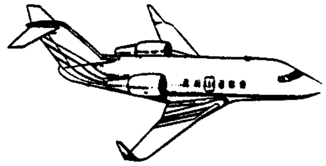


As you have watched an airplane take-off from the ground, climb, turn, maneuver, glide and land, you may have asked...How does it work? ...How does the pilot control it?...how does the designer know the airplane will fly before it is built?

These are very reasonable questions which will be answered in this study unit.

The aircraft designer knows the laws and principles of flight that apply to his work. He understands the relationship between the desired speeds, payload and flight control.

You will find some of the fundamentals upon which the science of aviation is based.

LIFT

You know that a balloon goes up in the air because it is filled with a gas that is lighter than air. The force that lifts the balloon is buoyancy, and we call an airship that is lifted by such means a **lighter-than-air** ship.

We are not concerned in this study with lighter-than-air craft, but we call it to your attention to begin the discussion of **lift**.

Anything that goes up into the atmosphere off the earth must have some force to lift it off the ground. Even the lightest airplane is a relatively heavy thing, and large bombers weigh many tons. Before an airplane can fly it must be lifted off the ground, and once it is in the air it must be kept there by some force. That force is called, logically enough, **lift**.

How Is Lift Produced?

There are three steps in the explanation of how lift is produced:

1. A wing is so designed that when
2. A force moves it at the right speed and in the right direction through the air,
3. The air so acts upon it that we get lift.

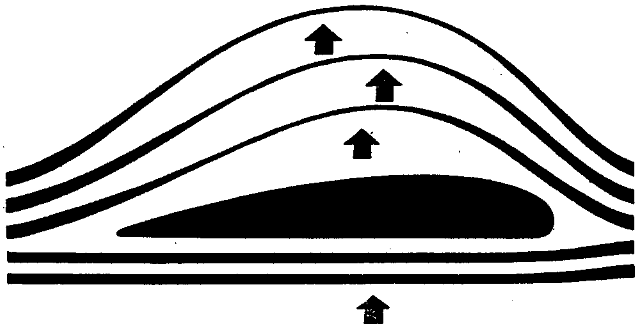
Let us take each of these steps and explain them.

FIRST STEP: *The Design of the Wing*

If you have ever built a flying model airplane, you remember the shape of the wing. It is rounded at the front, which is called the **leading edge** of the wing. It is sharp at the back, or **trailing edge** of the wing. The upper surface is curved; the bottom is almost a straight line. It is thick and stubby near the leading edge and thin and tapered near the trailing edge. You will soon learn why it's shaped that way.

Take that rib and study it, for it represents the cross section of almost any airplane wing. Wing sections of various airplanes differ slightly in detail, but the principle is the same in all airplane wings.

SECOND STEP: *The Effect of Moving an Airplane Wing Through the Air*



If we move the wing through the air at a relatively high speed with the blunt end (leading edge) forward the following things happen:

The blunt and thick leading edge pushes air out of the way. Part of the air so displaced flows over the wing; part of it flows under the wing rapidly (the speed is important). The layers of air, after going over and under the wing, join again behind the trailing edge. **But the important thing is that the air that flowed over the wing had to go farther than the air that went under the wing.**

In going farther it stretched out, so to speak, and became thinner. Loosely speaking, it formed a partial vacuum at the top of the wing and exerted force while the air at the bottom of the wing compressed slightly and exerted a certain force there. The sum of these two forces represents lift because—

THIRD STEP: *The air has weight and volume*

When air moves, its weight and the speed (velocity) with which it moves exert energy and do work. The same is true of anything which moves through or against air.

The design of the wing and the speed with which it is moved through the air give us lift.

WHY IS SPEED NECESSARY TO LIFT?

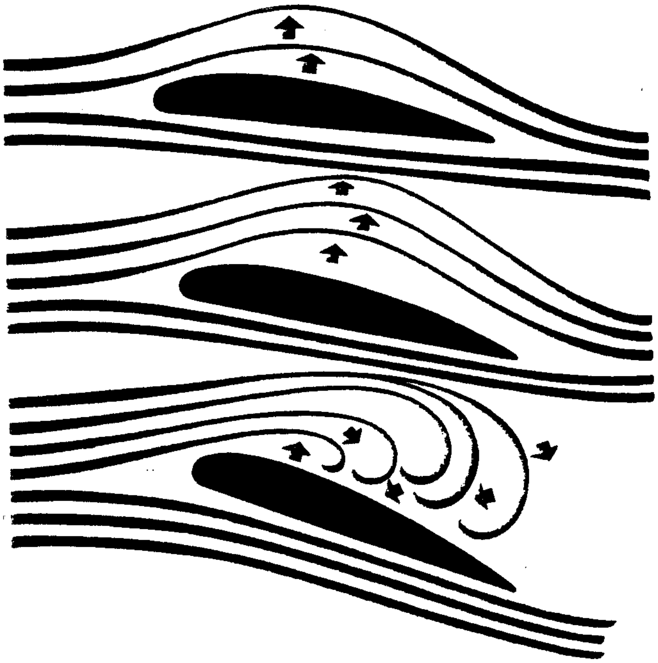
We mentioned in Step Two that we must move a wing "at a relatively high speed through the air" to make it work. What happens when we move it slowly?

Suppose you take a board and move it edgeways through the water, holding it at a slight angle to the direction in which you are pushing it. If you push it rapidly you will see that the water rushes out of the way of the leading edge, leaving a hole (or vacuum) at the top of the board. This water doesn't join the water from the bottom of the board until the board is well past.

Push it slowly, however, and the water swirls and burbles in on top of the board. That is what happens, approximately, to the air that your wing displaces. The low pressure area above the wing is spoiled if the wing moves too slowly; the air swirls and burbles into the partial vacuum.

The heavier an airplane is in relation to its total wing surface, the higher speed it requires to develop lift enough to get off the ground.

LIFT AND ANGLE OF ATTACK



There is another thing that affects the amount of lift you get from a wing and that is the angle at which you direct it into the air. In the example above we said we would move it straight ahead. We get some lift that way, but we can get more lift if we tip the front edge up and attack the air at a higher **angle of attack.**

The wing now displaces more air (that is, it makes the air over the wing travel farther) and, up to a point, gives us more lift. When we get past a certain point, however, we are pushing so much air out of the way that our airplane slows down. The air swirls and burbles into the low pressure area on top of the wing. We have increased the **drag** too much. (We'll explain that later.) Accordingly, we lose lift and approach a stall.

HOW MUCH LIFT DOES AN AIRPLANE NEED?

The amount of lift, then, is determined by (1) the design of the wing, (2) the speed of the airplane, and (3) the angle of attack. Now is it necessary or desirable to get as much lift as we can? Or is there a point at which we don't need any more?

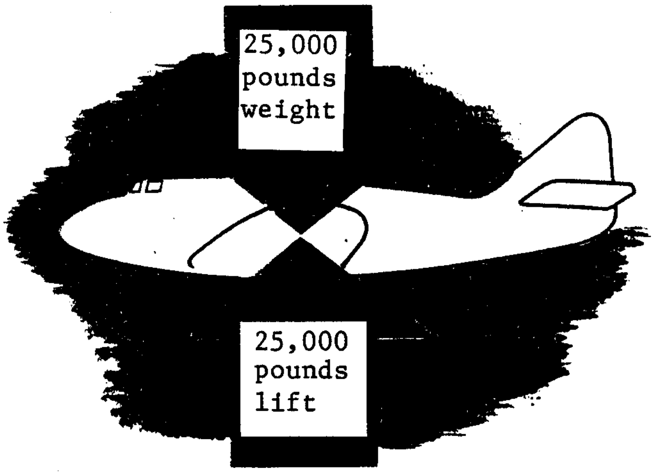
Think it over a minute. Just how much lift does an airplane need?

The answer to that is, how much does your airplane weigh? You need enough lift to overcome the force of gravity.

To climb you need more lift than the force gravity is exerting. As long as you have more lift than weight, your airplane will continue to climb.

However, when you wish to fly straight and level, at a constant altitude, lift and gravity must exactly balance each other. If lift is greater, you will climb; if gravity is greater, you will descend.

So you can see the designer of an airplane must figure his lift in relation to the gross weight of his finished airplane and the total load it is to carry.



We told you that to produce lift you have to move a wing through the air at relatively high speed. In flying model airplanes that you may have built, you produced the movement through the air by means of a propeller and strands of rubber. By winding the rubber strands you made the propeller rotate with enough speed to pull the model forward. When it got up enough speed it took off the ground and flew.

The force pulling the airplane through the air we call **thrust.**

How Much Thrust Does an Airplane Need?

That is an important question. You must know the answer to it before you can figure how powerful a powerplant you need. That is, how much horsepower your engine has to develop to do the work that you want it to do. Let's see just what that work amounts to:

1. You have to have thrust enough to overcome all the resistance (drag) that is built up as you move your airplane through the air.

2. Then you have to have enough additional thrust to start your airplane, build up speed, take off, and climb.

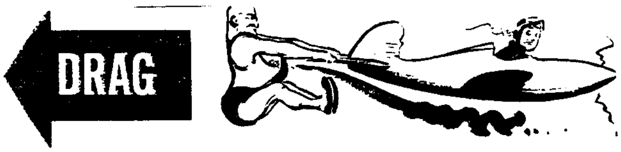
(It is important to remember that, because of what happens when your wing moves more rapidly through the air, some of your thrust turns to lift.)

You know it takes more power to start an automobile and speed it up than it does to keep it going once you have started it. That's why you have low and intermediate gears in a car. It takes more power to climb a hill in a car than it does to speed over a level highway. So in an airplane it takes more thrust to take off and climb than to maintain straight and level flight at a constant airspeed and a constant altitude.

But once you are in straight and level flight, and you want to fly at a constant speed and a constant altitude:

Thrust must equal **drag**, just as **lift** must equal **gravity**.

So let's find out what drag is.



Try to stand up in a high wind and you will realize how much force moving air exerts against your body. When an airplane moves rapidly through the air, it has the same effect as if the air were flowing at that speed against the airplane. It tends to hold the airplane back, or lower its speed. All that force that the air exerts against the airplane is called **drag.**

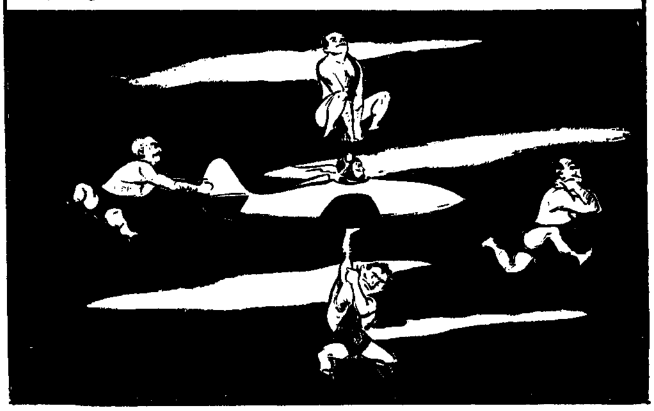
Some drag is useful. Some of it we would like to get rid of—it is merelv **dead drag.**

Dead Drag and Streamlining

Anything on an airplane that has a surface exposed to the air gives the air something to push against and therefore creates drag. Airplane designers, of course, have studied the effect of wind on various shapes and forms and have discovered those forms which offer the least resistance to the air. We call such shapes **streamlined,** and as far as possible everything on an airplane is streamlined. In that way we reduce **dead drag.**

THE FORCES OF FLIGHT

In the flight of any airplane, then, we have these four forces at work: Lift, weight, thrust and drag.



Useful Drag

But we can never get rid of all drag, for some of it is useful. The thrust that we use to pull the wing through the air so as to produce lift creates **useful drag.** It is one of the forces necessary to flight. So, no matter how well we streamline the design of an airplane we always have to have thrust and drag.

1. If we have more thrust than drag we begin to accelerate (go faster).

2. If we have more drag than thrust we begin to decelerate (go slower).

3. If we have exactly the same thrust as we have drag, we keep a constant speed at a constant altitude.

You have experienced these conditions in an automobile. Thrust in a car is the force that the engine exerts to drive the car forward. Drag is the friction and wind resistance of the car. You step on the gas to speed up—that is, increase the thrust until it is greater than the drag. Your car goes faster.

If you take your foot off the gas, you slow down because your thrust is less than your drag.

When you want to cruise along at the same speed on a level highway, you hold a constant throttle setting that gives you an exact balance between your thrust and your drag.

STABILITY

Before an airplane can be designed to fly, it must be so built as to balance the forces applied upon it in flight. In other words, it must be **stable,** and it must be **controllable.** It must tend to fly straight and level, without requiring the pilot to keep it on an even keel by main force. At the same time, it must be so built that the pilot may move it left or right, up or down, or from one side to the other at will.

Inherent Stability

In building model planes you have discovered that before they will fly they must be balanced. The distribution of weight is important.

A plane that is tail-heavy or nose-heavy or one-wing-heavy is badly balanced.

The center of gravity (as it is called) must be figured so that it is very near to the center of lift.

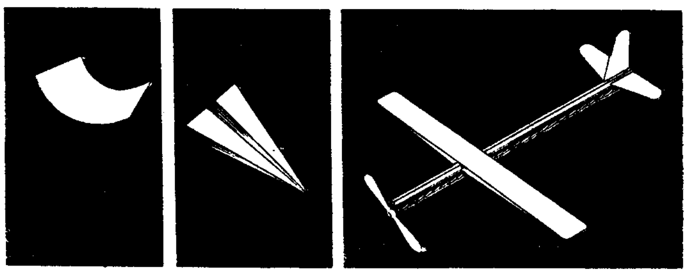
That is the first consideration for **inherent stability** (which merely means built-in stability).

The second thing that must be built in is some control that will keep the airplane flying straight and level.

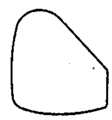
If you take a sheet of paper and skim it through the air, it will fly in an erratic and unpredictable way, but it won't go straight. If you fold it into a dart shape, it will do better, but it will still twist and turn and roll erratically. It has only a little inherent stability.

A carefully built model airplane, however, flies straight and level unless and until it gets blown about by air currents.

The stabilizers you build into a model airplane are the same in principle as those built into any airplane.

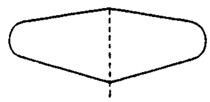


1. **The vertical stabilizer** is a fixed airfoil in the tail which stands vertically. It holds the airplane from turning left and right.



2. **The horizontal stabilizer** is like a small wing built horizontally into the tail. It holds the airplane from nosing up and down.

   There is still another way an airplane can move—it can roll, wing down or up. The wings are so constructed and so placed on the airplane that they tend to keep the airplane stable in that direction.



3. **The Axes of Rotation**

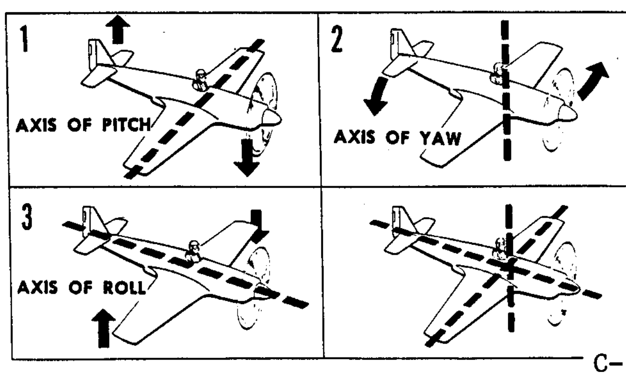
   You can see that an airplane can turn in three planes, whereas an auto, for example, turns only in one, left or right. Think of an airplane as having three axes of rotation.

   Take a piece of cardboard and cut it into a rough airplane shape. Then follow this explanation:

   (1) Turn to the left or right around the vertical axis. That is called the **axis of yaw.** That is the **axis** you can turn an auto in.

   (2) Put the nose down and the tail up, or the nose up and the tail down. That is called rotation about the **axis of pitch.** By controlling that rotation you put an airplane in the proper position to climb or dive.

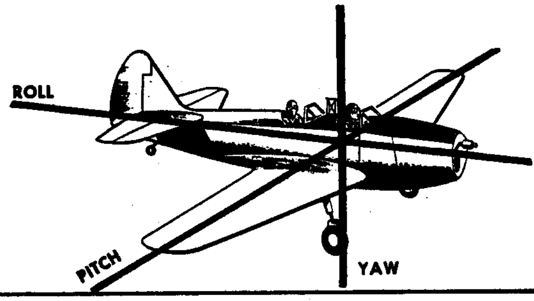
   (3) Now roll the left wing down and the right wing up, or the other way around, and you have rotation about the **axis of roll.**



CONTROLS

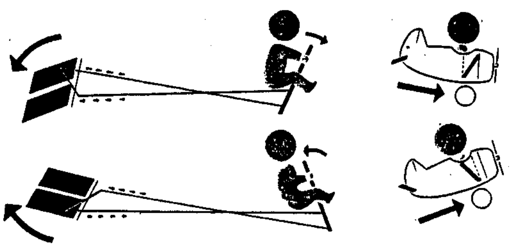
Control Surfaces

To control the flight path of the airplane around its three axes—the axis of pitch, the axis of roll, and the axis of yaw—movable control surfaces are used.



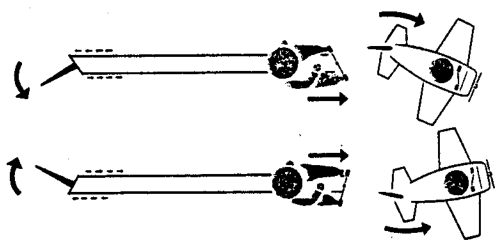
ELEVATORS

Movement around the axis of pitch is controlled by the elevators. The elevators answer to forward and backward pressures on the stick. When forward stick pressure is applied, the nose of the airplane is lowered. When backward pressure is applied, the nose of the airplane is raised.



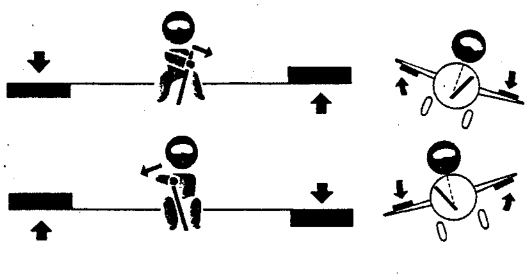
RUDDER

Movement around the axis of yaw is controlled by the rudder, which answers to pressure on the rudder pedals. When pressure is applied to the right rudder pedal, the nose of the airplane moves to the right. When pressure is applied to the left rudder pedal, the nose of the airplane moves to the left.



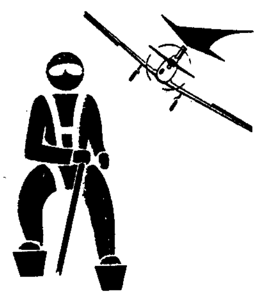
AILERONS

Movement around the axis of roll is controlled by the ailerons, which answer to sideways pressures applied to the control stick. Pressure applied to the stick toward the left depresses the left wing. Pressure on the stick toward the right depresses the right wing. The ailerons are so linked together by control cables that when one aileron is down, the opposite aileron is always up. In other words, pressure on the controls forces one wing down and the opposite wing up at the same time, and thus governs the movement of the airplane around the axis of roll.



Coordination of Controls

Control pressures are seldom used separately. The simplest maneuver needs coordination of all three pressures. A simple turn to the left requires coordinated pressures on ailerons, rudder, and elevator.

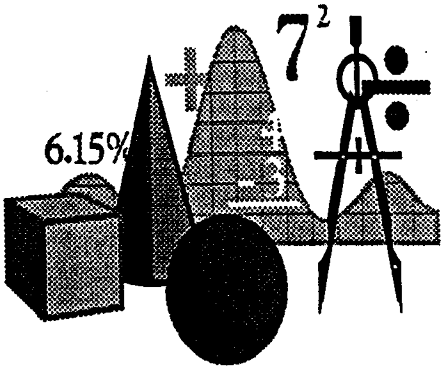


WHAT MAKES AN AIRPLANE FLY?

SOME QUESTIONS

1. What is lift ?
2. Describe how wing lift is affected by its:
    - A. Wing airfoil shape
    - B. Speed through the air
    - C. Angle of attack
3. What is the general shape of the wing airfoil ?
4. What happens to the air when a wing is moved through it at a relatively high speed ?
5. How much lift is required ?
6. What is thrust ? Drag ?
7. How much thrust is needed ?
8. What are the relationships between thrust-drag and weight-lift in straight and level flight ?
9. For what reasons is stability important ?
10. What is inherent stability ? How important is it ?
11. What are the stabilizing surfaces and their function ?
12. What are the axes of rotation ?

13 What contrils the airplane around each axis ?



MATH EXERCISE - Airplanes

ADDITION

1. If an airplane traveled 230 miles in the first hour of flight and 223 miles the next hour, how far did it travel in the two hours?
2. A Cessna 172 airplane is limited to hauling 904 pounds. If the pilot weighs 156 pounds and the cargo to be loaded weighs 812 pounds, can the airplane haul the cargo?
3. An SR-71 Blackbird is flying at 80,000 feet above the ground on a spy mission mapping parts of Iraq. The pilot puts the airplane in a right turn at 3 degrees per second to circle a surface-to-air missile site on the ground. If the pilots started his turn when he was headed south, what will his heading be after one minute. (HINT: south is 180 degrees.)

SUBTRACTION

1. A Beechcraft Baron B-58 twin engine airplane is flying 220 miles per hour while a single engine Cessna 206 is flying at 155 miles per hour. How much faster is the Baron flying?
2. If a Piper J-3 Cub fuel tank holds 23 gallons of fuel and burns 6 gallons of fuel per hour, how much fuel would be left in the fuel tank after one hour of flight?
3. While on a fishing vacation you and your friends rent a Dehaviland DHC-2 Beaver airplane to fly from Red Lake to Birch Lake Lodge. The trip should take about 1 $^1/_2$ hours. You have already flown for 32 minutes, how much longer will it take until you reach Birch Lake.

MULTIPLICATION

1. If a Douglas DC-3 airplane is transporting 232 pounds of cargo but is capable of hauling 40 times that amount, what is its hauling capacity?
2. You are the proud owner of a Cessna 210. Your aircraft will fly at up to speeds of 180 miles per hour. How far can your airplane fly in 6 hours?
3. A Piper Cherokee Six burns 17 gallons of fuel per hour. In three hours how much fuel will the aircraft burn?

DIVISION

1. If a Cessna 206 airplane burns 16 gallons per hour and its total fuel capacity is 72 gallons, how long can the airplane remain in the air until it runs out of fuel?
2. While cruising at 2000 feet above the ground air traffic control directs you to climb to 5,500 feet above the ground. If you climb at 500 feet a minute, how many minutes will it take to climb to your assigned altitude.
3. You are the pilot of a Boeing 747 jetliner traveling at 425 miles per hour. Your destination is 1400 miles away. How long will the trip take to complete?