



*James C. ...  
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**AIRCRAFT  
IN  
FLIGHT**



DESIGNED AND LITHOGRAPHED BY HENNAOE • WASH., D. C.



Price **FIFTY CENTS** per copy



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# AIRCRAFT IN FLIGHT

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## Foreword

The influences of aviation upon the modern world are so great that they still are not fully comprehended by those that they affect. Although aviation's effects are of importance to all of us, they are of greatest importance to our youth. It is the young men and women of America upon whom we must soon call for solutions to the problems which an air-age has generated.

The Civil Air Patrol recognizes this fact. Its cadet program centers around an aviation education curriculum. It is in the interest of the success of its cadet program that this book and the others of the Aviation Education series have been prepared.

If our nation is to fulfill its destiny, the young people of America must learn to employ toward this objective many aviation understandings and many aviation skills. The Civil Air Patrol's Aviation Education series will help lay the foundation upon which these understandings and skills may be built. Moreover, the basic information offered by this series can help give proper direction to the aviation understandings and attitudes of the general, adult public.

WALTER R. AGEE  
Major General, USAF  
National Commander  
Civil Air Patrol

## Preface

**Aircraft in Flight** is one of a series of six pocket-sized books prepared for use in the aviation education program of the Civil Air Patrol. It is to be used with an instructional 35 mm. color, sound filmstrip which illustrates the concepts which it introduces.

The purpose of this book is to describe in terms of secondary-school student understandings the scientific principles basic to flight, chiefly of heavier-than-air craft. The forces affecting an aircraft in flight are defined; simple problems of design encountered by aeronautical engineers are considered; the effects of high speed flight upon design are reported. Finally, the relationship of the principles of hydraulics and electricity to the operation of modern aircraft are summarized. Its treatment of the several areas with which it is concerned is sufficiently general to be of basic importance to all aviation career objectives. Yet, its content is detailed enough to challenge the interest of students and adults alike.

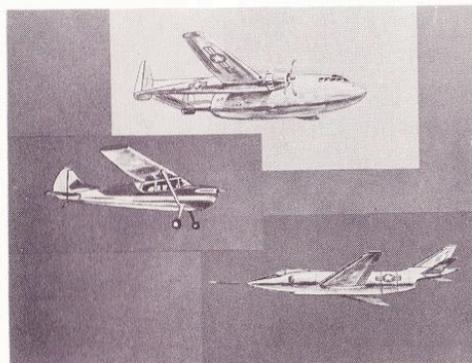
Although the first use of this booklet will be with Civil Air Patrol cadets, it will be found of considerable value in science classes and any other class that stresses the role of scientific concepts related to flight.

The books and filmstrips of this series are not limited to use with Civil Air Patrol cadets only. They will be found of value to students and teachers in any aviation education program. Those working with adults may also find this material helpful if the instructional or informational goal is general education as it relates to aviation.

Special acknowledgments for the technical advice given are due the following persons: Frank W. Hansley, Colonel, USAF, Deputy Chief of Staff, Operations and Training; Walter W. Thompson, Lieutenant Colonel, USAF, Director of Training; Seymore E. Latham, Major, USAF, Chief, Cadet Training; Evarice C. Mire, Major, USAF, Chief, Senior Training; and E. L. Jacobs, Captain, USAF, Executive to Deputy Chief of Staff, Operations and Training.

Members of the Civil Air Patrol National Educational Advisory Committee, whose names appear elsewhere in this booklet, and the Civil Air Patrol Regional Aviation Educationists whose names follow offered helpful suggestions: Victor E. Moore; John M. Ogle; Charles W. Webb; John E. Sims; Everett E. Collin; Arthur I. Martin; and John V. Sorenson.

Mervin K. Strickler, Jr.  
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# CHAPTER ONE

## AIRCRAFT IN FLIGHT

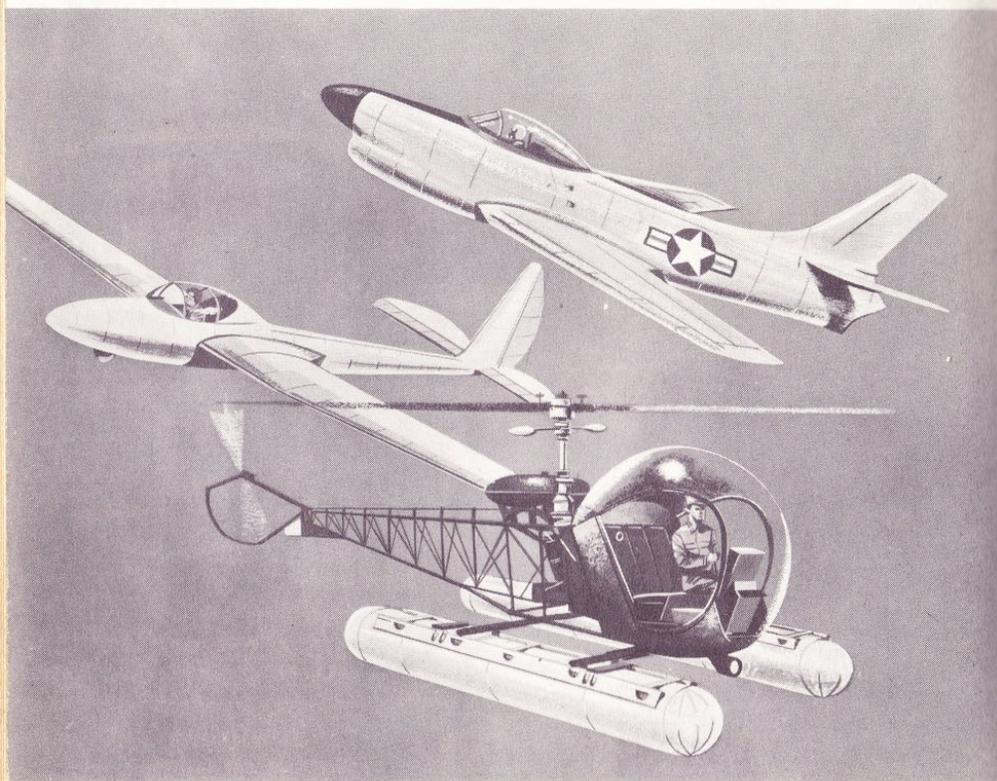
No doubt you have watched airplanes fly—"Cubs," "Helicopters," "Jets," or "Flying Box Cars." You marveled at the wisdom that designed them and at the skill which built them. Perhaps you have seen the "Thunderbirds" or the "Blue Angels" perform and were impressed by the skill of these daring pilots. Very likely you would like to learn why the airplane flies and how to fly it. If you look ahead to a career in aviation, you need eventually to learn these and other things about aircraft.

You have the same potential abilities as the men whose imagination conceived the airplane, whose energies created it, and whose skills operate it. These men are ahead of you only in terms of achievement. You are in a position not only to match their accomplishments but also to out-distance these—for you can put your imagination and energy to work adding to their discoveries. But first you must learn what already has been done in aviation. You must develop general understandings about aviation so that you have a basis for developing aviation skills and solving the problems of an aviation-age.

There are aircraft which are lighter, and aircraft which are heavier than air. Lighter-than-air craft include balloons, blimps, and dirigibles. The balloon was actually the first aircraft. At the close of the 19th Century, balloon ascensions were featured events at every special celebration. After its gas bag was filled with hot air and smoke produced by a bonfire right on-the-spot, the balloon rose into the air.

If it did not catch fire, it carried its aerialist aloft a few hundred feet. After this gentleman cut his parachute loose, the balloon turned over lazily, emitting a trail of smoke; the aerialist then competed with the balloon for the spectators' attention, performing, as he floated toward the ground, on a trapeze attached to his parachute.





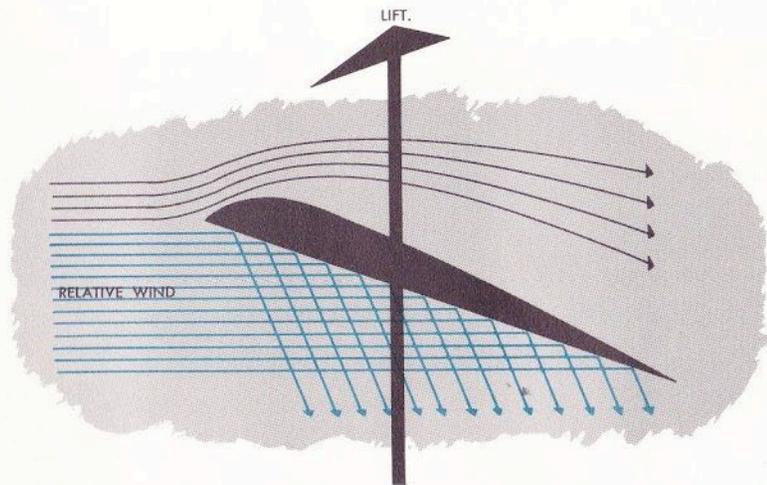
In later years, hydrogen (a gas lighter-than-air) served much better for lifting balloons and dirigibles than did heated air. Heated air lost its lifting power when it cooled; hydrogen exercised lifting power at normal temperatures. However, hydrogen easily catches fire. Eventually, helium, a more expensive but non-burnable gas, replaced hydrogen as the gas used to inflate the suspension bags of lighter-than-air craft.

Heavier-than-air craft include gliders, airplanes, and helicopters. All of these fly because some part of them is shaped to obtain a proper reaction from the air. The name of this special part is the wing or airfoil. *Helicopter rotors and airplane propellers are airfoils that have special uses. They are built strong enough to withstand the stresses resulting from these uses.*



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## CHAPTER TWO



The moving wing deflects the air. The air in turn deflects the wing.

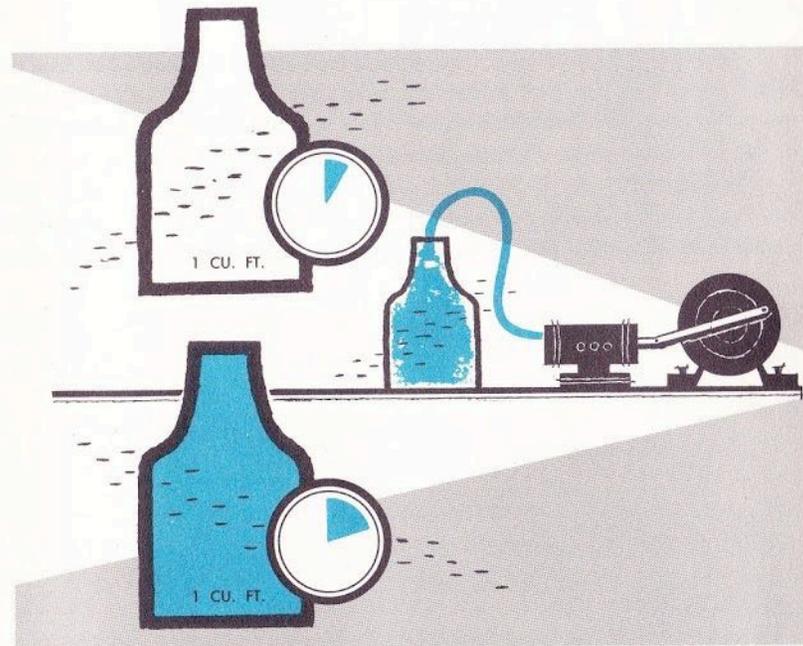
## WIND AND WING

Heavier-than-air craft fly because, through the application of power to the resistance of the air, airfoils are made to lift and support a given weight in flight. This is true whether the airfoil is the wing of the airplane or the rotor of the helicopter.

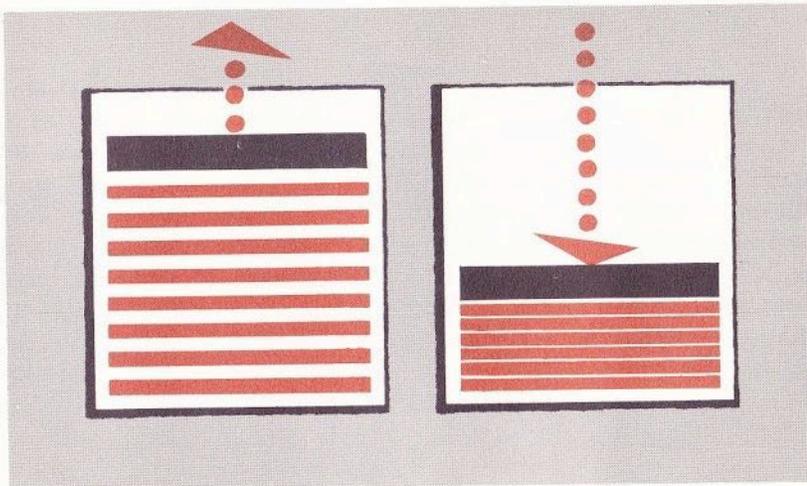
To help you understand the nature of the reaction between the moving wing and the air through which it flies, it is necessary to discuss the scientific principles whose applications make this reaction possible.

One of these principles is known as Newton's Law of Action and Reaction. You have observed it operating in many situations. The recoil of a gun; the back-lash of a hose as the water leaves its nozzle; gravel thrown by an automobile tire, each illustrates its application. Newton's observations led him to conclude that an object acted upon tended to resist this action with a force equal to the force applied to it. His conclusions may be stated as follows: "For every action there must be an equal and opposite reaction." A moving airplane wing acts upon the air. Consequently, behaving in accordance with Newton's Law, the air must act upon the airplane wing.

Another of these principles is the Bernoulli law of pressure-differential. One way to state this principle is to say that as the velocity of a fluid increases, its pressure decreases; or as its velocity decreases its pressure increases. A simple application of this principle is illustrated by the venturi tube of the carburetor used by some types of aircraft and automobile engines. The venturi tube is a tube, wide at each end but narrow at the throat between these openings. Moving air will speed up when passing through the narrow part of a venturi tube; hence, the pressure at this point becomes reduced. Fuel will consequently feed through a nozzle located at the venturi throat, since air pressure at the nozzle opening will be lower than that in the fuel chamber.



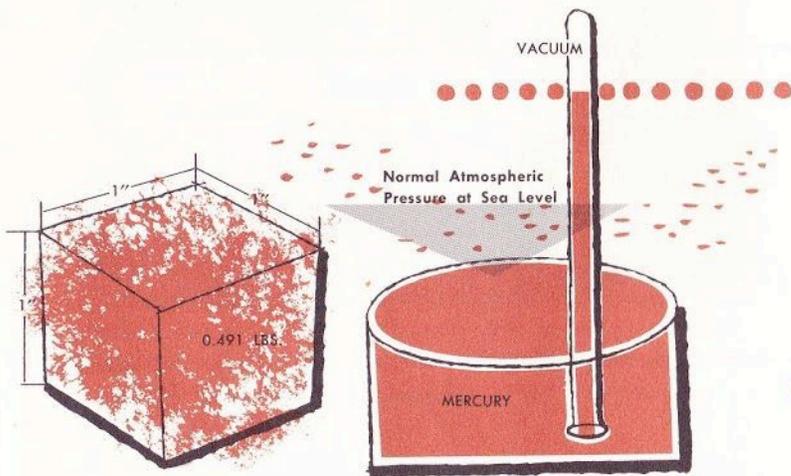
Air has weight; It is compressible; It exerts pressure.



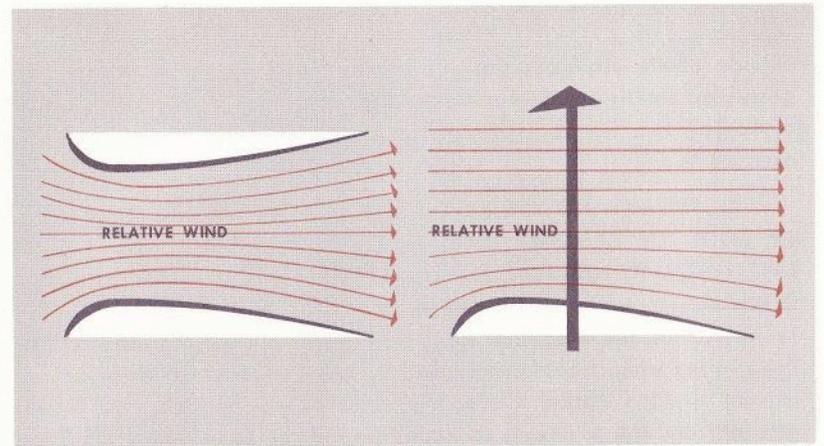
Air can be compressed or expanded.

The upper surface of an airplane wing is shaped somewhat like the inner surface of one-half a venturi tube split lengthwise. Consequently, the air moving over the wing moves more rapidly than that moving under it. As a result the air pressure above the wing is less than that below it.

In order to fully understand what happens when an airplane flies, you must learn something of the air through which it flies. Air is the least dense form of matter, as we are commonly acquainted with it. The ground



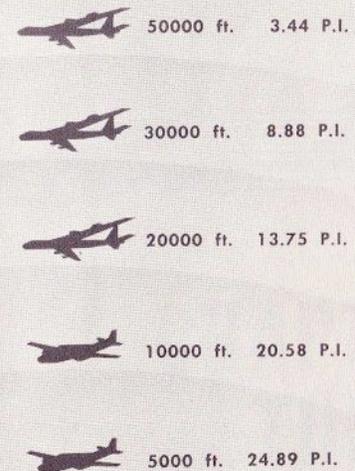
The pressure of the atmosphere can be measured.



As the air velocity increases, its pressure decreases.

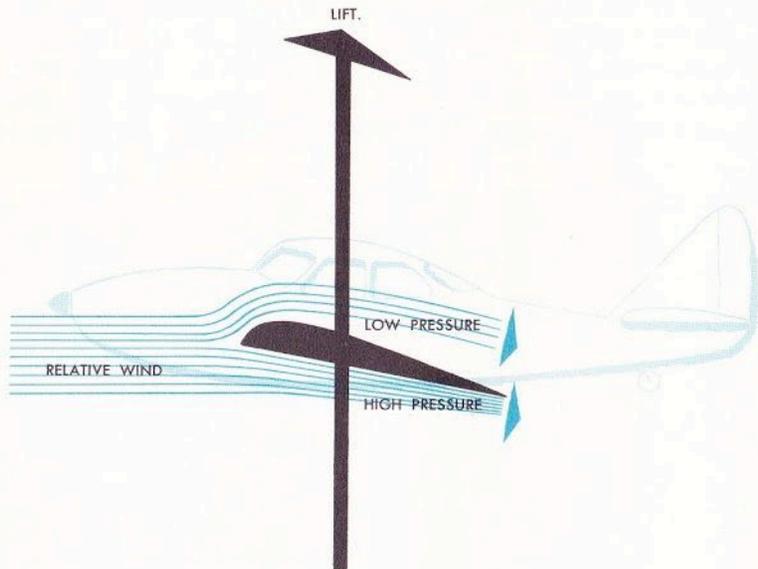
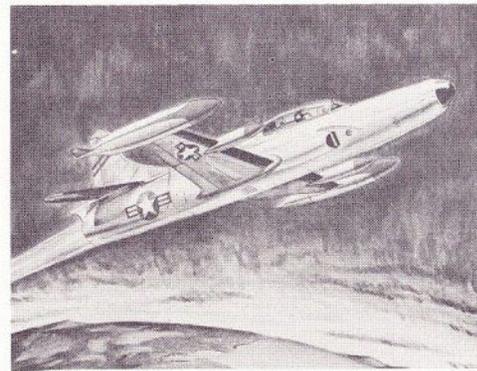
upon which we walk (a solid) is the most dense form. The water through which you swim (a liquid) is a third form. Arranged in the order of their increasing density, the forms of matter are gaseous, liquid, and solid.

Density is defined as mass per unit volume. But regardless of its degree of density, *air is a substance*. It has weight; it is compressible; at sea level it exerts a pressure of about 15 pounds per square inch, and a cubic yard of it weighs about two pounds. However, with the increase of

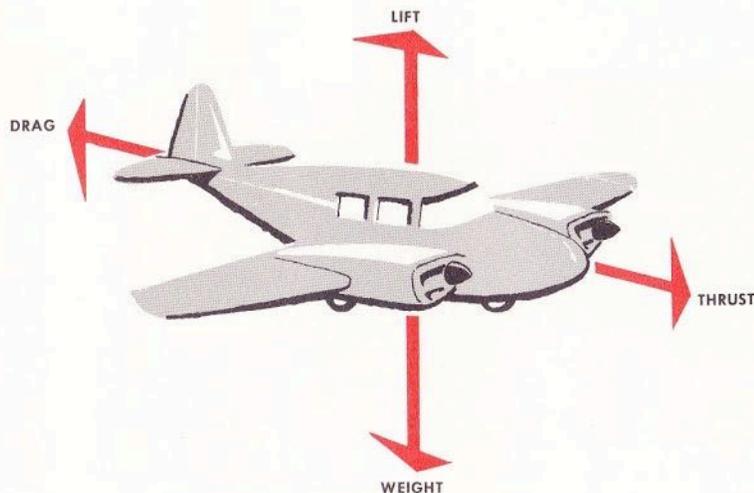


altitude above sea-level, both its *pressure* and *weight* decrease. Since gases and liquids are fluid substances, air is a fluid. As such, it is capable of flowing like water. Like water, it takes the form of any vessel that contains it.

AS THE MOVING AIRCRAFT WING ATTACKS THE AIR, IT MAKES USE OF BOTH THE PRINCIPLE DISCOVERED BY BERNOULLI, AND THE ONE DISCOVERED BY NEWTON. The moving wing deflects the air, and the air in turn deflects the wing. The moving wing also causes pressure differences to occur. Thus, the wing does something to the air, and the air does something to the wing. Consequently the airplane flies. During this process, the moving airplane creates the *relative-wind* (air movement in relation to an aircraft), and the relative-wind contributes to the force called lift. The direction of the relative wind is always parallel to the line of flight. One way to state the relationship between the moving wing and the air through which it moves is to say that they are involved in a process of interaction.



## CHAPTER THREE



## FORCES OF FLIGHT

An airplane in flight is acted upon by four forces called *lift*, *weight*, *thrust*, and *drag*. *Lift* in technical terms is defined as the force perpendicular to the relative wind. *Weight* or gravity is the force which acts downward, vertically. *Thrust* is the force that drives the airplane forward. It may be derived from a sailplane launching device, from propellers driven by reciprocating engines, or from the action of a jet or rocket engine. *Drag* is the force which opposes the forward motion of the airplane. Drag always acts parallel with and in the direction of the relative wind.

In the discussion of the action of wing and wind upon each other, we were actually talking about forces. These were observed emerging as the result of a condition brought about by the wing moving through the air. One of Newton's laws of motion states that once a body is set in motion it tends to move along a direct line until acted upon by another force. It is concluded, consequently, that when an airplane is flying straight

and level, the forces acting upon it are in balance. Actually, there is a complexity of such forces. "Lift" is a term employed to denote the effect of all those forces generated as the wing attacks the relative wind which lifts the airplane within the air mass. The point at which these aerodynamic forces are concentrated is called the *center of pressure*.

WITH RESPECT TO LIFT, THERE ARE A NUMBER OF RELATIONSHIPS WHICH MUST BE UNDERSTOOD. For example, *lift* is related to wing dimensions, to airspeed, to angle of attack, and to air density. Within certain limits, to increase any one of these increases lift. Hence, the ratio is said to be direct. However, in some instances the relationship is not quite so simple as the statements above would make it appear.

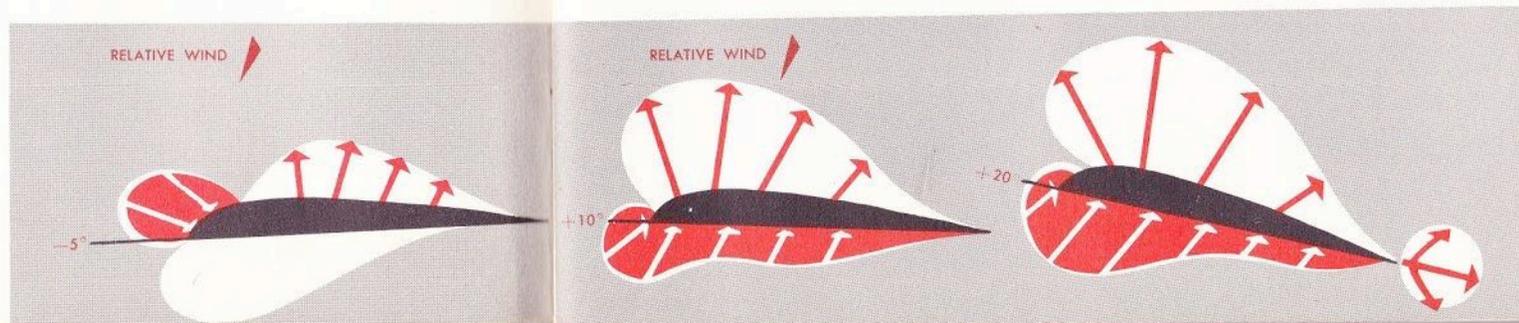
*Wing area* is the product of the wing span and its average chord. Span in relation to an airplane's wings is defined as their maximum tip-to-tip distance. The wing chord is the straight-line distance between the leading and trailing edge of an airplane wing. Sometimes it is defined as distance between imaginary perpendiculars erected to the leading and trailing edges of the wing. Within practical limitations the larger the wing, if other factors remain the same, the greater lift the wing will exert.

*Air speed* is the rate at which the airplane travels through the air. Of course should there be no surface wind or, with reference to the earth's surface, no movement of the air mass through which the airplane flies, the air speed and ground speed will be the same. However, it is in direct relationship to the airplane's movement not over the ground but through the air that lift increases. Within practical limitations the faster the airplane moves through the air, the greater will be the lift which results.

As you have already learned, it is not only the shape of the airfoil (wing) but also the angle at which it attacks the air which creates lift. The angle of attack causes deflection of the air which, in turn, causes an equal and opposite reaction of the wing or airfoil. Up to a point, the greater the angle of attack, the greater will be the lift which results.

Angle of attack must not be confused with angle of incidence. *Angle of attack* is the angle formed by the airfoil chord line and the direction of relative wind. It varies during flight, since it is controlled by the pilot. It

Lift also depends on angle of attack.





▼ Temperature affects density.

Altitude affects density. ▲

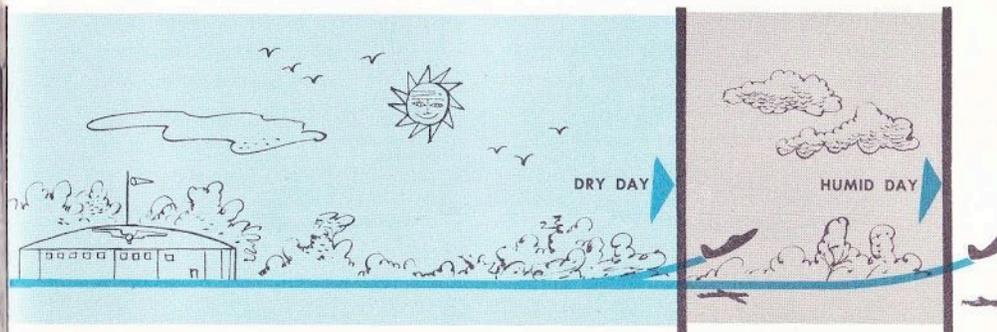


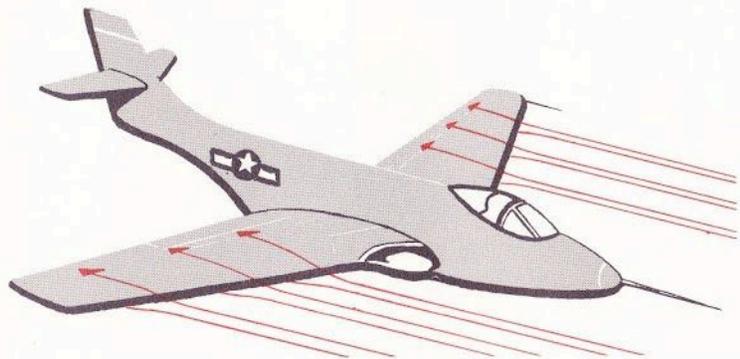
is one of the factors which determines the airplane's rate of speed through the air. The angle of incidence is the angle at which the wing root is fixed to the airplane's fuselage. Or more properly stated, it is the angle formed by the chord line of the airfoil and the longitudinal axis of the airplane. (See page 22.)

Density has been defined as mass per unit volume. Air density varies directly as pressure varies and indirectly as temperature varies. That air density varies with pressure means that if pressure is imposed upon a body of air, its density will increase. Such pressure will decrease its volume. Since air at sea level is pressed down by all the air above it, density at sea level is greater than density at higher altitudes. You can think of many implications of this fact. For example, when conditions at sea level are compared with those at higher altitudes, shorter take-off runs are possible; hence, runways at sea level are shorter. Also, at sea level, rate of climb may be higher and angle of attack may be greater.

That air density varies indirectly with temperature means that as air is heated, it becomes less dense. And, as its temperature increases, the volume of a given mass of air increases. Also, as its temperature increases, a given mass of air can contain a comparatively greater amount of water vapor.

There is relationship between density of the air and the amount of water vapor it contains. The reason for this is that water vapor is less dense than the other gaseous substances that make up the air about  $\frac{1}{8}$ . Water vapor weighs about five-eighths as much as an equal volume of dry air. Humidity is the term used to denote the presence of water vapor in the air. Relative humidity is the ratio, expressed in per cent, of the water vapor present in the air to the amount of water vapor which, under equal temperature and pressure conditions, it can contain.

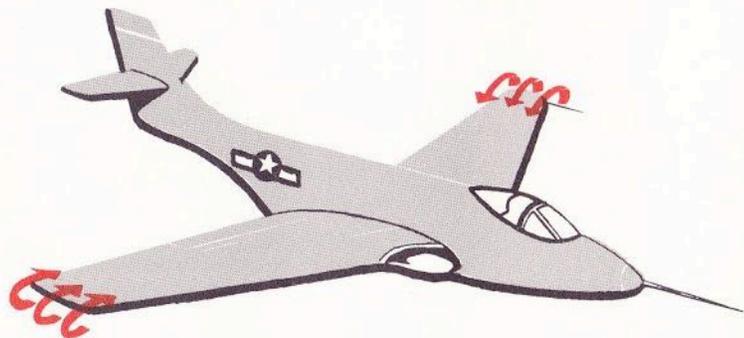




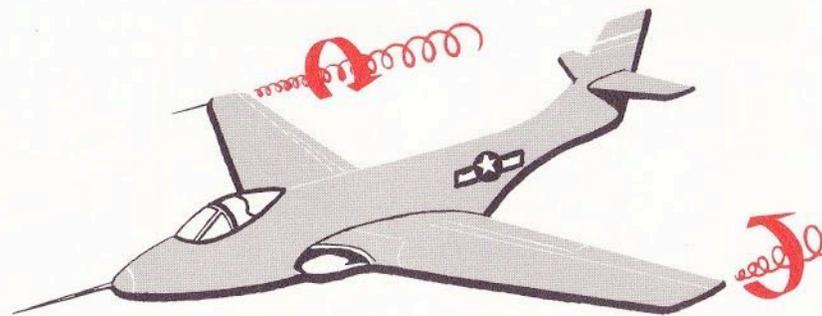
Air flows over and under the wing.

WEIGHT IS SIMPLY THE FORCE OF GRAVITY ACTING UPON THE AIRPLANE AND THE CARGO IT CARRIES. The center of gravity is the point at which the total weight of the airplane is concentrated. If a fulcrum were placed at this point, the aircraft would balance. The center of gravity (CG or c.g.) of the aircraft is normally located at approximately one-third the distance of the mean chord aft the leading edge of the wing. The relationship between the center of gravity and the center of pressure should be such that no serious instability of the airplane will result.

THRUST IS THE FORCE WHICH DRIVES THE AIRPLANE FORWARD. It always acts in the direction of the line of flight. Its source may be the propellers driven by reciprocating engines or it may be the reaction produced by a jet engine. Regardless of how this force is produced, it is of great importance. Its effect enables interaction of wing and wind. It bears a direct relation to engine speed and to the airplane's acceleration.



Air from under the wing tends to spill into low pressure area over the wing.

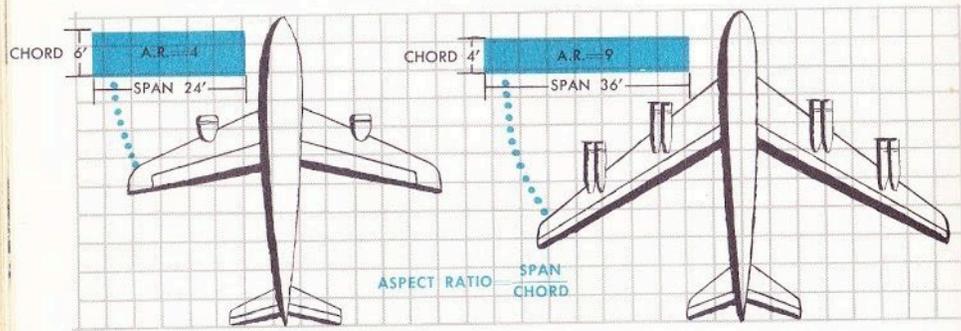


Air tending to spill over the wing tips causes vortices behind the wing.

DRAG IS THE FORCE THAT RESISTS THE FORWARD MOVEMENT OF AN AIRPLANE. As lift acts in opposition to weight, so thrust acts in opposition to drag. Consequently, when the drag forces acting on an airplane are great, the power required to develop thrust is great. Therefore, in the interest of economy of aircraft operation, aeronautical engineers are concerned with the problems of reducing drag. Drag, like the other forces acting on an aircraft in flight, is made up of a number of components. Among components of the total drag are included *induced drag* and *parasite drag*.

Induced drag is an unavoidable result of lift. As the airplane speeds forward, air from the high pressure area below the wings, as it tends to move into the low pressure area above the wings, causes trailing vortices to form. That is, this tendency imparts a whirling motion to the air at both the trailing edges and the tips of the wings. At the center of the vortices thus formed are low pressure areas. Obviously, such low pressure areas behind the wing will tend to retard the forward movement of the airplane.

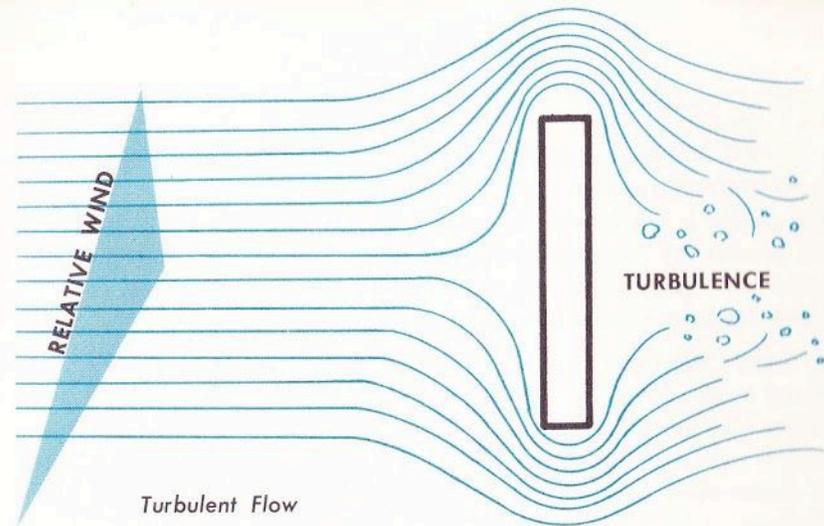
Induced drag is a function of factors over which pilots and designers have some control. It has a direct relation to the angle of attack. If the angle of attack is increased, induced drag will increase. It has an indirect relation to aspect ratio. If the aspect ratio is increased, the induced drag will decrease. *Aspect ratio* is defined as the quotient resulting when the span, the maximum distance from airplane wing tip to wing tip, is divided by the average chord. A rectangular airfoil with a span of 36 feet and a chord of 6 feet will have an aspect ratio of  $36 \div 6$ , or 6.



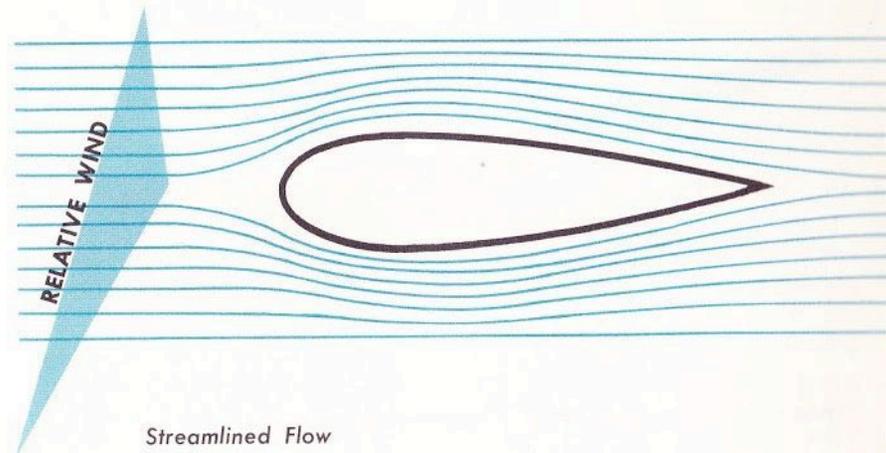
The facts stated above are important to aircraft designers. For example, in order to develop required lift, slow cargo aircraft which must fly at a high angle of attack have comparatively long, narrow wings (high aspect ratio). In order to develop required lift, fast fighter aircraft need fly at lower angles of attack. Hence, their wings may be comparatively wider and shorter without causing excess, induced drag. The designer must take these matters into account when planning the construction of an airplane wing.

PARASITE DRAG INCLUDES ALL DRAG COMPONENTS EXCEPT THOSE CAUSING INDUCED DRAG. Skin friction drag and eddy drag (or form drag) are names applied to two of these components. The drag caused by the friction between the outer surface of the aircraft and the air through which it moves is called skin friction drag. Whatever interferes with the streamline flow of air about the aircraft causes eddy drag (sometimes called form drag). To understand the causes of parasite drag you must learn about the boundary layer.

THE BOUNDARY LAYER IS A VERY THIN LAYER OF AIR WHICH SURROUNDS THE OUTER SURFACE OF A MOVING AIRPLANE. Air can be defined as a viscous fluid, and like other such fluids, gaseous or liquid, it tends to cling to an object passing through it. Have you ever observed, when one cuts griddle cakes drenched with syrup, how the syrup sticks to the knife? And, that which clings to the knife pulls more syrup along with it? Likewise, if you were to move your hand in a single direction through a basin of water, you would observe that your hand imparted motion to the water. In this instance the water against the surface of your hand will move as rapidly as your hand and in the same direction. However, as the distance of the water from your hand becomes greater, the motion of the water becomes less, until at a certain distance the water is not affected.



Now let us consider the resistance due to form drag. As you move your hand through water, you will observe that to change your hand's position will change the behavior of the water which flows around it. If you hold your hand rigid and move it edgewise through the water, the disturbance will be less than if you move the flat of your hand through the water. In this latter instance you will observe that more eddies occur in the water and that the water offers more resistance to the forward motion of your hand. The behavior of air when objects speed through it is quite similar to that of water when objects move through it.

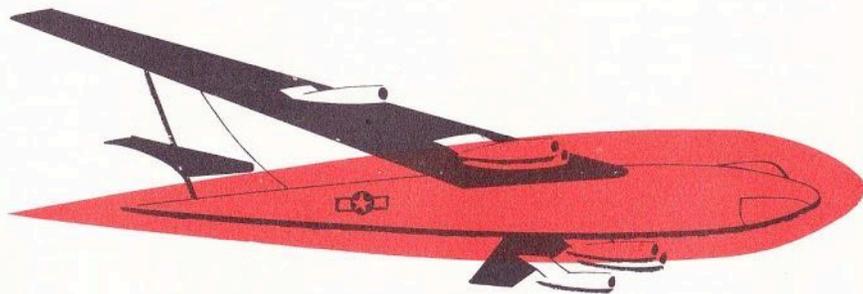


YOU WILL RECALL THAT THRUST EQUALS DRAG WHEN AN AIRPLANE IS IN STRAIGHT AND LEVEL FLIGHT. Consequently, the greater the drag, the greater is the horsepower needed to develop required thrust. And, the greater the horsepower required, the greater is the amount of fuel consumed. You observe that there are sound practical reasons for airplane designers to attempt to reduce drag.

SKIN FRICTION DRAG IS DIFFICULT TO REDUCE. Yet it can be reduced if the airplane is kept clean and well polished and surface irregularities such as those caused by protruding rivet heads are removed. Form drag is comparatively easy to reduce. To reduce it the designer has only to create designs which offer least disturbance to the airflow about the airplane.

It has been found that the best way to prevent formation of eddies in the air through which an object moves is to streamline the object—that is, to give it a shape approaching that of a tear drop. Consequently, to reduce eddy drag, airplane parts exposed to the airstream are streamlined. When an airplane part cannot be streamlined, it is inclosed in a streamlined cover. This auxiliary structure reduces the drag of the part to which it is fitted. Such a cover or structure is called a *fairing*.

You have observed that among the four composite forces that affect aircraft in flight there is one, the force of gravity, over which, since it is a constant force, neither designers nor pilots exercise control. The others are controlled to varying degree by those who design and build aircraft or by those who fly them.



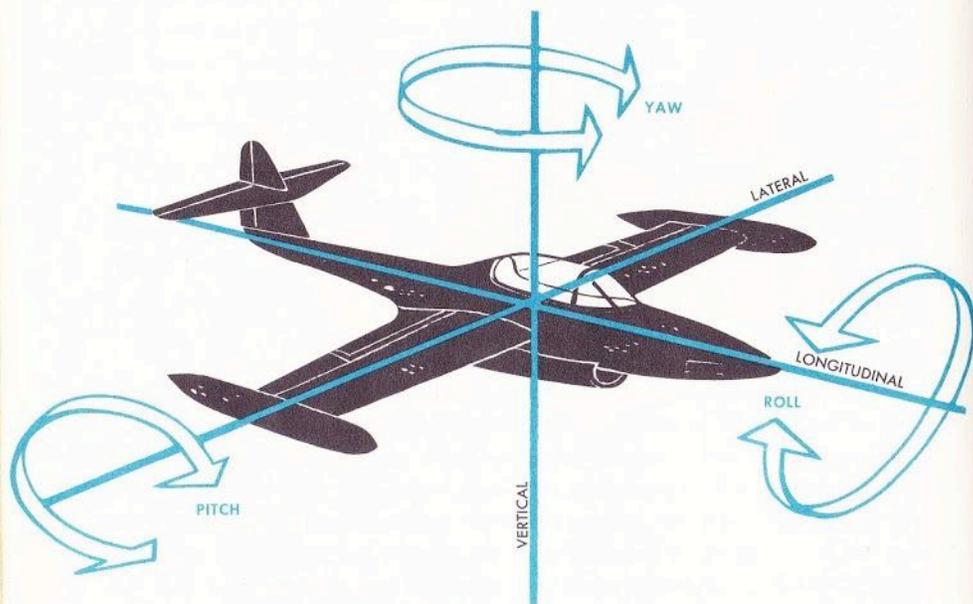
*Best streamlining approaches a teardrop shape.*



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## CHAPTER FOUR

## THROTTLE, STICK, AND RUDDER



In addition to its forward motion, an aircraft in flight may move about three axes, the vertical, the lateral, and the longitudinal. These axes remain fixed, not in terms of the earth's surface, but in terms of the aircraft. Each is actually defined by the planes of rotation through which the aircraft moves as a pilot operates the controls.

THE MOVEMENTS AROUND THE AXES ARE CALLED YAW, PITCH, AND ROLL. Yaw is movement around the vertical axis; pitch is that around the lateral axis; and roll is that around the longitudinal axis. If there is a tendency for the aircraft in straight and level flight to execute any of these movements voluntarily, it is termed unstable. An aircraft in flight which has desirable stability will not only respond readily to the controls but also tends to maintain a straight and level flight attitude. A stable aircraft can almost fly by itself. An unstable aircraft needs continuous control by the pilot in order to keep it at a constant altitude and on a constant heading.

The designer and the airframe mechanic actually build stability into the airplane. One means of preventing voluntary yaw is to use a surface called a vertical fin. A vertical stabilizer or vertical fin is the fixed portion of the tail assembly to which the aircraft rudder is attached.

The most important method used by the designer to obtain stability of movement around the longitudinal axis relates to wing dihedral. If you could draw a line from the tip of one airplane wing to the tip of the other, you would observe that such line did not coincide with the wing surfaces. Now, should you draw lines from the tip of each wing so that they did coincide with the wing surfaces and extend these lines until they meet, you would observe that the three lines drawn form a triangle. In order to find the degree of dihedral, you should measure the angle formed by the first line drawn and either of the other lines.

A tendency of an aircraft to roll is caused by propeller rotation. This tendency is called torque and is in the direction opposite propeller rotation. To compensate for torque effect, the angle of incidence is decreased toward the tip of the right-hand wing and increased toward the tip of the left-hand wing. (See page 13.)

THE PILOT CONTROLS THE ATTITUDE OF THE AIRCRAFT WITH REFERENCE TO THE THREE AXES BY MEANS OF THROTTLE, STICK, AND RUDDER. Learning to fly is in part learning to coordinate these controls so that the desired maneuver is successfully performed. The throttle is used by the pilot to supply fuel to the engine. To increase the fuel supply produces additional horsepower. When this is done the airplane tends to climb (unless the pilot applies forward-pressure to the elevator controls). To decrease the power (fuel intake) of the engine causes the aircraft to enter a glide (unless the pilot applies back-pressure to the stick, or wheel).

The stick (or wheel) operates both elevators and ailerons, hence are the pilot's controls over pitch and roll. The rudder pedals operate the rudder and are the pilot's controls over yaw and the horizontal direction of flight. Control surfaces are connected to cockpit controls by cables, push-pull rods, and linking devices, such as turnbuckles (See page 43).

In practice the pilot may make use of one or all controls at the same time. To apply forward pressure to the wheel of an aircraft in-flight tends to place the aircraft in a diving attitude; to apply back pressure, tends to place it in a climbing attitude. To turn the wheel to the right (to apply right aileron) tends to lower the right wing; to turn the wheel to the left (to apply left aileron) tends to lower the left wing. To exert pressure on the right rudder pedal causes the rudder to move toward the right and the nose of the aircraft in flight to move clockwise around the vertical axis of the aircraft; to apply pressure on the left rudder reverses the process.

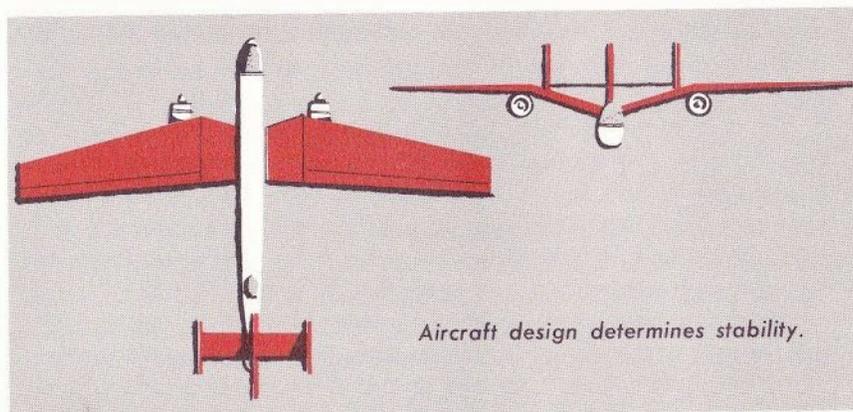
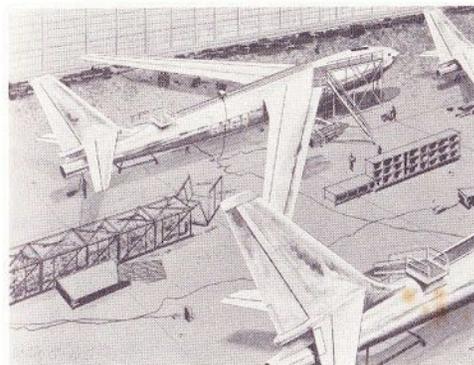
In order to perform certain maneuvers properly, the student-pilot must learn through practice to coordinate the operation of cockpit controls.

For example, should he want to turn the aircraft to the right, he must use right rudder and right aileron together, placing the aircraft in the turn. Just the right degree of pressure on each control is necessary, or the aircraft will either slip or skid. Once in the turn, he eases pressure on rudder and aileron, applying sufficient back pressure to complete the degree of turn desired. In order to resume straight and level flight, he eases elevator pressure and applies proper, coordinated pressure upon left rudder and aileron.

Ailerons, elevators, and rudder are equipped with trim tabs, also controlled by the pilot. These enable him to keep the aircraft in straight and level flight when its stability has been affected by cargo, fuel load, or other cause.

Simply stated the aircraft controls enable the pilot to take the aircraft off the ground, execute necessary climbs and turns, set it upon its course in straight and level flight, keep it on course until his destination is reached, enter the traffic pattern, and make a landing. Control surfaces function in accordance with the principle of *action and reaction*. Just as the rudder of a boat reacts with the water through which it is moving to change the heading of the boat, so do rudder, ailerons, and elevators react with the air to change the attitude of the airplane.

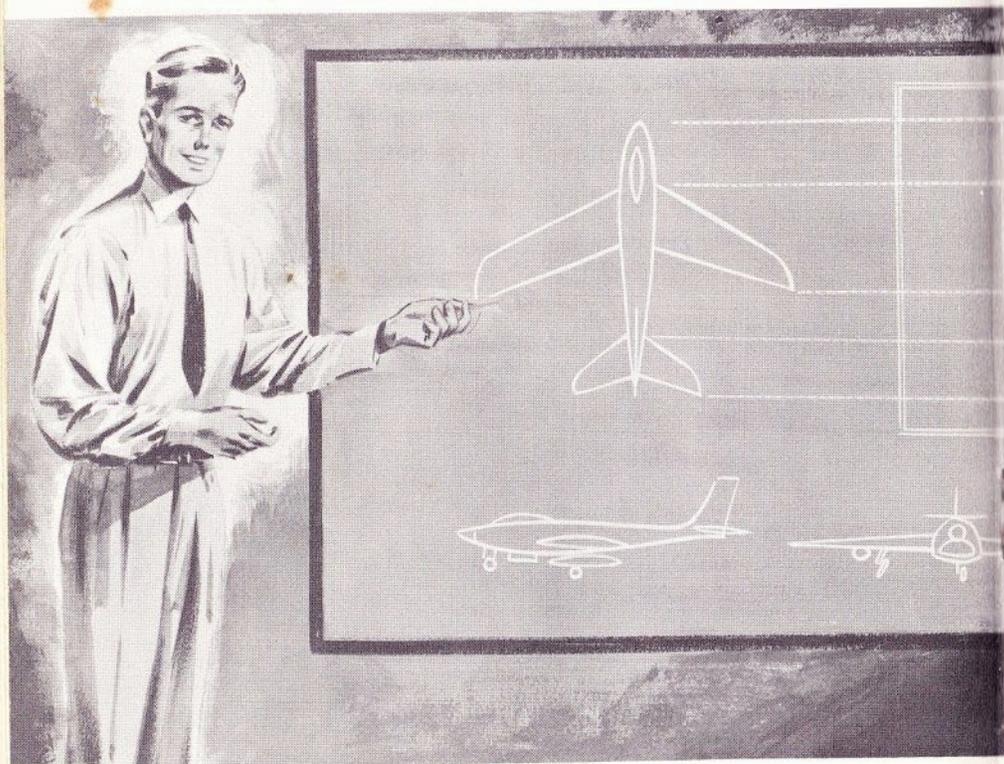
Handling of the aircraft on the ground brings other controls into play, such as brakes, but it also employs some of the controls used in flight. And certainly, landings or take-offs from a busy airport requires many pilot skills in addition to those needed to operate the airplane's controls.



## CHAPTER FIVE

# MANEUVERS, GUSTS, AND LOAD FACTORS

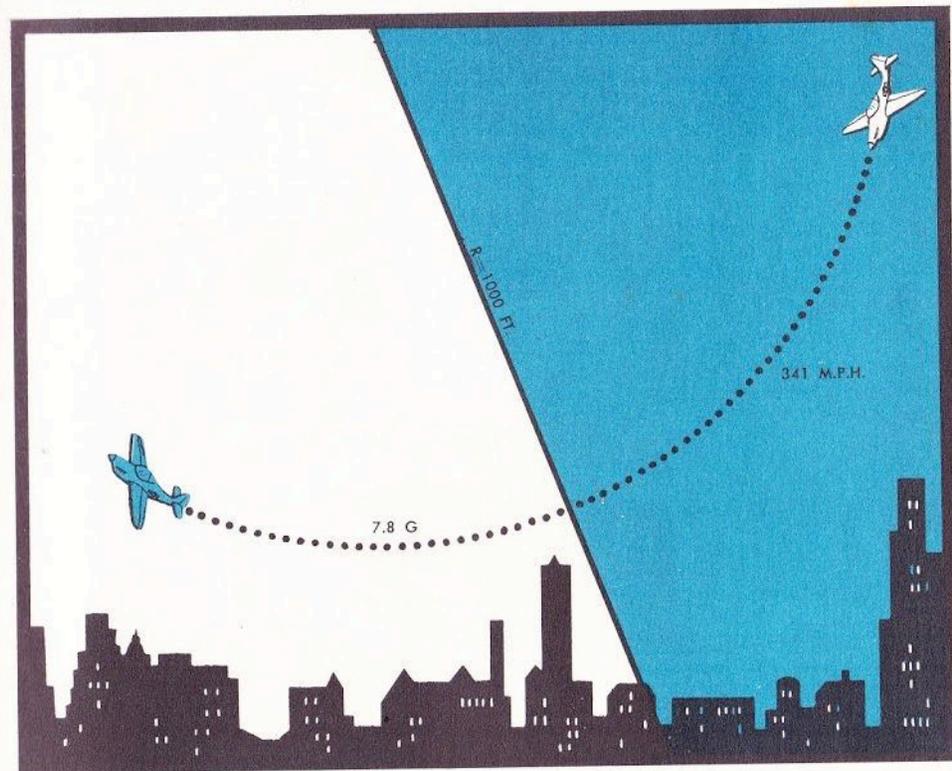
Aircraft are built to withstand prescribed loads. The aeronautical engineer who designs an aircraft is faced with problems similar to those confronting the engineer who designs any other structure which has to bear both its own weight (dead weight) and the weight of other loads (live weight) placed upon it. The task of the aircraft designer is more complex, however, than that of other builders, because the dynamic forces affecting the airplane in flight are more variable than forces affecting other structures, and these act from many separate and combined angles. By way of illustrating the comparative complexity of forces acting on an airplane let us consider the nature of forces acting upon a bridge.



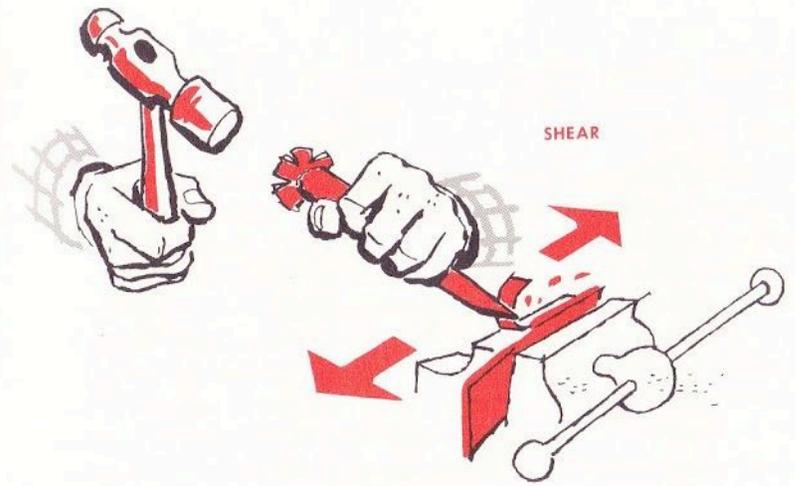
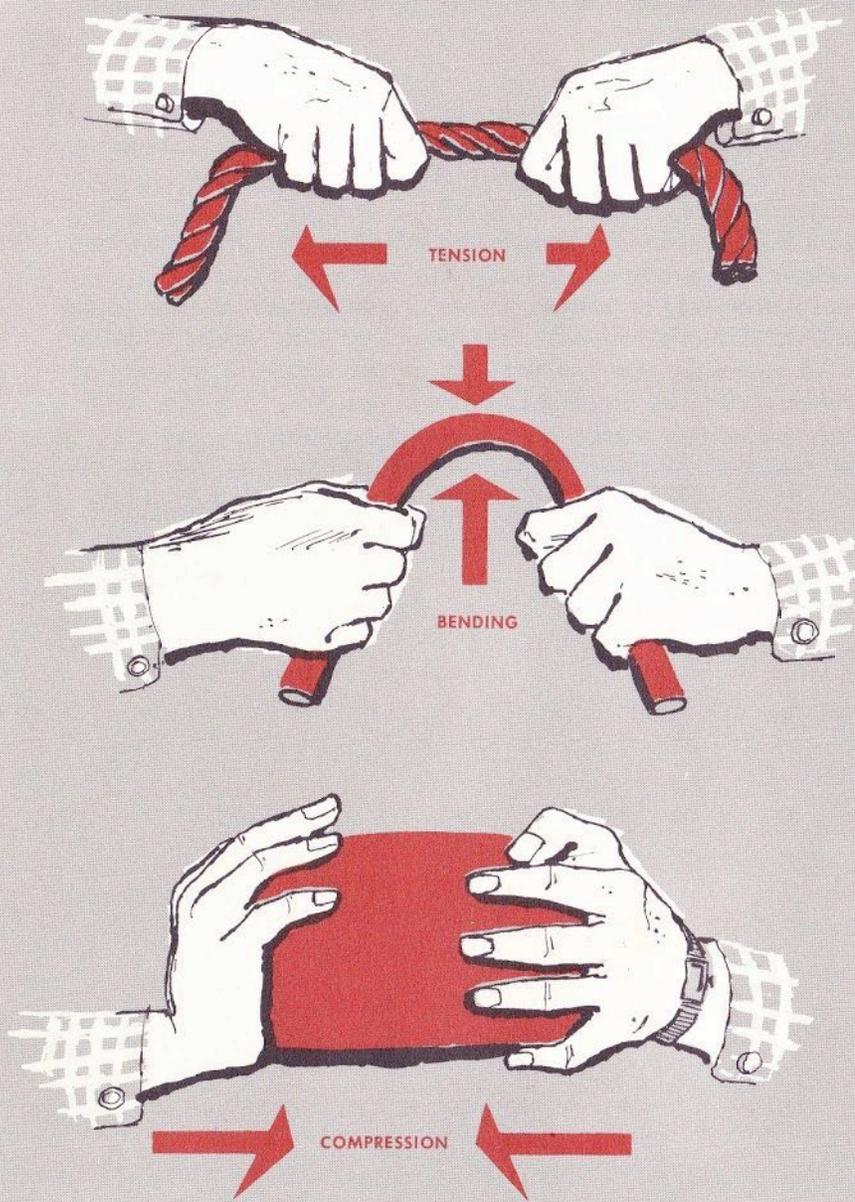
Designers consider forces affecting aircraft in flight.

The live load stresses placed upon a bridge are produced by traffic passing over the bridge. The weights of the live loads vary continuously, it is true, but the angles from which these act are not subject to much change. On the contrary as the airplane assumes different attitudes and flies through turbulent air, the stresses placed on its airfoils vary both in degree and direction.

The term used to indicate the load placed upon an airplane under certain conditions is *load factor*. The load factor is the ratio of a load to the design weight of an aircraft. Because the weight of an object is measured in terms of gravity, the load factor may be thought of as a ratio

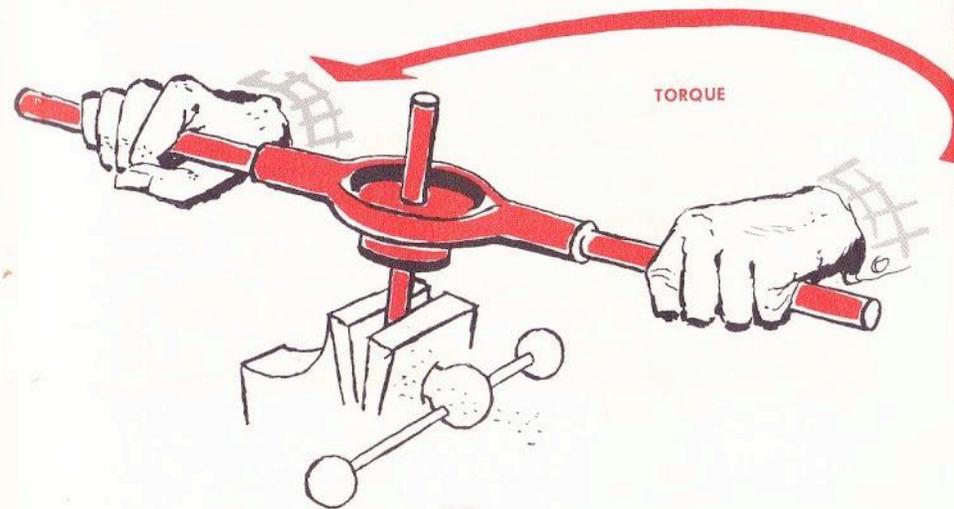


Load factors placed upon an aircraft recovering from a dive.



between the normal weight of an airplane, its cargo, and passengers and the pull of gravity under different conditions.

The acceleration produced by gravity is 32.17 feet per second per second (32.17 ft/sec/sec). The letter "g" used in a formula refers to the acceleration produced by gravity. Sometimes a load factor is symbolized by the letter "g". This is because a maneuver which abruptly checks acceleration will subject the aircraft to increased stresses. For



example, during a flight maneuver an airplane which weighs 3500 pounds may have a load of 10,500 pounds placed upon it. In this case the load factor it sustains might be expressed as 3g.

THE STRESSES TO WHICH AN AIRPLANE ARE SUBJECTED INCLUDE TENSION, COMPRESSION, BENDING, SHEAR, AND TORSION. DIFFERENT MATERIALS RESIST THE EFFECT OF THESE STRESSES IN VARYING DEGREE. When design engineers specify the kind of material the builder should use, they take this fact into consideration.

Tension tends to pull materials apart. Compression tends to push materials together. Bending tends to distort a member by curving. Shear tends to divide a member. Torsion tends to distort a member by twisting.

The load which may be imposed with safety upon an airplane depends upon the degree of stress that it is designed to withstand. The maximum safe loads for airplanes weighing less than 4,000 pounds in four principal airplane classifications are as follows:

### Maximum safe loads for aircraft under 4000 lbs.

<b>Aerobatic</b> .....	<b>6.0 times gross weight</b>
<b>Utility (mild aerobatics including spins)</b> .....	<b>4.4 times gross weight</b>
<b>Normal (no aerobatics or spins)</b> .....	<b>3.8 times gross weight</b>
<b>Non-spinnable</b> .....	<b>3.5 times gross weight</b>

As airplanes increase in weight a corresponding decrease must be made in the load factor to which they may be subjected. Consequently, airplanes of over 4,000 pounds have a corresponding load limit reduction. However, a safety factor of 50% of the LIMIT-LOAD is always built into an airplane.

AN INCREASE IN THE LOAD IMPOSED UPON AN AIRPLANE IN FLIGHT MAY BE CAUSED BY INCREASING THE DEGREE OF BANK (THE ATTITUDE ASSUMED BY AN AIRPLANE DURING A TURN), BY BACK PRESSURE ON THE ELEVATOR CONTROL, OR BY SUDDEN GUSTS. Actually the pull of gravity upon an airplane in a turn when the wings are banked 60° is twice as great as that upon the airplane in level flight; consequently

in a 60° bank twice its normal load is placed upon the aircraft structure. Speed is also important in relation to limit load. This is not that speed by itself imposes a greater load, but that maneuvers at high speeds do impose greater stress than do maneuvers at lower speeds. An abrupt pull-out from a dive can place a load upon the aircraft wing sufficient to cause structural failure. Flying through gusty air or turbulence caused by storms places extra stress upon an airplane. Flying speed should be reduced in this latter instance to 90% of normal cruising speed.

*During maneuvers no pilot (other than those testing experimental aircraft) will ever intentionally exceed the maximum speed limit established for the airplane he is flying. However, should he accidentally approach the never-exceed speed restriction marked on his air speed indicator, he will handle the controls very carefully and use back pressure very gently to "pull-out" of the dive. Incidentally, never-exceed-speeds can be attained only when the airplane is diving.*

*The never-exceed-speed is marked on the air-speed indicator by a red radial line. The range at which flaps may be operated is shown by a white arc. The range from normal stalling speed to normal operating speed is shown by a green arc. The cautionary range from normal operating speed to never-exceed speed is shown by a yellow arc. Maneuvering speed is not generally designated by air-speed indicator markings. However, normal stalling speed is so indicated. Since maneuvering speed is 70% greater than normal stalling speed, the pilot can readily compute the safe speed for his airplane's operation during maneuvers or upon encountering gusts. For example, a light aircraft whose normal stalling speed is 55 miles per hour (mph) has a maneuvering speed of 83.5 mph.*

STALLS AND SPINS ARE NORMAL REACTIONS OF THE AIRPLANE TO THE PILOT'S USE OF THE CONTROLS. An airplane will not enter either of these maneuvers if its trim and control systems are functioning properly. Once it has been put into such a maneuver, if the altitude is sufficient, the well-designed airplane will recover of its own accord. It is only when an aircraft is handled unskillfully that accidental stall and spins occur.

An airplane stalls because it loses the lift necessary to sustain its attitude. Lifting power is lost when the angle of attack is too great. For most airplanes the maximum effective angle of attack is 20°. Any increase in this angle causes the boundary layer to separate from the upper surface

of the wing. This creates eddies over the wing and a corresponding loss of lift.

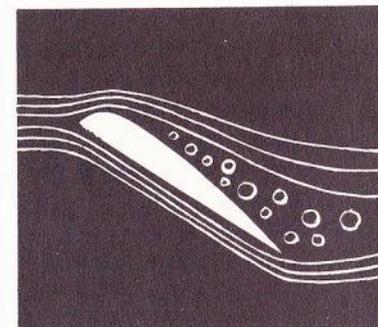
*Stalls are associated with slow air speed.* There is a relationship between air speed and stalls. We speak of normal stalling speed, defining this as the appropriate forward speed of the aircraft upon contact with the ground when landing. However, an airplane can stall at any speed from its minimum to its maximum, and the higher the speed the more violent the stall. The controlling factor in a stall is the angle of attack; not the air speed.

To recover from a stall the pilot needs only to release back pressure on stick, or wheel. This permits the nose of the airplane to drop quickly, the speed of the airplane to build up, and lift to increase. Once flying speed has been reached and lift regained, gentle back pressure will return the airplane to level flight. If too abrupt back pressure is applied after stall or spin recovery, the angle of attack may be increased enough to cause a second stall.

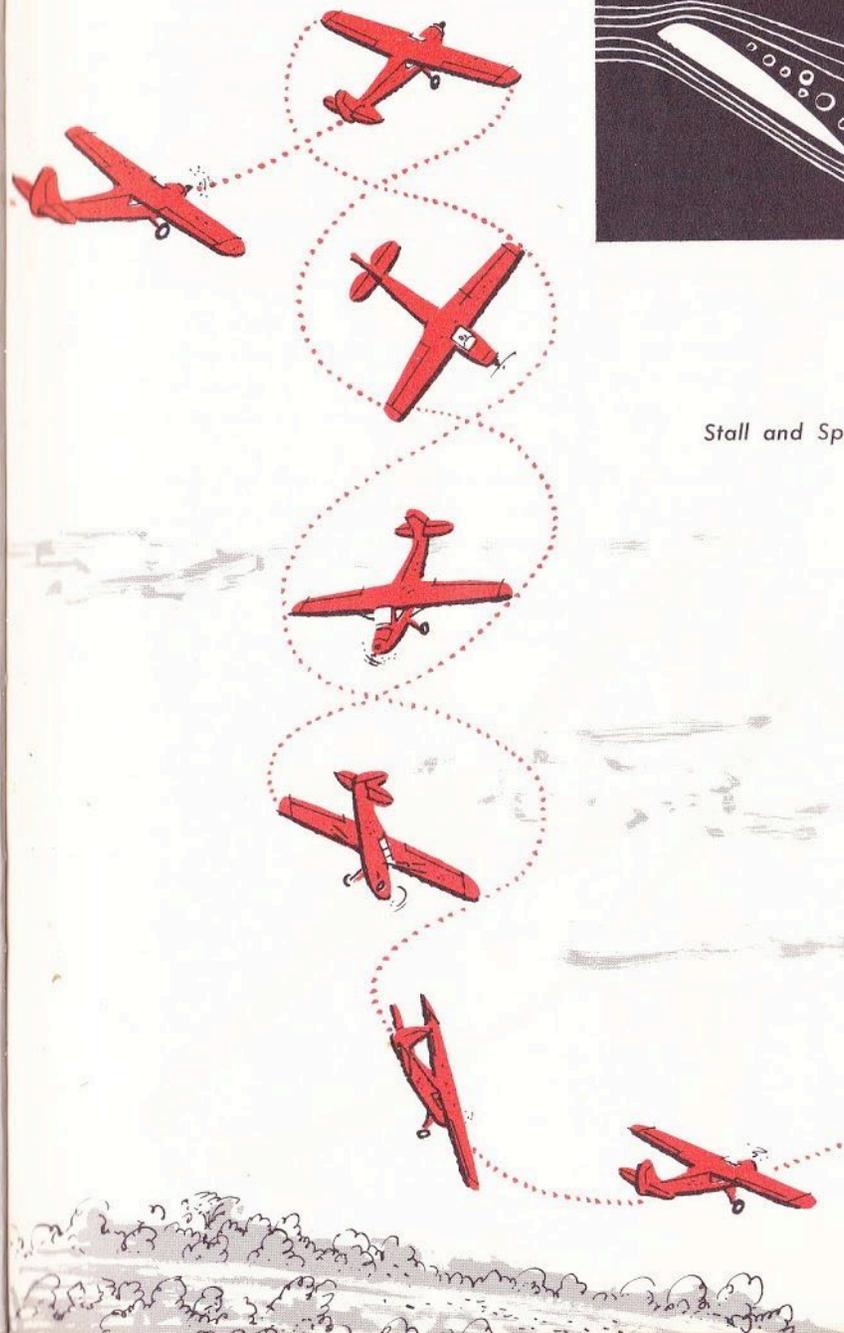
A spin results when, after it stalls, an airplane begins to travel downward along a spiral path. Rudder pressure applied after the stall will cause the airplane to begin to rotate in the direction the rudder pedal operated. When recovering from a spin the pilot proceeds as follows:  
1. He holds complete back pressure on the stick until the application of rudder opposite the direction of the spin checks the rotation of the airplane.  
2. He returns the stick to a neutral position until flying speed is reached and lift regained.  
3. He then applies gentle back pressure on the stick until the airplane is again in level flight.

Stalls and spins are dangerous only when they occur unexpectedly at altitudes too low to permit recovery. Unintentional stalls happen most often during turns. Since the lift required in a turn is greater than that required for straight and level flight, an aircraft in a turn stalls at a comparatively higher airspeed. It is well to remember that the steeper the bank, the greater the airspeed required to maintain adequate lift and constant altitude.

Abnormal use of the rudder during turns cause skids and slips. If the lower rudder of the airplane is held during a turn, its nose swings toward the inside of the turn, and it skids sideways, just as a car sometimes skids on a wet and slippery pavement. If during a skid, back pressure is applied to the elevator control to aid in the turn or to maintain altitude, the angle

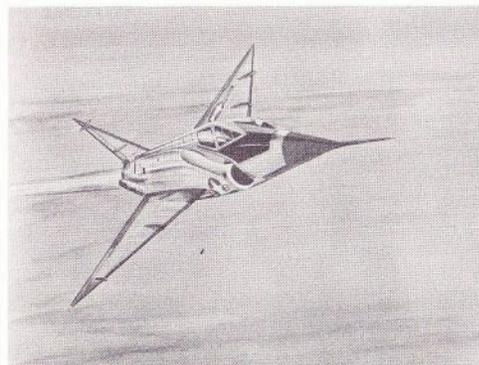
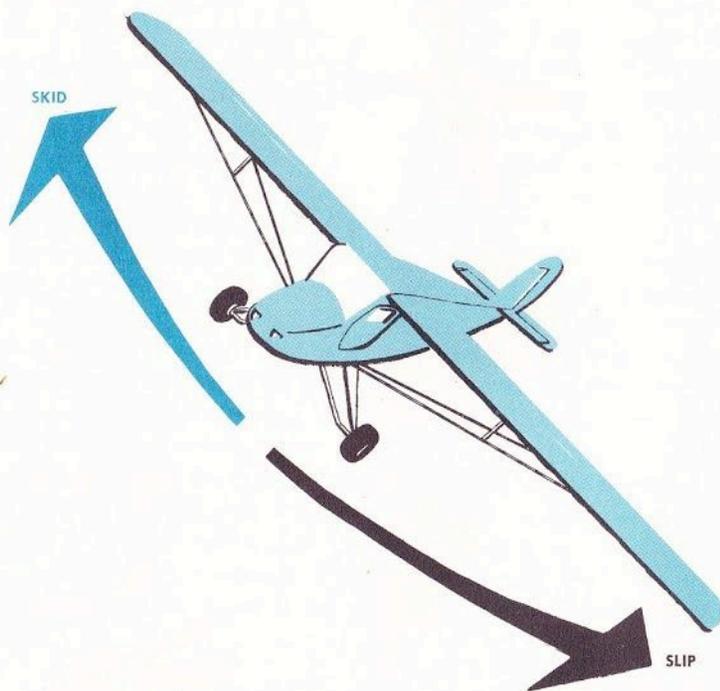


Stall and Spin



of attack might be increased enough to cause a stall or spin. To execute a turn, the pilot uses the rudder control, coordinated with the aileron and elevator controls, to place the airplane in the turn. He then releases pressure upon rudder and aileron controls. The skillful pilot never rides the controls and uses only the degree of control pressure necessary under the circumstances.

To hold the upper rudder of the airplane during a turn causes its nose to swing toward the outside of the turn and causes a slip with a consequent loss of lift. Slips are sometimes executed deliberately to lose excess altitude during a landing approach. Under such circumstance, as long as the airplane's nose is kept down, there is no danger of stalling or spinning.



## CHAPTER SIX

## HIGH SPEED FLIGHT

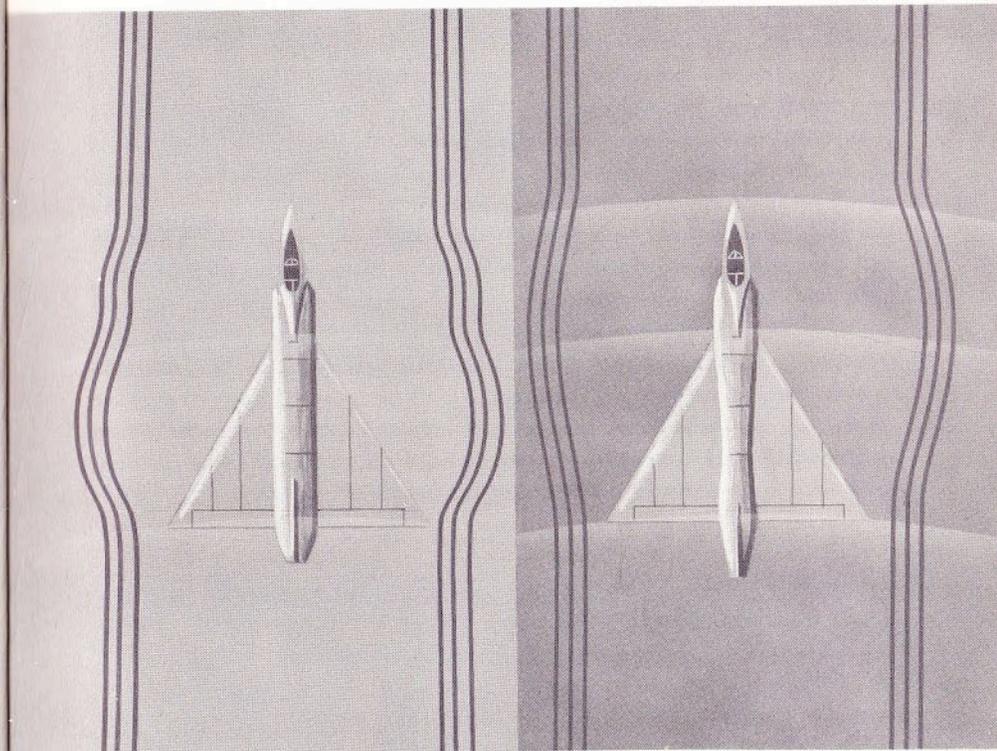
Even before jet aircraft flew at supersonic speeds, the speeds of airplanes with reciprocating engines began to approach the speed of sound. Supersonic speeds are designated by a *Mach number* instead of by miles per hour or knots. The Mach number of an aircraft is its air speed in feet per second divided by the speed of sound. An airplane that can fly at the speed of sound is flying at a Mach number of 1; one that can fly twice the speed of sound is flying at a Mach number of 2.

Sound, as you know, is actually a sensation produced through the organs of hearing. However, this sensation is caused by a disturbance (called a wave) in the equilibrium of a substance. The speed of sound waves in air increases as air density or air temperature increases. Under standard conditions the speed of sound at sea level is 760 mph; at an altitude of 35,000 feet, 660 mph.

When the speed of any projectile, a rifle bullet for example, reaches Mach 1, a shock wave is formed at, or in front of, the nose of the projectile. A shock wave may be simply defined as a piling up of the air in front of an object moving faster than the speed of sound—it also may be regarded as an accumulation of sound waves. Sometimes two shock waves will form in front of an object moving at a supersonic speed. An airplane flying at transonic speeds may create three shock waves; one in front of the aircraft's nose, another in front of its wings, and a third in front of its tail section.

Sometimes shock waves become attached to the upper surface of the wing of an airplane flying at subsonic speeds. This is because the air flow across the curved upper surface of the wing is moving more rapidly than the aircraft and does reach the speed of sound. (See p. 9.) When the speed of this relative airflow is not too great, the shock wave forms near the trailing edge of the wings, and high speed difficulties may not occur. However, as the speed of the relative airflow increases, the shock wave moves toward the leading edge of the wing, and in this position it causes a separation of the boundary layer (See p. 18), which makes the airplane hard to control and causes violent shaking of the wing.

The so-called sonic barrier is reached when the speed of an airplane reaches the speed of sound. Yet, aircraft, penetrating the transonic zone, now fly at supersonic speeds. If the leading edges of the wings of



OLD DESIGN

NEW DESIGN

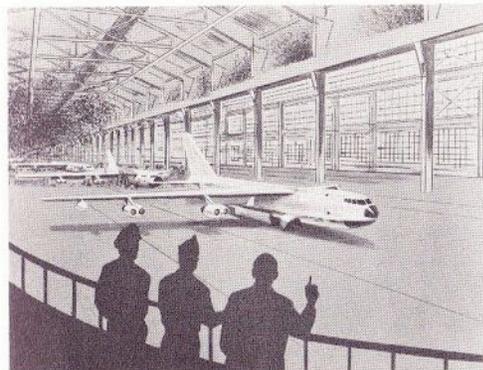
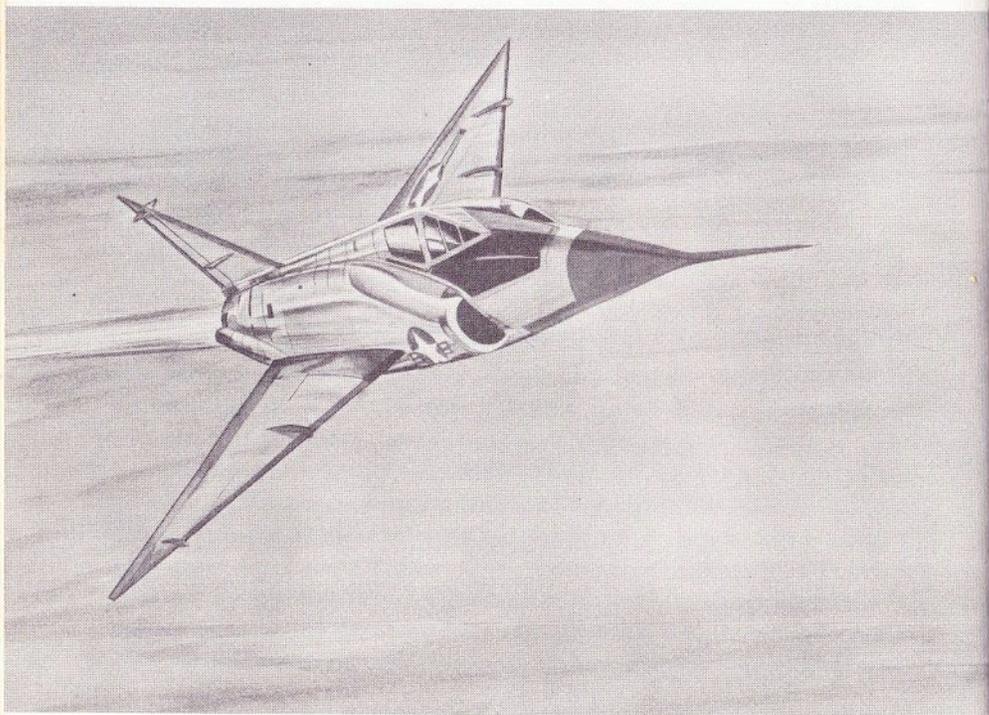
*Shock waves are carried through the transonic zone.*

the airplanes which fly at supersonic speeds are blunt, the shock wave forms in front of the wings; if these are sharp or thin, the shock wave attaches to them. ~~Less drag results when the shock wave is attached to the leading edge of the wings.~~ However, in either instance when aircraft speed is above Mach 1, no boundary layer separation takes place, no shaking of the airplane occurs, and no control difficulties are experienced.

A shock wave generated by an aircraft in supersonic flight tends to follow the original line of flight after the airplane changes its course. Consequently, a shock wave generated by an airplane diving at a super-

sonic speed will sometimes strike the surface of the earth with considerable impact. The noise of this impact is called the *supersonic boom*.

Airplane designers have learned that to decrease the thickness of an aircraft wing, reduces the speed of the relative airflow over the wing. They have also discovered that if they increase the degree of "sweep-back," an airfoil moving at a high subsonic speed reacts as would an airfoil with less sweep-back moving less rapidly. Hence, in order to delay the formation of shock waves on the wings of both high subsonic speed and supersonic speed aircraft, their wings are swept back, are comparatively thin, and have comparatively sharp leading edges. Airplane designers have also learned that drag builds up when shock waves are carried through the transonic zone. Discovering that the shock wave drag of the total airplane is greater than the sum of such drag on its parts, they have formulated the Area Rule. Applying this rule, in order to enable air to be displaced less violently, they now design aircraft with nose sections tapered and lengthened and fuselages pinched at the waists.



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## CHAPTER SEVEN

## STRUCTURE AND STRUCTURAL UNITS

AIRCRAFT ARE CONSTRUCTED TO SUIT DIFFERENT PURPOSES. You have observed that some military aircraft are quite different from civilian airplanes. However, a military airplane used to transport personnel is quite similar in appearance to one used by an air transport company to transport passengers. Among military aircraft you will observe that fighters do not look like bombers, nor do liaison aircraft look like fighters. Among civilian aircraft, the single engine utility airplane appears to be a craft completely different from a two-engine cargo carrier.

The differences between two airplanes are the differences between specific identical units of each. All airplanes are very much alike in that each is made up of power plant, fuselage, wings, stabilizers, flight control members, and landing gears. Each is alike in that pilot controls are throttle, stick (or a substitute for it), and rudder pedals regardless of airplane classification. Each requires for its operation the same general pilot skills and understandings. In general airplanes are alike; specifically airplane types differ in detail one from another.

The specific differences among airplane types makes possible aircraft classification. Consequently, airplanes may be classified on the basis of purpose, engine, wing, and landing gear. An aircraft may be powered by jet, reciprocating, or turbo-prop engine. It may have one engine, two engines, four engines, or more. These may be radial or in-line engines. The propeller may be behind the engine, as in the pusher-type aircraft. Or, it may be in front of the engine, as in the more common tractor-type engine.

An airplane's wings may be characterized, by their position with reference to the fuselage, as low-wing, mid-wing, and high-wing. Wing shape is also a factor in airplane classification. Consequently, descriptive terms such as clipped wing, swept-back wing, and delta wing are employed.

Landing gears are termed conventional when the traditional type landing gear is used. Two main wheels and a tail wheel comprise this landing gear type. The tricycle landing gear uses two main wheels and a nose wheel. On heavy aircraft each of these may be of dual construction. Some of the more recently constructed heavy bombers have two sets of main wheels, one near each end of the fuselage, and smaller wheels, one attached to each wing. This type is called a bicycle landing gear.

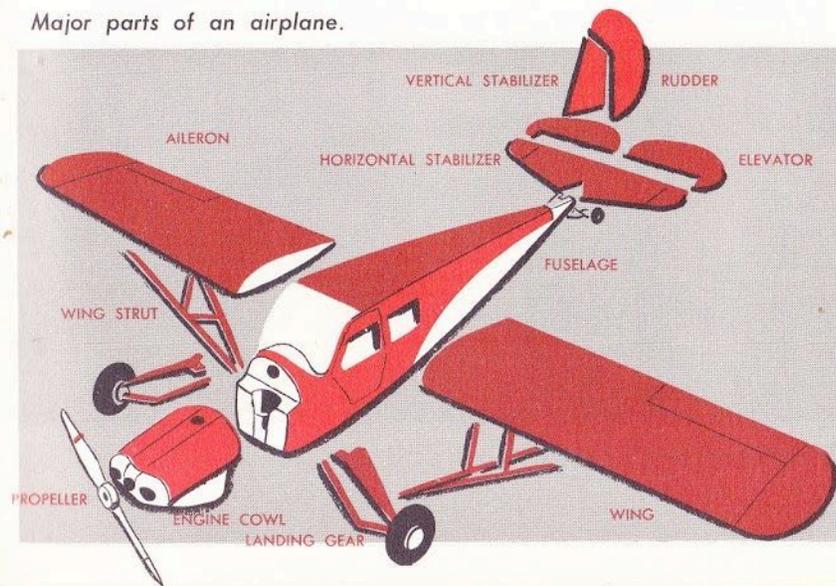
THE STRUCTURAL UNITS OF ANY AIRPLANE ARE FUSELAGE, WINGS, STABILIZERS, FLIGHT CONTROL SURFACES, NACELLES, AND LANDING GEARS. When these parts are assembled they are termed the *aircraft structure*, or the *airframe*.

The fuselage is the principal structural unit. It houses crew, passengers, cargo, instruments, and other essential equipment. On single engine aircraft the power plant is attached to it. There are two basic types of fuselage construction, the truss and the monocoque. In the construction of some aircraft a combination of truss and monocoque design is used. In truss type construction strength and rigidity are obtained by joining tubing, steel or aluminum, to produce a series of triangular shapes, called trusses. In monocoque construction rings, formers, and bulkheads of varying sizes give shape and strength to the stressed-skin fuselage.

In practice a semi-monocoque construction is most often used. In this type of construction lengthwise members called longerons and stringers hold the bulkheads, rings, and formers in position. These members also provide rigidity to the fuselage, a more adequate foundation for the skin, and a means by which it can be attached. The longerons are comparatively heavy and run the full length of the fuselage. The stringers are lighter and serve as "fill-ins." The skin is aluminum alloy, generally covered on both sides with pure aluminum. After it has been heat treated it is about as strong as a light steel. It is fastened to bulkheads, rings, stringers, and longerons by means of rivets.

The partition between the rear of the engine and its nacelle must be fireproof. This partition is called a firewall and is made of a highly heat-

Major parts of an airplane.

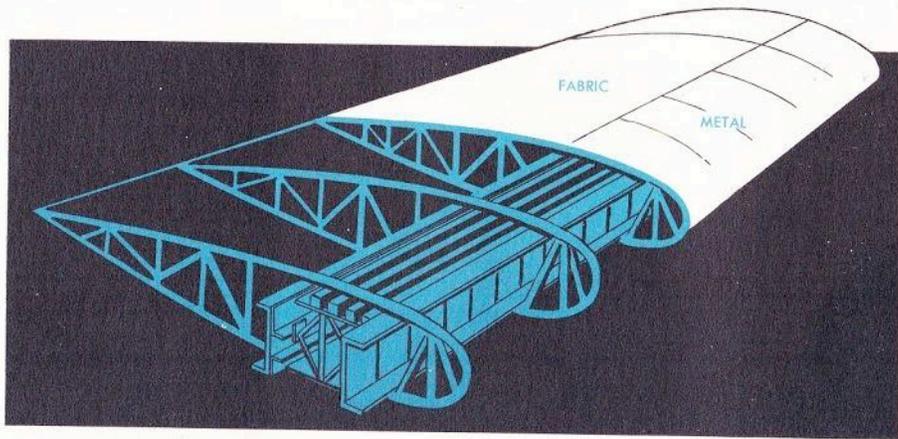


resistant, stainless steel. Nacelles house aircraft engines or other objects larger than the boundaries of the airfoil section. Their purpose is the fairing of such an object to reduce drag.

Wings are of two main types, semi-cantilever and cantilever. The semi-cantilever wing is braced both externally by means of wing struts and internally. The cantilever wings require no external bracing. In such wings the stress is carried by the wing spars, ribs, and stringers. Generally in this type wing, the skin or metal wing covering is constructed to carry wing stresses. Aircraft with wings so stressed are called *stressed skin types*.

The principal structural parts of the wing are spars, ribs, and stringers. These are reinforced by trusses, I-beams, tubing, or other appropriate devices. Cap strips provide a base to which the skin is attached and carry a portion of the "bending-load." The web forms the depth portion of the spar. Stiffeners give strength to the spar structure. Treated aluminum alloy is most commonly used as wing covering. The thickness of the covering depends upon the load carried or the stresses imposed upon the wing area where it is used.

The wing ribs actually determine the shape of the wing. Since a wing rib is an outline of a wing cross section, it can be used to help understand such terms as chord line, camber, and mean line. The chord line is a straight line, which extends from the leading to the trailing edge of the wing section. The camber is the rise of the curve from this line to the outline of the airfoil. Or to state this more simply, the distance from the chord to the upper surface of the airfoil is upper camber; that from the chord to the lower surface is lower camber. The mean line is a curved line equi-distant at each point from both upper and lower airfoil surfaces.



One type of wing construction.

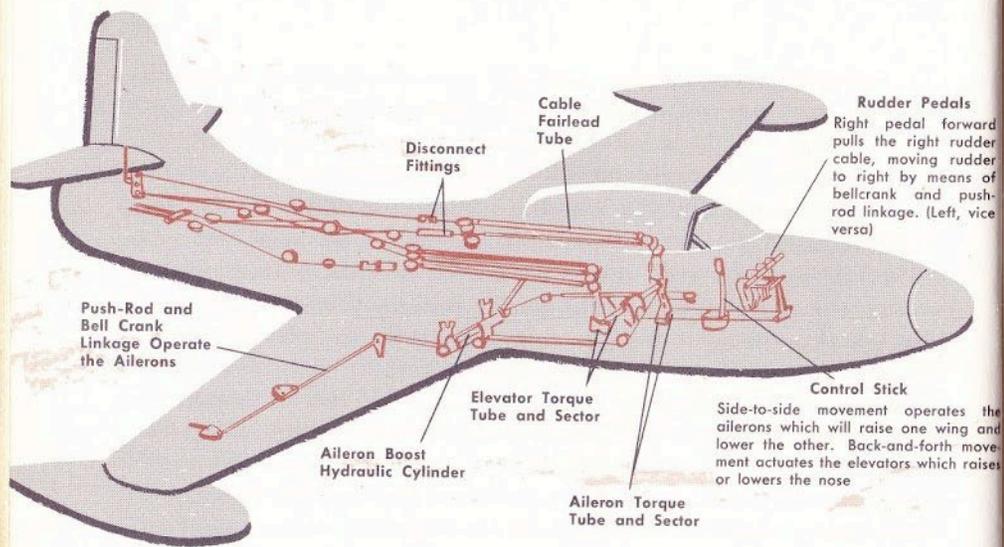
Sometimes wings are constructed with open spaces near their leading edge. Such an opening is called a slot. Slots delay the separation of boundary layer from the airfoil while its angle of attack is being increased. Hence, they help reduce the possibility of unintentional stalls.

IT IS THE PRACTICE TO TEST THE ACTUAL PERFORMANCE OF AN AIRPLANE, AIRPLANE WINGS, AND OTHER PARTS OF AIRPLANES IN WIND TUNNELS. However, models constructed to scale, although miniature replicas of airplanes, do not show the same aerodynamic characteristics that these airplanes display. A scientist named Reynolds discovered this. He also discovered that the airflow around an unconfined object changed when the size of the object changed, when the velocity of the flow changed, or when the air density changed. As a result of these discoveries, he concluded that if he were to increase, during a wind tunnel experiment, either the speed of the airflow or the density of the air, or both, a scale model would react as the full-sized airplane reacted under normal airspeeds and under standard atmospheric conditions. Experiments proved that his conclusions were correct. When he knew its dimension, its airspeed, and the density of the moving air, he was able to compute a value for any aircraft. He called this value the Reynolds Number (RN). The RN changed not only as the size of the aircraft or airfoil changed, but also as the speed, density, and viscosity of the air changed. Yet different aircraft with the same Reynolds Number displayed identical aerodynamic characteristics regardless of difference in their dimensions.

Moreover, when the Reynolds Number of a full sized aircraft, its dimensions, its air speed, and the density and viscosity of the atmosphere are known, the formula for the Reynolds Number can be used to find proper airflow speeds and/or air density necessary when during wind tunnel tests models rather than full-size airfoils are used.

THE FLIGHT CONTROL MEMBERS ARE DIVIDED INTO TWO GROUPS. The main group of controls consists of ailerons, elevators, and rudders. The auxiliary group consists of trim tabs, balance tabs, servo tabs, and landing flaps. The ailerons are attached by means of hinges to the trailing edge of the wing sections of both right and left wings. The elevators are similarly attached to the trailing edge of the horizontal stabilizer; the rudder, to the trailing edge of the vertical stabilizer. The horizontal stabilizer with the elevators and the vertical stabilizer with the rudder comprise the tail assembly, generally called the empennage. Ailerons, elevators, and the rudder are controlled by the pilot from the cockpit.

The tabs listed among the auxiliary controls help the pilot trim and balance the airplane in flight. They also help him operate the main

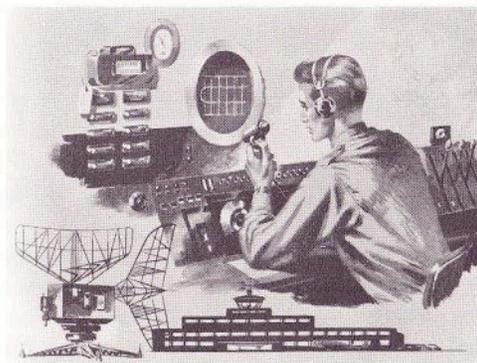


One type of control system.

controls by reducing the amount of pressure he would otherwise need to apply in order to actuate one of them. Landing flaps increase wing camber and consequently lift and drag, enabling the reduction of landing speeds and the distance required for landing runs. Flaps are either attached to the trailing edges of the wing or recessed into airfoils.

*Landing gears must provide both a rolling medium between aircraft and ground and a shock absorbing system.* A landing gear must be stressed to absorb great shocks. Two types of shock struts are in common use on light aircraft, the *spring strut* and the *air-oil strut*. The spring strut is made of spring steel and bends like the leaf-type automobile spring. The air-oil strut is composed of piston and cylinder. The cylinder is filled with air and fluid. The piston operates in the fluid. Holes in the piston permit the passing of fluid from one side of it to the other. In this manner abrupt shocks are prevented.

*Landing gears are generally the wheel type, although pontoons are used on aircraft operating from water surfaces.* Wheel type gears are either fixed or retractable. Retractable gears reduce drag. They may retract into the fuselage or into nacelles. They may retract backward, forward, or sideways, and they are operated manually, electrically, or hydraulically.



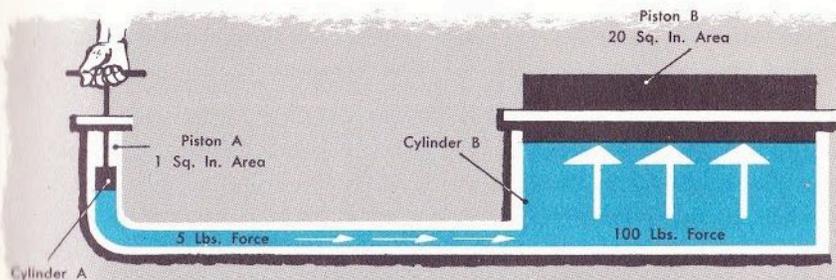
## CHAPTER EIGHT

## HYDRAULIC AND ELECTRIC SYSTEMS

As an airplane passenger you have no doubt noted changes in the sound of the propellers. These sound changes take place as the airplane engines are "warmed-up" just before "take-off," shortly after "take-off," and after the airplane reaches the desired cruising altitude and speed. During the "warm-up" period, the propeller pitch is changed to find out whether or not the pitch-changing mechanism is working properly. During "take-off" the propellers are turning at maximum rpm (revolutions per minute) with the blades set at a low angle of attack (low-pitch). When the airplane becomes airborne, its engine rpm changes from maximum to climbing and the propeller pitch changes from low toward high pitch. After the airplane reaches its cruising altitude and changes from climbing to level flight, its engine rpm changes from climbing to cruising and the propeller changes from intermediate to high pitch. It is these changes in propeller pitch which cause the changes in sound made by the propellers.

Some airplanes have reversible propellers. After one of these lands, the pitch of the propeller is reversed and, although the engine rpm is increased, the forward speed of the airplane is abruptly reduced. This is because the reversed propeller acts as a brake. Incidentally, airplanes with reversible propellers have safety devices which keep propellers from being reversed while the aircraft is in flight.

The scientific principles whose applications have developed the devices which control airplane propellers or start airplane engines are the same as those upon which are based many of the commonplace appliances which you use every day. When you apply the brakes to stop your car, you make use of the principles of hydraulics which, on some airplanes, enables changes of propeller pitch in flight, changes in the position of flaps, and operation of the airplane's brakes. When you step on the starter-switch of your car you make use of the principles of electricity which underlie the construction and operation of your radio and television, and of such household conveniences as electric lights, heaters, freezers, mixers, and the like. In order to fly a modern airplane, a pilot makes use of many auxiliary airplane-accessories which employ the principles of hydraulics and electricity. During your airplane journey, while you relaxed in comfort, the pilot, co-pilot, and engineer were busy with many tasks. The successful completion of each of these depended not only upon the skills with which the pilot operates the aircraft's controls, but also upon the proper functioning and skillful use of the airplane's hydraulic and electrical systems.



HYDRAULIC SYSTEMS AND ELECTRICAL SYSTEMS ARE AMONG THE MOST IMPORTANT OF THE AIRCRAFT'S COMPONENTS. The aircraft hydraulic system employs fluid to bring about the movement and force needed to operate brakes, to lower landing gears, and to extend and lower flaps. Also, the mechanism which controls the pitch of the propeller may be hydraulically operated. A physicist named Pascal discovered the principle of hydraulics. It may be stated as follows: "A pressure exerted anywhere on a confined fluid is transmitted undiminished to every portion of the interior of the vessel containing the fluid. This pressure acts at right angles with an equal force on equal areas."

The application of the hydraulic principle makes it possible to increase a force originally exerted. Assume that attached to the container of the hydraulic fluid were two pistons and their cylinders. Assume that one of these has an area of 1 square inch; the other an area of 10 square inches. If 5 pounds of pressure is placed on the smaller piston, 10 x 5 pounds of pressure will be created by the larger. This is true since the pressure applied on the 1 square inch surface of the small piston will be transmitted undiminished to each of the 10 square inches of the surface of the larger piston. Also, pressure applied to one piston in an hydraulic system is transmitted undiminished to all pistons throughout the system.

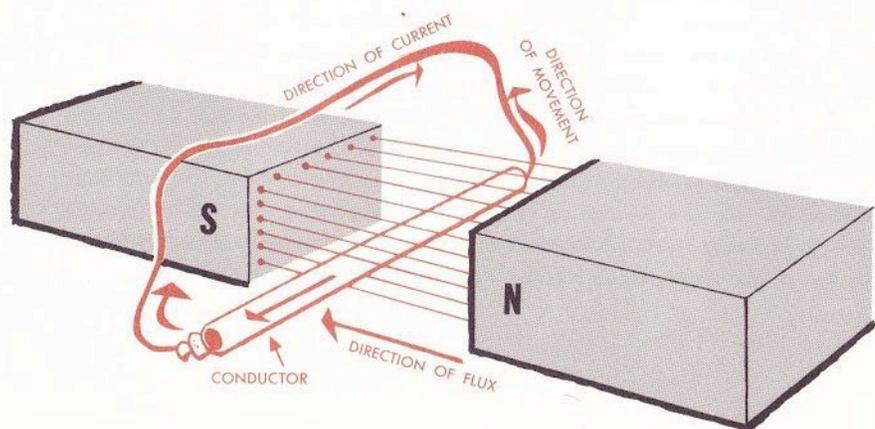
Pascal's principle is the principle upon which the braking system of your car is based. The pressure of your foot on the brake pedal is multiplied by the hydraulic mechanism so that by the time it reaches the brake bands it is sufficient to control the car's weight. It is a similar system that enables the pilot of a large aircraft to retract landing gears weighing hundreds of pounds, or to operate other component parts when great power is required. One significant difference between the hydraulic system of your car and that of the aircraft is the manner in which pressure is built up in the system. Hydraulic pumps generate and maintain pressure in the aircraft's hydraulic system. The pilot, instead of generating it as

you do when you step on the brake pedal of your car, regulates it, applying only that needed to do the work required.

AN AIRPLANE IN FLIGHT MAKES MANY USES OF ELECTRICITY. The air-route that an airplane travels is marked by signals broadcast from a range-station. Pilots can communicate, while in flight, with stations on the ground or aircraft in the air. The use of electricity makes such communication possible. The electricity which is generated in flight is also used for many other purposes. Generators charge storage batteries; magnetos provide current which spark plugs convert to sparks that in turn ignite the fuel mixture which keeps engines operating. Solenoids use electric currents from batteries to supplement the pilot's muscles, making it possible by cockpit control to operate large switches, valves, and mechanical devices. Electric motors further increase the power at the disposal of the pilot. They help him start the engines, and when these are not included in the hydraulic system, they help him operate flaps, and change the pitch of the propeller. In fact they can be adapted to serve wherever power is required.

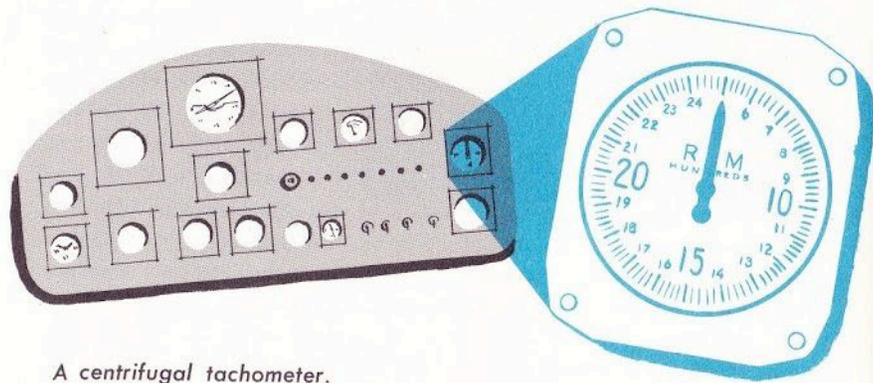
Whenever a conductor of electricity is moved through a magnetic field, voltage is induced in such conductor (wire, cable, etc.). Voltage is the force that "pushes" an electrical current through the conductor. Generators and magnetos, a special kind of generator, make use of this principle to produce electricity which is used to help the pilot navigate, control his aircraft, inspect the weather ahead of him, and analyze his engines operation, discovering the location of trouble spots before these can do series damage.

All this means that when aircraft are designed and their parts built and assembled, provision must be made for magnetos, generators, storage batteries, and motors and for the proper location of these. It is also necessary, when assembling an aircraft, to install the electric cables, linkage, and servo-mechanism which makes it possible for the different electric motors to do their work.



## CHAPTER NINE

## AIRCRAFT INSTRUMENTS



A centrifugal tachometer.

The operation of modern aircraft as they perform their civilian or military tasks is possible because they are equipped with instruments. It is said that the instrument board is the nerve center of an airplane. The number of instruments housed in this panel range from a few, such as those found on small airplanes—a magnetic compass, airspeed indicator, oil-pressure gauge, tachometer, and altimeter—to well over 100 instruments and other devices employed by large multi-engine aircraft.

Instruments are classified either in terms of their use or with respect to the principle underlying their construction. When instruments are classified according to use, there are four major groups—engine instruments, aircraft instruments, flight instruments, and navigation instruments. Engine instruments keep the pilots and flight engineer aware of engine rpm, engine temperature, oil pressure, fuel on board, fuel flow, manifold pressure, and carburetor pressure. Aircraft instruments reveal to the pilots and flight engineers, air temperature, position of landing gears and flaps, hydraulic pressure, and the like. Flight instruments inform the pilot of his altitude, air speed, and the attitude of the airplane. Navigation instruments help the pilot find his way from point of departure to destination. These include clock, compass, directional gyro, drift meters, sextant, radio, radar, and radio direction finders.

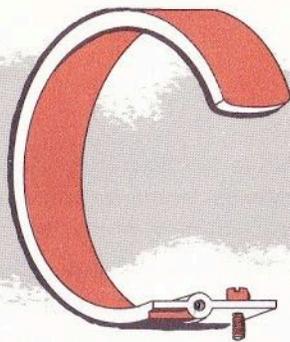
With respect to the theory basic to the operation of the instruments found on an airplane's instrument board, there are three groups: mechanical, pressure, and electrical instruments.

THE MECHANICAL INSTRUMENTS ARE CAPABLE OF BOTH DIRECT AND INDIRECT MEASUREMENT. Sometimes direct measurement may be obtained by mechanical linkage. One kind of tachometer uses mechanical linkage to measure the number of times per minute (rpm) that the engine crankshaft rotates. One aircraft instrument, the bank indicator, employs a gyroscope and rate of change forces. The gyro-horizon, which indicates fore and aft attitude of an airplane, is activated by these forces. The accelerometer, an instrument used to indicate the degree of stress which might be placed on an aircraft in flight, is an instrument activated by the force of gravity. The drift meter, certain types of fuel level gages, and the navigator's clock are all considered mechanical instruments.

PRESSURE INSTRUMENTS ARE OF TWO GENERAL TYPES DEPENDING UPON THE PRINCIPLE BASIC TO THEIR OPERATION. One type employs the bourdon tube. The bourdon tube is made of spring-tempered brass, bronze, or beryllium copper. It is curved, so that it tends to straighten when pressure is imposed upon the fluid which it contains and to assume its original shape when the pressure is released. Among instruments which use a bourdon tube are temperature gages, fuel-pressure gages, oil-pressure gages, and hydraulic-pressure gages. Sometimes a single unit incorporates the temperature, oil, and fuel-pressure gages of the engine.

The second type of pressure instrument employs a diaphragm. The altimeter and the airspeed indicator are instruments of this type. The diaphragm employed by an altimeter is sealed after all the air has been removed from it. The diaphragm of the airspeed indicator is attached to the pitot tube. The instrument case of the airspeed indicator is attached to the static side of the pitot-static system. The difference between the pressure of air upon the opening of the pitot tube and that contained in the instrument case is indicated on the dial of the instrument as knots or miles per hour.

An altimeter measures the air pressure at an airplane's position above the ground. It is actually an aneroid (or diaphragm type) barometer which reads in feet rather than in units of barometric pressure. Since we know that as altitude increases, pressure decreases, we need only to measure pressure to discover our approximate altitude above sea level. We also

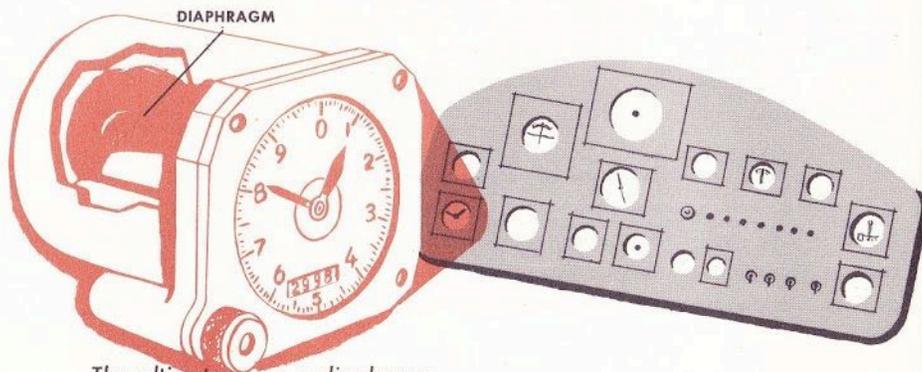


### The Bourdon Tube

know that atmospheric pressure is affected by temperature and other weather conditions. Consequently, it is necessary to correct indicated readings by taking temperature and pressure variations into account when exact altimeter or airspeed indicator readings are needed. The rate of climb indicator, the manifold pressure gage, and vacuum gages all use the diaphragm as their pressure element.

Electrical instruments may be used instead of some of the mechanical and pressure instruments. This is the case when the distance between source and cockpit is comparatively great and, as a consequence, no other method can transmit the measurements so readily. Electrical instruments include the electric tachometer; cylinder temperature indicators; oil, air, and coolant temperature indicators; fuel-air mixture indicator; pressure warning units; and even the magnetic compass.

A NUMBER OF PRINCIPLES ARE EMPLOYED IN DESIGNING ELECTRICAL INSTRUMENTS. The magnetic compass takes advantage of the fact that the earth itself acts as a great magnet. A magnetized bar of iron suspended so that it may turn freely in any direction will always align itself so that one end points to the earth's north magnetic pole and the

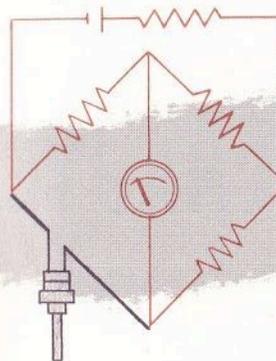


The altimeter uses a diaphragm.

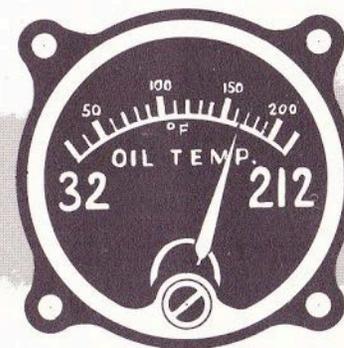
other end points to its south magnetic pole. Designers and builders of magnetic compasses discovered these facts long ago and have since that time employed them to devise instruments by which men orient themselves in their surroundings.

Two wires made of different metals, when connected at one end, will, when heated, generate an electric current, provided the other ends of the wires remain at the normal temperature. This fact is recognized in the construction of cylinder temperature indicators. The combination of dissimilar wires is called a thermocouple. The very small voltage generated by the thermocouple is measured by an indicating instrument which employs the principle of the galvanometer. The galvanometer makes use of a magnetized needle, suspended within a coil of wire, and a flexible spring. When a current is passed through the wire, a magnetic field is produced. The needle attempting to align itself with this field activates the indicator and shows the strength of the current passing through the coil of wire, hence, of the current generated. The ordinary thermocouple gives only 30 millivolts (30/1000 of a volt) at a temperature of 1000°F. At 500°F it produces enough voltage to deflect the indicator, but at temperatures below 300°F it does not provide sufficient voltage to assure accurate readings; consequently, it is not an appropriate measure for temperature variations below 300°F. For this reason oil, air, and coolant temperature indicators employ the principle of the Wheatstone Bridge.

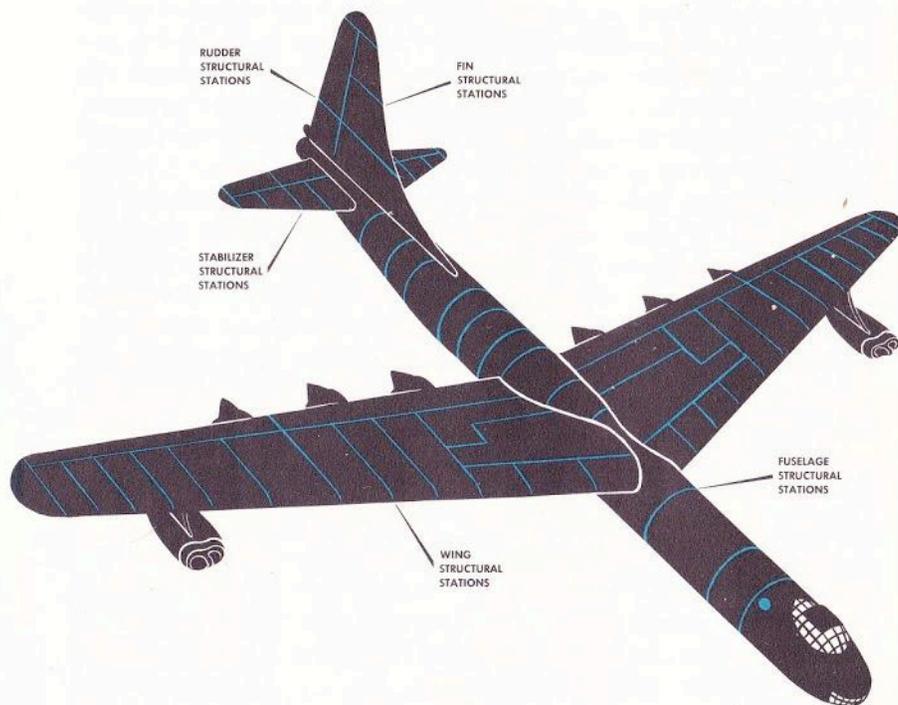
The Wheatstone Bridge makes use of the fact that the resistance of a metal to the flow of an electrical current changes directly as its temperature changes. The Wheatstone Bridge converts this change-in-resistance to change-in-current in order to obtain pointer deflection across the scale of the temperature indicator.



The Wheatstone Bridge



## STATION NUMBERING



## CHAPTER TEN

IN ORDER TO HELP THOSE WHO BUILD AIRCRAFT AND THOSE WHO REPAIR THEM ASSEMBLE THE PARTS OF AN AIRPLANE PROPERLY, THE MAJOR AIRCRAFT COMPONENTS—THE FUSELAGE, EACH WING, STABILIZER, RUDDER, NACELLE, AND CONTROL SURFACES—ARE MARKED OFF IN STATIONS. To mark the stations on an aircraft part, a zero reference point is selected, and other reference points are marked off from this measured in inches and fractions thereof. For the fuselage, the zero reference point may be at the nose of the aircraft, at an imaginary point in front of the nose, or at some other forward point, such as the firewall.

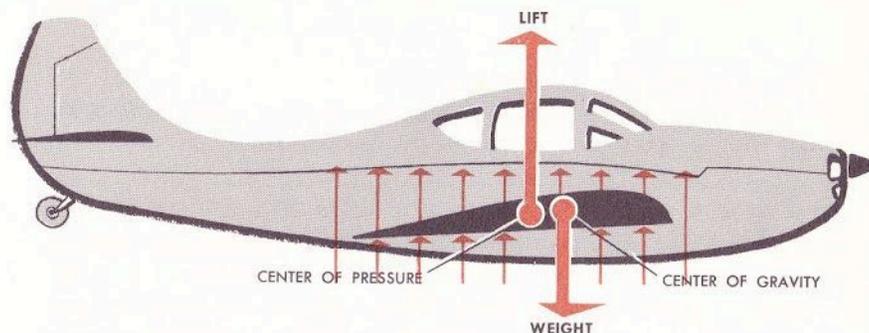
Among the components of an aircraft whose locations are indicated by station number are fuel tanks and baggage compartments. To assure the aircraft proper balance, those who assemble it are guided by station markings. In order to load the aircraft so that proper relationship is kept between the center of pressure and the center of gravity, the flight engineer also must calculate the effect of the contents of fuel tank and baggage compartments upon the lateral and longitudinal stability of an airplane.

THE CENTER OF GRAVITY IS THE POINT AT WHICH THE FORCE OF GRAVITY AFFECTING ALL THE AIRCRAFT'S PARTS IS ASSUMED TO BE CONCENTRATED. It is usually defined in terms of the mean<sup>1</sup> aerodynamic chord.<sup>2</sup> A line drawn through the CG and erected perpendicular to the longitudinal axis of an airplane will bisect the wing at approximately one-third of the chord length aft its leading edge. Airplane manufacturers specify fore and aft center of gravity (CG) limits to guide those responsible for aircraft loading.

*The center of pressure is the point at which the aerodynamic forces acting upon the aircraft are concentrated. This concentration of pressure forces contributing to lift, like the concentration of gravity forces, is assumed to be upon the chord. The center of pressure (cp) moves forward as the angle of attack increases, and moves backward as the angle of attack decreases. For most airfoil sections (wings) the most forward cp position is about three-tenths of the chord length aft of the leading edge of the wing, and the most rearward cp position is four-tenths of the chord length aft of the leading edge. It should be noted that the center of pressure and the center of gravity always must be sufficiently close together to assure longitudinal balance.*

<sup>1</sup>Average.

<sup>2</sup>Chord is defined as the distance between imaginary perpendiculars erected at the leading and trailing edges of a wing.



In order to determine whether or not the proper relationship exists between CG and cp, the flight engineer makes use of the theory of weight and balance. If you were to hold a weight of some kind at arm's length from your body, the downward force of the weight expressed in inch-pounds would be equal to the length of your arm multiplied by the weight in pounds of the object held. For example, if you held a ten-pound weight 20 inches from your body, the downward force at your hand would be 200 inch-pounds. From this condition we can derive the formula  $M=AW$ , where  $M$  is a product known as a moment;  $A$  is the length of the arm in inches; and  $W$  the weight of an object in pounds.

Suppose that two weights are suspended from a bar (assumed to be weightless) and that we want to find the center of gravity of the bar and its weights. One weight of 10 pounds is located two inches from the left hand end of the bar as we stand facing it; the other weight of 5 pounds is located 32 inches from the same reference point.<sup>1</sup> In order to solve for CG, we find it convenient to use the following table.

Item	W (in pounds)	×	A (in inches)	=	M (inch pounds)
Object	10		2		20
Object	5		32		160
Totals	15				180

Since  $W \times A = M$ ,  $\frac{M}{W} = A$ . If  $M=180$  and  $W=15$ ,  $\frac{M}{W} = \frac{180}{15}$  or 12.

<sup>1</sup>For convenience in computing the CG of an aircraft the reference point is generally, but not always, located so that moments will all be positive.

Consequently  $A=12$ . The distance of the CG from the reference point is found to be 12 inches.

Do you see how easy it is to locate the center of gravity of an assembly of weights attached to a bar? It is just as easy to locate the CG of an airplane; or to find a new center of gravity when changes are made in the weights that the airplane carries; or to determine readjustment of cargo so that CG limits are not exceeded. All you have to do is establish a center of reference and proceed much as we did in the above illustration.

Assume that we want to discover whether or not the CG of a loaded airplane exceeds the prescribed forward or aft CG limits, which for this particular craft are 27.38 inches and 31 inches from the reference point. Also given are the following data.

Item	W	A	M
Airplane	682	26.56	18113.92
Fuel	32.5	25	812.5
Oil	7.5	-14	-105
Baggage	30	57	1710
Pilot	170	37	6290
Passenger	170	37	6290
Totals	1092	—	33276.42

Remember:  $\frac{M}{W} = A$ ;  $A = \frac{33276.42}{1092} = 30.47$  inches

Therefore, the number 30.47 inches is the length of the arm which, when multiplied by the total weight (1092 pounds), will give the total moments (33276.42 inch-pounds). Hence, 30.47 inches is the distance of the CG from the reference point. In this case the CG is within the specified fore limit of 27.38 inches and aft limit 31 inches from the reference point.

## SUMMARY

Heavier-than-air craft fly because their construction is based upon principles which have been established as scientifically sound. The moving aircraft wing reacts with the air through which it moves. As a result lift forces are created. Other forces act upon the aircraft-in-flight. Among these are thrust, drag, and gravity. Since forces are balanced when an aircraft reaches cruising speed in straight and level flight, thrust is equal to drag; consequently, the greater the drag, the greater the required thrust.

In the interest of economy of aircraft operation aeronautical engineers are faced with the problem of reducing drag. They must also design aircraft which are inherently stable, yet which react readily when pilots operate aircraft controls. Aeronautical engineers need to know of the stresses which are placed upon an airplane in flight. Materials which will withstand the stresses of all normal flight maneuvers must be specified for use in aircraft construction. Pilots must prevent placing stress upon aircraft in flight which the aircraft are not built to withstand.

High speed flight has introduced new engineering and operational problems. Research has overcome many of these problems. Research and testing of new aircraft design make use of such devices as the wind tunnel. Research determines the type of construction best suited for each type of aircraft.

The application of scientific principles, such as those of electricity and hydraulics, have made possible great advances in aviation and its related fields. Aviation safety requires understanding of, and observance of, these principles. The pilot who flies the aircraft, the mechanic who maintains it, and the engineer who supervises the loading of it, must all, in the interest of its successful operation, be guided by fundamental understandings of its nature and of the aerodynamic principles which make its flight possible.

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