THEORY OF FLIGHT

Introduction

Possibly from the beginning of time, one of man's greatest ambitions has been to be able to fly like a bird, to transport himself from place to place through the air. Unfortunately we have not been born with wings. We have, therefore, had to use our own ingenuity to create mechanical devices that would do for us what wings do for birds. Man, being a naturally dissatisfied being, has improved upon design to such an extent that airplanes are now flying several hundred m.p.h., whereas birds average from 40 to 100 m.p.h. These developments have not come overnight. In spite of this, they have come so rapidly that the average person on the street seems to think that there is some strong mysterious force that keeps an airplane in the air, instead of the practical application of a few of the simplest and oldest laws we have.

Atmosphere.

Before commencing to study what makes the airplane fly we must consider the medium in which it flies—the air. People are too apt to forget all about this important substance, possibly because they have never known a lack of it, but it is important that something be known about it, and its behaviour under all conditions. Air is a mixture of gases and has mass, and thus under specific conditions of temperature and pressure, density or

weight per unit volume. It has mutual adherence for adjacent particles, which is called viscosity. It follows that with weight and viscosity, air must be classed as a fluid. This, at first, may be hard for the student to realize. He can come to a better appreciation of this fact by testing the heavy "feel" that the air has as he puts his hand out of the window of a fast moving automobile.

Surrounding the earth to a depth of about 40,000 feet is a layer of air where temperature decreases about 3°F. per 1,000 feet, and this is called the *troposphere*. Outward from this, where temperature does not decrease with altitude so far as is known, is what is called the *stratosphere*. It is in this stratosphere that all future long distance high speed flights are proposed. Much greater progress than has yet been made will be possible when the complications due to reduced pressure and temperature, at which the human body could not live if exposed to them, have been solved.

The Air.

The air is a mixture of gases, which has weight and pressure, and flows like water. One cubic foot of air at sea level weighs 1¼ oz. (Fig. 1). The weight of a two hundred mile column of air resting on the surface of the earth, creates a pressure of 14.7 pounds to the square inch. (Fig. 2).

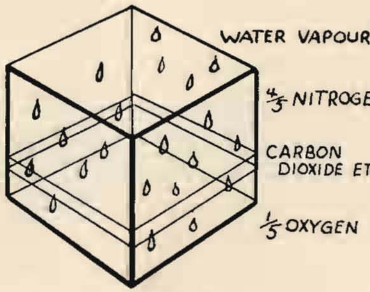

Fig. 1.

The Principles of Flight.

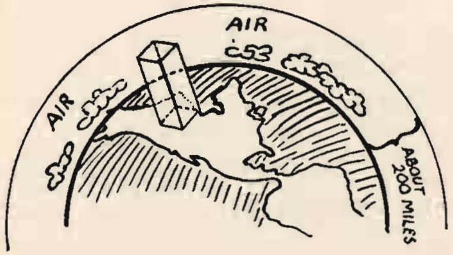

Fig. 2.

The flight of the airplane (or heavier than air machine), is due to the functioning of several basic natural laws. As these are studied the student will see that there is nothing more mysterious about flight, than there is about the wind blowing, or water flowing in a stream.

Newton's Laws of Motion.

(1) A body will continue in its state of rest, or uniform in a straight line, unless it is compelled by force to change that state.

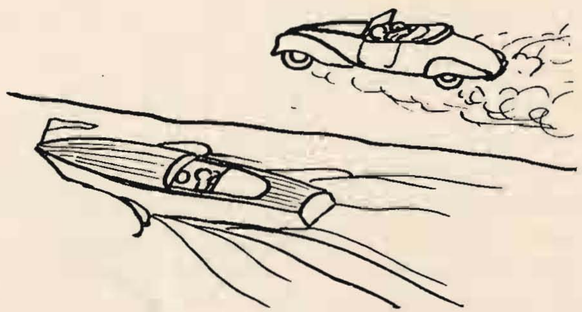

Fig. 3.

The turbulent airflow behind a moving car, is like the agitated flow of water in he wake of a boat.

(2) Any change of motion is proportional to the force applied, and takes place in the direction of the straight line in which the force acts.

(3) To every action there is an equal and opposite reaction.

Pascul's Law of Fluid Pressure.

(1) Pressure exerted on a mass of fluid filling a closed vessel, is transmitted undeminished in all directions, and acts with the same force on equal surfaces in a direction at right angles to them.

(2) The pressure against a solid moving through a fluid, is proportional to the square of their relative velocity.

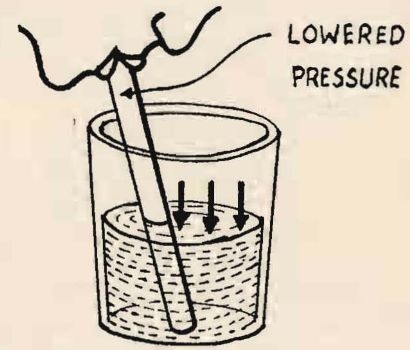

Fig. 4.—Suction.

It can be seen from the above laws, that the speed of a boat or aircraft is directly dependent on the amount of power obtainable, and to get even small increases in speed will take more power than one might first think reasonable.

Bernouilli's Theorem.

As the velocity of a fluid in motion increases, the pressure exerted by the fluid grows proportionately less.

From Bernouilli's theorem, it can be seen that if we have a velocity change we have a pressure change, and we know from previous study that *all pressures tend to equalize*. Hence it follows that the force exerted by the equalization of pressures, can vary in direct proportion to the change of pressure. It is on this simple law that flight is largely dependent.

If we have a glass of water, and we put one end of a drinking straw in it and draw, a simple action takes place. The pressure in the straw is reduced, and atmospheric pressure forces liquid up the straw. The pressure reduction in the straw is quite low, but it can be seen that the action is quite large. An aircraft has been so designed that the wings have a definite shape. It can be seen in the diagrams that follow that as the air strikes the leading edge of the wing, the velocity on the top surface is increased and the pressure reduced (Bernouilli's theory). While the pressure of the under surface is increased, the velocity decreases due to the angle which the wing meets the air. Now we have a condition of unequal pressure, and in the action of equalization, a force acting at right angles to the airflow is generated. A simple proof of how this works can be seen by holding a flat piece of paper so that it bends downward. If you blow over the top, you will notice that the trailing edge rises. In the same way roofs from barns and buildings are lifted during a severe wind storm.

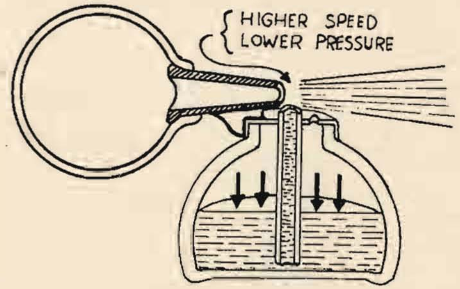

Fig. 5.

Bernoulli's Principle (Atomizer).

Lift.

This force that is generated, as mentioned above, is termed lift or wing generation, and it varies accordingly to the size and shape of airfoil (the name given to any shape from which lift can be created when moved through the air), and to the velocity through which it is passing through the air or the airflow over it. It can be readily seen that air, being a fluid, will offer resistance to this moving body and this resistance is known as **Drag.** Drag is the price we pay for lift, and every effort must be made by the designer to keep it at a minimum.

Airfoil.

In the previous paragraph we used the term airfoil (aerofoil), but very little has been said about it. By experimenting, it has been found that various shapes give

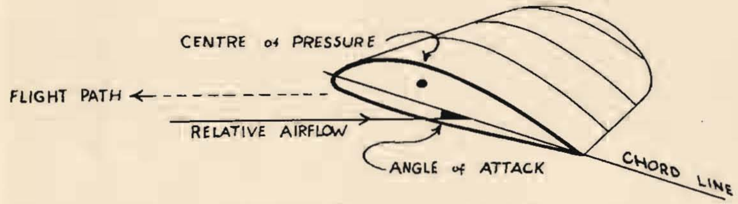

Fig. 6.

A line drawn from the leading to the trailing edge of the airfoil is the Chord Line. The aerodynamic reaction acts through an imaginary point in the airfoil called the Centre of Pressure. The Relative Airflow is the direction from which the air strikes the airfoil as it moves along its Flight Path and the angle between this direction and the Chord Line is the Angle of Attack. (See Fig. 6).

different amounts of lift (aerodynamic reaction) for the same amount of drag. Remembering that the drag increases as the square of the velocity, it can be readily seen that there will be an airfoil section for each individual aircraft; for example an aircraft used for carrying heavy loads at a comparatively low speed, will use a wing section that would create too much drag for a racing machine. A racing or fighting aircraft, where speed is of utmost importance, will use a wing section that will make that particular machine as fast and manoeuvrable as possible. (See Figs. 7, 8, 9 and 10).

Fig. 7.
High Lift. High Drag.
Low Speed. (Birds, Gliders.)

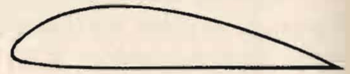

Fig. 8.
Good Lift. Average Drag.
Low Speed. (Trainers, Transports.)

Fig. 9.
Low Lift. Low Drag.
High Speed. (Fighters, etc.).

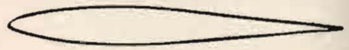

Fig. 10.
Symetrical Section. Very Low Drag.
Any Speed. (Tail Surfaces, Fuselage.)

Airflow.

When the air strikes the leading edge of the wing it divides, and part goes above and part goes below. In order that the air passing above the airfoil may join up with the air that has just left the under surface, its velocity must increase, and therefore the pressure it exerts on the upper surface is reduced. Thus, as the pressure on top of the wing becomes less, the normal or higher pressure against the lower surface pushes the wing upwards, this push being known as wing reaction or lift. As the angle between the wing and the airflow is increased, the reaction becomes greater.

It can be seen from the illustration (Fg. 11) that at the increased angles something is happening to the air near the trailing edge, it is starting to break away from

the surface of the wing. Further increasing of the angle of attack causes the air to no longer flow smoothly over the surface, and it breaks up into eddies or burbles. The wing is now said to be stalled, and this angle is known as the burble point, or the point of stall. When this condition is reached the drag becomes excessive, and the lift falls off very rapidly as the angle of attack is increased.

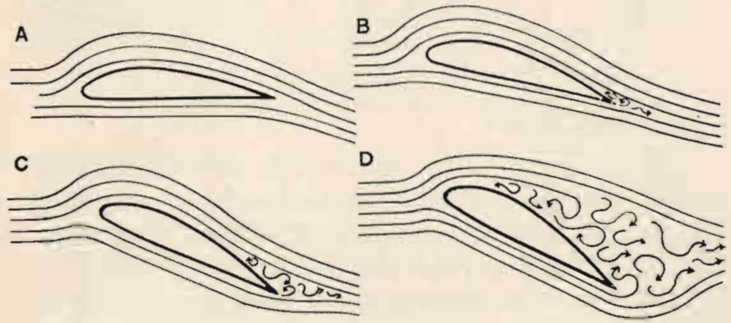

Fig. 11.
The airflow about an airfoil at different angles of attack. A and B show small angles, C is the angle of maximum lift, and in D the airfoil is stalled.

Some airfoil sections start to stall rather slowly, and give the pilot plenty of warning, as the airplane shudders and starts to sink in a nose dive attitude. This particular condition is classed as a mild, or gentle stall. When the opposite is true, and the burbling sets in without any warning, we say the wing or aircraft has an abrupt stall characteristic. If at the time when the aircraft is stalling, a yawing couple is introduced, (as will be explained later) the aircraft will spin.

Drag.

Drag is the resistance of a body to its movement through the air. There are three types:

(a) *Form Drag*:

(Sometimes called Profile Drag) is due to the actual shape of the body. The better the streamlining of a body the less turbulence is set up in its wake, and the less drag it has. (Fig. 12).

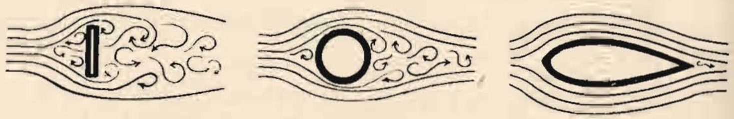

Fig. 12.

(b) *Skin Drag*:

This is caused by the retardation of the layers of air in the immediate vicinity of the body, the air next to the surface tending to stick to it and be dragged along with it. This particular action takes place in a layer of air only five to seven thousands of an inch in thickness, next to the body, known as the Boundary Layer. Rivet heads, seams, and roughness on the surface tend to increase this kind of drag. The drag set up by this action is perhaps one of the most important we have, and the exact behaviour of this layer and the control of it is at present under investigation.

In Fig. 13 the Laminar Theory is illustrated. Note that the layers of air are not to scale, each being actually about one or two thousands of an inch in thickness.

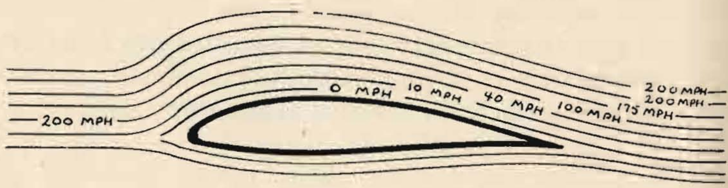

Fig. 13.

(c) *Induced Drag*:

This occurs at the wing tip, where a swirling vortex of air is formed by the interference between the low pressure air above the airfoil and the high pressure air below, the formation of this swirl absorbing otherwise useful power.

(d) *Parasite Drag*:

This is exactly what the name implies; drag set up by the non lifting parts of the aircraft such as the undercarriage, flying wires, interplane struts, etc.

Centre of Gravity.

The point in an aircraft, or any body, through which a resultant of all the weight acts (an imaginary point which can be calculated according to the design of the aircraft is called its centre of gravity). In normal conditions it can not be changed but the shifting of cargo, etc., can cause a change in the centre of gravity. (C. of G. See Fig. 14).

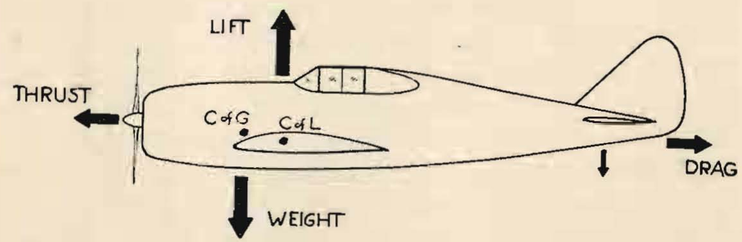

Fig. 14.

Centre of Lift.

The centre of lift is the point on an aircraft through which the resultant lift from all lifting surfaces acts.

In an ideal aircraft, if it were possible to design one, the C of G and the C of L would coincide. It can be seen that in movement of the centre of lift (which changes with the angle of attack) will cause the movement depending on which way the C of L is moved.

Straight and Level Flight.

When the aircraft is on the ground it represents a dead weight, and in order to support it in the air, sufficient lift must be generated to offset the weight of the aircraft. To do this we use an engine and airscrew; as the engine rotates the airscrew Thrust is developed, causing the airplane to move forward. As the aircraft accelerates, sufficient speed is attained to generate enough lift on the wing surface to offset the weight of the aircraft, which will then leave the ground. Then we say it is airborne. With the aircraft at a speed safely and efficienttly above the stall, the extra Thrust is used to keep the aircraft climbing.

When an aircraft is in straight and level flight, approximately seventy per cent of its total horsepower is used. The Thrust balances the Drag, the Lift balances gravity or the weight of the aircraft, and flight may be sustained indefinitely, as long as gasoline is supplied and the engine functioning normally. It can be seen from this that as the throttle is opened, the extra Thrust available beyond that required to balance Drag at that speed, may be used to climb, and the aircraft will take on a new climbing attitude. Similarly, if the Thrust is reduced the speed falls off, and the aircraft coming to a larger angle of attack to generate sufficient Lift, may stall. Therefore, we lower the nose and glide, utilizing the weight of the aircraft to keep it airborne.

Controls.

To manoeuvre an aircraft, to keep it level fore and aft and on an even keel, suitable control surfaces must be designed. The exact position, size, and shape of the control surfaces will depend on various things such as the type of machine, whether landplane, seaplane, flying boat, or amphibian. It is the designer's problem through careful calculation to find the most suitable position and arrangement. The success of the aircraft will depend on its general flying characteristics and its efficiency. The "actual feel" is something that is hard to explain; either an airplane has it or it has not, and the best looking aircraft is not necessarily the most pleasant to fly.

An airplane that is quiet, comfortable to sit in, and takes little effort on controls will be one that a pilot will consider to have a good "feel". If the visibility is restricted, the aircraft is noisy and uncomfortable, and has to be handled with harsh movements to get results, it is more than likely that its reputation will not be desirable.

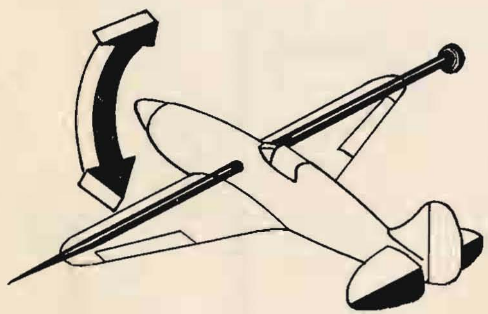

Fig. 15.

Elevators. (Fig. 15. These are flat-like controls behind the tail-plain that move upward or downward, as the control column is moved fore and aft, thereby forcing the tail up or down, and moving the nose about the lateral axis in the looping or pitching plane.

Ailerons. (Fig. 16).

These are flap-like surfaces on the training edge of each wing near the tip. As the control column is moved to either side, a suitable linkage brings one aileron up and

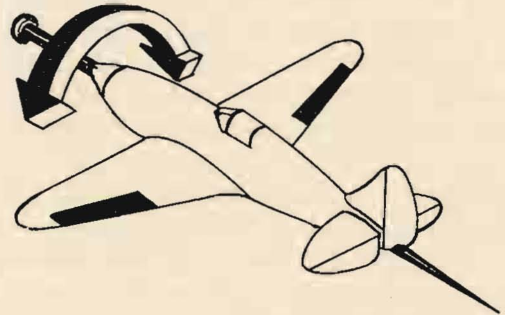

Fig. 16.

the other down. The up-going aileron causes a loss of lift on that wing, while the down - going aileron increases the lift on its wing. The resulting action is a movement about the longitudinal axis, called rolling.

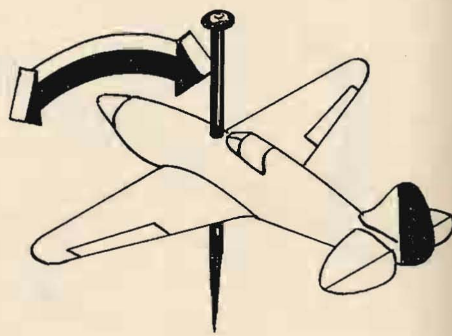

Fig. 17.

Rudder. (Fig. 17).

This surface is at the end of the tail assembly behind the fin. It is controlled by the rudder pedals and moves the tail to the left or right, causing a corresponding movement of the nose about the normal axis called yawing.

Stability.

It can be seen that in order to have an aircraft that has good handling qualities, it should have a certain amount of stability; that is, the ability to return to its original position, after being disturbed from level flight. If features are incorporated in the design of the aircraft to give it this characteristic, which functions automatically, we would say the aircraft had *Inherent Stability.*

The Tail Plane. (Fig. 18).

The Tail Plane gives the aircraft longitudinal stability.

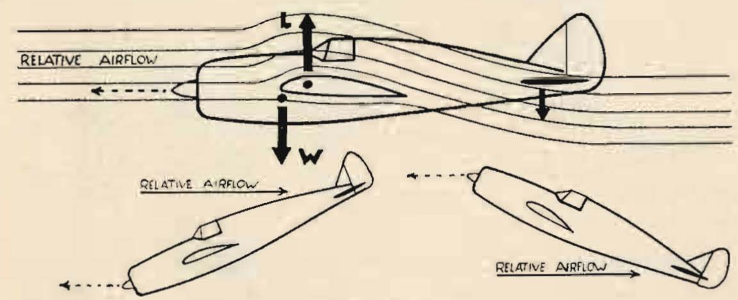

Fig. 18.

The Centre of Lift is always a little behind the Centre of Gravity and the two forces thus form a couple, so there is a tendency for the nose of the aircraft to be turned downward. Note that in Fig. 18 the tail plane, in level flight, has a negative Angle of Attack to the Relative Airflow, in this case, the downwash of air from the wing; therefore, its Lift is downwards to balance the weight-lift couple.

If the nose of the aircraft falls, the tail rises and the angle of attack of the tail plane becomes even more negative; a greater downward lift therefore brings the aircraft back to level flight.

If the nose of the aircraft rises, the tail falls and the angle of attack of the tail plane becomes less negative or even positive; a smaller downward lift or an upward lift therefore allows the weight lift couple to lower the nose.

Actually, after any disturbance the tail rises and falls through successively smaller distance called Harmonic Oscillations, till level flight is restored.

Lateral Dihedral.

This is the angle between the lateral or sidewise axis of the airplane, and the wing or mainplane.

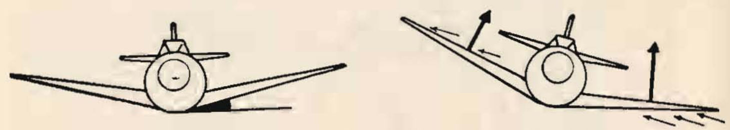

Fig. 19.

There is a small loss of lift or efficiency of the mainplane but this is offset by the improvement in stability. The reactions of both wings are equal in level flight. When one wing drops it has a more effective lift than the raised wing. Also the aircraft slips toward the down wing, the angle of attack of the wing toward the slip is increased, while it is decreased on the higher wing away from the slip, which is also slightly blanketed by the fuselage. The difference in lift on the two wings rolls the aircraft back to level flight. (Fig. 19).

Keel Surface.

This is the whole side area of the aircraft, including the fin and rudder. (See any illustration of a side view).

Since there is more surface behind the Centre of Gravity than ahead of it, the aircraft tends to head into its Relative Airflow, like a weather vane; this is known as Directional Stability, or Weathercocking.

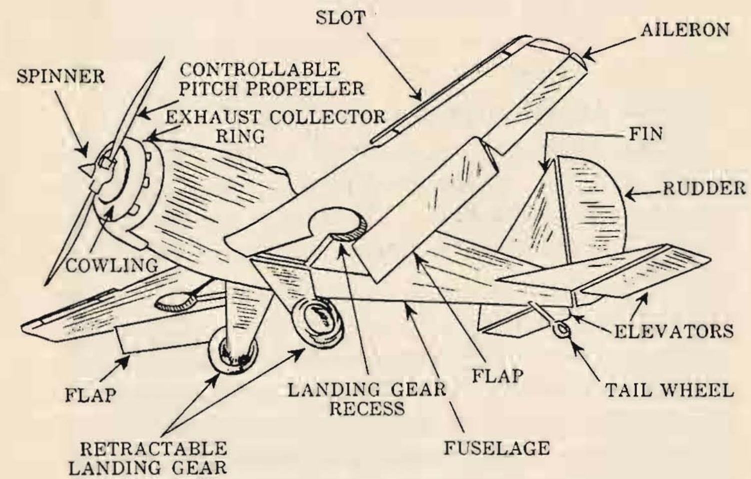

Fig. 20.

Drawing of a Modern Type Airplane showing major parts.