SUBCOURSE
AL0966

EDITION
B

BASIC AERODYNAMICS

THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT

ARMY CORRESPONDENCE COURSE PROGRAM

BASIC AERODYNAMICS

Subcourse Number AL0966

EDITION B

US Army Aviation Logistics School
Fort Eustis, Virginia 23604-5439

2 Credit Hours

Edition Date: JULY 1994

SUBCOURSE OVERVIEW

This subcourse is to be completed on a self-study basis. You will grade the practice exercise when you complete it using the answer key which is enclosed. If you have answered any question incorrectly, study the question reference shown on the answer key and evaluate all possible solutions.

There are no prerequisites for this subcourse.

This subcourse reflects the doctrine which was current at the time it was prepared. In your own work situation, always refer to the latest official publications.

Unless otherwise stated, the masculine gender of singular pronouns is used to refer to both men and women.

TERMINAL LEARNING OBJECTIVE

ACTION: You will identify policies, procedures and methods for discussing the effect of the atmosphere on flight, basic aerodynamics, and helicopter fundamentals.

CONDITIONS: You will use the material in this subcourse.

STANDARD: To demonstrate competency of this task, you must achieve a minimum of 70% on the subcourse.

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GRADING AND CERTIFICATION INSTRUCTIONS

Examination: This subcourse contains a multiple-choice examination covering the material in the three lessons. After studying the lessons and working through the practice exercises, complete the examination. Mark your answers in the subcourse booklet, then transfer them to the ACCP examination response sheet. Completely black out the lettered oval which corresponds to your selection (A, B, C, or D). Use a number 2 lead pencil to mark your responses. When you complete the ACCP examination response sheet, mail it in the preaddressed envelope you received with this subcourse. You will receive an examination score in the mail. You will receive two credit hours for successful completion of this examination.

LESSON 1

EFFECT OF THE ATMOSPHERE ON FLIGHT
Critical Tasks:

OVERVIEW

LESSON DESCRIPTION:

In this lesson you will learn the effect of the atmosphere on flight.

TERMINAL LEARNING OBJECTIVE:

ACTION: Know the effect of atmosphere on flight.

CONDITION: You will be given the information provided in this text, a list of reference manuals, and charts provided in the text.

STANDARD: As a result of this instruction you will know and be able to describe how and why an aircraft flies and the effect atmosphere and flight control have on an aircraft.

REFERENCES: Listed in appendix I.

INTRODUCTION

The atmosphere is the envelope of air that surrounds the earth. Over one-half of the air, by weight, is within the lower 18,000 feet of the atmosphere; the remainder is spread out over a vertical distance in excess of 1,000 miles. No definite outer atmospheric boundary exists: the air particles become fewer with increasing altitude until they gradually overcome the earth's gravitational force and escape into space. The atmosphere rotates with the earth as a gaseous outer cover. Within the atmosphere, other air movement occurs. Differences in the temperature of the earth's surface affect the density of the atmosphere and cause a continuous internal air movement called circulation. The force of this circulation varies between breezes and winds. The latter can have forces that range from mild to gales, hurricanes, and typhoons.

1.1 GENERAL

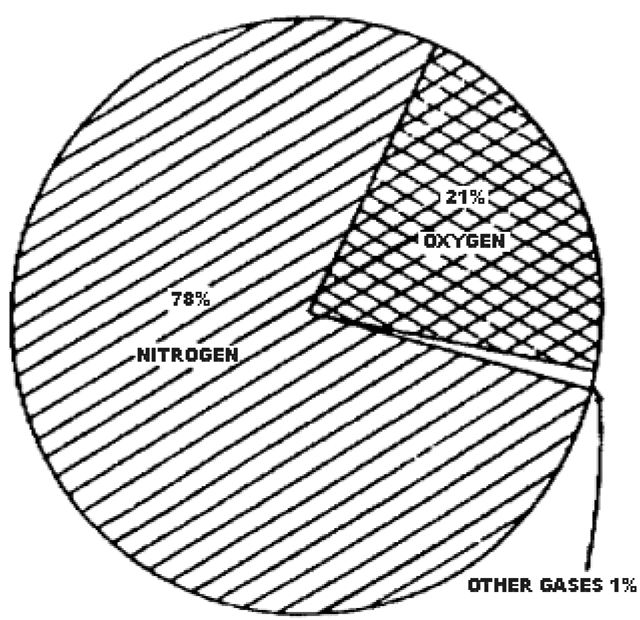
The atmosphere is the envelope of air that surrounds the earth. Over one-half of the air, by weight, is within the lower 18,000 feet of the atmosphere; the remainder is spread out over a vertical distance in excess of 1,000 miles. No definite outer atmospheric boundary exists: the air particles become fewer with increasing altitude until they gradually overcome the earth's gravitational force and escape into space. The atmosphere rotates with the earth as a gaseous outer cover. Within the atmosphere, other air movement occurs. Differences in the temperature of the earth's surface affect the density of the atmosphere and cause a continuous internal air movement called circulation. The force of this circulation varies between breezes and winds. The latter can have forces that range from mild to gales, hurricanes, and typhoons.

1.2 COMPOSITION OF THE ATMOSPHERE

As shown in figure 1.1. a given volume of dry air contains approximately 78 percent nitrogen; 21 percent oxygen; and 1 percent argon, carbon dioxide, and minute amounts of other gases. Air contains, in addition to the gases just mentioned a variable amount of water vapor, most of which is concentrated below 30,000 feet. The maximum amount of water vapor the air can hold depends primarily upon the temperature of the air; the higher the temperature, the more water vapor the air can hold. Water vapor in the atmosphere varies from insignificant amounts to 4 percent by volume (100 percent humidity).

Air also contains variable amounts of impurities such as dust, salt particles, and products of combustion. These impurities are important because of their effects on visibility and especially because they are necessary to cause the water vapor to form into clouds and fog and to condense into rain and snow. If the air were absolutely pure there would be little condensation.

Figure 1.1. Composition of the Atmosphere



1.3 STRUCTURE

Although light and elastic, air does have weight. Because of its weight, the atmosphere has a pressure of approximately 14.7 pounds per square inch at sea level. Put another way, imagine a square 4 inches on one side and 5 inches on the longer side. This is a space 20 inches square, and at sea level, the atmospheric pressure on the square is 294 pounds (14.7 x 20). Standard air is 15°C., and normal barometric pressure at sea level is 29.92 inches of mercury. The three figures (14.7 pounds, 15°C., an 29.92 inches) make up "standard conditions," a term often used instead of the three figures. Assuming a constant temperature, the density of a volume of air varies directly with the pressure. If the pressure is doubled, the density is doubled.

The letter C in 15° stands for Centigrade, a scale in the metric system for measuring temperature. The temperature of 15° C is equal to 59° Fahrenheit. The conversion formula to change Centigrade to Fahrenheit is: 9/5 x (15°) + 32° = 59°F. To convert from Fahrenheit to Centigrade, the formula is: C = 59° - 32° x 5/9).

Figure 1.2 shows the atmosphere divided into layers circling the earth. The layers, starting with the one next to the earth, are the troposphere: most of our weather occurs in this layer. Next are the stratosphere, ionosphere, and exosphere. The tropopause is a narrow area between the troposphere and the stratosphere. Notice in figure 1.2 that the various cloud formations appear to straddle the line identifying the tropopause location. The jet stream is near the upper portion of the troposphere. The troposphere varies in height from 60,000 feet above sea level over the Equator to 25,000 feet over the poles. Its height varies with the seasons; it is higher in summer than in winter. In the temperate zones, it is about 35,000 feet above sea level.

1.4 TEMPERATURE VARIATION WITH ALTITUDE

The temperature in the troposphere decreases as an aircraft gains altitude, because the air closest to the earth is warmer and receives the largest amount of the sun's energy. The variation in temperature with altitude is called the temperature lapse rate and is usually expressed in degrees per thousand feet. If observations taken day after day at thousands of locations around the world were averaged, the average temperature lapse rate would be about 2°C or 3 1/2°F per thousand feet.

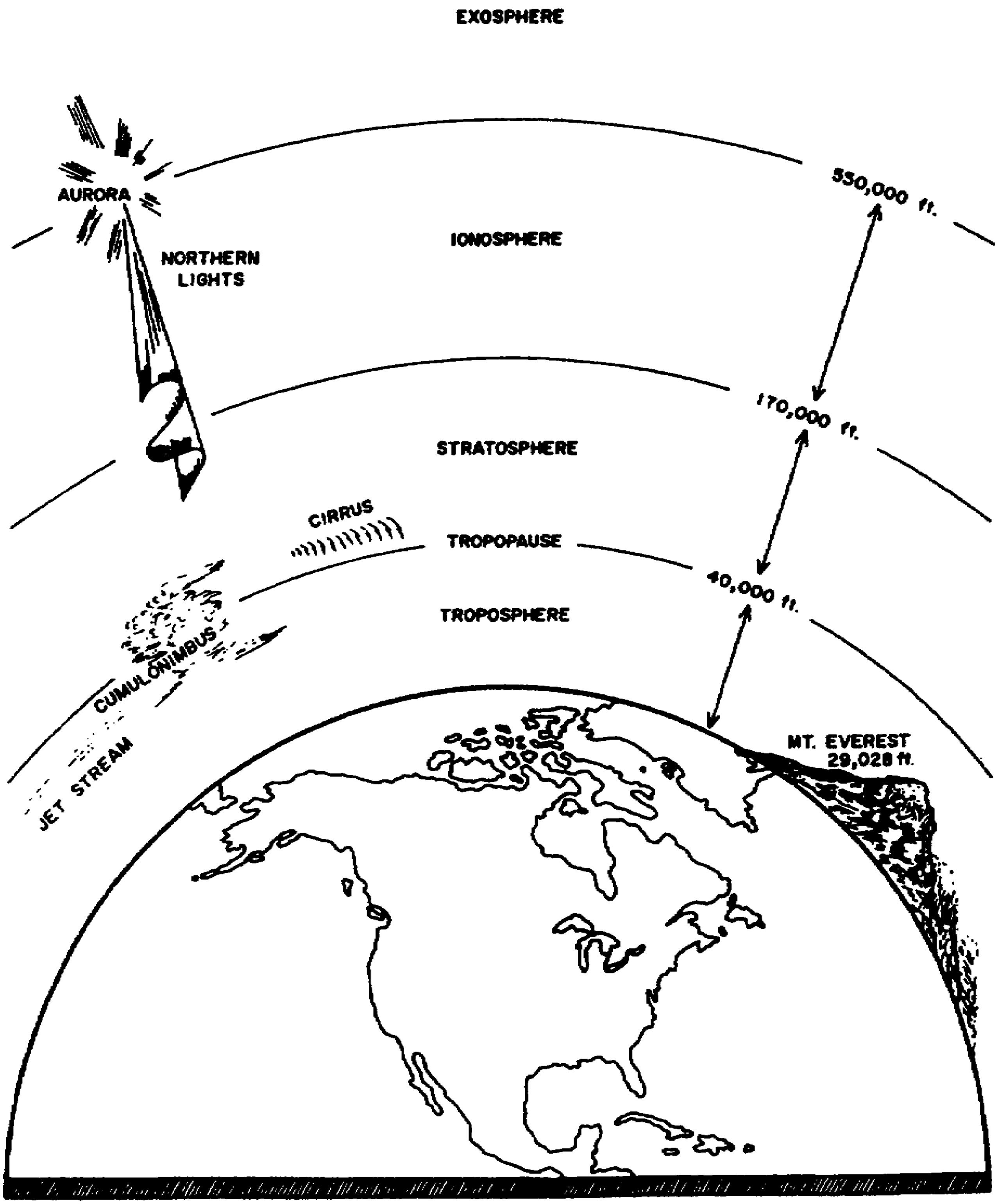


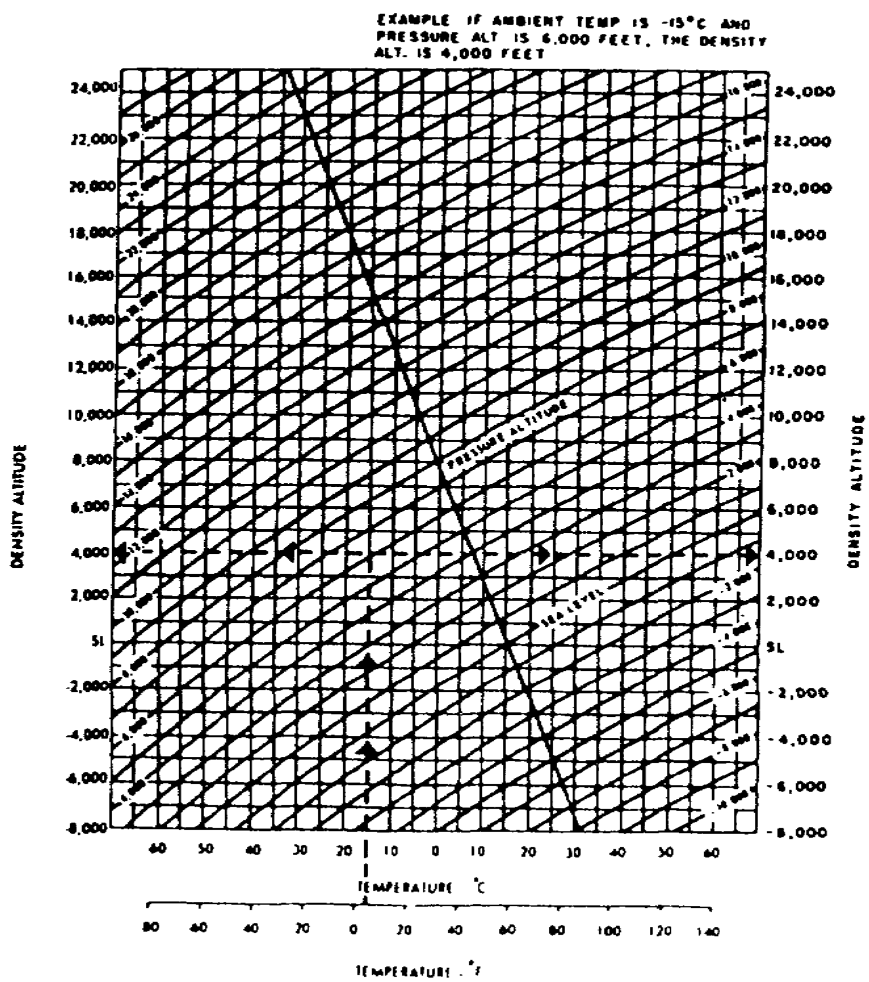
Figure 1.2. Layers of the Atmosphere

1.5 DENSITY ALTITUDE

Density altitude is the air density that exists at a given altitude for a given temperature. An airfoil's efficiency, either a wing or a rotor blade, is decreased at high altitudes by the lack of air density. All aircraft, regardless of design, have a ceiling (limit) where the air is too thin to sustain flight. The effect of air density on helicopter performance is vital because of the critical load limit and confined-area operation usually required of the helicopter.

Density altitude is pressure altitude corrected for temperature. Figure 1.3 shows the density altitude chart used in operating Army aircraft. An airfield may have a density altitude that varies several thousand feet from the mean sea

Figure 1.3 Density Altitude Chart.



level (MSL) elevation of the field. If the density altitude is higher than average for the field, this field has a high density altitude. An example of this is an airfield at 5,000 feet MSL with a density altitude of 10,000 feet. Aircraft operating from this field would be in air of the same density that would usually be found in the atmosphere at 10,000 feet. The efficiency of the aircraft can be seriously affected in high density altitudes, especially when the aircraft is critically loaded. If the density altitude is lower than average for a given altitude, the efficiency of the aircraft increased. A pilot operating from a field of 5,000 feet MSL with a density altitude of 1,000 feet is in the same air density field elevation that usually exists at 1,000 feet. Further, the density altitude on any airfield varies from hour to hour and day to day.

1.6 SUMMARY

Nitrogen, oxygen, argon, carbon dioxide, and small amounts of other gases make up the air surrounding the earth. The amount of water vapor in the air depends upon the temperature of the air. Impurities in the air are important because of their effect on visibility and the fact that they are necessary for forming clouds and condensing water vapor.

Air has weight and is in layers surrounding the earth. The layers, starting with the one next to the earth, are the troposphere, stratosphere, ionosphere, and exosphere. The tropopause is a narrow area between the troposphere and the stratosphere. The jet stream is near the upper portion of the troposphere.

As altitude is increased, temperature decreases at an average lapse rate of 2°C or 3 1/2°F per thousand feet. As temperature increases or altitude becomes higher, wings and rotor blades become less efficient. Density altitude must be evaluated before takeoffs or landings can be accomplished safely.

LESSON 2

BASIC AERODYNAMICS
Critical Tasks:

OVERVIEW

LESSON DESCRIPTION:

In this lesson you will learn basic aerodynamics.

TERMINAL LEARNING OBJECTIVE:

ACTION: You will know basic aerodynamics.

CONDITION: You will be given the information provided in this text, a list of reference manuals, and charts provided in the text.

STANDARD: You will correctly answer all the questions in the practice exercise before you proceed to the next lesson

REFERENCES: Listed in appendix I.

INTRODUCTION

2.1. GENERAL

Aerodynamics involves the motion of air and other gases and the forces acting on objects in motion through the air. Put another way, aerodynamics deals with aircraft, wind movement, and atmosphere. A working understanding of aircraft flight must start with a basic knowledge of flight theory as it pertains to conventional aircraft.

2.2. BERNOULLI'S THEOREM

At any point in a tube through which a liquid is flowing, the sum of pressure energy, potential energy, and the energy of motion is constant. This theory was discovered by Daniel Bernoulli, a Swiss mathematician and physician. How the theory works is illustrated in figure 2.1. An American engineer, Clemens Herschel, invented the venturi tube and named it in honor of Giovanni Venturi. If the same amount of air that enters the airflow inlet is to leave the airflow outlet, then the velocity of the air must increase while passing the venturi throat. As the velocity increases, the air has less time to push against the sides of the tube, thereby exerting less pressure. Figure 2.1 shows the decrease in pressure gages. Because there is no change in the velocity of the air about the open end of the tube, there is no change in pressure. The differential pressure on the ends of the tubes attached to the venturi throat causes the fluid to move toward the end of the tube that has the least pressure.

2.3. NEWTON'S LAWS

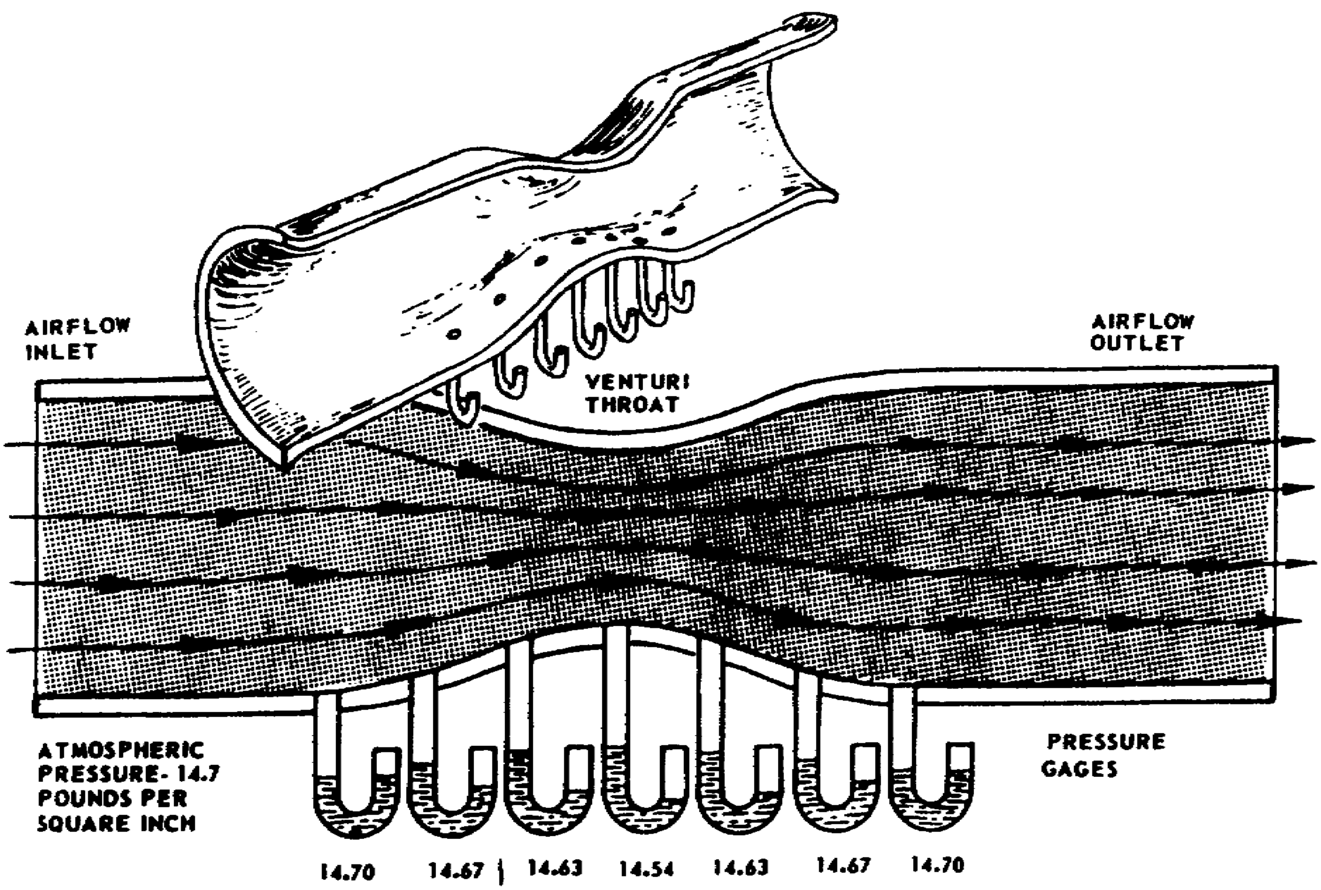
Sir Isaac Newton formulated the three laws of motion upon which classical dynamics are based. These laws are directly applicable to modern aerodynamics and are discussed in the subparagraphs that follow.

a. The first law. A body at rest remains at rest, or if in motion it continues to move in the same direction with the same speed, unless a force acts upon it. To accelerate an airplane, for example, the engine must deliver a thrust greater than the existing drag or resistance force. For unaccelerated flight, the thrust must be exactly equal to the drag.

b. The second law (two parts). (1) When different forces are allowed to act upon moving bodies, the rates at which the momentum changes are proportional to the forces applied. For example, two forces are judged equal if they produce a change of momentum at equal rates. One force is twice as great as another if it changes the momentum at equal rates. One force is twice as great as another if it changes the momentum at twice the rate. (2) The direction of the change in momentum caused by a force is that of the line of action of the force. For example, when a rope operates over a pulley, the force is always combined with one or more auxiliary forces, resulting in the changed direction of the momentum.

c. The third law. For every action there is an equal and opposite reaction. For example, a propeller can bite into the air forcing the air rearward and thereby producing a force sufficient to propel the airplane forward.

Figure 2.1. Venturi Tube.

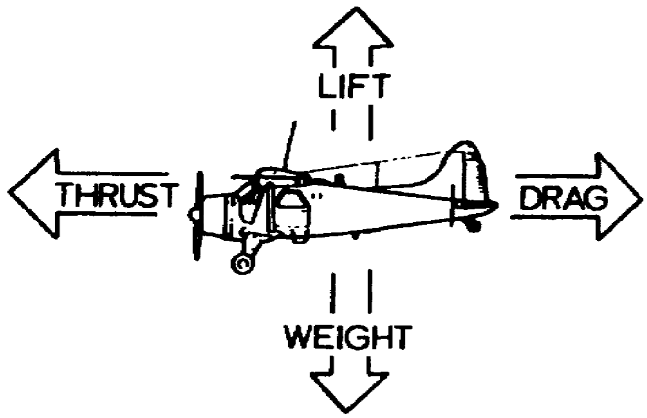


2.4. FORCES ACTING ON AN AIRCRAFT

Figure 2.2 shows the four forces that act on an aircraft in flight; they are weight, lift, thrust, and drag. The weight of the aircraft and its occupants, fuel, and cargo must be lifted against the force of gravity. In designing aircraft the lightest and strongest materials possible are used.

Lift is the force that overcomes gravity. Lift is obtained through the action of air moving past the wings or rotor blades of an aircraft. How to get maximum lift is a major problem in wing and rotor-blade design.

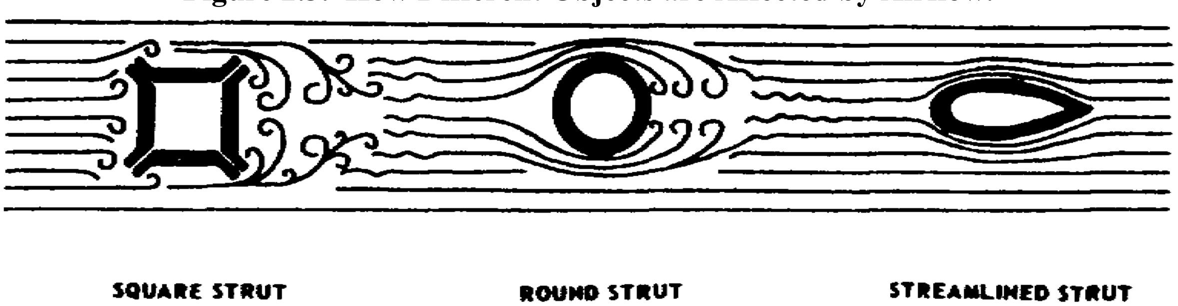
Figure 2.2. Four Forces Acting on an Aircraft.



Thrust is the force that puts the aircraft into motion relative to the ground and brings the force of lift into existence. Conventional aircraft are pushed or pulled forward by one or more reciprocating or turbine engine-driven propellers or jet engines.

Drag, the resistance to forward motion, is created by the flow of air over the surface of the aircraft. Figure 2.3 shows how different shaped objects are affected by airflow. The two kinds of drag are induced and moving through the air. While the aircraft is flying, high-pressure air below the wing tends to flow into the low-pressure area above the wing. The two pressures mix at the wing tip and create a vortex (whirlpool). The vortex creates a suction effect at the ends of the wing and causes induced drag that varies directly with the angle of attack. Parasite drag is created by the entire aircraft, excluding induced drag. It is caused by protrusions such as landing gear, rough surfaces, and air striking on the aircraft's frontal surfaces.

Figure 2.3. How Different Objects are Affected by Airflow.



2.5. AIRFOILS

An airfoil is any surface, such as a wing or rotor blade, designed to produce lift when air passes over it. Air passing over the upper surface of a foil produces two-thirds of a foil's lift by creating a lower pressure. One third of the foil's lift is produced by the higher pressure of air on the foil's under surface.

Relative wind is the air flowing opposite and parallel to the direction of airfoil motion. When an aircraft is at rest, relative wind does not exist, only wind created by nature. Relative wind, shown in figure 2.4, is created by the motion of the aircraft traveling through the air using its own power to reach its desired speed.

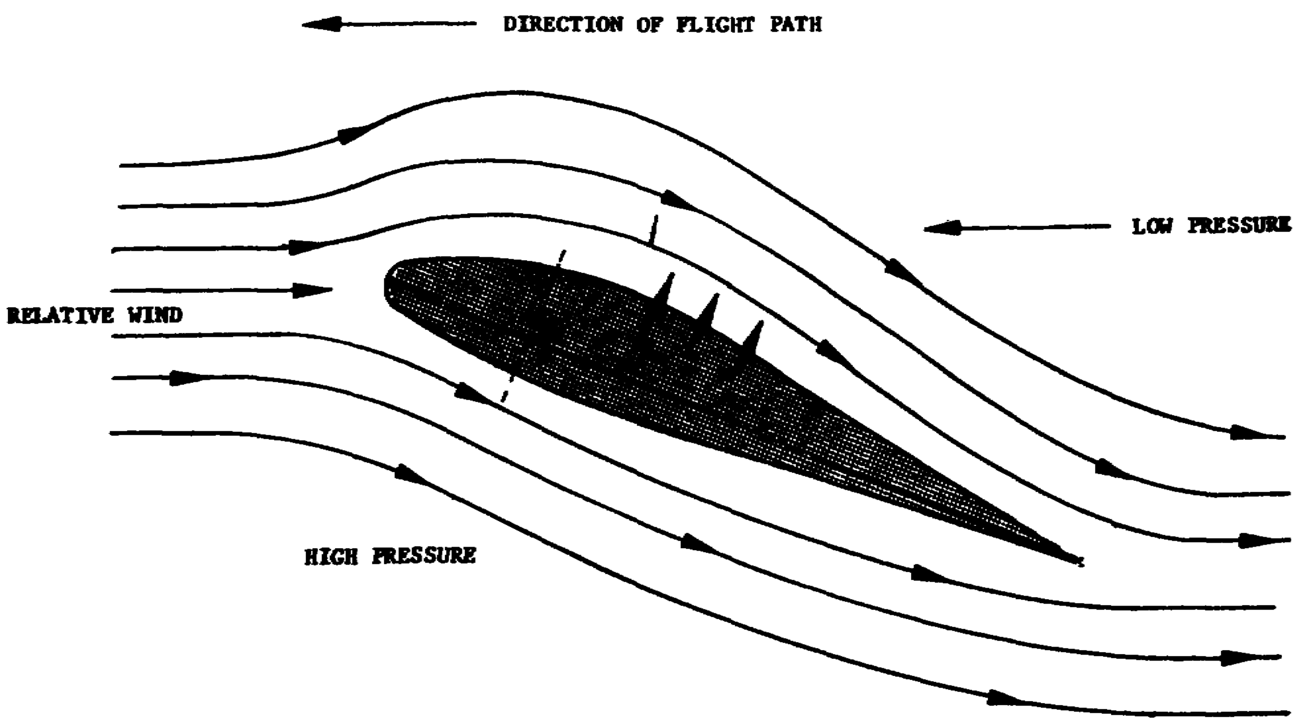
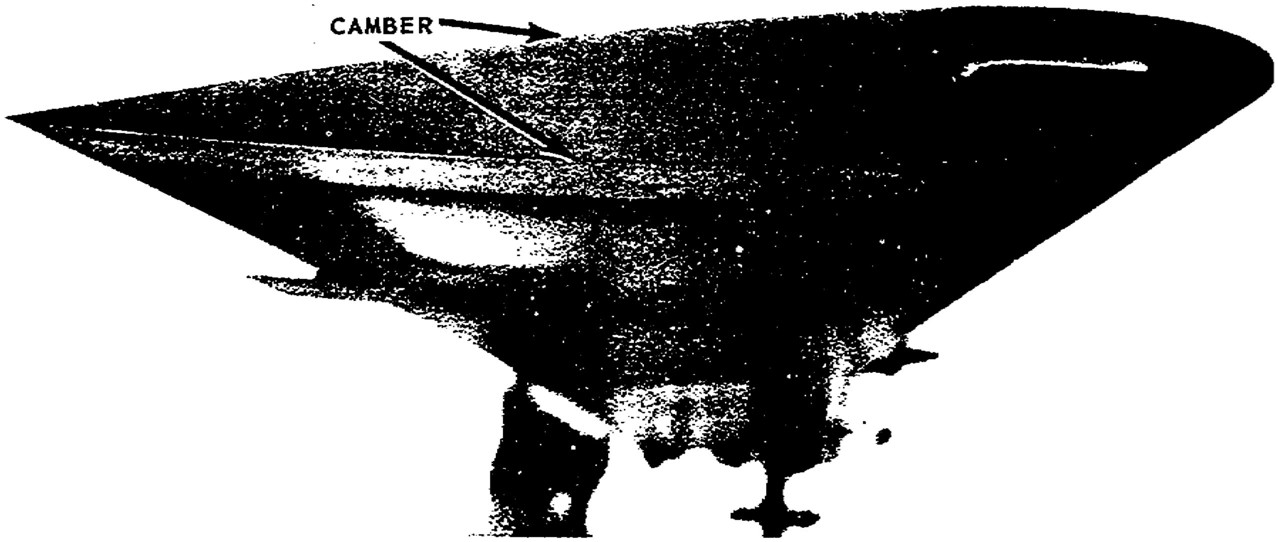


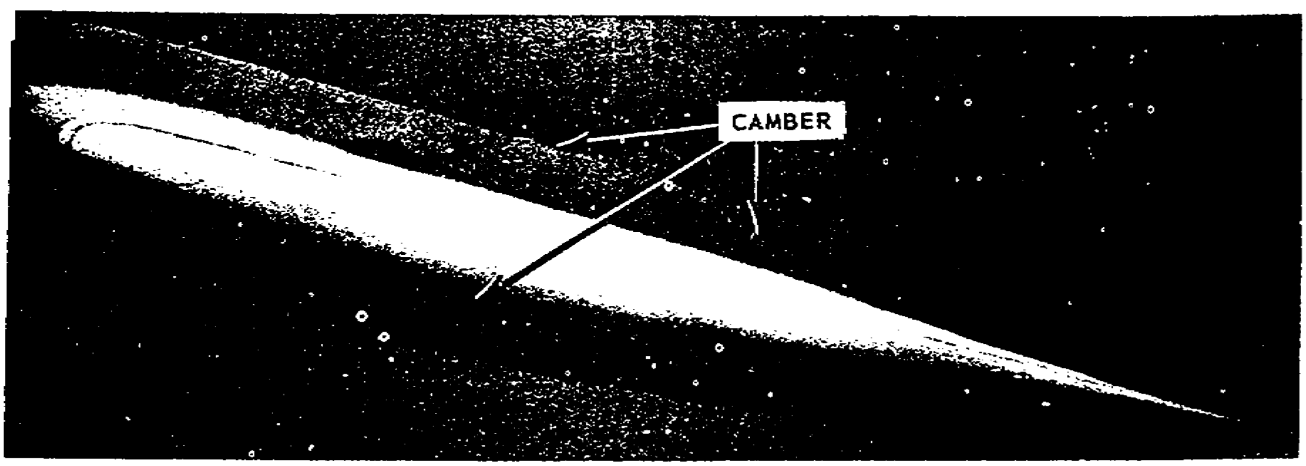
Figure <u>2.4.</u> <u>Relative Wind</u>.

A symmetrical airfoil is designed to have equal cambers on both sides. This kind of airfoil has the characteristics of limiting center-of-pressure travel.

An asymmetrical airfoil is designed to have unequal cambers. This type of airfoil has the characteristic of a rapid movement of center-of-pressure travel. Figure 2.5 shows the contrast between a symmetrical and an asymmetrical airfoil.



A. Symmetrical.



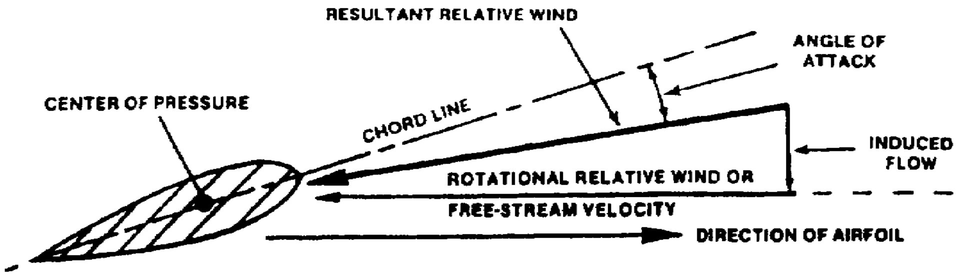
B. Asymmetrical.

Figure 2.5. Symmetrical and Asymmetrical Airfoils.

2.6. ANGLE OF ATTACK

The angle of attack is the angle at which an airfoil passes through the air. This angle is measured between the chord of the airfoil and the relative wind, as shown in figure 2.6. The chord is an imaginary line from the leading edge to the trailing edge of an airfoil. Increasing the angle of attack deflects the airstream and causes an upward pressure on the underside of the airfoil. This in turn increases the speed of the airflow over the topside of the airfoil. As air-flow-speed increases, pressure on the foil's top side is further reduced. The upward pressure on the foil's underside and pressure reduction on the top side combine to furnish lift.

Figure 2.6. Angle of Attack.



The angle of attack and angle of incidence are measured angles.

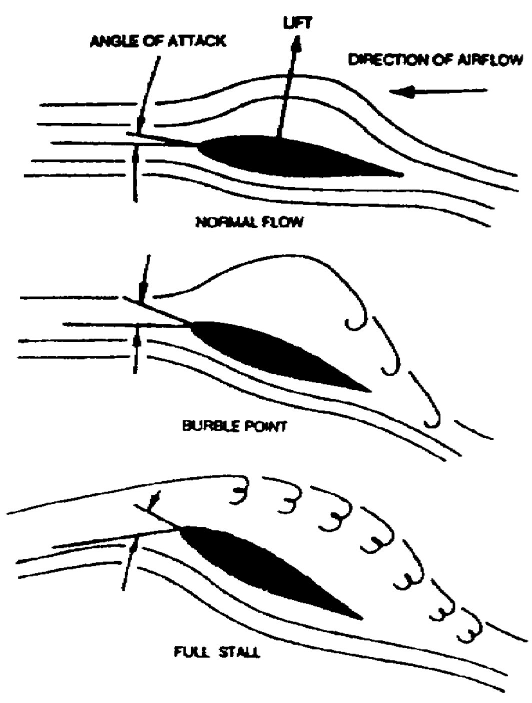
Angle of incidence (fixed-wing aircraft) is the angle between the airfoil chord line and the longitudinal axis or other selected reference plane of the aircraft.

Angle of incidence (rotary-wing aircraft) is the angle between the chord line of a main or tail rotor blade and the plane of rotation (tip path plane). It is usually referred to as the blade pitch angle. For fixed airfoils, such as vertical fins or elevators, the angle of incidence is the angle between the chord line of the airfoil and a selected reference plane of the helicopter.

2.7. STALL

As the angle of attack is increased, lift is also increased up to a certain angle. Beyond this angle airflow can no longer follow the contour of the airfoil's upper surface, as shown in the sequences in figure 2.7. After the burble point the airfoil goes full stall.

Figure 2.7. Stall Angle.



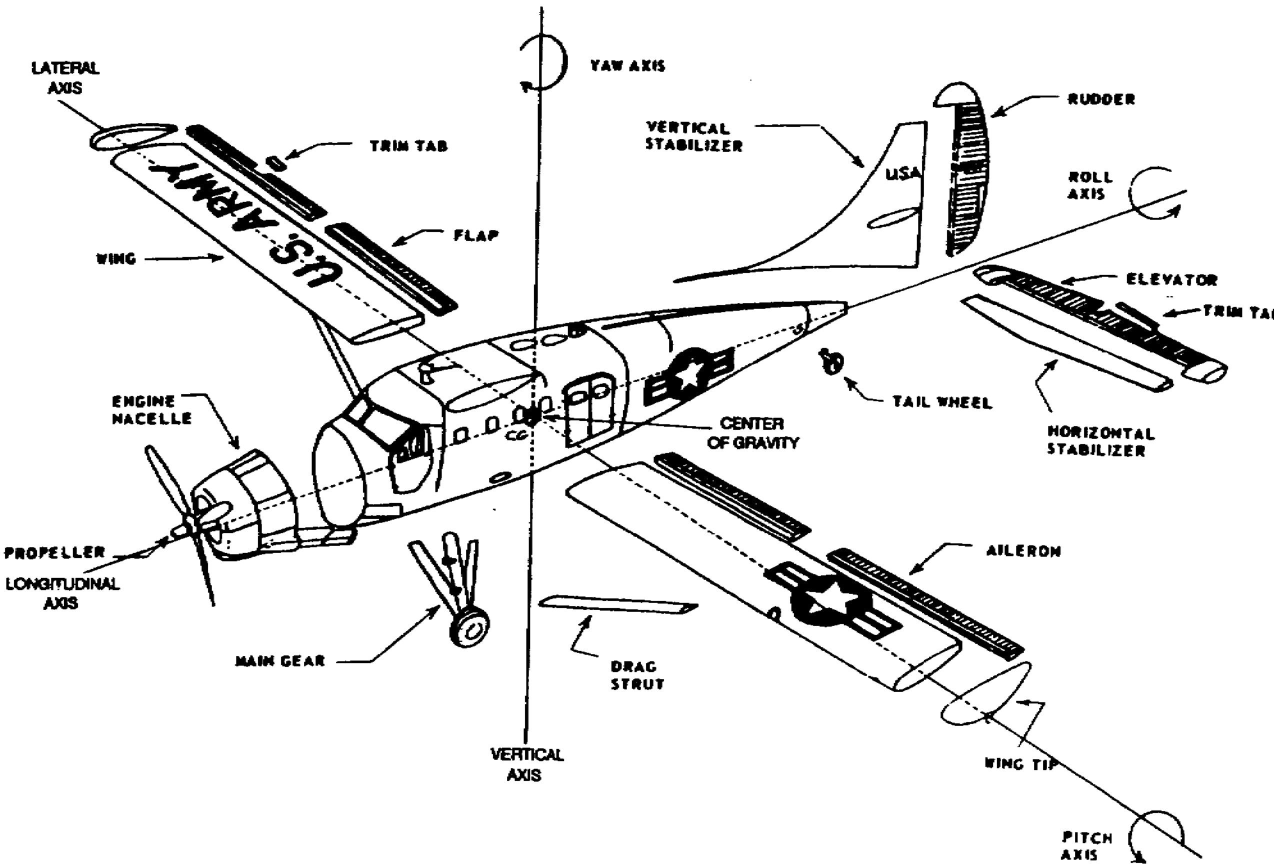
2.8. AILERONS AND FLAPS

Figure 2.8 illustrates both ailerons and flaps. The aileron is the surface control mounted on the trailing edge near the wing tip that allows the pilot to change the angle of bank as desired.

The flaps are mounted inboard of the ailerons and are probably the most used lift device in service. They increase the lift capability of the airfoil to the maximum attainable. This means that an aircraft can become or remain airborne at lower speeds with flaps extended. They also permit a shorter ground run on landing when used as airbrakes.

When the flaps are extended, the curvature (camber) of the wing is increased. On a high lift aircraft, the ailerons are interconnected to the flaps. In this arrangement, as the flaps are extended, the ailerons droop to add more lift and better control response at slower speeds. Flaps and ailerons are shown in figure 2.8.

Figure 2.8. Parts of a Fixed Wing Aircraft



2.9. ASPECT RATIO

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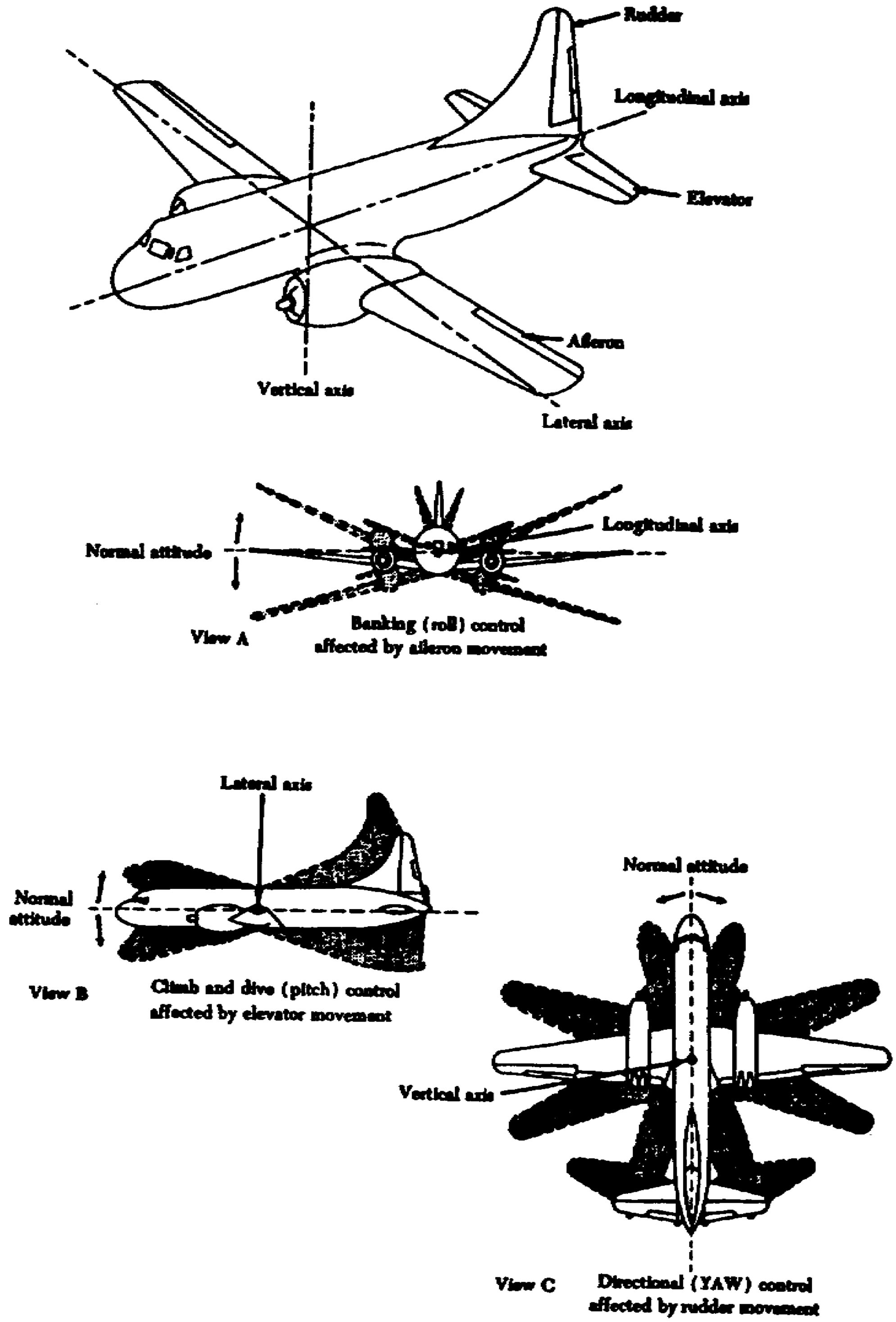


Figure 2.9. Motion of an Aircraft about its Axes.

2.10. STABILITY

For lateral stability, positive dihedral is designed into the wing. In simple terms, this means that the wing tips are higher than the wing roots and the aircraft's center of gravity is below the wing's mean center of pressure. Notice in figure 2.10 that the wing tips for the U-21 and U-6 aircraft are 7º and 2º higher than the wing roots. On the U-21 the tips of the horizontal stabilizer are also higher than the roots. A definition for dihedral then is: the spanwise inclination of a wing or other surface such as a stabilizer relative to the horizontal gives the wing or other surface dihedral. This angle is positive if it is upward and negative if it is downward.

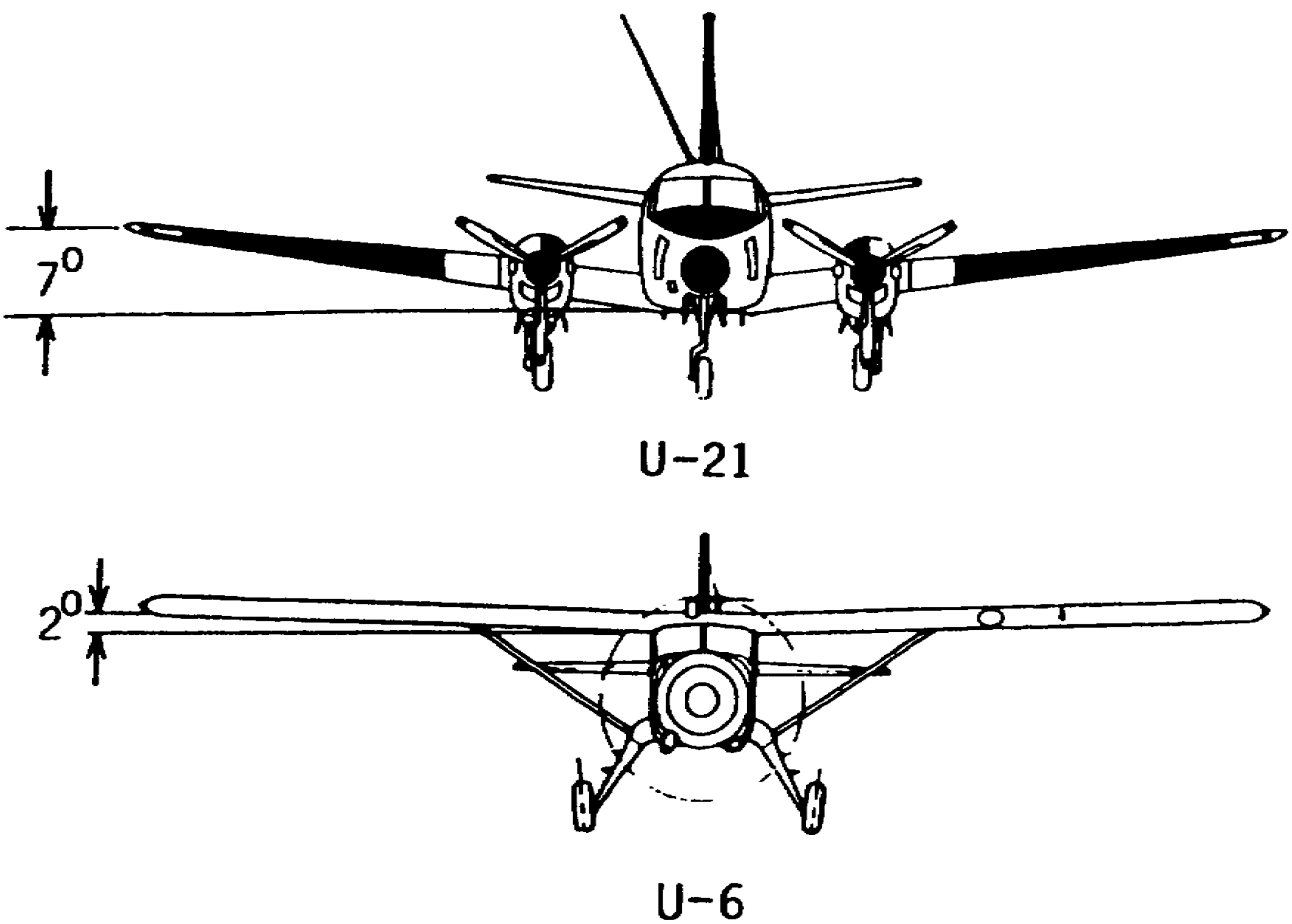


Figure 2.10. Wing Dihedral.

2.11. CANTILEVER WINGS

Figure 2.11 shows a cantilever wing and a noncantilever wing. A cantilever wing has no external supports and its structural strength is derived from its internal design. The advantage of this kind of wing is it eliminates drag caused by wing struts. Its disadvantage is the added weight required to give the wing its strength.

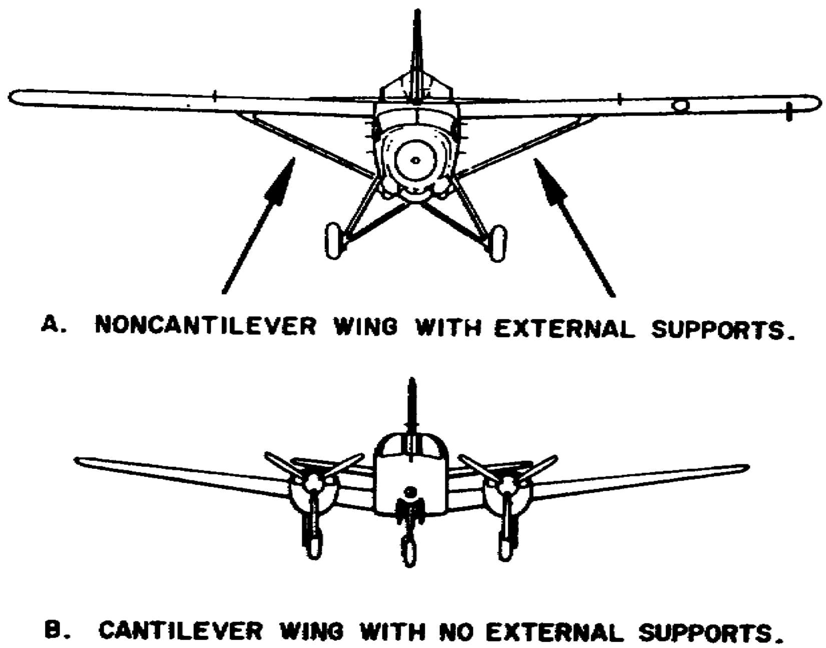


Figure 2.11. Cantilever and Noncantilever Wings.

2.12. BOUNDARY LAYER

Figure 2.12, Boundary Layer Flow, shows laminar and turbulent flow and the transition point in between. The boundary layer is the air close to the aircraft wings' upper surfaces. In the forward portion of the boundary layer, the air flows in layers, or separate sheets, called laminae. These layers slide over one another with little mingling of the air particles. However, behind the leading edge there is a transition point where the layer thickens, the airflow becomes turbulent, and one layer mixes with another. This results in increased drag. To aid in preventing boundary-layer turbulence, fences are installed as shown in figure 2.13.

2.13. SPEED BRAKES

Figure 2.14 shows an extended speed brake. These brakes are manually or hydraulically operated flaps that project into the airstream. Generally, they extend from the sides of the aircraft. However, they can

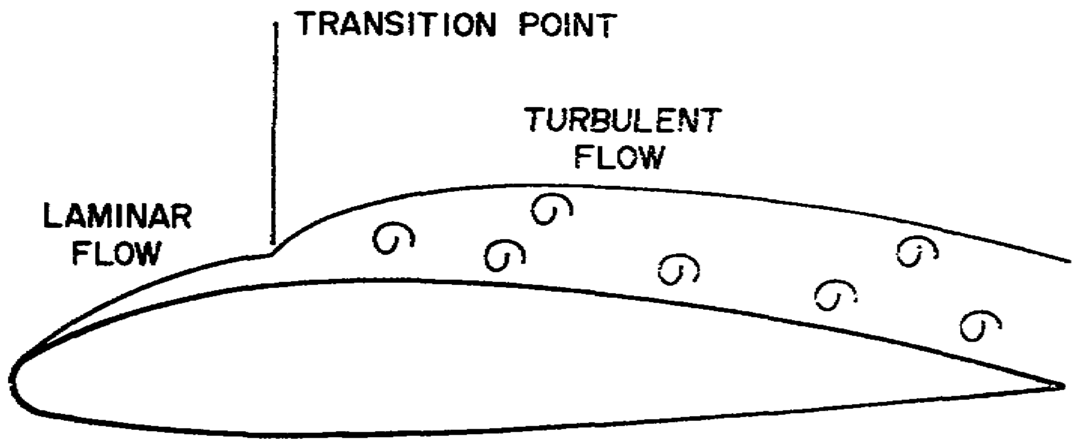


Figure 2.12. Boundary Layer Flow.

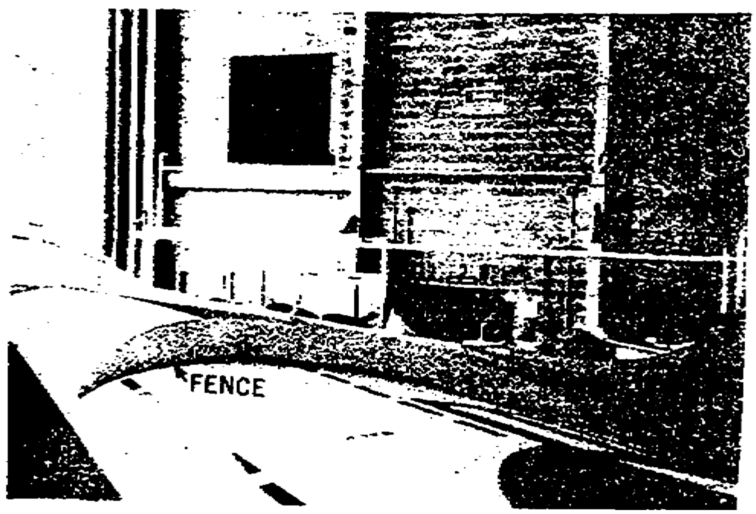


Figure 2.13. Wing Fences.

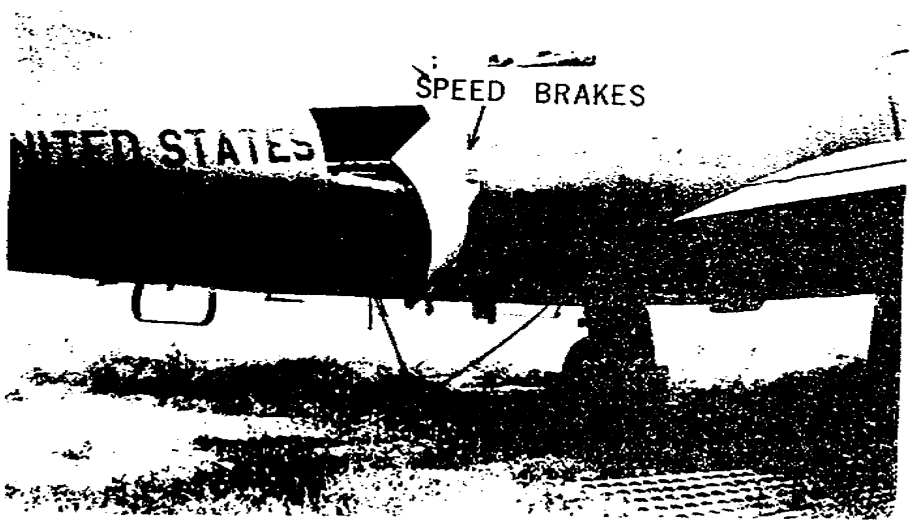


Figure 2.14. Speed Brakes.

be located on the bottom centerline of the fuselage or on the wings' upper surfaces. The purpose of speed brakes is to retard an aircraft's speed. Such brakes are generally used on aerodynamically clean aircraft such as jets.

2.14. EMPENNAGE GROUP

The tail section of an aircraft consists of the horizontal stabilizer and elevator, vertical stabilizer, and rudder as shown in figure 2.8.

The horizontal stabilizer gives the pilot control about the aircraft's lateral (pitch) axis. Some aircraft have a flying tail in which there is no elevator, only one large movable surface called a stabilizer.

The vertical stabilizer acts the same as a keel surface on a boat, and it is needed for adequate directional stability. The rudder is also used for the same purpose as a rudder on a boat and it controls the aircraft around its vertical (yaw) axis.

2.15. SUMMARY

Daniel Bernoulli, born 1700, discovered the principle bearing his name. Giovanni Venturi, in 1822, noted the effects of constricting a passage through which fluid flowed. The Venturi tube was invented by Clemens Hershel, an American engineer. He named it in honor of G. B. Venturi. Newton's three laws on force and motion are applicable to aerodynamics.

The four forces acting on an aircraft are weight, lift, thrust, and drag. Flight becomes possible when lift overcomes weight and thrust overcomes drag. The two kinds of airfoils used on Army aircraft are symmetrical and asymmetrical. An airfoil uses low-pressure air on top of the wing and high-pressure air under the wing to produce lift. When the wing's angle of attack is increased, the deflection of the airstream over the wing's upper surface creates more lift. However, if the angle of attack is too great the airstream breaks away from the upper surface and burbles. At this point, the aircraft can stall.

Ailerons control the aircraft about its bank or roll (longitudinal) axis. Flaps are used to increase the lift capability of a wing and are used mostly in landing and takeoff.

A true cantilever wing derives its strength from internal wing-design. The boundary layer is that air closest to the surface of an aircraft's wings, and flows in layers called laminae.

LESSON 3
HELICOPTER FUNDAMENTALS
Critical Tasks:

OVERVIEW

LESSON DESCRIPTION:

In this lesson you will learn Helicopter Fundamentals.

TERMINAL LEARNING OBJECTIVE:

ACTION: You will know helicopter fundamentals.

CONDITION: You will be given the information provided in this text, a list of reference manuals, and charts provided in the text.

STANDARD: You will correctly answer all the questions in the practice exercise before you proceed to the next lesson

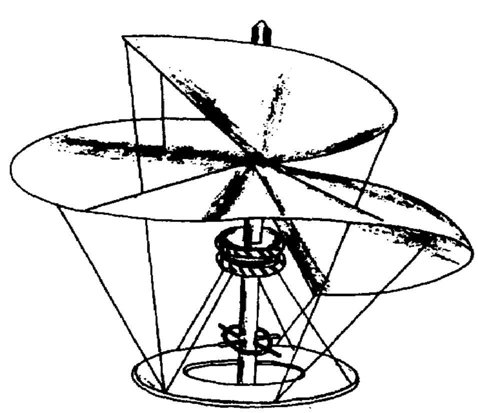
REFERENCES: Listed in appendix I.

INTRODUCTION

3.1. GENERAL

If developing vertical flight has proved as simple as the idea itself, the helicopter undoubtedly would have been the first practical aircraft in the field. In its first form, the helicopter was conceived by Leonardo da Vinci in the early 1500's. Figure 3.1 shows a sketch of his idea. In his notes da Vinci used the Greek work helix, meaning a spiral, and he is believed to have combined this word with the Greek work pteron, meaning wing. It is from this combination of Greek words that our word helicopter is derived.

Figure 3.1. Leonardo da Vinci Sketch of a Helixpteron.



Development proved too difficult and complicated for the early experimenters because they did not have an engine that could ensure flight. When larger, lighter, and more reliable engines were developed, the dream of a helicopter became a reality.

The same laws of force and motion that apply to fixed wing aircraft also apply to the helicopter. Controls for the helicopter are complex, and torque, gyroscopic precession, and dissymmetry of lift must be dealt with. Retreating blade stall limits the helicopter's forward airspeed.

This chapter presents a basic discussion on helicopter controls, velocity, torque, gyroscopic precession, dissymmetry of lift, retreating blade stall, settling with power, pendular action, hovering, ground effect, translational lift, and autorotation.

3.2. THE FOUR FORCES ACTING ON A HELICOPTER

Weight and drag act on a helicopter as they do on all aircraft. However, lift and thrust for a helicopter are obtained from the main rotor. In a very basic sense, the helicopter's main rotor does what wings and a propeller do for an airplane. Moreover, by tilting the main rotor, the pilot can make the helicopter fly to either side or to the rear. The controls used by the pilot are discussed in the next paragraph.

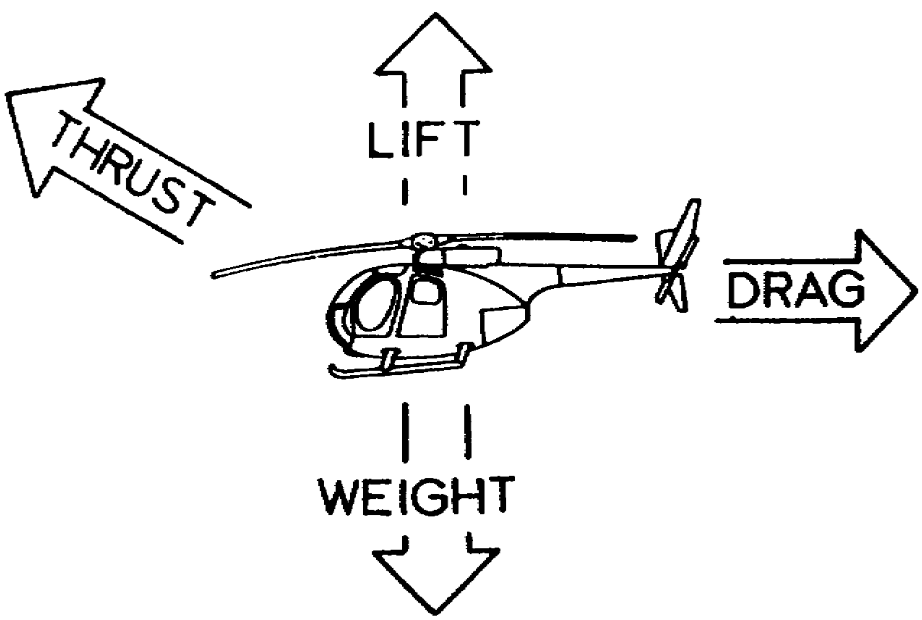


Figure 3.2. Forces Acting on a Helicopter.

3.3. CONTROLS

The sketch in figure 3.3 shows the main rotor, cyclic and collective controls, antitorque pedals, and antitorque rotor. Basically, the cyclic control is a mechanical linkage used to change the pitch of the main rotor blades. Pitch change is accomplished at a specific point in the plane of rotation to tilt the main rotor disc. Most of the helicopters now in the Army inventory have hydraulic assistance in addition to the mechanical linkage. The collective pitch is the control that changes the pitch of all the main rotor blades equally and simultaneously. The antitorque pedals are used to adjust the pitch in the antitorque rotor blades to compensate for main rotor torque. Torque is explained in paragraph 3.5.

3.4. VELOCITY

A helicopter's main rotor blades must move through the air at a relatively high speed to produce enough lift to raise the helicopter and keep it in the air. The main rotor can turn at the required takeoff speed while the antitorque rotor holds the fuselage speed at zero.

The helicopter can fly forward, backward, or sideward as the pilot desires. It can also remain stationary in the air (hover) with the main rotor blades developing the lift to support the helicopter.

3.5. TORQUE

The torque problem is related to helicopters of single-main-rotor design. The reason for this is that as the helicopter's main rotor turns in one direction, the fuselage tends to turn in the opposite direction. This effect is based on Newton's third law which states "To every action there is an opposite and equal reaction." The torque problem on single-rotor helicopters is counteracted and controlled by an antitorque (tail) rotor, discussed in paragraph 3.6.

On tandem rotor helicopters the main rotors turn in opposite directions and thereby eliminate the torque effect.

3.6. ANTITORQUE ROTOR

Figure 3.4 shows the direction of travel for a main rotor, the direction of torque for the fuselage, and the location of an antitorque (tail) rotor.

An antitorque rotor located on the end of a tail boom extension provides compensation for torque in the single-main-rotor helicopter. The tail rotor, driven by the engine at a constant speed, produces thrust in a horizontal plane opposite to the torque reaction developed by the main rotor.

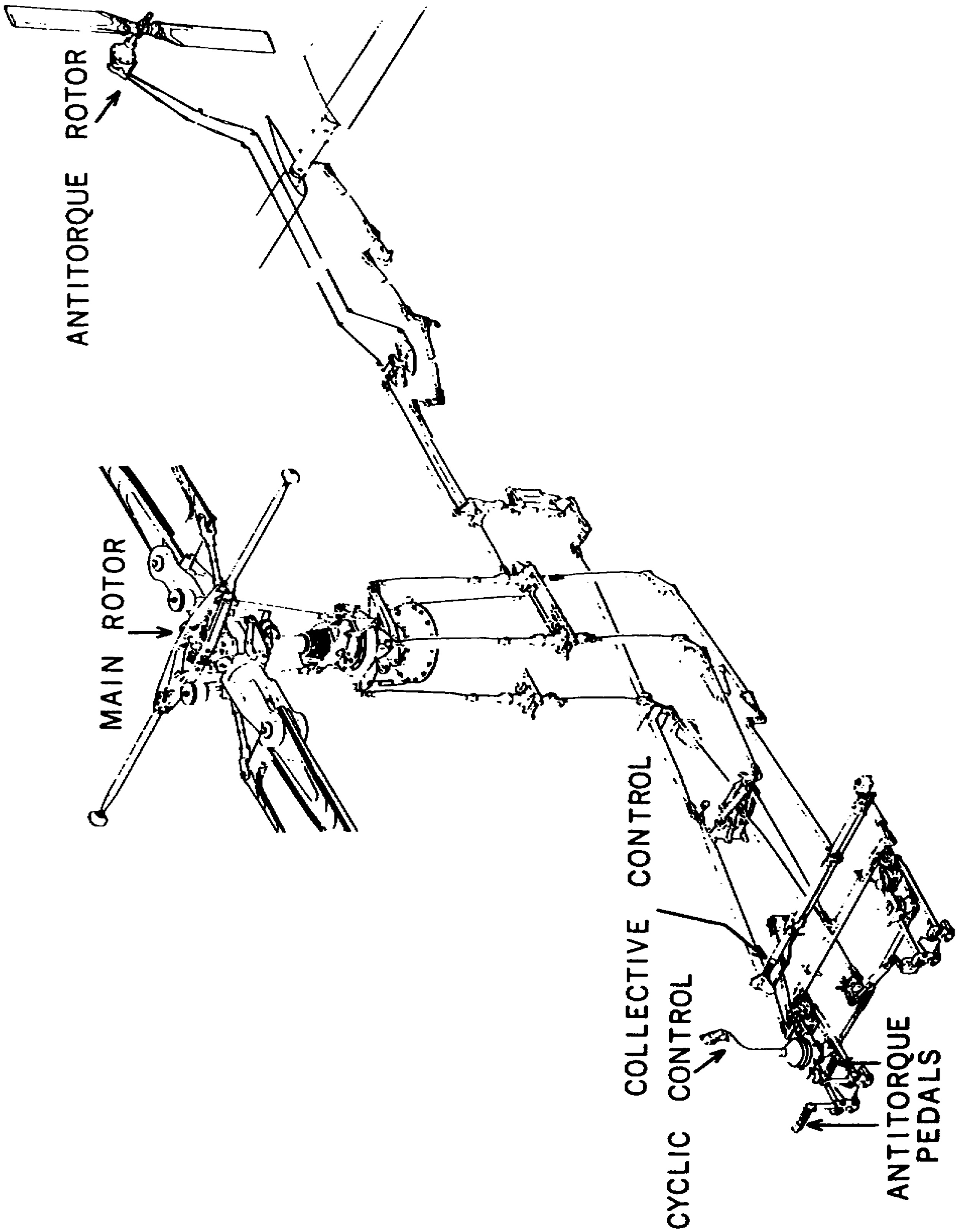


Figure 3.3. Helicopter Controls.

3.7. GYROSCOPIC PRECESSION

The result of applying force against a rotating body occurs 90° in the direction of rotation from where the force is applied. This effect is called gyroscopic precession and it is illustrated in figure 3.5. For example, if a downward force is applied at 9 o'clock, as in the figure, the result appears at 6 o'clock as shown. This will make the 12 o'clock position in the figure tilt up an equal amount in the opposite direction.

Figure 3.6 illustrates the offset control linkage needed in a helicopter to enable the pilot to tilt the main rotor disc in the direction he wants to go. If such linkage were not used the pilot would have to move the cyclic stick 90° out of phase or to the right of the direction desired. The offset control linkage is attached to a lever extending 90° in the direction of rotation from the main rotor blade.

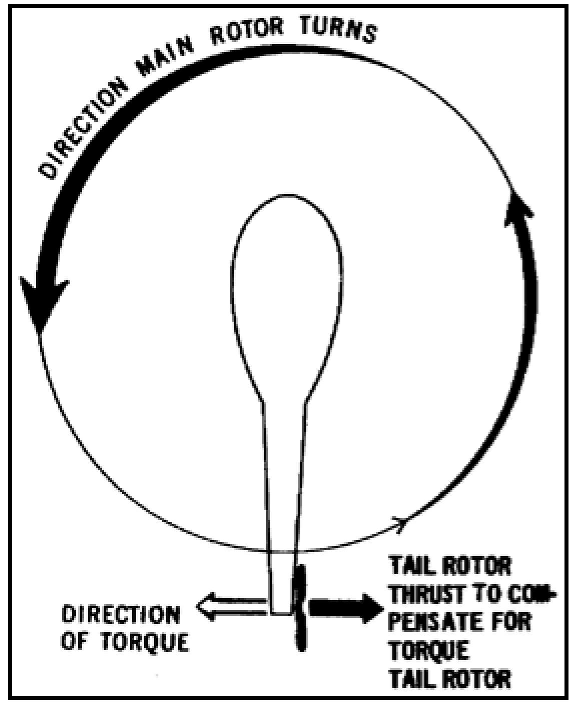


Figure 3.4. Tail Rotor Thrust to Compensate for Torque.

Figure 3.5. Gyroscopic Precession.

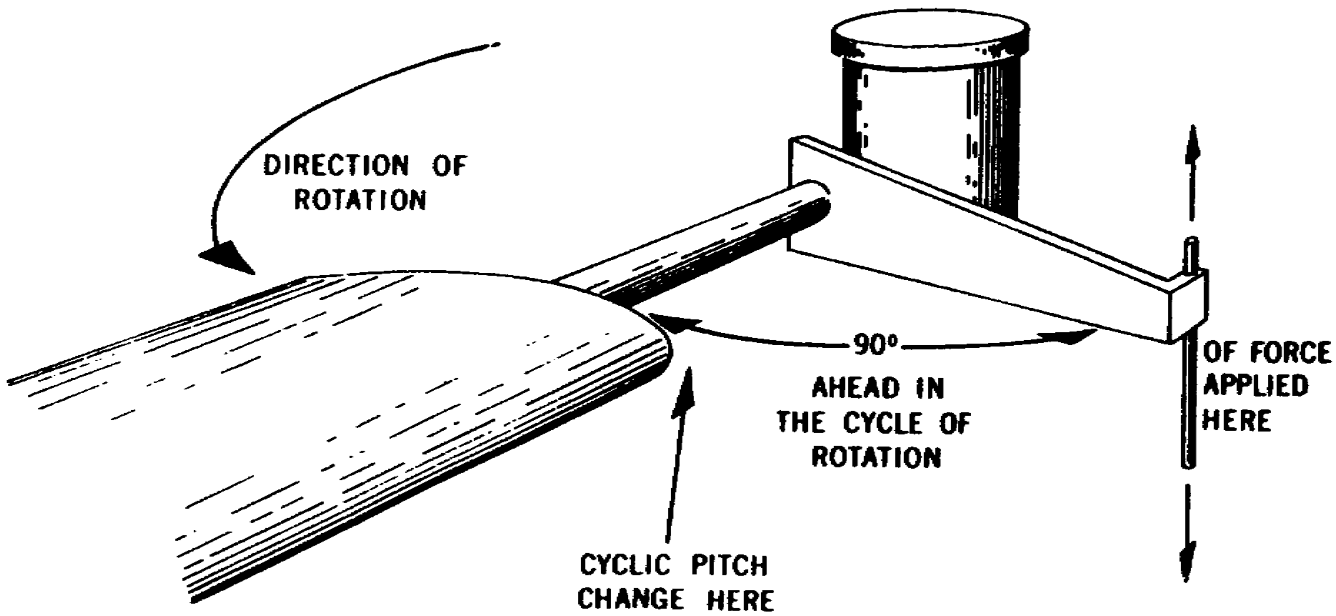


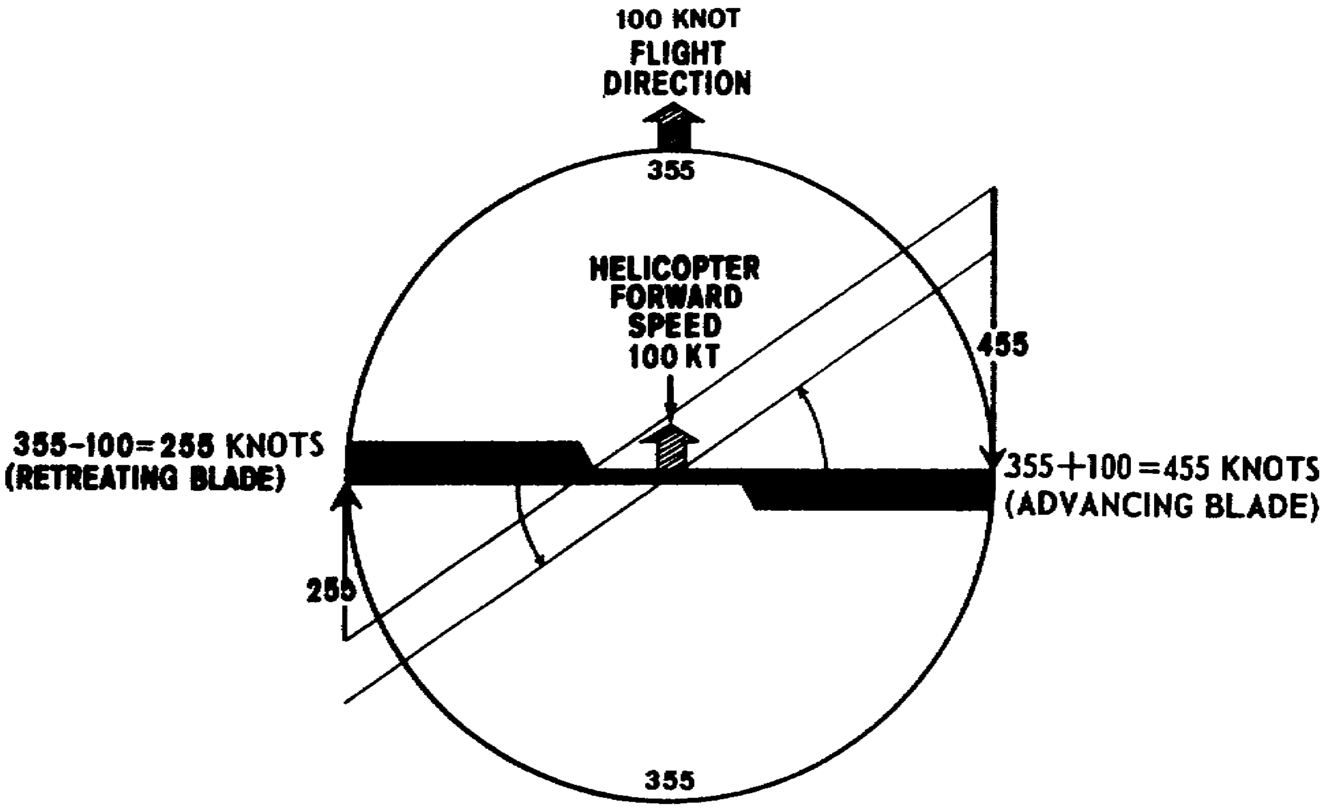
Figure 3.6. Offset Control Linkage.

3.8. DISSYMMETRY OF LIFT

The area within the circle made by the rotating blade tips of a helicopter is known as the disc area or rotor disc. When hovering in still air, lift created by the rotor blades at all parts of the disc area is equal. Dissymmetry of lift is the difference in lift that exists between the advancing half of the disc area and the retreating half, and it is created by horizontal flight or wind.

When a helicopter is hovering in still air, the tip speed of the advancing blade is about 600 feet per second. The tip speed of the retreating blade is the same. Dissymmetry of lift is created by the horizontal movement of the helicopter in forward flight, and the advancing blade has the combined speed of blade velocity plus speed of the helicopter. The retreating blade loses speed in proportion to the forward speed of the helicopter.

Figure 3.7 illustrates the dissymmetry of lift and shows the arithmetic involved in calculating the differences between the velocities of the advancing and retreating blades. In the figure, the helicopter is moving forward at a speed of 100 knots, the velocity of the rotor disc is equal to approximately 355 knots, and the advancing rotor speed is 455 knots. The speed of the retreating blade is 255 knots. This speed is obtained by subtracting the speed of the helicopter (100 knots) from the tip speed of 355 knots. As can be seen from the difference between the advancing and retreating blade velocities, a large speed and lift variation exists.



(ROTATIONAL VELOCITY) ± (HEL FORWARD SPEED) = (AIRSPEED OF BLADE)

Figure 3.7. Dissymmetry of Lift.

Cyclic pitch control, a design feature that permits changes in the angle of attack during each revolution of the rotor, compensates for the dissymmetry of lift. As the forward speed of the helicopter is increased, the aviator must apply more and more cyclic to hold a given rotor disc attitude. The mechanical addition of more pitch to the retreating blade and less to the advancing blade is continued throughout the helicopter's range.

3.9. RETREATING BLADE STALL

Figure 3.8 illustrates the tendency for the helicopter's retreating blade to stall in forward flight. It is a major factor in limiting their forward speed. Just as the stall of an airplane wing limits the low-airspeed possibilities of the airplane, the stall of a rotor blade limits the high-speed potential of a helicopter. The airspeed of the retreating blade slows down as forward airspeed is increased. The retreating blade must produce an amount of lift equal to that of the advancing blade, as shown in figure 3.8B. As the airspeed of the retreating blade is decreased with forward airspeed, the blade angle of attack must be increased to equalize lift throughout the rotor disc area. As this angle increase is continued, the blade will stall at some high forward airspeed as shown in figure 3.8C.

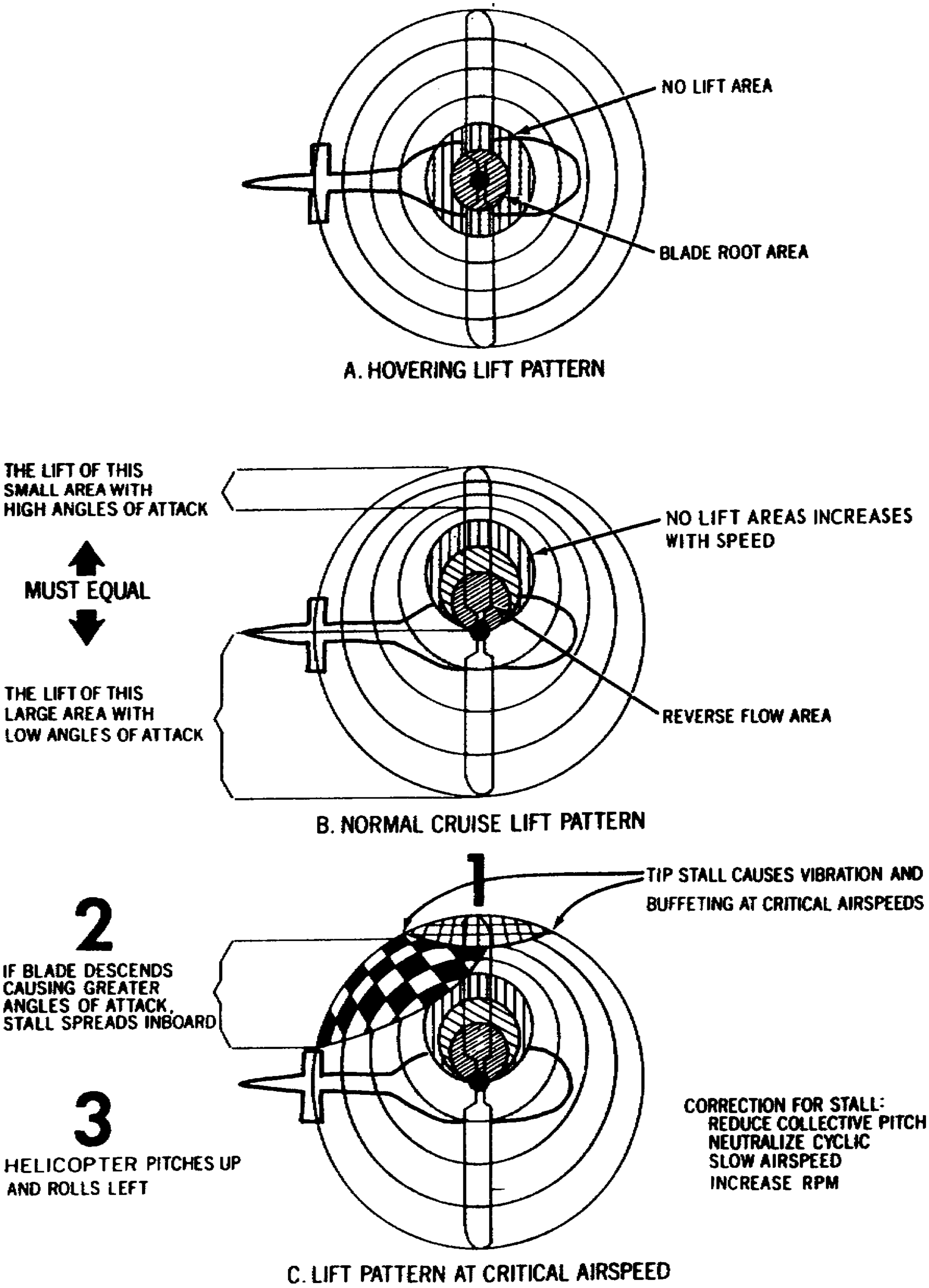


Figure 3.8. Retreating Blade Stall.

Upon entry into blade stall, the first effect is generally a noticeable vibration of the helicopter. This vibration is followed by the helicopter's nose lifting and a rolling tendency. If the cyclic stick is held forward and the collective pitch is not reduced, or is raised, the stall becomes aggravated, and the vibration increases greatly. Control of the helicopter may then be lost.

3.10. SETTLING WITH POWER

An aviator may experience settling with power accidentally. Causes of settling with power are typified by a helicopter in a vertical or nearly vertical powered descent of at least 300 feet per minute with a relatively low airspeed. The rate depends upon the load, rotor rpm, and density altitude. The rotor system must be using from 20 to 100 percent of the available engine power and the horizontal velocity must not exceed 10 knots. The helicopter descends in turbulent air that has just been accelerated downward by the rotor. This turbulence reacts upon the main rotor blades at increased angles of attack and stalls the blades at the main rotor hub. The stall then progresses outward along the blades as the rate of descent increases. To recover from settling with power, reduce collective pitch, lower the helicopter's nose into the wind, and, as airspeed increases, start a slow right turn.

3.11. PENDULAR ACTION

In general, the fuselage of the helicopter is suspended from a single point and has considerable mass. Because of this it has some freedom to move laterally or longitudinally, a pendular action. However, correct aviator cyclic control movements, free of overcontrol, cause the rotor tip path and the fuselage to move in unison.

For semirigid helicopters, the normal corrective device is the addition of a synchronized elevator attached to the tail boom and operated by the cyclic stick.

3.12. HOVERING

A helicopter hovers when it maintains a constant position at a selected point in the air, usually a few feet above the ground. To hover, a helicopter main rotor must supply lift to equal the total weight of the helicopter, including crew; fuel; passengers and cargo, if carried; and armament, if armed. The necessary lift is created by rotating the blades at high velocity and increasing the blade angle of attack.

At a hover, the rotor system requires a great volume of air upon which to work. This air must be pulled from the surrounding air mass; this is an expensive maneuver that takes a great deal of horsepower. The air delivered to the rotating blades is pulled from above at a relatively high velocity, forcing the rotor system to work in a descending column of air.

The main rotor vortex and the recirculation of turbulent air add resistance to the helicopter while hovering. Such an undesirable air supply requires higher blade angles of attack and an expenditure of more engine power and fuel. In addition, the main rotor is operating in air filled with abrasive materials that cause heavy wear on helicopter parts while hovering in ground effect.

3.13. GROUND EFFECT

Figure 3.9 illustrates air flow in and out of ground effect. Notice the information in A and B that is printed close to the sketches. Ground effect is a condition of improved performance found when hovering near the ground. The best height is approximately one-half the main rotor diameter.

The improved lift and airfoil efficiency while operating in ground effect are due to the following effects. First and most important, the main rotor-tip vortex is reduced. When operating in ground effect, the downward and outward airflow reduces the vortex. A vortex is a flow involving rotation about an axis or center. This makes the outward portion of the main rotor blade more efficient. Reducing the vortex also reduces the turbulence caused by recirculating the vortex swirl, as shown in figure 3.9A. Second the angle of the air is reduced as it leaves the airfoil, as illustrated in figure 3.9B. When the airfoil angle is reduced the resultant lift is rotated slightly forward, making it more vertical. Reduction of induced drag permits lower angles of attack for the same amount of lift and reduces the power required to drive the blades.

3.14. TRANSLATIONAL LIFT

The efficiency of the hovering rotor system is improved by each knot of incoming wind gained by forward motion of the helicopter or by a surface headwind. As the helicopter moves forward, as shown in figure 3.10, fresh air enters in an amount sufficient to relieve the hovering air-supply problem and improve performance. At approximately 18 knots, the rotor system receives enough free, undisturbed air to eliminate the air supply problem. At this time, lift noticeably improves; this distinct change is referred to as translational lift. At the instant of translational lift, and

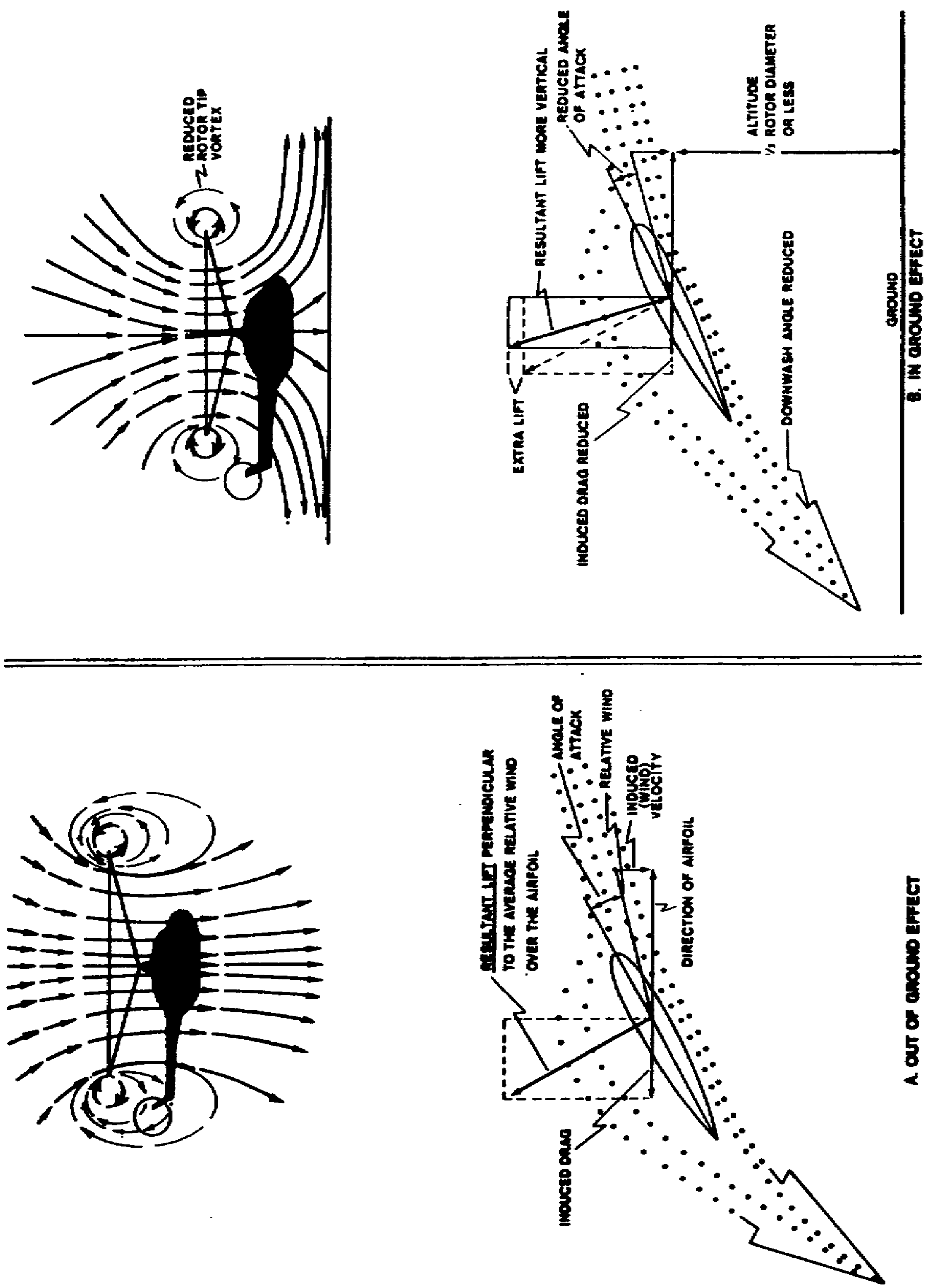


Figure 3.9. Airflow In and Out of Ground Effect.

as the hovering air supply pattern is broken, dissymmetry of lift is created. As airspeed increases, translational lift continues to improve up to the speed 'that is used for best climb.

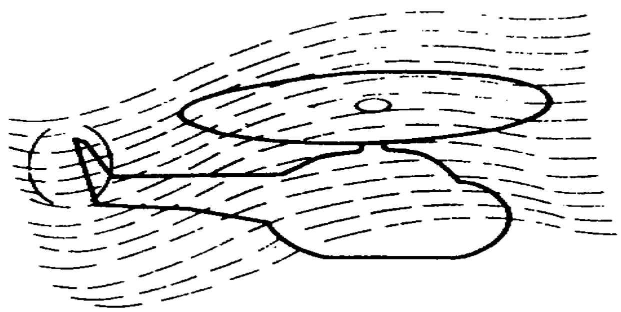


Figure 3.10. Airflow with Translational Lift in Forward Flight.

In forward flight, air passing through the rear portion of the rotor disc has a higher downwash velocity than the air passing through the forward portion. This is known as transverse flow effect and is illustrated in figure 3.11. This effect, in combination with gyroscopic precession, causes the rotor to tilt sideward and results in vibration that is most noticeable on entry into effective translation.

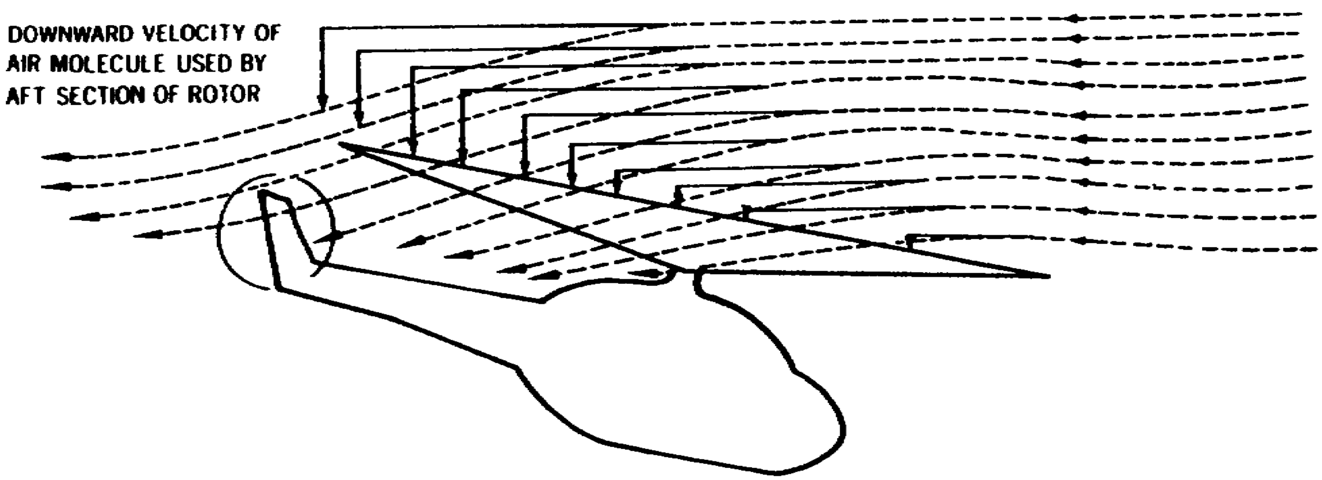


Figure 3.11. Transverse Flow Effect.

3.15. AUTOROTATION

If engine power fails, or certain other emergencies occur, autorotation is a means of safely landing a helicopter. The transmission in a helicopter is designed to allow the main rotor to turn freely in its original direction when the engine stops. Figure 3.12 illustrates how the helicopter is allowed to glide to earth and by using the main rotor rpm, make a soft landing.

The rotor blade autorotative driving region is the portion of the blade between 25 to 70 percent radius, as shown in figure 3.13, blade element A. Because this region operates at a comparatively high angle of

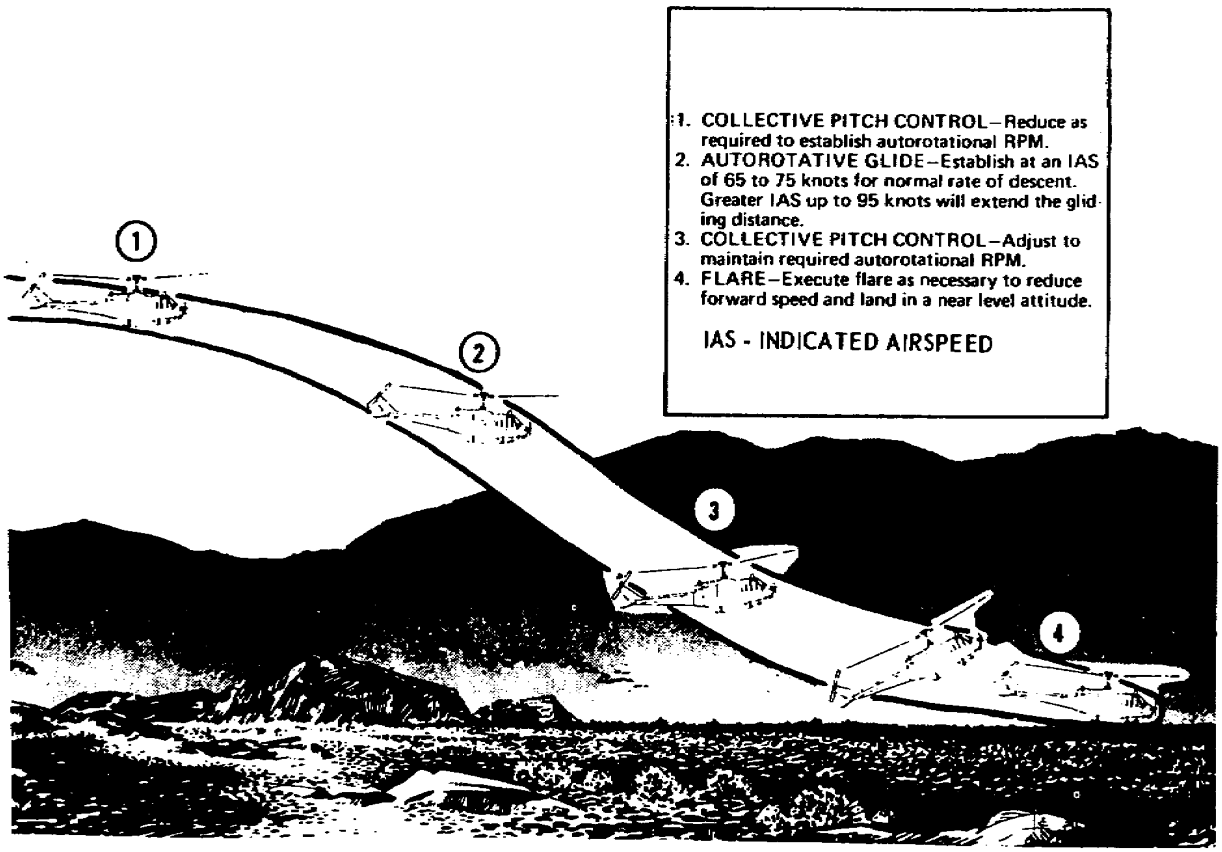


Figure 3.12. Approach to Landing, Power Off.

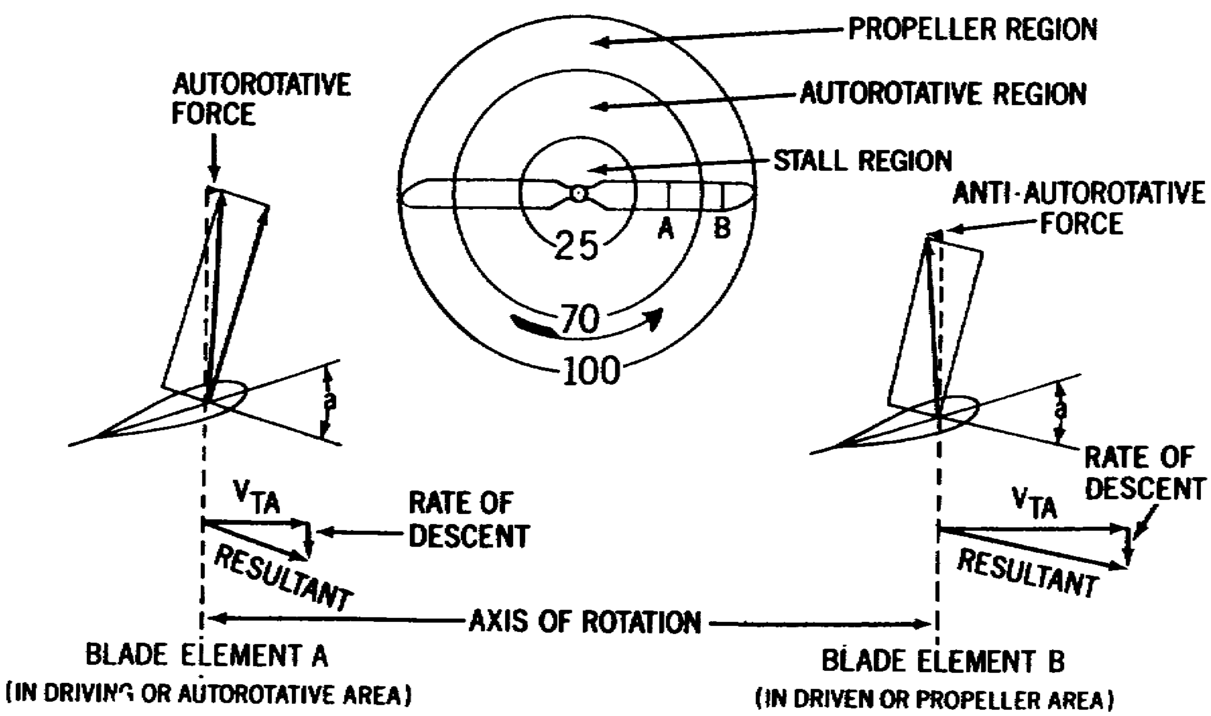


Figure 3.13. Autorotation Blade Forces.

attack, the result is a slight but important forward inclination of aerodynamic force. This inclination supplies thrust slightly ahead of the rotating axis and tends to speed up this portion of the blade during autorotation.

The blade area outboard of the 70 percent circle is known as the propeller or driven region. Analysis of blade element B in figure 3.13 shows that the aerodynamic force inclines slightly behind the rotating axis. This inclination causes a small drag force that tends to slow the tip portion of the blade. Rotor rpm stabilizes, or achieves equilibrium, when autorotative force and antiautorotative force are equal.

The blade area inboard of the 25 percent circle is known as the stall region because it operates above its maximum angle of attack. This region contributes considerable drag that tends to slow the blade.

All helicopters carry an operators manual (-10) that has an air speed versus altitude chart similar to the one shown in figure 3.14. The shaded areas on this chart must be avoided. The proper maneuvers for a safe landing during engine failure cannot be accomplished in these areas.

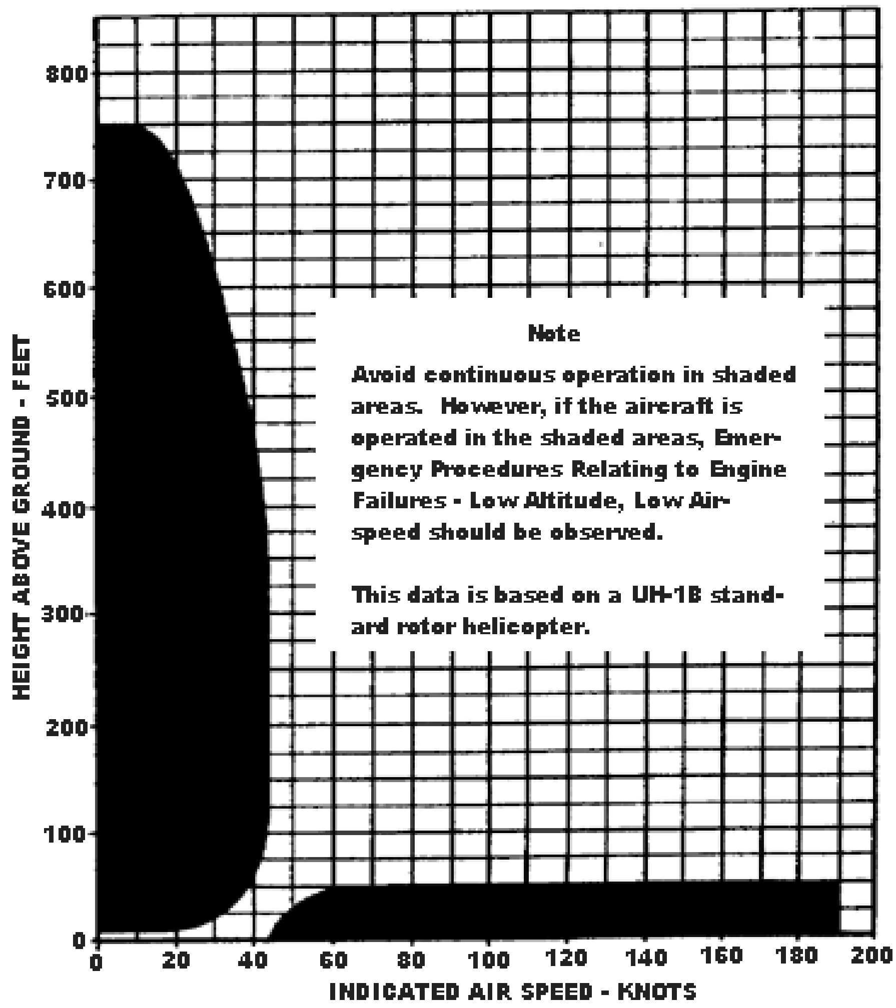


Figure 3.14. High Velocity Diagram.

3.16. SUMMARY

Weight, lift, thrust, and drag are the four forces acting on a helicopter. The cyclic for directional control, the collective pitch for altitude control, and the antitorque pedals to compensate for torque are the three main controls used in a helicopter.

Torque is an inherent problem with single-main-rotor helicopters. Gyroscopic precession occurs approximately 90° in the direction of rotation from the point where the force is applied. Dissymmetry of lift is the difference in lift that exists between the advancing and retreating half of the rotor disc.

Settling with power can occur when the main rotor system is using from 20 to 100 percent of the available engine power, and the horizontal velocity is under 10 knots. At a hover, the rotor system requires a great volume of air upon which to work. This air must be pulled from the surrounding air mass. This is a costly maneuver that takes a great amount of power.

Ground effect is improved performance when hovering near the ground at a height of no more than approximately one-half the main rotor diameter. Translational lift is achieved at approximately 18 knots, and the rotor system receives enough free, undisturbed air to improve performance. At the instant translational lift is in effect and the hovering air-supply pattern is broken, dissymmetry of lift is created. Autorotation is a means of safely landing a helicopter after engine failure or other emergencies. A helicopter transmission is designed to allow the main rotor to turn freely in its original direction if the engine fails.

LESSONS 1, 2, and 3

PRACTICE EXERCISES

The following items will test your grasp of the material covered in these lessons. There is only one correct answer for each item. When you complete the exercise, check your answer with the answer key that follows. If you answer any item incorrectly, study again that part of the lesson which contains the portion involved.

<u>True - False</u>

Write T for true or F for false).

1. On an aircraft having aerodynamically clean characteristics, speed brakes are used to improve the rate of ascent.

2. The surfaces of a wing or rotor blade are designed to produce lift when air passes over it. Two-thirds of the lift is produced by the lower pressure air passing over the wing's or blade's upper surface.

3. The rotor system is using from 20 to 100 percent of the available power and the horizontal velocity is 10 knots or less. Under this condition a pilot may experience settling with power.

4. The lateral axis runs from wing tip to wing tip.

5. The man who first sketched the helicopter and referred to it as a helixopteron was Giovanni Venturi.

6. Sir Isaac Newton's third law of motion is: for every action there is an equal and opposite reaction.

7. Improved lift and airfoil efficiency while operating in ground effect are due to the recirculation of the main rotor tip vortex.

8. The term "standard conditions" refers to atmospheric pressure of approximately 14.7 psi or 29.92 inches of mercury at sea level with a temperature of 15°C.

Cluster True - False

NOTE: (Each question of this kind consists of a series of statements related to the stem that precedes them. Write T or F by each question.)

9. A given volume of dry air contains a variety of gases representative of the earth's atmosphere. Indicate which of the following statements most accurately states the composition of this variety.

   a. Nitrogen, oxygen, argon, carbon dioxide, and minute amounts of other gases.

   b. Water vapor, dust, and salt particles.

   c. A percentage of gases varying with the temperature of the air.

   d. One percent of other gases, 21 percent oxygen, and 78 percent nitrogen.

   e. Fifty percent oxygen, 48 percent nitrogen, and 2 percent argon.

Matching

10. Match the statements in column I with the terms to which they apply in column II by writing the proper letter by each question. Items in column II may be used once, more than once, or not at all.

Column I	Column II
(1) Control surfaces in the empennage group.	A. Chord line.
(2) An imaginary line drawn from the center of the leading edge to the trailing edge of an airfoil.	B. Rudder an elevator.
(3) Three basic controls in a helicopter.	C. Ailerons.
(4) Control an aircraft about its bank or roll axis.	D. Flaps, aileron, tail rotor.
	E. Cyclic, collective pitch, and antitorque pedals.
	F. Rudder.
	G. Center of gravity line.

Multiple Choice

NOTE: (Each question in this group contains one and only one correct answer. Make your choice by circling the proper letter for each question.)

11. The blade element located between approximately 25 and 75 percent radius is known as the auto-rotative or driving region.

    A. This region operates at a negative angle of attack and has no effect.
    B. This region operates at a comparatively high angle of attack.
    C. This region operates at a complete stall angle of attack.
    D. This region operates at a comparatively low angle of attack.

12. An airfoil's angle of attack is measured between the.

    A. Aircraft fuselage and the empennage group.
    B. Wing root and the wing tip.
    C. Airfoil chord and the relative wind.
    D. Angle of airfoil and the airstream.

13. The average temperature lapse rate is:

    A. Based on the worldwide variation of temperatures with altitude.
    B. Dependent upon weather over land or sea.
    C. Measured in degrees of change per kilometer.
    D. Affected by the height of the stratosphere and time of year.

14. Gyroscopic precession is the result of a force applied against a rotating body, and it occurs, approximately, at a point:

    A. Two hundred and seventy degrees later in the direction of rotation from the point where the force is applied.
    B. One hundred and twenty degrees opposite that of rotation from the point where the force is applied.
    C. Ninety degrees later in the direction of rotation from the point where force is applied.
    D. One hundred and eighty degrees out of phase from the point where force is applied.

15. If the pressure altitude is 7,000 feet and the temperature is +15°C the density altitude is:

A. 9,800.
B. 7,200.
C. 8,600.
D. 6,500.

16. A wing that has no external supports is called a:

A. Cantilever wing.
B. Symmetrical wing.
C. Wing chord.
D. Laminate wing.

17. Lift, weight, thrust, and drag are the four forces that act on an aircraft. You are correct in making which of the following statements.

A. Induced and parasite are two types of drag forces.
B. On a conventional aircraft, the propeller or jet engine is used to overcome gravity.
C. The four forces must be unequal to maintain straight and level flight.
D. Only the weight of the aircraft and its fuel must be against gravity.

18. When the helicopter is moving forward at a speed of 150 knots, and the velocity of the rotor blade tip is 363 knots, the advancing and retreating blade speeds are:

A. 513 and 213 knots.
B. 513 and 313 knots.
C. 531 and 213 knots.
D. 531 and 231 knots.

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BASIC AERODYNAMICS

PRACTICE EXERCISE
SOLUTIONS

1. F. (Par. 2.15)

2. T. (Par. 2.5)

3. T. (Par. 3.10)

4. T. (Fig. 2.9)

5. F. (Par. 3.1)

6. T. (Par. 2.3)

7. F. (Par. 3.13)

8. T. (Par. 1.3)

9. a. T. (Par. 1.2)

   b. T. (Par. 1.2)

   c. F. (Par. 1.2)

   d. T. (Par. 1.2)

   e. F. (Par. 1.2)

10. (1) B. (Par. 2.14.)

    (2) A. (Par. 2.6)

    (3) E. (Par 3.3)

    (4) C. (Par. 2.8)

11. B. (Par. 3.15)

12. C. (Par. 2.6)

13. A. (Par. 1.4)

14. C. (Par. 3.7)

15. C. (Par. 1.5, Fig. 1.3)

16. A. (Par. 2.11)

17. A. (Par. 2.4)

18. A. (Par. 3.8)

Appendix I

REFERENCES

Army Regulations

AR 310-25	Dictionary of United States Army Terms.
AR 310-50	Authorized Abbreviations and Brevity Codes.
AR 750-31	Technical Publications for Army Files.

Field Manuals

FM 1-50	Fixed Wing Flight.
FM 1-51	Rotary Wing Flight.

Technical Manuals

TM 1-300	Meteorology for Army Aviation.
TM 55-1520-209-10	Operator's Manual CH-47.
TM 55-1520-210-10	Operator's Manual UH-1D/H.

Appendix II

GLOSSARY

Aileron--movable part of an airplane wing or a movable airfoil external to the wing which imparts a rolling motion and thus provides lateral control.

Airbrakes--airspeed-retarding devices which increase the resistance of the aircraft during a glide, landing, or maneuver.

Airfoil--any object, such as a wing or rotor blade, with surfaces designed to produce lift when air passes over it.

Angle of attack--angle at which an airfoil passes through the air.

Antitorque rotor--variable-pitch small rotor mounted on the tail of the helicopter to compensate for the torque created by the main rotor.

Argon--colorless, odorless, inert gas obtained from the atmosphere and used in some incandescent light bulbs.

Burbles--whirlwinds of air moving against the main current, causing turbulence and spoiling lift.

Camber--rise in the curve of an airfoil section from its chord, usually expressed as the ratio of the departure of the curve from the chord to the length of the chord.

Carbon dioxide (CO_2)--inactive, harmless gas formed when carbon burns with a clear flame in the presence of oxygen.

Center of pressure--point on an airfoil at which the resultant aerodynamic forces acting on an airfoil intersect the zero lift chord.

Chord line--an arbitrary datum line from which the curvature of an airfoil section is measured. It is the straight line passing between the centers of leading and trailing edges of the airfoil.

Collective pitch control--the control that changes the pitch of all the main rotor blades equally and simultaneously.

Cyclic control--mechanical means employed to change the plane of the main rotor disc.

Dissymmetry of lift--difference in lift that exists between the advancing half and the retreating half of the disc area in forward flight.

Exosphere--outermost fringe or layer of the atmosphere, where collisions between molecular particles are so rare that only the force of gravity will return escaping molecules to the upper atmosphere.

Gyroscopic precession--result of an applied force against a rotating gyro. It occurs approximately 90° in the direction of rotation from the point where the force is applied.

Helixpteron--Greek word used in Leonardo da Vinci's notes meaning spiral wing.

Horsepower--unit of energy. One horsepower is the amount of energy that must be expended in order to raise 33,000 lb through a distance of one foot in one minute.

Induced drag--the resistance offered by the large area of the wing moving through the air.

Ionosphere--that part of the earth's atmosphere consisting of layers of highly ionized air that can bend certain radio waves or reflect them back to the surface of the earth.

Jet stream--narrow band of high-velocity wind near the tropopause.

Laminae--sheets of air in the boundary layer that slide over one another without much mingling of the molecules.

Lapse rate--rate at which air temperature decreases as altitude increases is 2°C or 3 1/2°FR per thousand feet average. Also called temperature lapse rate.

Mean sea level--average sea level elevation.

Nitrogen--one of the chemical elements. Its symbol is N; it is the most abundant component of the atmosphere.

Oxygen--element that is found free as a colorless, tasteless, odorless gas in the atmosphere.

Parasite drag--resistance created by the entire aircraft passing through the air.

Rotor disc--plane made by the rotation of the rotor blades.

Rotor tip vortex--air swirl at the tip of wings or rotor blades.

Standard air--14.7 pounds per square inch at sea level, 15°C., 29.92 inches mercury, or 1,013.2 millibars.

Stratopause--upper boundary of the stratosphere.

Stratosphere--upper region or external layer of the atmosphere, in which the temperature is practically constant in a vertical direction.

Tandem rotors--on a helicopter, two or more sets of main rotors, placed one in front of the other.

Torque--measurement of a force producing rotation about an axis.

Tropopause--dividing line between the troposphere and the stratosphere.

Troposphere--lower portion of the atmosphere extending from the earth's surface to an altitude of about ten miles at the equator, and about five miles at the poles.

Venturi--short tube having a large opening in the front and the rear with a smaller-diameter neck in between. The flow through the venturi causes a pressure drop in the smallest section. The amount of the drop is related to the velocity of flow.

Vortex--conflicting whirling or circulating airflow around a wing tip. It is caused by the air flowing laterally out from the high pressure area on the under surface of the wing into the lower pressure area on the upper surface of the wing.

Wing dihedral--acute angle between an airplane wing and true horizontal.

Wing root--that section at the base of the wing or next to the fuselage where it is attached to the aircraft.

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