hammered and jerked into place, since if the parts do not fit together snugly and smoothly there will be some extra strain somewhere, when they are finally assembled. In this connection it must be borne in mind, however, that treated linen covering may tighten so much on a wing frame that, if left standing for a long time, it may twist and warp the wing out of shape.

Assuming a biplane of the common tractor type, with a small center section and wings, each of two panels, in which the chassis and body are assumed to be in proper alignment, it may prove of interest to consider the assembly and trueing up by methods (3) and (4), outlined above.

Assembly and Alignment by Cross Distances.

The several steps in the assembly are indicated by referring to the sketch on p. 124. To begin with, the center section of wing over the body, is set over the body, on the four small struts. The first step in alignment is to make this center section parallel to the body and centered over it. Since the body is lined up, and the section aff′a′, is a parallelogram, it follows that the cross distances, indicated as af′, may be made equal, in order to center up. When this is done for both front and rear trusses, the center section is bound to lie parallel to the body axis, providing, of course, the distances were measured between symmetrical points.



Diagrams for Alignment.

It then remains to adjust the front and rear wires until the section has been pulled forward or back, so that one measurement f″a agrees with the similar one on the other side of the body and with the data on the machine. But these wires should not be tightened up until the wings are on, in order to give play for the spar fittings of the wing section. Unless the center section is somewhat near centered, however, difficulty will be found in fitting the rest of the wings. The next step is to fit the lower wings on either side to the body, and to hold them up by means of their landing wires, fastened to the proper fittings at aa′, but not tightened up. The top wings next to the body are then fastened to the center section and held in place by hand until the struts de, d′e′, are inserted, when the landing wire ae, a′e′, will hold both wings in place. If the wings have no dihedral and the fittings are symmetrical, the distances ae and bd, should be equal and can readily be made so, by taking up the landing wire on both sides, front and rear. This will then give the proper setting laterally. If a dihedral is employed, there will be differences in the measurements, ae being shorter than bd, but for proper alignment it is merely necessary to have similar wires on the other side, the same length. Of course, it is assumed that the struts and the size and position of fittings on the spars are unalterably correct. The outer sections may now be put on by the same method, the lower one first, held by the landing wires, and then the top one, supported on the struts, and the cross distances made equal similarly by taking up on the landing wire. The entire wing structure is now assembled, attached to the body, which is resting on the chassis. It is assumed that, laterally, the wings are symmetrical to the body and properly transverse thereto. This is readily checked by measuring the two distances, a h and c d, as indicated. The cross wires running from front to rear between the struts are next adjusted, just to tautness, and the alignment of the struts as viewed from the side is checked by eye. Measurements of these cross distances from top front to lower rear, and lower front to top rear, at the body, are then carried out to the tips, and thus the angle of incidence is checked. The "flying wires" are then all tightened up, just so as not to give the landing wires more than the strain of carrying the weight. Final measurements are then made from the rear point of the tail to panel points h, h′, out at the ends of the wings, in order to determine if the transverse wing axis is symmetrical with the longitudinal body axis. The machine is then lined up correctly — providing that the distances measured are all taken to some points on fittings or marks on spars and struts, that are absolutely symmetrical for the two sides.

Alignment by Sighting.

The process of assembly, as outlined above, would be the same. After the wings are attached to the frame, the trueing up process proper begins. The method consists merely in doing by eye what was done in the previous example by extensive measurements. The first sight is taken, from below the body, up to the center section, so as to get the points a, a′, over the points b, b′. Both sides, front and rear are sighted and the positions averaged up by the wires. In assembling, however, no lining up is done, until all the wings are on, held by the landing wires. The observer then stands at s, to one side, and sighting along the top plane, establishes the line across the bolt heads or fittings at a, a′, and proceeds first, to bring up d, d′, by means of the wires a e, a′e′, and then g g′, on either side, are brought up by taking up their landing wires until they are in line with a, a′, d, d′, etc. In other words, the transverse line, across the top of the center section, is projected to either side. The same is done for the rear spar, and then the load wires for the front spar only are tightened, just enough so that when the point h, for example, is alternately raised and lowered no wires are seen to slack or sag, — the alignment held by the landing wires being the correct one to be held.

The final and important element in the sighting is to establish the correctness and uniformity of the angle of incidence, which is the main object of the alignment. To do this best, the observer stands 15 to 20 feet in front of the fuselage, taking care to center himself, by sighting along the center struts, shaft, axle center, tail piece, etc. The observer then chooses a height, or tilts the machine, so that, when sighting along the top plane, he can see just a little of the under side. This permits him to see a certain point of the rear strut sockets showing against the lower side of the front beam. Then, by holding the head, central, and just high enough to see these points, and moving only the eyes, to right and left, he can note any lack of alignment of the rear spar, parallel to the front spar. This is corrected by means of the rear spar landing wires, if necessary, after which the rear load or flying wires are also tightened.

The fore and aft cross wires are now set, so that when standing 10 feet or so from either end of plane all struts will lie in line and parallel with each other and with the center struts. These wires are then set no tighter than necessary, for if too tight they merely tend unduly to compress and buckle the ribs.

A check on the perpendicularity of the transverse wing axis to the longitudinal body axis is then made by measurement, and if necessary, adjusted by the "drift" wires running from the nose of the machine to the front intermediate struts.

The tail pieces are then lined parallel to the wing axis, by merely sighting and adjusting them until they are parallel. It is well to sight from behind and below, so as to get the tail line just below the front edge of the top plane.

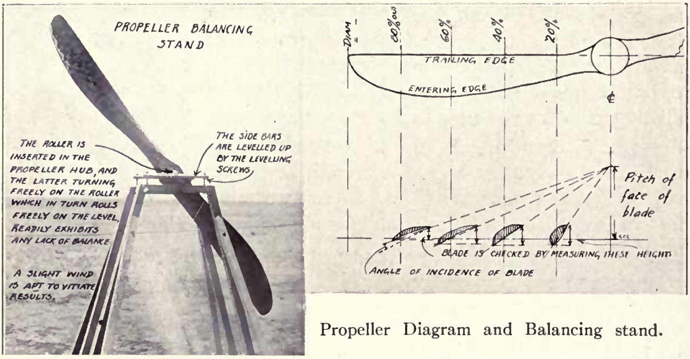
The last wires to be tightened are any auxiliary wires from the chassis to the wings.

This method, in the hands of one who has had some experience, is the quickest, easiest, and accurate enough for field work.

A judicious combination of the sighting method and the method of measuring cross distances, gives the best results in the alignment or trueing up of aeroplanes.

Particular attention is called to the systematic manner of doing the aligning with the landing wires, leaving the tightening of the "flying" wires to the very last thing.

On the diagram, a note is given relative to the importance of loosening up the proper wires when a local adjustment of one panel point is made, on a machine already all wired up.



Propeller Diagram and Balancing stand.

Propeller Balance.

After the machine is assembled and lined up the propeller may be mounted, but before doing so its balance should at least be checked up. A propeller "out of balance" is heavier on one blade than on the other, and when run on the engine will vibrate. Any vibration of this nature is, really, a severe strain on the machine, and particularly on the engine. A propeller may also be troublesome in vibrating if the blades are warped, and lacking in symmetry. This may be checked up by measurements of offsets on the blade.

The accompanying diagram shows a method of propeller balancing that is effective, and also shows the manner in which the useful data on the shape, section and angles of the blade may be presented.

If the propeller is slightly out of balance, a little more varnish on the light side is the best way to equalize it.

Metal tips along the entering edge of the tip of the blades are a great protection against both water and shrubbery, to prevent cracking and splitting of the edge of the blade. These, however, must be very firmly attached and because of the centrifugal force should be made as light as possible. For water work, it is necessary to bore a few small holes in this metal tipping, in order that the water, that has soaked in by impinging so hard, may be freely thrown off by centrifugal force, instead of tending to work in under and finally to split open the metal tipping, and for land work such holes will prevent "dry rot."

Attention should also be given the propeller bolts to make sure that they are properly proportioned as to thread, that the nut fits and shows no sign of having been forced, and that the bolts are properly locked by a wire, which is not likely to be cut by the nut of the bolt "backing off."

Details of Construction.

Examination of the details of construction, to make sure of the proper fitting of parts and "follow thru," is most important, and special training in the proper inspection of machines is next in importance to training in flying. No matter how well built or how reliable structural features appear to be, there is always the possibility of breakage. Just because an aeroplane has flown very successfully is no excuse for being any the less careful in inspection of its construction.

It is well, first, to go over the entire machine and make sure that all the bolts are locked, and while doing so the material of the bolt, whether special steel or "commercial" iron bolts, should be examined, and also the thread of the bolt, and fit of the nut and its locking. If iron bolts (stove bolts) are found, with deep threads, in places taking any vital stress, they should be replaced.

Bolts may be locked in four ways:

1. By a lock washer, or cut washer, fitting under the nut and "biting" into it when the nut turns backwards.

2. By a pin, or lock wire, passing thru a hole drilled into the bolt, and fastened in such a way that vibration will not permit "backing off" of the nut, to break the locking wire.

3. By riveting the head of the bolts. This is the most positive lock.

4. By painting the bolt head. This is suitable only where a small, relatively unimportant fitting is concerned.

The practice of "spoiling the thread" of the bolt for locking is not a reliable one.

Knowing the comparative strengths of various bolts in shear and pull, as outlined in the table p. 136, the inspection will intelligently reveal the uniformity of "safety factor" and "follow thru."

After attending to the bolts, the pins in the fittings and the turnbuckles may be examined at each panel point, one by one — the pins for proper locking, unless already riveted, and the t. b.'s for the purpose of making sure that enough threads are everywhere engaged in the barrel and that the t. b. is, in each case, locked so that the safety wire will not wear or tend to break at any point.

The general inspection of the wires, struts and remainder of the machine can then be made, **special attention being given to the controls, so as to make sure that they are connected up to work properly,** and that all t. b.'s and pins are suitably locked, with no possibility of a cable binding by running off its pulley, or of parts of the control "catching" anything.

To assist in the detection of flaws in construction, improper proportioning of parts for a uniform strength and "follow thru," and for general information on the construction of aeroplanes, some tables and data are presented. It is perhaps necessary to state that the strength values are largely based on tests and experiences of the writer relative to aeroplanes, and may be taken as at least a beginning of a handbook for Aviation, to which new data of value should constantly be added.

The illustrations of details of construction, with examples of apparently reliable and unreliable features, should receive particularly close attention from military aviators. The small variety of details shown must, of course, be taken as serving merely as examples, since no attempt has been made to present all the structural features that might be found on a various assortment of types of aeroplanes.

In order to avoid the inconveniences of cross reference, notes relative to the various features have been incorporated on the illustrations themselves, and should be read and digested as carefully as any emphasized text.

Steel.

Steel is obtained from iron by many processes, differing in ore treatment, expense, etc., the most extensive ones being Bessemer, openhearth and crucible. All refer to the original method of obtaining the steel, and have little bearing on the quality of the steel, excepting in the amount of carbon, alloy, etc., in it. There are many instances, however, of Bessemer process steel proving less reliable than the others. The crucible process is used to obtain the most uniform tool steels.

The percentage of carbon in steel largely determines its hardness, strength and ductility, and ranges from .05 % to .25 %. The higher the carbon, the harder, more tenacious and less ductile is the steel. The lower the phosphorus or sulphur, the less likely is the steel to develop flaws and cracks.

The word "temper" is used by manufacturers to represent the amount of carbon in steel. Thus, a "high temper" steel is a "higher carbon" steel, and therefore hard, tenacious, but brittle. Steels may be "tempered," after manufacturing by applying various degrees of hardening and softening — that is, most uniform steels can be made as hard and tenacious, or as ductile and soft as desired.

"Hardening" is done by heating the steel — with particular attention to uniform heating of the metal — and then quickly immersing in brine, oil or water; the amount or nature of this quick uniform cooling, or of the heat to which the steel was brought, being determined by the kind of hardening desired (all of which requires personal skill and experience).

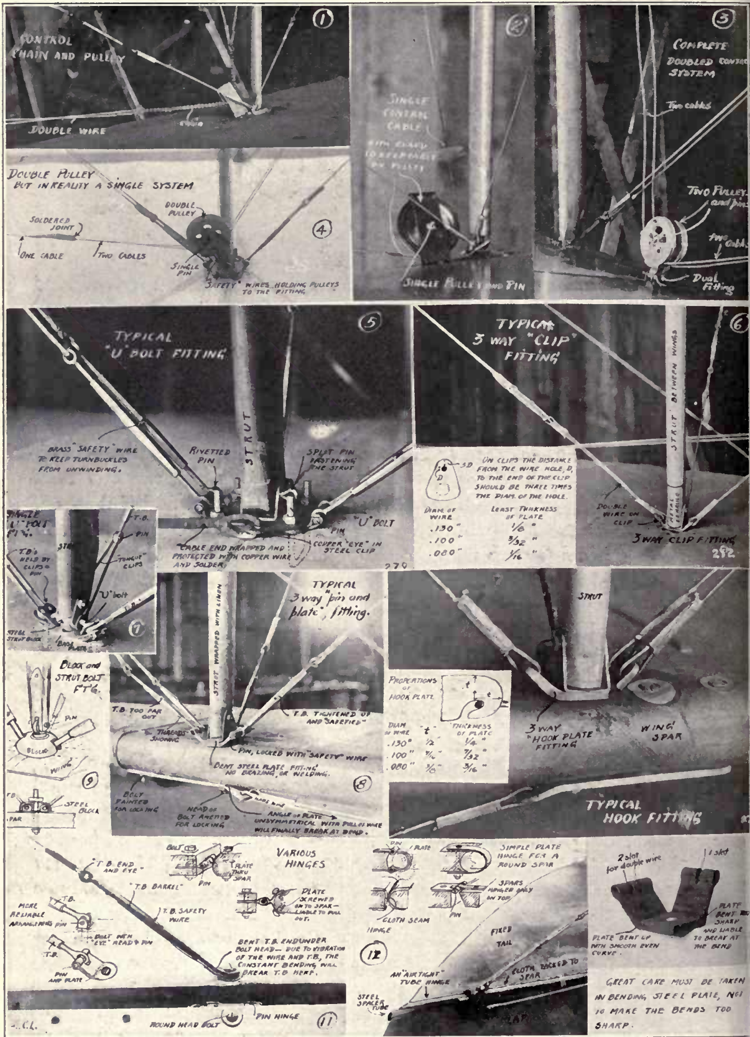
"Softening" of steel is designed to make its texture more uniform, easier to manipulate, and less brittle. This process is termed "annealing," and consists merely in heating steel up to a desired temperature and then letting it cool very slowly, the slower the cooling the softer the steel. As in any other treatment of steel, uniformity of heating or cooling is of the utmost importance. Practically all high grades of steel come from the mills in annealed condition, but if not, and **if it is desired to bend the steel sharply, great care must be exercised in heating it in a forge for annealing to make sure that the steel is uniformly heated, otherwise its grain and texture will be uneven and weakened.**

In this connection, it is important to point out that steel has as marked a "grain" as wood, only not as easy to see. Steel is always weakest across the grain.

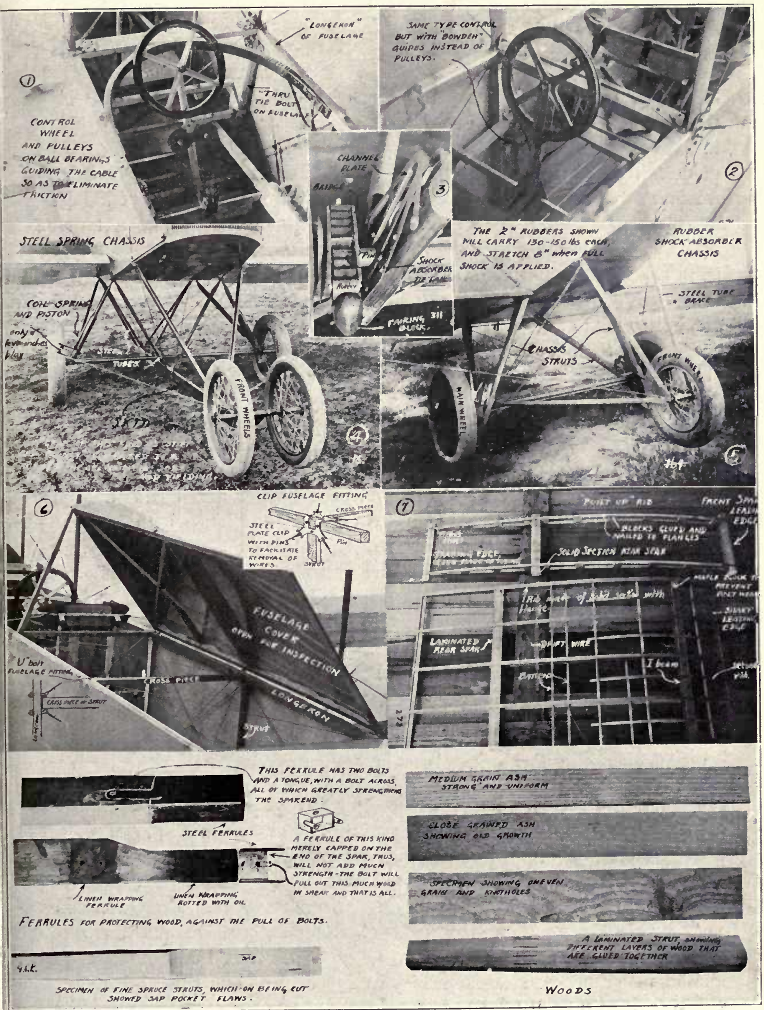
Alloy steels, by various heat treatments, can be made to give various strengths, but increased hardness or elastic limit is almost always obtained at the expense of ductility. In the annealed condition, which, because of the reduction in brittleness, is desirable for aeroplane work, steels do not show much variation. A table is given of the strengths of various grades of alloy steels, and the elongation or per cent that any length will stretch before breakage is given, and is an indication of the ductility.

In aeroplane work, it is essential to have the maximum of reliability, and since local thoughtless heating may have robbed a "special" steel of its special qualities, it is the best practice to proportion all parts for a ductile, easily bent, mild carbon steel, with the strength given in the table. Then, if any advantageous alloy like Vanadium steel is used, its greater resistance to fatigue is an added and much needed safety factor.

The commercial names of "tool steel," or "drill rod" (bars of tool steel), refer to a specially uniform and reliable grade of rather pure steel, particularly adapted to being heat treated, tempered and hardened for



1, 2, 3, 4. Various single and double pulley arrangements for control cables, —5. The Curtiss double U bolt fitting. —6. The Burgess clip fitting. —7. The Curtiss single U bolt fitting. —8. Signal Corps, pin and plate fitting. —9. The steel block and eye head strut bolt fitting used on German aeroplanes. —10. The Wright hook fitting. —11-12. Hinge details.



1. Control with cables and pulleys on ball bearings. —2. Same with friction leads. —3. Detail of rubber shock absorber bridge. —4. Steel Spring chassis, with central skid. —5. Softer rubber chassis with no skid. Both of them are typical chassis for exactly the same work. —6. Fuselage details. —7. Details of wing frames, ferrules and lumber.

special tool purposes. Tool steel and drill rod, in annealed condition, are good, mild steels for bolts, pins, etc.

Bolts, pins, turnbuckles, and particularly wires and cables, may often be of heat-treated special chrome nickel or vanadium steel, and care must be taken not to heat unequally any of these parts, and thus reduce the added safety factor they furnish. This is particularly important in the case of steel wires and cables, in which the material and method of drawing of the wire have been designed particularly to give a high tension strength, which any local heating, for the purposes of bending or attachment, may very seriously weaken. For example, a tension brace of a particularly fine grade of piano wire, received undamaged from the manufacturer and properly put into place, may be relied upon to give its average tested breaking strength. But let this same wire come into long contact with a torch flame, being used to bend, solder or braze some fitting, and it may well have been reduced in strength to one-third of what it is supposed to be.

Cold rolled steel (abbreviated c. r. s.), which is used so largely in aeroplane work, in fittings, ferrules, clips, etc., is steel that has been rolled out to the sheet or bar in question, but in doing so the grain of the steel becomes more marked. This steel is harder and more tenacious than mild annealed steel, but works very easily and has splendid wearing qualities. Bends in c. r. s., however, should not be made too sharp, and when plate more than 1-8″ thick is used, care should be taken to anneal before bending, or else to bend slowly in a vise in which the jaws are protected by thick copper pads, to avoid nicking the plate.

Other Metals.

The table on p. 136 gives the strengths and weights of other metals, but they are rarely used in the parts of an aeroplane carrying the main stresses, excepting the bronze barrels of turnbuckles.

Aluminum should never be used in any important fitting, and its alloys, though at times exhibiting remarkable characteristics, are almost as unreliable as aluminum itself. Many of them, however, are advantageously of use in castings, sheet metal coverings, etc., requiring a metallic construction, but carrying no great stress. Duralumin has very nearly the strength of mild steel, in spots, and is somewhat more weather and water-resisting than any of them. Aluminum sheeting should never be used on coverings in sheeting of less than 1-16th inch thick, as it eventually flakes and cracks.

Tin and copper are used for the ferrules of wire joints and for tankage.

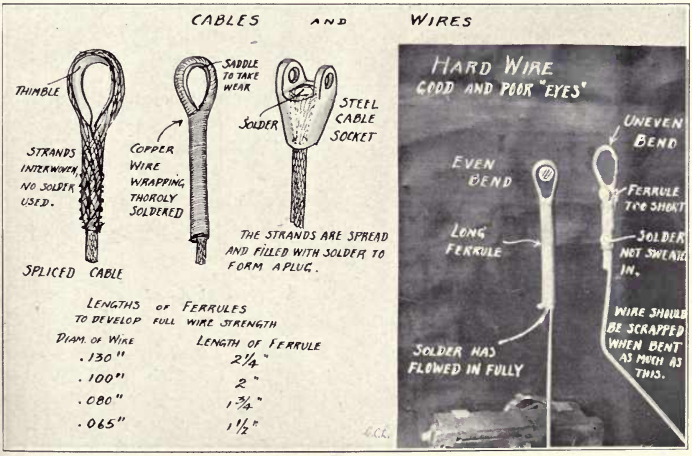
"Monel" metal, an alloy of about the same qualities as mild steel, is extensively used on metal fittings where particular rust resisting qualities are desired.

Crystallization and Fatigue.

The wearing down of the resisting qualities of a material by constant vibration and jar, is a familiar phenomenon met in practical engineering of all kinds — so much so, that a certain "life" is assigned to metal parts, after which their strength is considered unreliable. This should be followed in relation to aeroplane metal fittings, but a great error is made in attributing so much danger to "crystallization" in the failure of parts, since the vibrations on aeroplanes are neither sharp nor excessive.

"Fatigue," is the destruction of the resisting qualities of a material by repeated strains of bending or twisting, exceeding what the "springiness" of the material will stand, as illustrated by the ease with which a wire can be broken by repeated twisting or a steel plate by repeated bending. It is of the utmost importance, then, to make sure that the structural details are not such as to permit the pull or flexing of a part to result in bending or twisting strains on details not suitably made for them. Attention to some examples of this is given in the illustrations of structural details.

In the construction of military aeroplanes it is desirable to eliminate brazed and welded fittings as much as possible, not only because of the added difficulty of replacement, but because a welded joint does not always reveal a possible flaw to the naked eye, and, though apparently satisfactory, might actually prove dangerously inadequate for its stress. Practically all aeroplane fittings may be made of simple and effective steel plate clips, as light and as strong as more "refined" and elaborate arrangements—refined only in that they are harder to make, replace, and pass on.



Cable and Solid Wire Ends.

Aeroplane Woods

For use in the construction of aeroplanes wood has peculiar virtues, one of the best of which is the ease with which flaws can be detected. In this connection, it is a great mistake to paint wooden parts on aeroplanes, since varnish, or "dope," will give as good preservation and yet bring out clearly in evidence any defective features.

Among the woods used in aeroplane work attention may profitably be given to Spruce, Ash, Maple, Hard Pine, Walnut, Mahogany, Cedar and Hickory, strengths and weights of which are given in the table.

Spruce, of clear silver grain, straight, smooth and free of knotholes or sap pockets, is the lightest, strongest and most generally satisfactory material for aeroplane construction available. It must be properly ferruled, where fittings are attached, however, to prevent splitting. As a material for spars, ribs, struts, etc., it gives a splendid combination of flexibility, lightness and strength.

Ash is springy, strong in tension, hard, and very tough. Its weight, however, is considerably greater than spruce, which, when properly ferruled, can for the same weight be made stronger than any other wood.

Maple has excellent qualities, in strength and reliability, for very small wood details requiring unusual resisting powers—like the blocks connecting rib pieces across a spar.

Hard Pine is a tough, uniform wood, particularly applicable to members like the "longerons" of fuselages (longitudinal members).

Walnut and Mahogany are used extensively on propellers, their uniformity in finishing and strength giving excellent results for this purpose.

Cedar is often used as planking of hulls, or fuselage covering, is readily obtained in the boards, and quite uniform and easily worked.

In this connection, fuselages, particularly "monocoques," are sometimes made of veneers, or glued layers of wood, with the grains crossing for added strength. Tulip wood, bass wood, cedar, alder and mahogany, are used for veneer covering work. There are innumerable trade makes of "veneers," some of them very satisfactory in aeroplane work.

Hickory, which is tough and springy, and with a hard surface, is a favorite material for skids, control levers, etc.

For the preservation of wood several coats of spar varnish, or of aeroplane dope, should be used, after an original "filler" of oil or shellac.

Laminations in wooden members are designed to make splitting of the member more difficult by having different layers of wood with the grain running in opposite directions, glued firmly together. Weathering, however, is apt to affect the glue and open the laminations, and it is good practice to wrap the members with linen or paper, or to freshen up the paint or varnish from time to time.

The wrapping of wooden members with linen, may be made to increase the strength against splitting, if the linen is wound very tight and treated with "dope" or glue in such a way that it will forcibly tighten up. The "dope" should be renewed from time to time.

Due to the necessity of having a certain least width to a strut, so that the ratio of the length of a strut l to its least width r will not exceed by too great a margin, the l/r of 45, that engineering practice prescribes as a limit, wooden struts, particularly of spruce, are better than steel or any other material,—for the saving in width and therefore head resistance of a stronger material, would sacrifice strength against bending.

Experience in being able to pick out good lumber and detect flaws, is of great benefit, and should in a measure be acquired by any aviator who is interested enough in his machine to desire assurance as to its strength.

Wing Covering.

The general practice in wing construction is to cover the rib and spar framework with an air-tight cloth, giving a smooth finish to the surface and some degree of resistance to deterioration by exposure.

Rubbered fabrics were used for several years, but it was necessary to tighten them by hand in stretching on the frame, and the cloth would sag in dry, sunny weather, and tighten in damp weather.

An improvement in covering was made by the adoption of fine, unbleached linen, which is stretched rather loosely on the wing frame, and is then treated with "dope."

"Dopes" are of several kinds, but they are almost all cellulose or "collodion" compounds, some soluble in ether and some in aceton. "Cellon," "Novavia," "Emaillite," "Cavaro," "Titanine," are but a few of the trade names, all with some particular virtue—some fireproof, others lacking in bothersome chemical odors, but all designed to accomplish the same purpose, i. e., to tighten up the linen on the frame, and after a few coats, applied with a brush, to give to the surface a smooth, weather-resisting finish.

Skill in applying dopes and various "formulae" for the processes, give varying degrees of finish, but in general four or five coats of a tightening solution, followed by three coats of a thicker finishing solution, will give a good finish. It is customary to varnish this covering with spar varnish, after the dope has set, but, in view of the difficulty of patching and "re-doping" over the varnish, the advisability of this practice is questionable. To clean most doped fabrics, some soap and water will be found better than anything else.

The linen fabric used for this covering is woven in the customary way with "warp," the yarn running lengthwise, and "weft," the yarn running across the cloth.

Good aeroplane linen should test to a tension of at least 50 lbs. for 1-inch width strip of cloth undoped, and should be difficult to tear and rip. When doped it should show a strength of at least 70 lbs. per inch.

Cloth with a fine thread is not quite as strong as cloth with a coarser thread, but the latter absorbs very much more "dope" for a good finish.

Aeroplane linen, doped to a good finish, weighs approximately 0.10 lbs. per sq. ft. of surface, inclusive of tape or batten rib-covering and varnish, for both top and bottom faces of a surface taken together.

WEIGHTS AND STRENGTHS OF METALS

	Weights per cu. in.	Elastic Limit Tension	Ultimate Tension	Ultimate Compression	Ultimate Shear	Modulus of Elasticity
Steel c. r. s.	.283	35,000	50,000	50,000	40,000	29,000,000
Steel, piano wire	....	280,000	300,000	.....	.....	30,000,000
Aluminum	.096	10,000	15,000	12,000	10,000	11,000,000
Duralumin	.103	29,000	45,000	50,000	40,000	....
Tin	.265	3,000	3,500	6,000	4,000	4,000,000
Brass	.310	20,000	25,000	30,000	30,000	9,000,000
Mn. Bronze	.319	50,000	50,000	80,000	70,000	14,000,000
Copper	.320	12,000	20,000	30,000	20,000	16,000,000

All strengths are in lbs. per sq. inch and averages.

WEIGHTS OF SHEET METAL

B & S Gauge	Thickness Inches	Steel lbs. per sq. ft.	Aluminum lbs. per sq. ft.	Brass or Copper lbs. per sq. ft.
2	.258	10.5	3.59	11.6
5	.182	7.4	2.53	8.2
8	.128	5.24	1.79	5.8
10	.102	4.16	1.42	4.6
12	.081	3.30	1.13	3.65
14	.064	2.62	0.89	2.90
16	.051	2.07	0.71	2.3
18	.040	1.64	0.56	1.83
20	.032	1.31	0.45	1.45
22	.025	1.03	0.35	1.14
24	.020	0.82	....	0.91

Tension of c. r. s. steel plate in lbs. per inch width = Thickness × 50,000.
Bearing strength of wire in plate = diam. wire × thickness plate × 50,000.

STRENGTHS OF VARIOUS GRADES OF STEEL

Kind of Steel	Elastic Limit	Ultimate Strength	Elongation
Softest Low Carbon Steel	25,000	45,000	28%
Commercial Mild Carbon Steel, annealed	35,000	55,000	20%
Chrome Nickel Steel, annealed	55,000	80,000	25%
Type "D" Vanadium Steel, annealed	67,000	100,000	26%
Chrome Nickel Steel, tempered	134,000	150,000	15%
Type "D" Vanadium Steel, tempered	195,000	210,000	10%

STEEL BOLTS

Diam. Inches	No. of Threads to the Inch	Diam. at Root	Tension @ 50,000	Single Shearing @ 40,000
1/8	40 U. S. St.	.092	320	256
3/16	32 U. S. St.	.147	880	704
1/4	20 U. S. St.	.185	1,350	1,080
1/4	28 A. L. A. M.	.205	1,650	1,320
5/16	18 U. S. St.	.253	2,500	2,000
5/16	24 A. L. A. M.	.271	2,865	2,292
3/8	24 A. L. A. M.	.321	4,050	3,240
1/2	20 A. L. A. M.	.435	7,500	6,000
5/8	18 A. L. A. M.	.553	11,900	9,520
3/4	16 A. L. A. M.	.669	17,650	14,120
1	14 A. L. A. M.	.907	32,500	26,000

STRENGTH OF MILD STEEL RIVETS AND PINS

Diam. Inches	Lbs. Strength Double Shear	Diam. Inches	Lbs. Strength Double Shear
1/8	1100	3/8	9,500
3/16	2400	1/2	17,600
1/4	4400	3/4	39,000
5/16	6900	1	70,000

For single shear take 1/2 loads given.

CABLES

Diameter Inches	No. of Wires	Wt. Lbs. per 100 ft.	Breaking Strength in Pounds.
1/32 R.............	7	0.35	200
1/16 R.............	19	0.96	500
1/16 R.............	flexible	....	400
3/32 R.............	19	2.0	899
.091 MS............	..	....	1000
7/64 R.............	19	2.8	1400
.118 MS............	..	....	2100
1/8 R..............	19	3.6	2300
.138 MS............	..	....	3000
5/32 R.............	19	5.5	3000
3/16 R.............	19	7.2	3600
.158 MS............	..	....	4000
.209 MS............	..	....	6000
1/4 R..............	19	13.8	8300

R = "Roebling" MS = "Morane Saulnier"

SOLID WIRES

Diameter Inches	Gauge or descr.	Wt. lbs. per 100 ft.	Breaking Strength in Pounds.
.032	20 R	.264	225
.040	19 R	.436	340
.051	16 R	.718	540
.055	ASW	.78	530
.064	14 R	1.13	830
.065	ASW	1.21	680
.080	ASW	1.80	1000
.081	12 R	1.82	1300
.090	ASW	2.26	1300
.100	ASW	2.90	1500
.102	10 R	2.91	2000
.130	ASW Van.	4.50	3000
.250	ASW Van.	16.00	5000

R and No = gauge Roebling. ASW = American Steel and Wire Co.

STEEL TUBE TABLE

Outside Diam. Inches	Thickness	Area of Section sq. in.	Wt. per foot length	Moment of Inertia I	Rad. of Gyr. r.	Lbs. Tension @ 30,000
1/2	20 ga.	.051	.17	.0014	.165	1,530
1/2	1/16″	.086	.30	.0021	.156	2,580
3/4	18 ga.	.108	.37	.0067	.248	3,240
3/4	1/16″	.135	.46	.0080	.244	4,050
1	20 ga.	.106	.36	.0124	.341	3,180
1	1/16″	.184	.63	.0203	.332	5,520
1	1/8″	.344	1.17	.0336	.313	10,320
1 1/4	20 ga.	.134	.45	.0247	.430	4,020
1 1/4	1/16″	.233	.79	.0412	.420	6,990
1 1/4	1/8″	.442	1.50	.0708	.400	13,260
1 1/2	1/16″	.282	.96	.0730	.509	8,460
1 1/2	1/8″	.540	1.84	.1287	.488	16,200
1 1/2	3/16″	.773	2.63	.1699	.469	23,190
2	3/16″	1.07	3.63	.4431	.644	32,100
2 1/2	1/4″	1.77	6.01	1.132	.800	53,100
3	1/4″	2.16	7.34	2.059	.976	64,800

STANDARD GAUGES

No. of Gauge	Birmingham	Brown & Sharp	United States	Diameter of Amer. Steel & Wire Co's Gauge
00	.380	.36480	.34375	.3310
4	.238	.20431	.23437	.2253
8	.165	.12849	.17187	.1620
10	.134	.10189	.14062	.1350
12	.109	.08081	.10937	.1055
14	.083	.06408	.07812	.0800
16	.065	.05082	.06250	.0625
18	.049	.04030	.05000	.0475
20	.035	.03196	.03750	.0348
22	.028	.02535	.03125	.0286
24	.022	.02010	.02500	.0230

Birmingham, used for steel tubes; B and S for sheet metals.

TURNBUCKLE TABLE

Name	Length of Barrel	Length of ends	Last diam. of ends	No. of threads	Strength in lbs.
Burgess..........	3″	1½″	.2″	32	3370
Burgess..........	3″	1½″	.175″	32	2470
Burgess..........	3″	1½″	.15″	32	1700
National..........	5″	2½″	.23″	26	3457
National..........	4½″	2¼″	.20″	26	2492
National..........	3″	1½″	.15″	34	1442

WEIGHT AND STRENGTH OF WOODS

Kind of Wood	Weight in Lbs. per cu. ft.	Tension Strength	Extreme Fibre Stress
Ash................	50	14,000	6500
Bamboo	22	6,000	1000
Cedar..............	28	5,000	3000
Hickory............	48	13,000	7000
Hard Pine..........	45	12,000	6000
Mahogany..........	51	11,000	7000
Maple	46	10,000	8000
Oak................	52	10,000	6000
Spruce.............	32	10,000	5600
Walnut............	42	9,000	5000

All strengths in lbs. per sq. in.

AREAS AND VOLUMES

Triangle.—Area equals one-half the product of the base and the altitude.

Parallelogram.—Area equals the product of the base and the altitude.

Irregular figure bounded by straight lines.—Divide the figure in triangles, and find the area of each triangle separately. The sum of the areas of all the triangles equals the area of the figure.

Circle.—Circumference equals diameter multiplied by 3.1416.

Circle.—Area equals diameter squared, multiplied by 0.7854.

Circular arc.—Length equals the circumference of the circle, multiplied by the number of degrees in the arc, divided by 360.

(Useful for tanks, partly filled.)

Circular sector.—Area equals the area of the whole circle multiplied by the quotient of the number of degrees in the arc of the sector divided by 360.

Circular segment.—Area equals area of circular sector formed by drawing radii from the center of the circle to the extremities of the arc of the segment, minus area of triangle formed by the radii and the chord of the arc of the segment.

Prism.—Volume equals the area of the base multiplied by the altitude.

Cylinder.—Volume equals the area of the base circle times the altitude.

Pyramid or Cone.—Volume equals the area of the base times one-third the altitude.

METRIC CONVERSION TABLES

1 kilometer = 0.6214 mile	1 mile = 1.609 kilometer
1 meter = 3.2808 feet	1 foot = 0.3048 meter
1 centimeter = 0.3937 inch	1 inch = 2.54 centimeters
1 sq. meter = 10.764 sq. feet	1 sq. foot = 0.0929 sq. meter
1 sq. centimeter = 0.155 sq. inch	1 sq. inch = 6.452 sq. centimeters
1 cub. meter = 35.314 cub. feet	1 cub. foot = 28.317 liters
1 liter = 0.0353 cubic foot	1 U. S. gallon = 3.785 liters
1 kilogram = 2.2046 pounds	1 pound = 0.4536 kilogram

CHAPTER XI

MARINE AEROPLANES.

Hydro-aeroplanes and aeroboats involve all the features of aeroplanes that we have considered, and in flight, whether land born or water born, no distinctions can be drawn. But in the replacement of landing wheels by watertight pontoons for flotation, there is introduced an important feature worthy of special attention.

Because of the continuous and broad expanse for alighting, and the generally smoother air conditions, large water courses offer particularly practical inducements for flying, whether it be for the purposes of coast defence and naval operations, or for travel and sport. And for preliminary instruction in flying there are many who hold—and justifiably—that flying should first be taught over water, because of its greater safety, more uniform conditions, and continuous facilities for practice in alighting.

The general care and maintenance of aeroboat hulls, or pontoons, differs in no way from that of high-class boats, excepting that in being hauled out and in, with more or less abuse, the light structure necessary is apt to suffer rather severe wear and tear.

The necessity of strongly braced construction, the best of lapped and copper-rivetted planking, the elimination of metals liable to rust, the use of the proper wood and its protection, so as to avoid water soaking, protective keels and coating, all with a minimum of weight, are but applications of good motorboat practice.

In the form, functioning and adaptability, of pontoons or hulls to the aeroplane, however, there is found a specialty about which more than one entire textbook could profitably be written.

To assist in the solution of difficulties, in the proper application of pontoons or hulls to aeroplanes, a few brief notes are presented here, so that the military or naval aviator may understand the mechanics of water-flying machines, sufficiently to detect difficulties in balance or "planing," and be able to judge of the suitability of various units of flotation for any particular machine.

Air Resistance.

Attention should be given to having as little disturbance as possible to flying characteristics, by the addition of pontoons. Of necessity, the floating members must be low, and being bulky, more or less additional air resistance is introduced. The addition of this weight, so low, appreciably lowers the center of gravity.

Pontoons have, generally, a considerable expanse of side surface, which by being low and at the front, brings the directional center of a surface forward, and also introduces large fin effect below the c. g., a condition ordinarily giving serious lateral instability. Both of these features must be cared for, preferably by adding a fin at the rear and giving a slight extra dihedral to the wings, or by rebalancing the machine, unless the design was originally made for water flying. Reference is made to Chap. XII, on the significance of these features.

The difference in resistance of pontoons and wheels is not nearly as great as commonly supposed, excepting at cabré attitudes or large angles of yaw. Some values of K are given on p. 142 for several different pontoons.

When the fuselage and hull are combined,* as done in the aeroboats or flying boats, efficiency in flying may actually be gained by the elimination of the resistance corresponding to the chassis. Although the seaworthiness of this type is not necessarily greater or less than other types, the compactness of design and gain in efficiency that may be obtained by placing the crew, motor, etc., in the hull, — which of itself has the proper strength and form to serve as the fuselage — is considerable, and the entire craft becomes more boatlike in design, passing from the "aeroplane with floats," to the "boat with wings."

Flotation.

In order to support the weight of the machine on the water, the pontoons or hull must displace 1 cubic foot for every 62 to 64 lbs. of weight. The number of cubic feet necessary for the total weight of the aeroplane, loaded will then represent the volume of the pontoons or hull "under water." The center of flotation (merely the center of this volume) will be under the center of gravity.

The total available amount of flotation, for any kind of practical use, should be, at the very least, two and one-half times as much as this, and the subdivision of the pontoons or hull into water-tight compartments, is as necessary for reasons of safety in flotation as it is to prevent any water that has leaked in, from acting as a shifting ballast to the detriment of the flying qualities.

The distribution of the flotation used and the extra flotation provided must be such that there is:

1. Ample flotation at the rear of the c. g., in order to prevent the craft, when at rest, from being blown over backwards by a wind from the front. The amount is largely a matter of experience but depends on the size and height above the water of the wing surfaces and air-resisting parts.

* Several years ago the author proposed this feature, and was the first to put it into actual practice in his aeroboat, publicly exhibited in 1912, after months of pioneer experimenting.

2. An excess of flotation forward, to give plenty of lift over oncoming waves, and to prevent upsetting by a wind under the tail. Ordinarily ample flotation is given forward, because of the necessary forward position of the pontoon for hydro-planing.

3. Sufficient flotation on either side, to prevent side gusts from pushing a wing into the water, the construction of the wings being so fragile, ordinarily, that contact with the water may result in damage. This side flotation is usually obtained by using either a twin-float or a three-float system, the latter consisting of a large central float and smaller side floats placed on the tips of the wings Even where twin floats of large size are used additional floats on the wings are sometimes fitted.

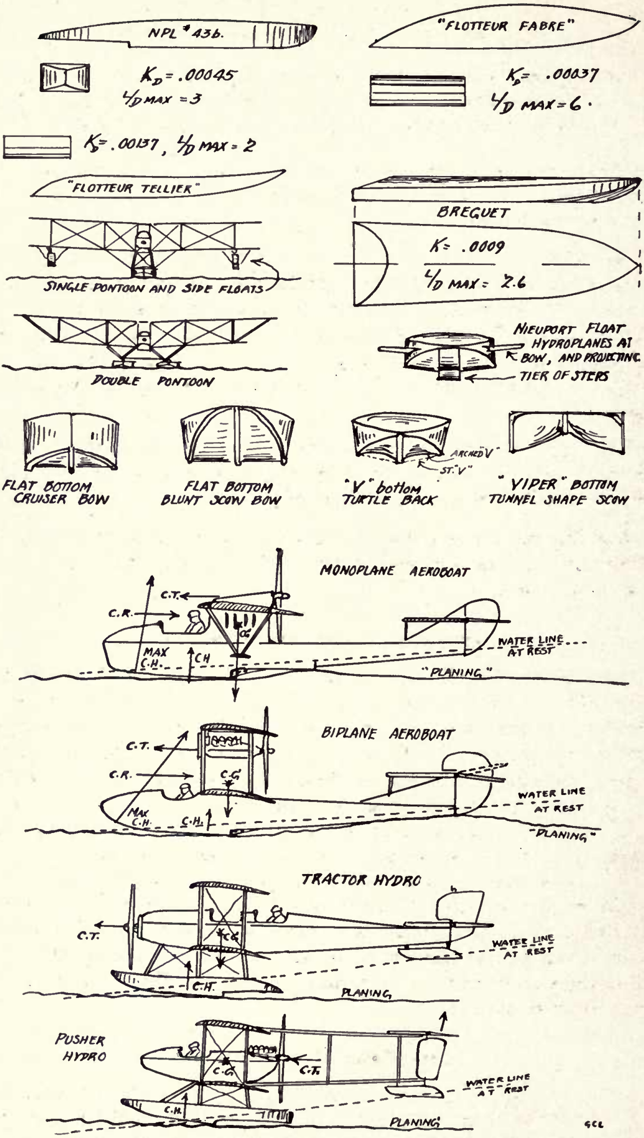
The provision for excess flotation, as indicated, is of the utmost importance, since high winds out on the water exert a most powerful force in tending to upset the craft when it is at rest, drifting or anchored. When anchored in a severe storm, it has often happened that the wind blowing on the wings has lifted the entire craft bodily out of water, upsetting it. In this connection the feature of folding back the wings, when on the water, is a particularly advantageous one.

Hydroplaning.

The action of a surface at an angle of incidence, moved in water or "hydroplaning," is the same as "aeroplaning" in air, in that a Lifting Force is generated at the expense of a Drift or Resistance. The planing surface on pontoons or hulls is obtained by suitable conformation of the bottom, the sides of the hull causing this action to be very similar to the action of a surface of the "wetted" area and shape of the bottom on which the water is impinging when immersed.

The various shapes of the bottom of aeroboat hulls, or pontoons, arched, flat, or double concave "V" all appear to have very nearly the same hydroplaning power in lifting force. The contours and disposition of these planing surfaces, however, differ greatly in efficiency.

In getting under way, the marine aeroplane ploughs thru the water as a displacement boat for some time, until the speed thru the water becomes great enough to cause the hydroplaning action of the hull to take effect, after which, as the speed increases, the "planing" surface lifts more and more of the hull out of the water, at the same time reducing its own surface and resistance. Meanwhile, the wings are acquiring speed enough relative to the air to acquire their lift, and, finally, the amount of surface "planing" on the water is reduced to a fraction of an inch, and the speed of the wings thru the air being sufficient for support, the craft leaves the water. In the acquirement of flying speed on the water, the greatest power is required at just that stage where displacement travel ceases and "hydroplaning" be-



Diagrams of Floats or Pontoons, and air resistance values — Aeroboats and Pontoon Hydro-aeroplanes, showing centers of forces and balance.

gins, and unless enough power is available to overcome the drift on the hull, necessary to obtain this lift, "planing" will not be attained.

Any suction tending to hold the craft down, or to add to the hull's resistance, may render "planing" at speed difficult, so that everything should be done to make the bottom of the hull or pontoon a good "planer."

This is secured primarily by having a high aspect ratio to the planing area of the bottom — as important in hydroplaning pontoons as it is in aeroplanes.

So definite a factor is this in determining "planing," that it may be laid down as a general rule, regardless of laboratory results, that for every 500 lbs. weight of machine there should be at least one foot width of bottom. If this be obtained in two pontoons, the increased side resistance would give slightly more drag than if a large central float were used, with the small side pontoons lifting readily out of the water.

The angle of incidence of the flat bottom that gives the best results is about 4° incidence; any greater angle than this gives too high a resistance and is, therefore, wasteful of power.

The contour of the bottom, so as to obtain this angle on the wetted surface and with the area and center of lift properly placed, is worthy of extensive study.

Centers of Forces and Balance.

As indicated in the diagram, the proper balance for planing is determined by considering the thrust, the lift on the tail in the propeller stream, the c. g., and the c. h., or center of the hydroplaning pressure on the bottom. The thrust, being so high above the water, exerts a powerful moment about the point of support, i. e., the water surface. This moment may be overcome by turning the tail up, giving a downward pressure and moment opposing that of the propeller. This is actually used at the very start, before the planing action on the hull is appreciable in order to prevent the propeller push from forcing the bow in too deep. When the planing comes into effect, however, it is possible to do away with this negative tail moment, — which is both slowing down and adding weight to what the pontoons must lift — by having the wetted hydroplane surface far enough forward to have the c. h. in front of the c. g.

The Shape of the Bottom.

The contour of the bottom of the floats must be such that the c. h. is well forward, when planing, and yet with sufficient planing surface aft to feather on the water and prevent the craft from jumping back too easily on its tail, since the latter condition, causing sudden changes in the angle of the bottom and its planing pressure, is what gives rise to the disagreeable effect of "porpoising" — a fore and aft rocking and jumping, which is, at times, difficult to stop.

At the front the contour should be such that there is a large expanse of hydroplaning surface in front of that wetted in ordinary operation, in order to give ample lift at the bow for proper recovery when alighting on the water at a steep gliding angle — otherwise the nose of the float might catch in the water and upset the craft.

It is interesting in this connection to point out a feature on many floats or hulls that defeats its own purpose. It is assumed by many designers that a bow gradually turning up steeply, presenting a greater hydroplaning angle, will be the most effective in recovery characteristics on a "nose down" landing. As a matter of fact, the recovery moment is dependent not only on the size of surface and speed of landing, but also on the lever arm of this pressure at the bow, about the c. g. As indicated on the diagram (the pressures being normal to the surface) a flatter angle at the bow gives a much more powerful recovery moment. This is fully verified by actual practice.

Steps.

In order to break up the contour into the various areas at different positions and angles, the practice of building the bottom in "steps" is resorted to. A reduction of friction resistance and splendid effect in dividing up the surface is obtained by this feature, if the steps are made from two to five inches deep, with ample ventilation, i. e., large air tubes or air slots in the hull, to feed air into the corner of the steps, for the relief of the suction created there by movement of the water.*

In considering the contour of a float, the fact that the water will acquire, and for a time hold, an acceleration downwards, produced by passing under an inclined surface, is often lost sight of. And the friction resistance of long surfaces is very great.

Seaworthiness.

Perhaps the most difficult incompatibility (excepting that of "stability and controllability" on an aeroplane) is to make a hydroplane type of hull seaworthy. The fact that the hull, when it gets up to speed, is supported by dynamic water pressure, means that any increase or decrease of angle or surface wetted, caused by choppy water, will result in terrific bumping and pounding, and the old saying about the hardness of water, if hit hard enough, becomes uncomfortably evident. If the angle at the bow, as the craft goes into a wave is very

* The surprising magnitude of this suction is illustrated by the fact, that, in the early development of hydro-aeroplanes, a single ½-inch air-tube was considered sufficient ventilation for a step, which today would be required to have at least three 2½-inch tubes.

steeply upturned, the bump is felt with unusual force, since it also tends to slow down the craft. Where a hull is used in which the upturn at the bow is kept as flat as possible, very little bumping is felt, in comparison, the hull riding over the waves instead of pounding into them. However, in the latter case, since considerable depth to the bow is necessary to avoid "tripping" on waves, a freeboard is obtained by a "cruiser" bow construction quite readily, or by use of a "turtle back" bow. The cruiser bow cuts thru very large waves, throwing a great amount of spray to be sure, but the speed of the craft is not stopped as suddenly as with an upflare bow, and spray is readily protected against.

The shape of the bottom is of importance for seaworthiness, since a V bottom is found to give much less pounding, an easier entry, a softer landing, and much less tendency to bounce on alighting. In addition, tendency of the craft to skid outwards, when being turned on the water, is somewhat provided against. Pounding on the bottom causes very great strains on the seams, by spreading, and a V bottom by relieving this, of necessity reduces the possibility of leakage.

The long dragging hull in the rear, on some types, greatly increases the length of run necessary to get off, because of its added and unnecessary resistance. The hull at the rear should be given a positive action that will lift it out of the water, but this may become too great, resulting at the start in digging the nose in too deeply.

All these features require careful compromise and balance. Several outlines of hulls and floats are given.

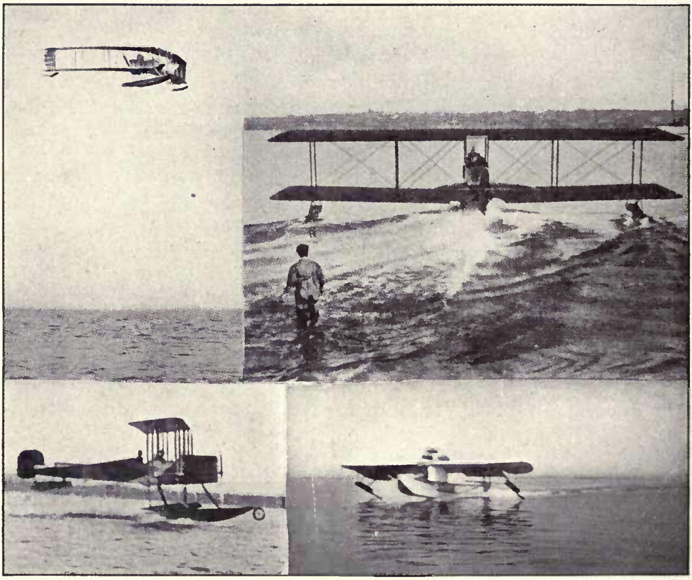
Many features, such as self-bailing cockpits, and thorough water protection of the motor, etc., require attention for increased sea-worthiness.

But the most seaworthy characteristic of marine aeroplanes has been, and possibly always will be, ability to rise out of the water quickly and with the shortest run.

The greater excess of flotation of the aeroboat type is a feature of considerable importance. On a marine aeroplane, consisting of a land machine mounted on pontoons, a very large pontoon at the rear is required, to give anywhere near the excess of flotation obtained with the aeroboat. In this — and in the greater ease with which the centers of flotation, hydroplaning, thrust and c. g., may be brought closer together — there are found the only real advantages of the "boat" type over the "hydro" since flying characteristics and even "planing," on either one, are governed by the same limitations. Structurally, the aeroboat type can be built stronger for the same weight than a "hydro," or pontoon aeroplane, and when the great stresses induced by "side swiping" in landing across wind are considered, the boat is decidedly advantageous in being so well self-contained.

The relative merits of the single pontoon and twin pontoon systems are not yet well defined. The single pontoon is handier in a sea, but twin pontoons, on a large craft, give a wider expanse of bottom, thereby improving the planing by a higher "aspect ratio," but at the expense of more frictional resistance. The twin pontoon system is apparently well adapted to launching devices.

Elements of seaworthiness found in the larger sized marine aeroplanes are distinctly advantageous, and indicate that for real work in the open sea, seaplanes will become huge in size, and will have to possess great range of action and excess of power.



Above left — The Burgess-Dunne Seaplane, pusher type with pontoons.

Above right — Martin Tractor Seaplane, shown also at lower left.

Lower right — Loening Monoplane Aeroboat, an early experimental marine aeroplane, the first of the flying boat class.

CHAPTER XII.

FLYING, STABILITY AND AIRWORTHINESS.

The characteristics of resistance, lift, speed, and power of the aeroplane having been studied, and attention having been given to the construction and adjustment of these machines, it is appropriate now to consider the actual flying of the machine.

As already outlined, it must be borne in mind that the aeroplane is supported in a perfectly free fashion on a medium that is, at times, very treacherous, and the most efficient aeroplane in the world, as to speed and power, and the very best and refined in construction, is more or less worthless unless it embodies "controllability" and, above all "airworthiness."

For the military aviator, the importance of acquiring a very sound and intelligent grasp of the principles of stability and operation involved in the notion "airworthy," cannot be overestimated.

Actual instruction in the manipulation of controls on the machines, thorough practice in acquiring the "feel" of the air, and development of unerring judgment on landings, form the major part of the practical work in the training of aeroplane pilots. But unless this is accompanied by an intelligent understanding of the actions of aeroplanes in the air, the pilot is little more than a somewhat instinctive automaton.

No mathematics, or formulae, need be involved in the consideration of the stability and operation of aeroplanes. But there is required a continued and judicious use of "common sense."

The subject may be divided into the three broad generalities of considering:

1. The flying of the machine, the assuming of different attitudes, unsafe positions that may be taken, and proper methods of operation.

2. The stability of the machine, which may at once be defined as the degree and manner in which the aeroplane tends of its own accord to keep a certain relative "even keel" attitude to the air stream.

3. The airworthiness of the machine, or degree in which comfortable stability is obtained without too much sensitiveness to air disturbances, and controllability, is obtained without making the aeroplane too easy to upset.

The absolute opposition of inherent stability to controllability is always met in flying characteristics, and it is a fact that an inherently stable and safe aeroplane is stiff and apt to "fight" its controls, while it is sensitive to and moved by air disturbances — whereas a "neutral" stability aeroplane, with powerful controls and no tendency to hold any position relative to the air, is handy and precise in answering its helm, and is not readily upset, if equipped with a good automatic pilot mechanism.

The popular notion, held by many intelligent people, that "stability" means "steadiness in flight" is very erroneous. The least air disturbance causes a "stable" aeroplane correspondingly to adjust itself to keep the same attitude relative to the air so that its position relative to the ground is changed by air movements, and so perceptibly that on a rough, puffy day an inherently stable aeroplane appears to roll, pitch and sway in a most alarming fashion, while, as a matter of fact, it is merely answering to the air billows. It is much more correct to conceive of an "inherently stable" aeroplane, primarily as "non-capsizable," and not at all steady in its flight. For that reason a neutral stability aeroplane, with a delicate mechanical automatic pilot, makes a much steadier gun platform.

CENTERS OF FORCES.

The aeroplane, in flight, is subjected to the action of four forces:

(1) **The Thrust — acting at the center of thrust, C. T.** — which is merely the line of the propeller axis.

(2) **The Total Resistance — acting at the center of resistance, C. R.** — which is determined by balancing the air resistances of all the separate structural parts (see Chap. IV) with the drift, and finding the resultant point at which a force equivalent to the total resistance would be applied.

(3) **The Lift — acting at the center of pressure, C. P.** — which is the center of pressure of the lifting forces for the particular angle of incidence, at which flying is taking place, and found from the surface section data and tail lift data.

(4) **The Weight — acting at the center of gravity, C. G.**

Center of Gravity.

It is of fundamental importance, before studying this subject further, to know how and where the center of gravity of any machine is located.

An aeroplane is suspended in the air and rotates about its center of gravity, so that it is proper to consider the path of the center of gravity, in considering the trajectory of any machine. An aeroplane distinctly does not rotate about any center of lift or resistance.

The center of gravity, therefore, must be known, and should be measured and marked on the machine.

The manufacturer furnishes drawings and data, indicating the proper position of the center of gravity. The aeroplane user, after fully loading the machine for flight, should determine whether or not the weight of the machine is properly balanced.

There are several methods of finding the center of gravity.*

(1) The machine could be swung, by flexible suspension from an overhead point, and a plumb line dropped from this point, would intersect the body at the c. g., no matter what the position of the machine.

(2) The machine could be supported on a large pipe, or knife edge, and moved until balanced on either side. The c. g. fore and aft, and side to side, may be obtained readily by this method, although it is, at times, awkward to support a machine in this way. In this method the height of the c. g. above the bottom of the body is not so easily obtained, and the total weight is not measured.

(3) The method of moments — in which the measurement of weight is made at any two points, and the distance between them measured. The total of the weight at any two points of support is the total weight of the machine, and as indicated on the diagram, p. 152, the center of gravity is very easily obtained by solving the suitable lever arms. This is an exceedingly quick, simple and accurate method for a combined determination of the weight and balance, and at any large aviation field, where platform scales are available, this method is particularly convenient. To determine the lateral correctness of the c. g., it is merely necessary to see if weights measured at either end strut, lifting the machine about the opposite wheel, are equal. The lateral c. g., however, is rarely variable enough to require checking. To determine the actual height of the c. g. above the wheels, it would be necessary to repeat the operation for the horizontal balance, with the tail very low and the front as high as possible, thus establishing an intersection where the two c. g. lines cross each other. Or, if the chassis permits, the machine may be tilted up at the rear, until a balance is obtained over the axle, and by projecting a plumb line above this an intersection point is also obtained.

The longitudinal position of the c. g. is the important one, and consideration of the accompanying diagram shows that if the total weight is reasonably well known, the single measurement of the weight carried by the tail skid, and its distance from the axle, will at once determine how far back of the axle the c. g. is situated. For this only a 200 lb. spring balance is necessary in the field, and data on the correct weight the tail skid should carry is given by the manufacturer.

* It is necessary to note that correct results in balancing are apt to be upset, if a draught or wind blows on the aeroplane, when being balanced. Still air is a prerequisite.

The Equilibrium of the Forces.

These four forces of Thrust, Resistance, Lift and Weight, acting at their respective centers, must be in equilibrium when the machine is in steady flight.

Generally, an aeroplane is so designed that the line of thrust passes very nearly thru the center of resistance and the center of gravity is made in line with the center of pressure. The aeroplane is then said to be balanced on the principle of "coincident centers" (*centres confondus*). But there are notable exceptions to this practice. For reasons of handiness in taking proper angles, as later explained, the center of thrust is often placed below the center of resistance. This couple, tending to turn the machine, as indicated on the diagram, is overcome by the couple obtained by having the center of lift in back of the center of gravity. This can be obtained either by having the center of pressure of the surface slightly back of the c. g., or by introducing a small lifting force on the tail. We are at once led then to consider,

The Effect of Tail Lift on the Center of Lift.

Up to now we have considered that the center of the lifting forces on the machine, was found at the center of pressure of the main wings. This is only true if the tail surfaces are perfectly neutral, as found in the majority of well balanced aeroplanes. If the tail surfaces receive a negative pressure — a downward air force — the center of lift of the aeroplane will be in front of the center of pressure of the main wing, and if the tail actually exerts a lift, then the center of lift will be proportionately behind the c. p. of the wings — so that the lift of the tail × its lever arm back of the resultant center of lift = the lift of the wings × the lever arm of the wing c. p. about the resultant center of lift. This, then, is the nature of the position of **the Total Lift force (tail + wings) acting at the center of pressure, C. P., of the entire machine, and is the point referred to, in considering the four forces in equilibrium.**

Lateral and Directional Centers.

There are two other centers to be considered. The center of support, or pressure, may shift slightly laterally as the aeroplane takes different positions in the air, due to differences in the lift of either wing. Attention is given to this under "rolling."

The aeroplane, with fins, covered body and wheels, rudders, etc., presents a sidewise expanse of surface to the air. It is necessary to know the position of the center of surface of all this side area. Of course, the areas can be computed and the center of area determined, but it is much easier to cut out a paper pattern to scale, of the side elevation of the aeroplane, and then by balancing this on a pin point, finding the center of gravity of the paper. The center of side surface, or **directional center,** as it is sometimes called, may then be taken as slightly in front of this point, and may be marked on the machine.

The centers having been defined, we are free to proceed with the study of the relative movements of the aeroplane and the air. Their classification into, Pitching, Yawing, Rolling, has already been outlined on p. 13.

The Moments of Inertia of the aeroplane about the various axes must also be considered, since the inertia largely governs the rate with which a machine responds to changes in attitude, with reference to the ground.*

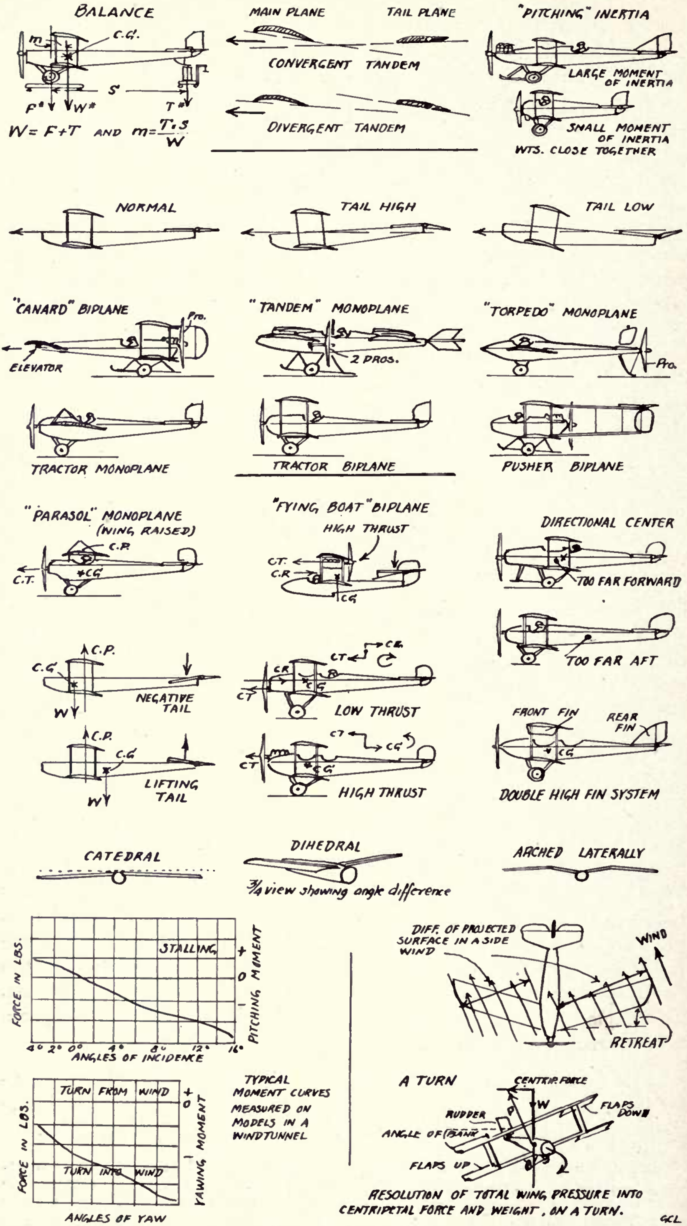
CHARACTERISTICS OF PITCHING OR LONGITUDINAL MOTION.

The longitudinal motion of an aeroplane in rising or descending, corresponding to changes in the angle of incidence, is controlled by the elevator, but is subject to inherent effects in the aeroplane itself, due to the disposition of surfaces and the magnitude of the longitudinal inertia.

The action of an elevator in merely steering the machine up or down, in its trajectory, is remarkably powerful, and only a fraction of a degree change in the angle of the flaps is sufficient in normal flying, to direct the machine to a different angle and path. For any one speed there is only one elevator setting and balance, corresponding to the one particular angle of incidence for that speed, and any change in the elevator manipulated by hand, changes the incidence, and for the same initial speed will cause the machine either to climb or point downwards. Flight at the different angles is effected by changes in speed obtained by throttling of the engine, combined with a more or less unconscious setting of the elevator to give the proper balance. The necessity of introducing lifts or depressions by the elevator, to keep the relation of the center of lift about the c. g., in the form that will balance the action of the centers of thrust and resistance, is always present for flight at any angle of incidence. The pitching control can be varied greatly in delicacy and power by alterations of the size, movement and leverage of the elevator flaps. The general characteristics of this control, however, and the movements, positions and limits of equilibrium longitudinally are common to all aeroplanes. The angle ranges that have been studied in Chap. VIII now assume a more particular significance.

1. There is a "normal flight" position of the aeroplane — generally when the body axis is in the line of flight — where there is the desired combination of speed, power, glide and climb characteristics.

* It must be borne in mind that inertia effects tend to keep the machine in whatever state of position, motion, or rest, it happens to be. And the greater the distance separating items of weight, the greater is the moment of inertia, and, therefore, the slower the oscillations.



STABILITY DIAGRAMS

In the negative and lifting tail diagrams, the total C. P. is at the C. G.

2. There is a "low angle," or "vol pique," position, generally corresponding to the attitude for highest speed and least angle of incidence at which the machine is said to fly "tail high."

3. There is a "high angle," or "vol cabre," position, corresponding to the attitude for slowest speed and large angle of incidence, at which the machine is said to fly "tail low."

The "regime" of flight, at different speeds and angles, is all the way from the "tail high" to the "tail low" position. At any of these positions, governed longitudinally by the elevator and the throttle, the machine has a certain climb, depending on the excess of the Power Available over the Power Required, a glide governed by the total resistance, and a certain fuel consumption, all as outlined in Chap. VIII. But in its path through the air, if the machine does climb or glide, **it must always be borne in mind that the angle of incidence is the angle between the chord and the flight path.** Just because a machine is pointed up very steeply, does not mean that it will necessarily climb steeply, since it might have much more excess power at a very much lower angle, and actually climb more feet per minute by the application of this excess power, with the machine on an apparently level keel. As a corollary, a machine does not necessarily glide best the more it is pointed down and speeded up. By holding a machine apparently pointed up, the actual glide slope would be flattest if the particular high angle of incidence, corresponding with this attitude to the air flow, was actually the angle for best glide. Speeding up a machine by nosing down on a glide may increase the Total Resistance so much as to cause the glide to steepen, greatly. All these characteristics may be studied from the Power and Resistance charts, and any aviator can profitably acquire familiarity with them.

Although its significance is often overestimated, consideration of the "reversed flight" region may be given here. Referring to p. 96, it is seen that at speeds below angles of 10°, increase of angle of incidence, corresponding to slower speeds, involves a pronounced rise in the Power Required, due to increased resistance. And above 17° the lifting power of the wings actually decreases. The effect of flying at these high angles is to ause an inversion of controls. Increasing the angle of incidence, whn in horizontal flight, without giving the engine "more throttle," actually causes the machine to sink, and whereas if flying at 14°, let us say, the machine's incidence were to be reduced to 10°, with the same engine power, the maneuver would result in a climb, due to gain in excess power. The old conception, then, of pointing a machine up for climbing, and down for gliding, is not always correct; and the aviator at some angles may, much to his surprise find himself climbing when he points the machine down, and sinking when he points it up for a climb. Such phenomena are only too often blamed on "puffs and uptrends," when, as a matter of fact, a glance at the power chart would show the reason for apparent inversions of this kind.

This leads at once to the realization that higher power is often of advantage in attaining slower speeds, since flying can then be done at angles where the resistance would prove too much for a lower-powered machine. Thus, referring to p. 96, it is seen that the slow speed attainable at 800 r. p. m. is 43 miles an hour, whereas an increase to 1400 r. p. m. would very likely permit of flying at 39 miles an hour. The "regime lente" or "slow," at which the aeroplane is flying, in cabre attitudes, is perhaps, the most difficult one to negotiate, and there are not many pilots expert enough to get the very slowest speeds out of their machines. Flying at the high speeds is merely a matter of giving the engine all the power it has, and being on the alert for the uncomfortable, quicker action of puffs. Flying a machine at its attitude for best climb, or best glide, is, of course, a matter of systematic practice, but information from the Power Chart is particularly of value for this.

Stalling and Diving.

An aeroplane's angle of incidence can be increased or decreased, providing the speeds are changed in proportion. But, at any angle, if the speed drops the aeroplane is subject to loss of headway, and consequently to loss of support. This condition is called a "stall." There are many ways in which an aeroplane can be stalled, either by a false maneuver or a peculiar air disturbance. Immediately after a machine has lost headway, however, it begins to sink, either sideways, tail first, or on a level keel. The latter condition corresponds merely to a sudden rise in the angle of incidence, and recovery is possible. In the other two conditions, speed for flight can be regained only after a long fall, and then only if the machine has the necessary recovery characteristics and the pilot the presence of mind to apply them.

Stalling on turns is considered later. Stalling due to pitching maneuvers may be considered here.

On a steep climb, continual incidence increase and slowing down may eventually result in exceeding the maximum lifting angle, and the condition of lost support, due to too great an angle and lack of speed, is merely a stall. Novices, when leaving the ground, often point their machines up too steeply and thereby lose headway, necessary for support.

Pancaking is usually taken to define the settling of a machine, on landing, due to having turned up so steeply that a stall is reached, and the machine robbed of speed and support sinks more or less abruptly to the ground, with little if any forward speed.

The acquirement of the proper skill in operation to feel an approaching stalled condition and to be in such position that, if the power suddenly ceases, a tendency to stall may immediately be overcome by taking a proper gliding angle, is better taught by experts in flight, on any particular machine.

In taking a downward path an aeroplane may be **gliding** — floating down on a long slope, held at a certain incidence, and therefore coming down at a constant speed — or it may be **diving,** i. e., coming down on what is practically a fall with no particular value to the incidence, and constantly increasing speed.

Any of the foregoing kinds of stalling may be met with as easily by sudden changes in wind direction, due to up or down trends, as by changes in the attitude or speed of the aeroplane.

Stalling, when on the gliding path or slope, is a frequent and little appreciated source of accident. The fact is lost sight of, only too often, that angles of incidence are just as important on the downward slope in a glide, as in horizontal flight, and stalling may be reached by a gradual loss of headway and increase of angle. After a long dive, a mistake in recovery to more level flight may result in a stall. It has frequently happened that aeroplanes with a small longitudinal inertia (resembling the old type "pusher" aeroplanes) have been turned up too quickly after a dive or glide so that the tendency of the machine to keep on going in the direction of the dive, for a moment results in the wings attacking the air at a very high angle of incidence and a quickly retarded speed. A characteristic of this kind is due largely to so small a longitudinal moment of inertia, that the aeroplane could be turned around its transverse axis, without much displacement of its center of gravity, and is distinctly a dangerous one. Lack of knowledge on this feature has cost, doubtless, many lives.

The usual pitching control of pushing forward on a post to go down and pulling back to increase the angle, is very instinctive.

The general construction of the elevator surfaces on aeroplanes, in the form of a large fixed area to which trailing flaps are attached, gives rise to an interesting phenomenon.

In flying at very high angles of incidence, since the entire machine is inclined, it follows that the fixed tail surface has a high angle of incidence to the air flow past it, and therefore is subject to a Lift. In the preservation of the balance, it may happen where the fixed portion is large and the flap small, that the flap is turned to a considerable angle upwards. The air flows past the inclined front fixed surface, and breaks up into eddies, seriously interfering with the air pressure on the flap, with the effect that a further up-turn to the flap would result in no appreciable change in the air forces. **In other words the pitching of the machine would lack any response to the elevator movement, due to the masking of the air on the flaps by the fixed plane in front of them.** If an action like this were to take place at about 11° incidence, on an aeroplane that would not stall before 12° to 14° had been reached, it would obviously be impossible in flying level to stall such a machine by pulling the elevator control to its limit. This feature, though in a sense a serious limiting factor in controllability, has actually been used on many aeroplanes for training purposes, with excellent success, as a "safety factor" against stalling.

Steep dives introduce other dangers than those already indicated as due to the possibility of stalling on recovery. The most important effect of a steep dive is the acquirement of very greatly increased velocity, which may prove exceedingly dangerous, due to the tail effect considered below, and due to the possibilities of great strains on the machine.

Different types of aeroplanes, of course, vary widely in their pitching characteristics, but in practically all aeroplanes with deeply cambered surfaces, at low angles of 1° or 2° flying becomes exceedingly uncomfortable. The machine apparently loses much of its handiness in the control of pitching, because the surfaces at these low angles are flying at low values of K_L, and greatly varying values of L/D, so that slight variations in the wind direction cause rather large and sudden changes in the pressures, and consequent "jumping" of the machine. Large surfaced, deeply cambered machines, with any considerable excess power, always exhibit this characteristic when flown with full power on the horizontal. And the angle on some sections may come so perilously near to the angle of no Lift, and rear most c. p. position, as to introduce the danger of a sudden dive, which the elevator may not be big or powerful enough to negotiate. Aeroplanes with deeply curved wing sections and an excess of power for climb, should never be flown on the horizontal, with "all power out," if this low angle region is approached thereby.

Longitudinal Stability.

The attitudes assumed and limits of control reached in pitching having been considered briefly, attention may be given to the natural characteristics of the longitudinal equilibrium of aeroplanes quite independent of manually controlled pitching.

The center of pressure on practically every type of aeroplane surface extensively used at present, excepting the "Taube," moves backward as the incidence is decreased, and forward as the incidence is increased, within the ordinary range of flight angles of 0° to 12° (see Chap. VII). This means that the main lifting force has a pronounced tendency to make a machine dive still more when the angle of incidence is decreased, and to stall when the angle is increased. This is, clearly, a condition of **instability, i. e., any pitching is accentuated by the air pressure.** For stability — that is, a tendency for the machine to right itself — it would be necessary to have the center of pressure move back on increase of angle, and move forward on decrease of angle. Many attempts have been made to attain this by the use of reversed curve sections of wing, but up to now they have all been at a great sacrifice of efficiency. A c. p. position that is almost stationary, thru the range of angles, has been closely approached by some of the newer flat section wings, and by use of a washout in the angle or the upturned tip as in the "Taube." But for actual positive stabilizing action, it has been necessary to rely on the action of a tail plane or auxiliary surface.

This brings us to the consideration of, perhaps, the most important and essential inherent stability characteristic of an aeroplane — **the powerful corrective action, on disturbances of longitudinal equilibrium of the convergent tandem arrangement of surfaces.**

The definitions of the convergent tandem system, often called the "longitudinal dihedral," which is so desirable for longitudinal stability, and sketches of several systems of tail and main surface combinations, are given in the accompanying diagram.

For most practical purposes, on the average present day aeroplane, the complete tail surface, situated at about three chord lengths from the main surface, is made to have an area of about 1/6th of the main surface. This is inclusive of the flaps, which are merely a means of altering the camber and pressures on the tail surface for purposes of control. The error should not be made of considering the fixed tail pieces as separate from the flaps, because of the continuity of the two, except in the extreme case of "masking" already considered. The main and auxiliary surfaces could be of various different proportions, such as the tandem disposition of equal surfaces, as in the old Langley machines, or the "Canard" arrangement with the smaller surface in front (see p. 152).

Whatever the relative size of the surfaces, if the angle of the front one is positive and the angle of the rear one negative,* the system is said to be a "convergent tandem"; and its characteristic is that when the angle of incidence of the aeroplane is decreased, the air force on the tail becomes more negative, acting downwards, thus tending to force the nose of the machine up, while if the aeroplane assumes a cabre position, the rear surface lifts more, thus pointing the nose of the machine down. This action is accentuated, in addition, by the slowing

* In all this discussion the angle of the tail surfaces with the air is meant, i. e., interference of the air flow by the main surface is taken account of by the usual reduction of a degree or two.

down of the machine at high angles and the speeding up at low angles. Practically all Lift values on aerofoils increase at a much steeper rate at low angles than at high angles. So that the rear surface, as in the divergent tandem, will actually change its Lift in less proportion than the front one, for changes in incidence, — and this accentuates the action of the pressures on the main surface alone, tending to make the machine nose over still further of its own accord when it pitches forward, and to make it nose up still more when the incidence increases. The "divergent tandem," then, is naturally an unstable system. The convergent tandem is often spoken of as a "longitudinal dihedral," because the surfaces are turned up relative to each other.

It is not always necessary to have a negative tail in order to obtain the desirable pitching stability, since the main surface may be set at + 3° and the tail surface at + 2°, with an interference on the tail causing a 1° negative flow, which would give a longitudinal dihedral of 2°, and still leave the tail a lifting one, at an incidence to the air of 1°.

This leads to the consideration of the effect on the balance of speed variation of the air passing the tail surfaces. Varying the r. p. m. of the propeller by the throttle varies the speed of the air thrown back by the blades. In every type, excepting the "torpedo" type, the propeller is in front of the tail surfaces, and **therefore changes in the propeller stream affect the pressures on the tail.*** In machines with a neutral tail, neither negative nor lifting, the effect of stopping or speeding up the propeller is not felt. But on a lifting tail machine, sudden stoppage of the propeller will relieve the lift on the tail, and give a tendency to stall just at the wrong time, while sudden starting again will nose the machine over. This can, of course, be offset by having the center of thrust below the center of resistance. Where the tail is a negative one, with a large longitudinal dihedral, sudden stoppage of the propeller stream causes the negative tail pressure partly to be relieved and the machine to nose over to a proper gliding angle. And, when the propeller is speeded up, there is introduced an increased negative tail pressure, tending to make the machine climb at just the right time. On overpowered machines this tendency of a negative tail surface, to make the machine climb when the full power is applied, is an exceedingly comfortable and air-worthy feature.

The most dangerous feature of a pronounced lifting tail is in the acquirement of higher and ever-increasing speeds on a steep dive. The lift of the tail is directly increased as the square of the speed, but its lever arm about the center of gravity remains the same; so that, as the speed increases and this tail lift moment increases, an unbalanced force is introduced. The speeds attained on dives increase so greatly and this tail lift action may become so powerful that the maximum

* It must be borne in mind that, due to "slip," the actual velocity of the air thrown back by the propeller averages 20 to 25% faster than the velocity of the aeroplane.

exertion on the part of the pilot on the elevator control, may not be enough to overcome it. This exceedingly dangerous feature of the lifting tail has resulted in some very severe accidents.

It is seen, then, that a longitudinal dihedral giving the "convergent tandem" system, favorable to inherent stability, is far preferable to a lifting tail, for safety, stability and airworthiness. Their comparison on a basis of efficiency is not favorable to the negative tail, because the machine must constantly carry double the negative air load, and extra resistance, whereas a large lifting tail will add just that much area for the load lifting capacity and give very great improvement in Climbing Rate, Speed, Range, etc.

At times it is necessary to compromise stability and safety for efficiency, and for special performances in the hands of an expert a powerful lift on the tail is often used. Rarely, however, does this exceed 50 to 60 pounds.

The effect of having the Center of Thrust below the c. r. and the c. g., is to introduce a tendency for the machine to assume a glide angle when the engine is shut off, and to cl mb when the power is applied — characteristics that are certainly more desirable than a high thrust, which, when the power is shut off, would tend to stall the machine.

The control of longitudinal balance and the natural tendency of machines to keep an even keel, fore and aft, having been considered, we may proceed with a study of

ROLLING AND LATERAL BALANCE.

The lateral balance of an aeroplane is understood to refer to the balance of the wings transversely across the flight path. And rolling is the movement about the longitudinal axis, caused by alterations in lateral balance in distinction to pitching, which is the movement along the longitudinal axis.

The lateral balance of an aeroplane may be varied by air disturbances and by the torque of the propeller (assuming that the wing setting and weight are symmetrical).

The Torque of the Propeller, is an air force due to the pressure of the propeller blades on the air, which on single propeller machines must be resisted or else the propeller might stand still and the motor turn about it. The tendency of the machine is to turn opposite to the propeller, so that the effect of the torque is to unbalance the aeroplane laterally, — in so much as it is necessary to introduce a lift on one side by a slight increase in the incidence, which will have a tendency to make the machine roll in the same direction as the propeller turns. Of course, where two propellers are used, working in opposite directions, the torque is neutralized. When the engine is suddenly turned on or off, on single propeller aeroplanes of high power and small surface, the torque is a very perceptible force. It is interesting to note that the torque of small, high-speed propellers is very much less than that of large, slow, geared-down propellers.

The effect of air disturbances on lateral balance is merely to tip up one side or the other, or to throw the entire machine sideways, thereby affecting its transverse attitude.

Since the actual attitude of the aeroplane to the air that is passing it, governs the stability characteristics, it follows that we are concerned here with the effect on the wings of a sidewise flow of air, and of a difference in the angle of attack on either side. The latter, on any type of aeroplane, merely makes the air force on one side greater than on the other, and for the preservation of the balance requires a corrective effort.

Lateral Stability and Instability.

Pitching requires control for the attainment of different angles of incidence and altitudes. Yawing requires control for the steering of the machine. But, independent of the necessary feature of banking on turns, the lateral control of an aeroplane is primarily for the preservation of lateral balance.

"Lateral stability" may be defined as a natural tendency for an aeroplane to keep an even keel transversely. If a machine departs from an even keel laterally, it may roll over and fall sideways, and it is well for any pilot to realize, that of all conditions of instability, lateral instability is the easiest to acquire and the most difficult to eliminate, without sacrificing controllability.

The lateral stability characteristics of an aeroplane are considered before taking up the study of lateral controls, so as to acquire a better understanding of their function.

The effect of side winds, or, what amounts to the same thing, a sidewise movement of the machine, is not necessarily destructive of lateral balance, as will be explained presently.

On the older type of open-bodied aeroplanes, with the wings straight across the span, and at constant incidence, a side wind would pass thru the machine with very little effect in tipping up one side more than another. But as soon as a large covered fuselage or nacelle is used, it is obvious that a side wind on the body will blanket the wing away from the wind, to a certain extent, so that the machine will have a slight tendency to lift up on the inside wing. This, however, is largely overcome by the effect of the body wheels, etc., which as covered areas below the c. g., catch the side wind and tend to turn the inside wing down. This opposition may be balanced on a machine quite readily and neutral lateral stability obtained, to the degree that the machine will not tip up sideways. The entire machine, however, being acted upon by a sideways flow of air of less velocity fore and aft, has less lift and would tend to stall, were it not that the "weathercock" action, considered later, turns it to meet the side wind. The "side wind" referred to is not of "puff" nature giving an actual incidence difference on the wings and tipping up the side with the greater angle. This must be borne in mind.

It is well to realize, at once, that any arrangement for natural corrective effort when the machine moves sideways, relative to the air, makes the same machine roll when hit by a side wind.

There are three general ways of obtaining natural lateral stability:

1. By a Dihedral Angle to the Span.

The wings are bent up, as indicated on the diagram, and when the machine, due to some disturbance, rolls over, the low wing lifts more than the high wing and tends to correct the roll. When the machine moves sideways the dihedral angle of the wings causes a greater area and angle to be presented to the air on the leading wing, thus lifting it up. At the same time, however, the higher resistance on this wing tends to make the machine turn into the relative wind. A side puff will lift up the inside wing that it first attacks and then throw the machine sideways — after which the dihedral causes a greater lift on the low wing, tending to bring the machine back to an even keel. **This answer to a side puff, followed by the righting effect, is always characteristic of a dihedral wing, and is uncomfortable.**

2. By a Retreating Wing Shape.

The shape of wing in the form of a retreat, as indicated, gives clearly a difference in projected entering edge, and shape of wing, which, without quite as much sensitiveness to sharp side puffs, at the same time gives considerable difference in lift, and strong recovery. Like the dihedral, however, the difference in wing, laterally, causes a difference in resistance, tending to turn the machine into the side wind, and the great leverage of the difference in lift and resistance about the c. g. makes both systems exceedingly sensitive.

3. By the Double "High Fin" System.

As indicated (diagram p. 152), the rudder is placed high and a fin above the c. g. is placed forward. The action of a side wind on this system tends to roll the machine up on the inside wing, but while the dihedral and retreat are exceedingly sensitive to the least sideways deviation of the air flow from its direction along the axis of the machine, fins of this class require a most pronounced sideways attack of the air before any considerable effect is created. Ordinary deviations of the wind direction in flight (which would cause a dihedral or retreat to roll the machine) have very little effect on this fin system, and the small leverage of the fin pressures about the c. g. rob them of sensitiveness. **At the same time, when the machine itself moves sideways, to any great extent, the high fin action resists the movement and tends to bank the machine up properly, and to overcome lateral instability.**

If the fin surfaces were below the c. g., or if the angle across the span is made catedral (turned down) instead of dihedral, a side puff would press down the inside wing, and a side movement of the machine would introduce a force tending to roll the machine over, and to upset it, i. e., lateral instability.

It is clear, then, that on a machine with provision for corrective effort, tending to right the machine laterally when it is thrown over sideways, it is actually necessary for the machine to be disturbed and moved sideways before this corrective force is created. Every inherent lateral stability feature, as a corollary, has more or less tendency first to permit air disturbances to roll the machine — high fins less so than any other system.

The position of the c. g. may effect this, in so far as a low c. g. does tend to give a lateral righting effect, although the machine is apt to swing in increasing amplitude if too low, while a high c. g., if above the center of support and displaced, would tend to roll the machine over and upset it. The lateral moment of inertia is ordinarily small, since the weights are practically at the same height, laterally. But on the old Wright aeroplanes, and the Curtiss flying boats (with motor high and hull low), there is a considerably greater inertia laterally, which makes the roll slower, and the resistance to initial movement by air puffs greater. However, this feature causes the machine, after it has acquired a roll, to keep on rolling with considerable force, which is detrimental to controllability.

Lateral Controls

For the purposes of assuming the proper banking on turns and the preservation of equilibrium, laterally, aeroplanes are provided with transverse controlling devices.

Practically all of these take the form of adjustable surfaces out at the sides, in which changes of incidence or changes in camber (as in wing flaps), are relied upon to give a greater lift on one side than on the other, thereby rolling the machine.

The several different arrangements for lateral control — warping of the wings, ailerons and wing flaps — have been explained in Chap. II. Other devices for this purpose, such as variable surface area and a movable center of gravity, have been proposed and tried, but not as yet with any degree of success.

Because of extensive patent litigation, great stress has too often been laid on a relatively unimportant point, i. e., the difference in the air resistance of either side, due to the operation of the transverse control. If a wing is warped to a greater angle of incidence on one side and a lesser angle of incidence on the other, and if the Drift of the higher angle is greater than the Drift of the lower angle, obviously the machine will tend to turn about the wing with the greater angle. The relative nature of this difference, however, depends on the L/D characteristics of the particular surface section used. The old circular arc sections normally, at an incidence of 5° or 6°, had this characteristic. But the placid assumption that all wings when warped must necessarily have a higher resistance on the side with the greater incidence, needs but a little intelligent investigation to be amply discredited and is fully refuted by actual flying experiments. For example, referring to Chap. VII, the Eiffel 13 bis section may be taken as an illustration. If flying normally at an angle of incidence of 2½°, the wings are warped to incidences of 0° at one side and 5° at the other, it is seen that K_L will be .0006 for 0° and .00175 for 5°, and that L/D will be 5 at 0° and 15 at 5°. Since the surface area and speed may be taken as the same (the machine flying normal), **it follows that this mean warp, applied to the wing will cause the side with the lesser angle to have the higher resistance.** The values of K_L for the two sides will determine the difference in Lift, that will result in rolling and the values of L/D will determine the resistance. The ratio, then, of $K_L \div L/D$, will give (in the form of K_D) the actual numerical proportion of the resistances. For 0°, $K_L \div L/D = .0006/5 = .000120$, and for 5°, the same quantity $= .00175/15 = .000117$, which means that the wing with 0° incidence has the greater resistance. R. A. F. 6 section in the form of a biplane warped 3° either way for an incidence of 3° (which would be an excellent one to use), would also exhibit a higher resistance for the lower angle. Various angle combinations, on different sections, exhibit every shade of increase and decrease of the resistance of one side over the other, and in the tuning up of a machine with warping wings, it is readily possible to adjust the amount of warp and washout, so as largely to eliminate this characteristic of turning, when the wings are warped.

In sharp turns, the difference in the higher speed of the outside wing and slower speed of the inside wing, must also be considered in determining which wing has the greater Drift. But even in this case it is possible to have KL div. L/D low enough, on the high wing, to make its resistance equal to or less than the lower wing.

Whether or not ailerons can be made to function without showing tendencies to turn the machine, depends so much on their shape, setting and interference with the flow on the main surfaces, that it is necessary to analyze particular cases. As a general rule, they always exhibit turning tendencies, due to "choking" effects.

With wing flaps, however, the combination of change of camber and angle at the same time, gives splendid latitude for proportioning the transverse control, so as to eliminate any tendency to turn the machine. Particularly is this true where very large flaps on a flat section are used, which, because of their ample size, may be operated thru a small range. In the consideration of modern aeroplanes any very pronounced tendency to turn, when the lateral control alone is operated, is considered as evidence of poor balance and careless design and adjustment. **It is high time to explode the absurd contention of the necessity of always having to overcome a tendency to turn, when the lateral control is operated, although this uncomfortable characteristic is still found on some types of aeroplanes.**

A change in Lift on either side, then, is made use of to control the lateral equilibrium of the machine, in those instances where the inherent features on an aeroplane do not give the required response. It is important to note here, that the inherent features of lateral stability are steadily receiving attention and development, and it may well be possible, in view of the great progress already made, that the lateral balancing by manual control will give way to an automatic functioning of the aeroplane itself, thus eliminating one of the controls, and rendering flying that much easier. At any rate, the assistance to lateral balancing given by natural stability features, at present, is very great and very promising.

TURNING.

In several instances reference has been made to the necessity of banking up an aeroplane, so as to obtain a centripetal force sufficient to hold the aeroplane to the degree of turn dictated by the amount of rudder movement given. The manner in which the added pressure on the wing is resolved into this banking force, and the weight, is shown on the diagram, and for very steep banks the magnitude that this pressure must attain in order to have a component equal to the weight is evident.

The steering by rudder is simple enough; and wide turns may be made, in calm weather, without any appreciable degree of bank, but for maneuvering of any consequence **there is but one proper bank for any particular turn, and that is the one that will give just the proper centripetal force to keep the machine flying on the turn at the same angle of incidence relative to the air, without any gain or loss of altitude.**

The faster the speed and the greater the weight the steeper must be the bank for any turn. And fast, small-surfaced machines are limited in the sharpness of turns that can be made, since the centrifugal force may exceed the maximum pressure the wings can give at the aeroplane's speed, with the result that the machine will slip outwards, and in doing this the aeroplane may perform the odd maneuver of sliding outwards uphill — the path of least resistance.

Skidding.

If the bank assumed by an aeroplane is not sufficient to hold it to a given turn, the centrifugal force generated by the turn will cause the machine to skid outwards, and in doing so the relative flow of air past the machine changes from axial to more or less sideways. A fairly sharp turn, in which the tail was whipped around by the rudder without enough bank, would find the machine facing around after completing the turn, but with its speed so greatly reduced, that a stall — and a bad one — would be apt to follow. In riding with a pilot who skids badly on his turns, the side wind created by the skidding outward of the machine is readily detected, and the feeling is distinctly uncomfortable. **The relative side wind created will give a powerful corrective effort tending to bank the machine more steeply, if a dihedral, retreat, or high fin, are incorporated.** Here is one of the important stability characteristics of these features.

Even though some pilots of long experience skid their turns badly, the fact that so many serious accidents have resulted directly from stalling after a skidded turn can but lead to the conclusion that the practice is distinctly inadvisable, excepting under some very exceptional landing conditions where the pilot desires to "kill" his speed.

Side-Slipping.

Too much bank for a given turn causes the machine to roll over into the turn and to slip down sideways. This error ordinarily results in a nose dive, which, after a long fall may, on a well-balanced machine, permit of recovery. A bad side slip, however, is as serious and positive a destruction of the equilibrium of the machine, as is possible in ordinary flying, and certainly a tendency on the part of a pilot to skid his turns is far preferable to overbanking them. Side-slipping also introduces a sidewise flow of air, and, consequently, the inherent stability characteristics obtained from a dihedral, a retreat, or a high fin system, tend at first to stiffen a machine against slipping and then to exert a positive corrective effort. It is safe to say that in their recovery power on this characteristic alone these features, particularly a high fin system, are distinctly desirable and fully justified.

The proper combination of bank and rudder for any particular machine, and skill in the detection of skidding or slipping, are drilled into the pilot by instruction in flying on the field. But the following general principles may be stated:

Skidding is apt to result in a stall, and is overcome by decreasing the rudder, or increasing the bank.

Side-slipping is apt to result in a nose dive, and is first overcome by more rudder and less bank, and later, if too far gone, by ruddering outwards.

These features, relative to turns, however, are subject to modification, because on steep banks and turns there is

The Inversion of the Rudder and Elevator.

The degree in which this is accentuated varies greatly for different machines and steepness of banks. But, as a general rule, a turn banked to over 45° has begun to make the rudder perform the function of the elevator, and if left, offset for the turn, the machine will begin to spiral down. Whereas, on a steep bank the elevator becomes the rudder, and to keep the degree of turn, whether to right or left, the elevator must be pulled in.

The "Feel" of a Proper Turn.

Whether to the pilot or to the passenger who, by experience, has acquired sensitiveness to the movement of the aeroplane in the air, a properly made turn, should give rise to no change in the relative wind, no tendency of the body to swing either out or in, but only to a slight increased pressure on the seat.

Yawing and Directional Stability.

There remains to be considered the stability of direction, or "yawing." If the directional center were in front of the c. g., a side wind would obviously tend to turn the machine away from the wind and either stall or upset it laterally. Some tendency to head into the relative wind is necessary. **This is obtained by having enough rudder or fin surface aft to bring the directional center back of the c. g. and is called "weathercock" stability.**

However, if this feature is accentuated too much, the machine tends to yaw uncomfortably, on meeting the least side wind. What is called "spiral instability" may also be developed, i. e., the machine, when making a spiral turn downwards, has a tendency to sharpen the spiral and dive, due to the side pressure on the body, and when spiralling upwards on a climb, a tendency to stall is readily developed. In this connection modern fuselage tractors should prove more difficult to get out of a small field by a spiral climb than the old open-bodied pushers.

It is important to point out that struts of large fineness ratio, and propellers, present considerable side surface and affect the directional center, at different angles of yaw, by the amount indicated for any machine on its yawing moment diagram.

The Dunne.

An examination of the photographs of this type (p. 23) reveals an aeroplane with a very accentuated retreat, with the angle of incidence varying from positive at the nose to negative at the tips, and controlled solely by flaps on the ends of the wings. While there is no tail, there are virtually what amounts to two tails on this type, and the operation of pitching consists of turning all flaps up or down for rising or descending. There is the added feature of the large braced panel, on either end of the wing span. The "bustle" and change in camber are not considered vital.

Studying this type of machine, it becomes apparent that the change in angle of incidence gives the effect of the "convergent tandem" surface arrangement, but with an exceedingly powerful negative tail. For a normal flap setting there is no question but that stalling or diving are rendered practically impossible by this inherent stability feature. This might lead to the conclusion that the machine was, in consequence, a constant incidence, constant speed machine, with no range, and a climb obtained solely from excess propeller push. This, however, is actually not the case, due to the changes in trim obtained from flap adjustment in flight, and it is found that the speed range, glide and climb of this type compare favorably with the more common types, excepting in the loss of efficiency due to the negative pressures at the tip.

The retreat, combined with the change in angle, give most remarkable effects on rolling and yawing. To begin with, the least deviation of the air is immediately felt, and the machine has a powerful tendency to turn into any side wind, which results in a great deal of yawing in flight, although the action is slow and deliberate. Yawing and rolling, however, appear to be inseparably combined. Operation of the flaps, inversely, will lift up one side and press down the other, and in doing so the machine will tend to sideslip in. This, however, is met by the presentation of the low inside wing, across its entire span, to the relative side movement, which causes the low side to lift and turn at the same time. In being thrown over on one of its sides in this fashion the inside side-panel of the machine receives a considerable pressure, which tends still more to accentuate the turn. A skid is, of course, impossible, since the machine would turn into it and the negative tips would keep the wing from rising. Various degrees of climbing on turns, or spiralling downwards, are obtained by pulling up the flaps on the low side, or pulling down the flaps on the high side, both maneuvers causing the machine to be thrown over on one wing, in the first case at a high angle of incidence, and in the other at a lower one. Any turn is at the expense of a roll, and any roll, even when caused by a puff, results in a turn.

The inherent tendency and power of the machine to hold an even keel, with respect to the air, is unmistakable. Because of its constant answering to air disturbances, however, the machine is not comfortable and handy in flight.

The safety features of its inherent stability when used over water, where there is a great deal of room for alighting, makes the Dunne type of practical use. But for land flying, where operations in more or less restricted places are necessary, it is apparent that the Dunne inherent stability features hardly compensate for the dangers of catching a wing or landing across wind, due to the inherent rolling and yawing movements of the machine. These, however, may be capable of improvement, though they might very possibly lead to this type becoming more and more like the ordinary airworthy, controllable type of "main surface and tail" aeroplane, so widely and successfully used.

The Taube

The outstanding feature of this type, a German "pigeon" shape monoplane, is a retreating wing shape combined with upturned wing tips, of flexible construction. The upturned wing tips, when warped for lateral control, give a distinctly greater resistance on the side that it is desired to lower, thus helping to turn the machine properly when banked. This, combined with the retreat, does give a strong, inherent stability action, tending to eliminate side-slipping and skidding, very much as on the Dunne, but the Taube has rudders which permit of powerful control, near the ground. The flexible, upturned wing-tip feature, renders the c. p. movement for the wing favorable to longitudinal stability, by increased negative pressure at the rear of the wing when the incidence is decreased, and reduction of this pressure when it is increased. In addition, the flexibility of the wing causes the tip to be pressed up, thus giving a righting effect, when an upward puff hits the wing tip, and vice versa. Since the inertia of the machine resists movement at first, this flexibility causes the machine to cede to side puffs without rolling and yet to have an inherent corrective action. Any side wind action "washes out" the negative tip, just enough to prevent the machine from swerving into it too strongly, and yet without sacrifice of the inherent stability features of the retreating wing. The upturned flexible wing tip, however, is wasteful of power, but developments along this line are apparently promising.

Summary

There may be drawn from the consideration of the common elevator rudder and laterally controlled "main and tail surface" aeroplane, several interesting conclusions on airworthiness.

The most airworthy combination for longitudinal control and stability would appear to be a slightly negative tail, on a convergent tandem system, of which the flaps form a large percentage of the area, so that ample control is obtained with minimum effort and drag.

On the lateral equilibrium, handy control, wind-fighting qualities, natural stability and comfort, seem best obtained by a combination of powerful lateral controls, on an aeroplane with a high fin system and a slight retreat or dihedral. In a high fin system it must be borne in mind that a dihedral in side projection is virtually a fin.

The arching of the wing transversely (see p. 152), appears to give excellent "fin" qualities without being too sensitive to rolling in side winds.

Since the approach to the critical angle and a stall greatly affect the sensitiveness of the lateral control, thus accentuating tendency to side slip, a very powerful control by large flaps (variable camber) is most desirable.

The degree in which many qualities of controllability and inherent stability can be combined and accentuated are much more a matter for the personal taste and "feel" of the pilot than has been supposed. Some pilots rather prefer a quick handy machine, while others favor a high degree of natural tendency to a level keel, requiring less attention and being less tiring to operate.

The necessity at present of considering the landing and starting conditions as the real limitations for flying, need hardly be emphasized. And the constant effort of designers to extend the speed range, not only to higher speeds but to slower speeds for landing, and to obtain greater climbing rate for rising out of confined areas, must be accompanied by an equally great effort to make the machines handy, quickly controllable, and devoid of tricks or whims, in order to make operations under puffy, treacherous conditions as practical as possible. It is unfortunate that, thus far, every device for inherent stability or automatic mechanically controlled stability lacks the flexibility and quick power of judgment of the human brain, necessary for operations in landing in difficult places in a bad wind. Flying aloft is, after all, not so very difficult, on a comfortable, well-balanced "inherently airworthy" machine, but aside from the advantage gained in relieving the pilot of having constantly to operate the controls, all "inherent" or "automatic" stability features fail to add in safety, unless they first render safer the operation of coming back to earth. In this connection safety is, perhaps, better served by a robust landing gear on a machine that is perfectly controllable, and in the hands of a pilot with good judgment.

A few notes in the form of directions may prove of value:

1. If a machine is tail heavy, with a lifting tail, move the entire c. g. of the machine forward. If tail heavy with a negative tail, first reduce the negative tail angle, slightly.

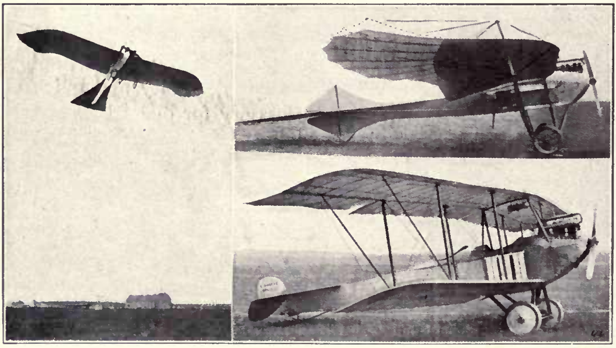
2. If a machine is nose heavy with a lifting tail, thus tending to dive, first move the c. g. back by some weight in the rear, and if the characteristic is still exhibited, take the weight out, and reduce the angle of the tail two or three degrees.

3. If there is a pronounced tendency for the machine to yaw, at the least puff, and to want to dive steeply into a spiral, there may be too much "weathercock" action, in which case, either mount a small rudder, or put some fin surface forward.

4. If an unbalanced (flap and fin) rudder is too hard to operate, increase the lever arm. If a balanced rudder "catches" it is a sign that its hinge is too far back.

5. Adjustment of flaps is capable of giving various degrees of sensitiveness and ease of operation, depending on the machine. The best all-around results are given by having the trailing edge of the flap a little below the trailing edge of the plane.

6. Only two maneuvers need be resorted to, as tests of the important inherent features. When the aeroplane is flying horizontally, application of excess power without any elevator change, should cause the machine to climb. And in a turn with rudder alone, skidding out strongly, the machine should display a natural tendency to bank.



A Taube in flight. The upturned wing tips are evident.

Above — A modern Taube. — the flexing of the wing end is indicated.

Below—A typical modern German biplane—an Aviatik. Note the retreating wing.

CHAPTER XIII.

THE EYES OF THE ARMY AND NAVY.

A proper appreciation of military aeroplanes, cannot be had without giving consideration to the manner in which aeroplanes may be used in military and naval operations. But, in doing so, let us not trespass on the special studies of flying officers in the use of aeroplanes in strategy and tactics, further than to state that aeroplanes are used,

1. To see with;

2. To communicate with;

3. To attack with.

Superiority in speed, facility and accuracy of observation, combined with fighting power to run the enemy's aeroplanes "out of the sky," or to do damage to important points, must be sought for in company with efficiency in construction, equipment, repair and operation.

The command of the sea belongs to the ship that can "overtake, observe the most, hit the hardest, and run away" — with the greatest reliability.

And the command of the air belongs to the aeroplane that can get up into the sky the quickest and observe the most, with precision and ease, and with sufficient fighting power to prevent the enemy from doing the same — all of which also must be accomplished with reliability and efficiency.

Structural Perfection.

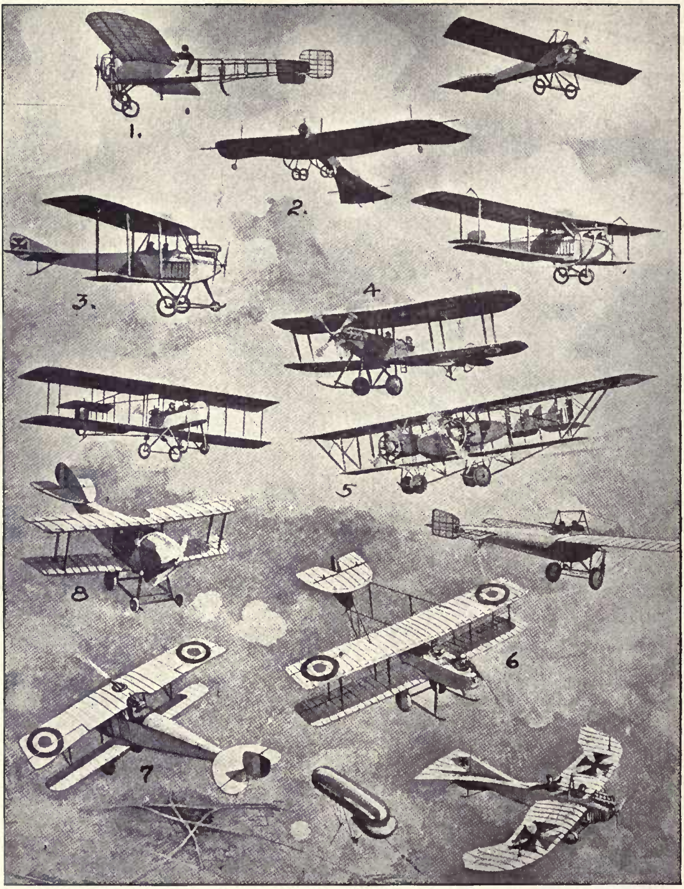
For military purposes, efficiency and reliability in the structural features of the machines must be sought in:

1. The utmost simplicity in construction, ease of repair and facility in rapid assembly.

2. Resistance to deterioration by weathering and hard use, minimizing the requirements for parking and overhauling.

3. Standardization of parts, requiring a minimum of stores and facilitating interchangeability.

There are many different types of metal fittings, wooden parts, struts, controls and chassis (see Chap. X), that differ so slightly from



TYPES OF MILITARY AEROPLANES

1. The Bleriot Monoplane used by France earlier in the war.

2. The Taube Monoplane used by Germany, at the start of the war.

3. The Aviatik Tractor, a German high powered biplane.

4. The B. E. 2 British Reconnaissance Tractor.

5. The Twin-Motored Caudron, used by the French. This machine climbs very fast but is not very speedy.

6. The Vickers Pusher with gun.

7. The French Nieuport Speed Scout — a highly successful type, with excellent speed and splendid climb.

8. The Martinsyde Biplane, a typical British speed scout.

one another in the use to which they are put that a Flying Corps can readily standardize many of these features for all machines. In general, welded or brazed fittings, or laminated wooden members, requiring special facilities for manufacture, can largely be eliminated, and aeroplanes for military purposes with a few rugged, easily accessible and repaired parts, are far more preferable than aeroplanes with delicate construction and countless small parts, clips, pins, bolts and "gadgets," all differing from each other. The "military" aeroplane is bound to be the one the construction of which is typified by the feature — that only one size of bolt, with the same thread and nut, is required for the entire structure.

It is not at all impossible to have an aeroplane so designed, with solid wire braces and simple steel plate fittings, that the crew of the machine need carry on the machine in flight only a few tools, a blow torch, a soldering iron, a roll of wire, and a piece of steel plate, with an extra wheel or two and a few wooden members (and engine spares) for the immediate repair of the machine without outside assistance.

How impossible this would be on some types of otherwise satisfactory aeroplanes, is evident at the first glance. The more difficult an aeroplane is to repair, and the more extensive the expert labor and equipment required to do it, the less satisfactory is the machine for military work in the field.

Observation.

Whether in actually observing the movements of troops, the effect of artillery fire, or in taking sights for and noting the results obtained by gun firing or bomb dropping, the most important requirement in military aeroplanes is that the field of view be as unrestricted as possible. Obviously, the "pusher" type offers a better view and arc of gun fire than does the "tractor," but in the latter type many modifications, such as openings in the planes near the body, the raising of the wing, as in the "parasol" type, and special posts for the observer ("prone" below the fuselage or above the wings), are certain to be incorporated. The ordinary tractor monoplane is exceedingly difficult to observe from. In this connection the use of suitable periscopes is well worth experiment.

The effect of speeds of aeroplanes in rendering observation more difficult is not of as much consequence now, in view of the great height from which observations are made.

Although it generally has not been so considered in the design of the more common tractors, it is the writer's opinion that, **for military purposes, the "eyes" of the army and navy should be made to see, and everything that is possible should be done to extend the field of view.**

SEVERAL MILITARY AEROPLANES

1. The Morane-Saulnier "Parasol" Monoplane, a highly successful French speed scout, later copied in the German Fokker Monoplane.

2. The Albatros — a long range, heavy duty German Tractor, which has proven to be an effective type.

3. The Twin Tractor German Battleplane, with gunners in center nacelle.

4. The Voisin "avion de guerre," a pusher gun carrier.

5. The Bristol Speed Scout used by the British.

CHAPTER XIV.

CONCLUSION.

Whether monoplanes or biplanes, tractors or pushers, with rotary engines or water cooled engines, the most suitable aeroplanes for military purposes will be the ones that are superior in flight to the aeroplanes of the enemy. And this means that, precisely as in naval work, a "race" is on between nations for superiority in aircraft!

In what, then, may we find "superiority?"

Simplicity of construction and efficiency in organization for maintenance of the machines is not all. More is required than numbers, although a Flying Corps is not of much use without plenty of spare machines. Thorough training and great personal skill, on the part of the flying officers — as important as the personal equation in any line of human endeavor — may still fail to give superiority, because our aeroplanes in flight must have command of the air, which can be obtained only by ability to start from and alight in more difficult country, higher climbing rate, greater speed and radius of action, better facilities for observation and gun fire, and greater load-lifting capacity.

High speed, so desirable for operations in the air, means a reduction in load-lifting capacity, and limitations of landing and starting, requiring special aerodromes. Facilities for observation and gun fire may necessitate sacrifice of flying efficiency and simplicity of construction. Great radius of action and climbing speed may limit the load capacity, in bombs, etc. So that the ingenuity and skill of the engineer officers of a Flying Corps, must be exerted to the utmost in compromising properly these opposing features.

It is barely possible that there will be many types of military aeroplanes, light, fast speed scouts, slower load-carrying, gun and bomb machines, aeroplanes especially adapted to artillery observation, to naval coast defense work, to messenger service — but the fact remains, that from all of them the maximum possible view must be obtained, with fighting quality superior to the enemy's and with the greatest load-lifting capacity and climbing speed possible. Everything must be done, therefore, to improve the aeroplane's efficiency for military work, in extending the speed range, the climbing rate and the load capacity.

Instruments.

Although flying is properly taught on a basis of acquiring the "feel" of the air, any instrument of assistance to flying without adding considerable weight is most desirable. On the dashboard of a well-equipped aeroplane there are found the usual clock, aneroid, fuel gauges, and engine tachometer. But, in addition to these, other devices are mounted to indicate the relation of the aeroplane to the air. For this purpose pitot tube or pressure plate air speed indicators are used. Angles of incidence to the air may be indicated by a vane floating in the stream, operating a needle on a dial. The inclination of the aeroplane to the ground may be indicated by inclinometers, such as a bubble in a curved tube, or a pendulum. Various simple devices, such as strings or light vanes, may be used to indicate any sidewise movement or skidding of the aeroplane thru the air. In the determination of the speed, climb, etc., for any position, the pilot, having at hand a power chart of the machine, may read the r. p. m. of his engine, thus establishing its power; by reading the air speed or the angle of incidence (either one determines the other) he readily notes the power required — so that he can judge what his climbing power and rate are, and what the fuel consumption is. Or, if he is flying on the horizontal and desires to use the minimum of fuel per mile, he throttles to the r. p. m. indicated, and checks the speed of greatest economy, by reading his angle of incidence and referring to his power chart. A very extensive use of these charts may be made in flight, the only two instruments necessary being the engine tachometer and an angle of incidence indicator. Comparison of the inclinometer and incidence dial will readily reveal whether or not he is flying in up or down trends, since the one reads the "air angle" and the other the "ground angle."

Stabilizers or Automatic Pilots.

In addition to giving the pilot information on his flying, there are the "automatic stabilizers," — instruments to relieve him of having to hold the controls. Inherent features of airworthiness in the machines will also do this, but only after answering to disturbances in much greater measure than a delicately adjusted stabilizer. The latter, also, if pendulum of gyroscope governed, holds the aeroplane to a "base line" relative to the ground and not to the air.

Level flight is thus obtained, with more or less success, and with pendulum and gyroscope stabilizers it is possible for the pilot to be relieved of having to attend to the controls, in that the "stabilizer" or "automatic pilot" keeps the aeroplane on a fixed and steady course. This requires careful adjustment for each particular type of aeroplane, however, and since flying on an airworthy machine, with inherent features not too much accentuated is comfortably possible with controls locked, reasons of safety alone do not demand "automatic stabilizers," in view of their added complication.

Stabilizers can also be made to bank an aeroplane properly on a turn and hold it, with an accuracy and precision that is remarkable.

For night flying, an automatic pilot mechanism has very great advantages. And for bomb dropping, etc., in improving the steadiness of the aeroplane as a platform, it is a valuable auxiliary.

Performances and Operation.

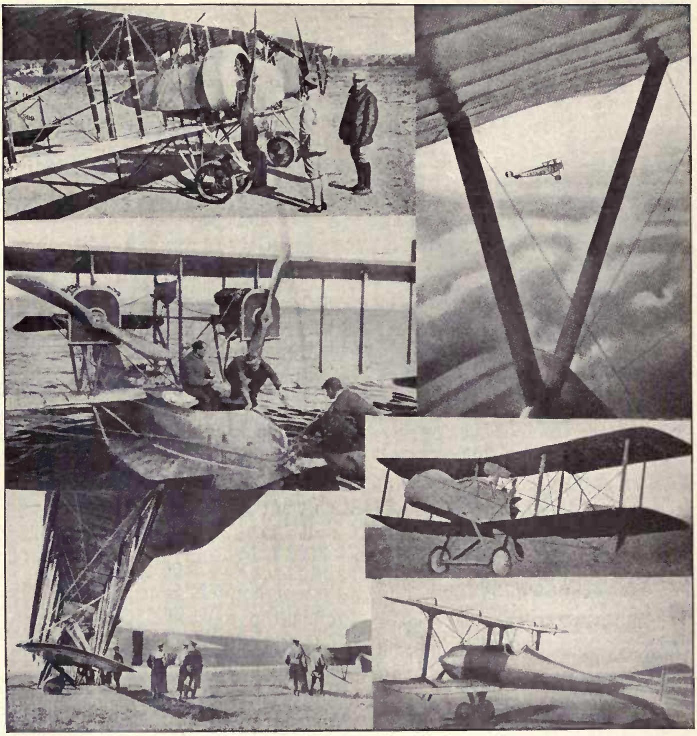
It is of the utmost importance in military operations to have information on the radius of action, the load-lifting capacity and the speeds of the aeroplanes to be used. For the purpose of assisting in these matters, particular attention has been given to the prediction of the performances of aeroplanes.

In choosing machines to lift a great load of bombs here, or to travel a great distance at high speed on a raid there, or to climb up very quickly and return with information for some other purpose, a study of the Power Charts and data on fuel consumption and lifting capacity (Chap. VII and VIII) is not merely helpful — it is necessary. And for all intelligent military aviators, a study of this kind is of great importance. In fitting auxiliary devices, guns, bomb droppers, etc., information on the resistances (Chap. IV), and on proper balancing of the weights (Chap. XII), as well as the strength of parts necessary to do the work desired (Chap. IX and X), may be applied directly to such problems in the field.

The conditions of actual operation of aeroplanes as dictated by the weather are quite variable. Fog is the most serious detriment to flying, next to which may be put the possible limitations of starting and alighting. In certain winds some small fields are not difficult to negotiate, but under different conditions they may prove impossible. Here again local conditions bring up questions of suitability of various aeroplanes in such a way that countless problems are presented requiring "heady" resourcefulness. For example, a condition may readily arise where a machine of slow speed, which gets off the ground in a short run but does not climb fast, may be preferable to a very much faster machine of longer run, even though its climb is better.

Not only may the performances of an aeroplane be studied on the field, but in their work the technical officers and engineers of a Flying Corps should be able to judge of the probable performances of an aeroplane from charts and drawings — sufficiently to limit the acceptance tests to satisfactory construction and balance, and to choose the aeroplanes needed for any particular purpose before delivery. It is decidedly inefficient blindly to try a machine out for some special performance without first going through all the simple computations and determinations bearing thereon.

The operation of aeroplanes in a wind requires consideration of the direction and force of the wind, in determining the radius of action. The aeroplane always keeps its particular attitude and speed relative



INTERESTING WAR LESSONS

The Caudron Twin Tractor, with centre nacelle for gunner (upper left) gained excellent climb, at the sacrifice of speed, by the two-motor arrangement. This, however, obstructs the view of the pilot. Below it is shown the Curtiss Seaplane, with two tractor motors of so called "America" type. This large craft, due to its size shows good seaworthiness, but at the expense of flying characteristics. At lower left is shown a view of the huge Sikorsky multi-motored machine, used by Russia. In general, huge land aeroplanes have not yet attained the perfection or excellence in performance that will warrant their adoption as Zeppelin fighters, although large gun carriers are very successfully used at night as "avions de bombardement."

On the right are shown some speed scouts. The big aeroplane has still much to prove for itself, although its gradual development is inevitable. The light, fast speed scout, however, is decidedly the success of all war aeroplanes. Operated by one man only, who is expert in both flying and military work, these small machines outclimb and outspeed all the heavier, larger types. Their offensive value has consisted merely of a light machine gun, shooting over or through the propeller. The Nieuport, as seen from a companion machine in flight, is shown at the top right. Below it is a "pusher" type speed scout, built in England, and at lower right is the S. E. 4, a very fast machine, constructed by the British Government.

Speed scouts are frequently equipped with an automatic pilot such as the Sperry gyroscope, to relieve the pilot of having to operate the controls, and making the aeroplane a steadier platform for gun fire.

Great excess of power gives these small machines a very real advantage in acquiring command of the air.

to the body of air it is passing thru, but this entire body in the form of wind may be moving — so that the aeroplane's travel relative to the earth becomes the resultant of its velocity and the wind velocity.

In naval work, only speeds on the horizontal need be considered, **but in speed thru the air an aeroplane must have superior velocity upwards as well as onwards.**

For tactical observation and for artillery work, it becomes of the utmost importance to consider that climbing speed, after all, may prove the most vital criterion of superiority — since a slower machine, superior in load capacity and climbing speed, may dominate a faster machine, and climb away from it — so that efficiency may well be strained to the limit to obtain speed upwards.

The fight between aeroplane and aeroplane is where the real test of superiority is certain to be found, and both the moral ascendency and actual command of the air, goes to the pilot whose aeroplane and whose skill permits him to climb over and dominate or drive the enemy out of the sky.

It has been assumed throughout this work that one of the most vital parts of an aeroplane — the motor — was working smoothly and without a miss. If not universally the case, at present, the day is certainly not far distant when aeroplane motors may be relied upon exactly as are automobile motors today.

Attention has purposely not been given to the military technique of the use of aeroplanes in military or naval operations, neither has any special attention been given to the art of flying, cross country navigation, etc. — features that are acquired by the military aviator from the officers and instructors of the Flying Corps, in their routine work. Consideration has been given to the military aeroplane, for the particular purpose of assisting the military aviator or student to acquire a better appreciation of the machine, a fuller knowledge of why it flies and what he may expect of it, in performance, in strength and in flying characteristics.

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