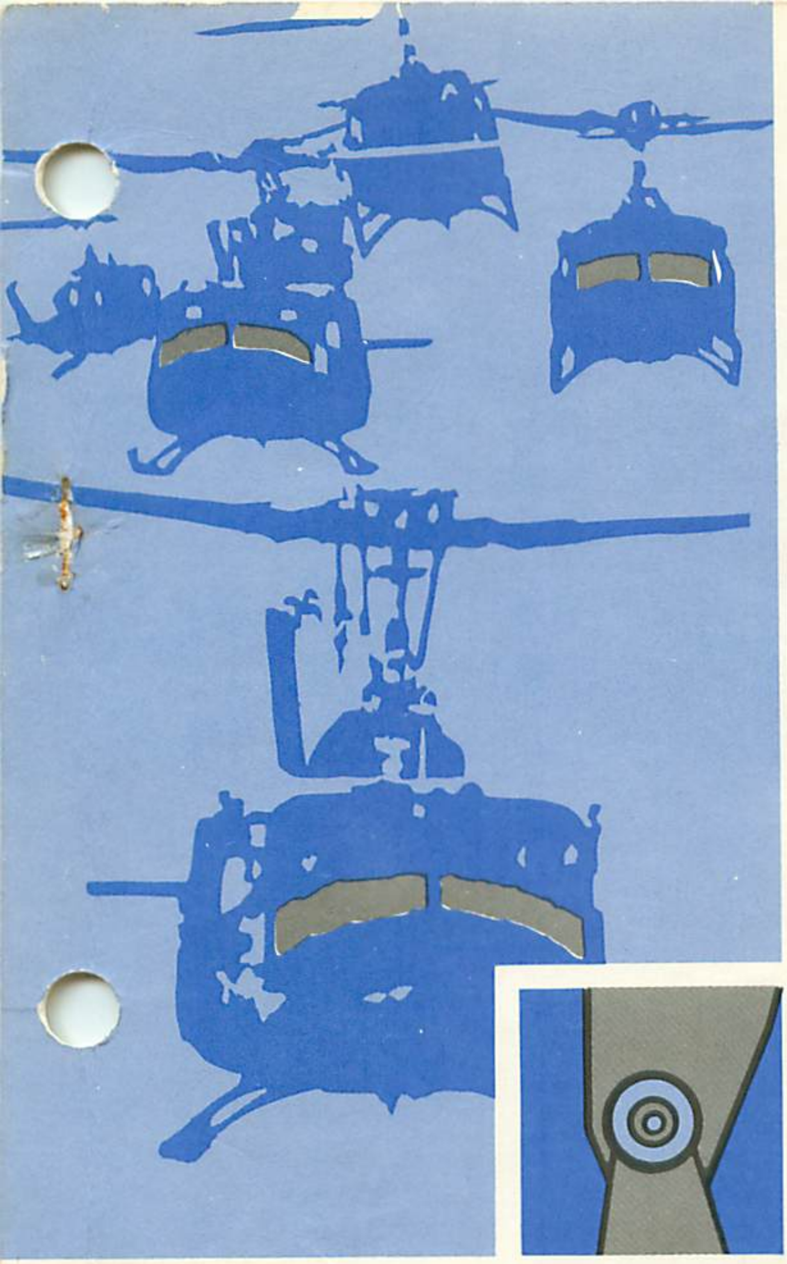
FM 55-414

FUNDAMENTALS OF ROTOR AND POWER TRAIN MAINTENANCE



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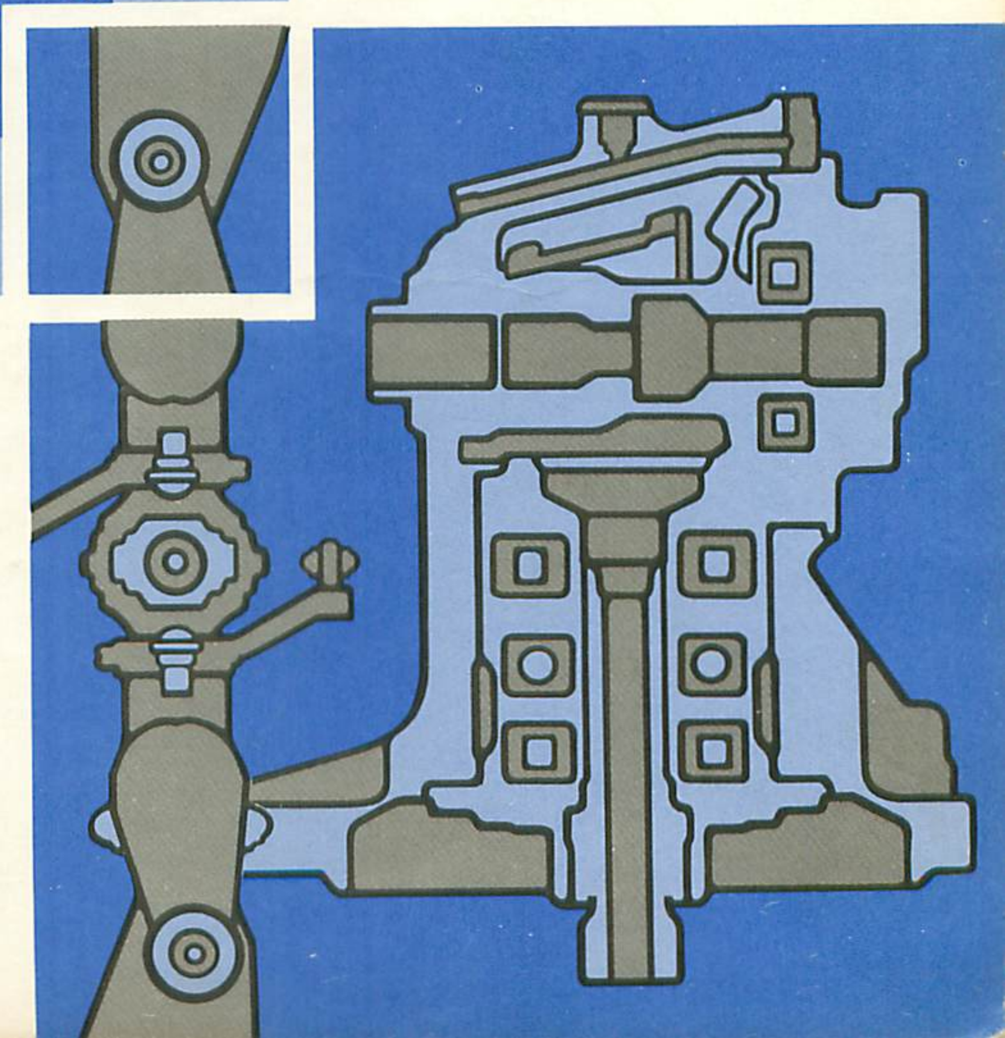
HEADQUARTERS, DEPARTMENT OF THE ARMY



FIELD MANUAL
NO 55-414

*FM 55-414

HEADQUARTERS
DEPARTMENT OF THE ARMY
Washington, DC, 27 June 1984

FUNDAMENTALS OF ROTOR AND POWER TRAIN MAINTENANCE

PREFACE

This manual is a guide for Army repairers on maintaining aircraft rotors and power trains. It contains descriptions, construction features, operating principles, elementary repair procedures, and basic repair shop allied subjects.

The rotor and power train information in this manual is general. For detailed information and specific repair procedures on a particular aircraft, refer to the technical manuals for that aircraft or component.

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Fort Eustis, VA 23604

The words "he," "his," "him," and "men" in this manual are intended to include both the masculine and feminine genders.

*This manual supersedes TM 55-406, 4 February 1969, TM 55-414, 10 October 1970, and TC 55-17, 8 September 1980.

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CHAPTER 1

THEORIES AND PRINCIPLES OF HELICOPTER FLIGHT

1-1. INTRODUCTION

The principles of basic flight theory and aerodynamics are considered in full detail when an aircraft is designed. The rotor repairer must know these principles to perform safe and proper maintenance. To make repairs that are structurally sound and aerodynamically smooth, the repairer must have an understanding of the theory of flight principles and the aerodynamic forces acting on an aircraft.

1-2. FORCES ACTING ON AN AIRCRAFT

Aerodynamics deals with the motion of air and the forces acting upon an object moving through air or a stationary object in a current of air. The principles of aerodynamics are the same for rotary-wing and fixed-wing aircraft. Four forces that affect an aircraft at all times are weight, lift, thrust, and drag.

a. Weight is the force exerted on an aircraft by the pull of gravity. This pull acts through the aircraft center of gravity, which is the point at which an aircraft would balance if suspended. The magnitude of this force changes only with a change in aircraft weight.

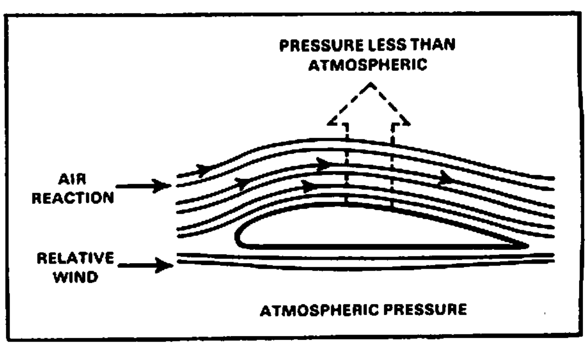
b. Lift is produced by air passing over the wing of an airplane, and over the rotor blades of a helicopter. Lift is the force that overcomes the weight of an aircraft so it can rise in the air.

c. Thrust is the force that moves an aircraft through the air. In a conventional fixed-wing aircraft, thrust is provided by the propeller and acts forward, the wings supplying the lift. In a helicopter, both thrust and lift are supplied by the main rotor blades.

d. Drag is the force of resistance, by air, to the passage of an aircraft through it. The force of thrust sets an aircraft in motion and keeps it in motion against the force of drag.

1-3. AIRFOIL

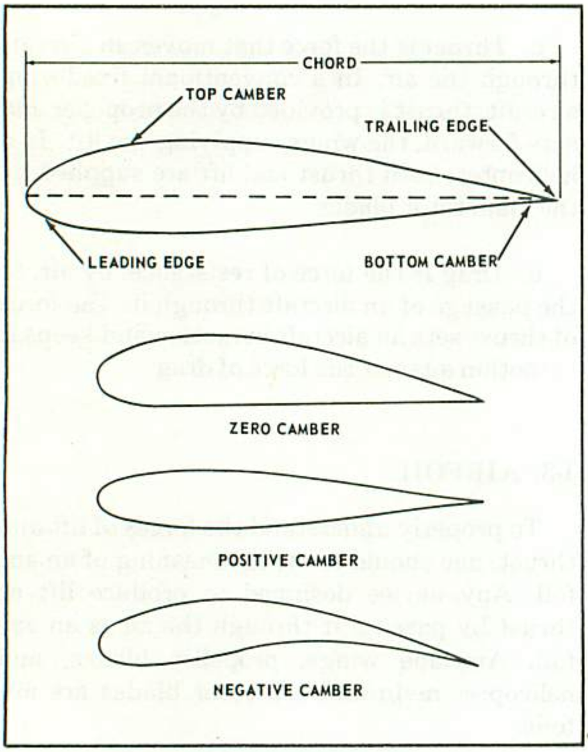
To properly understand the forces of lift and thrust, one should know the meaning of an airfoil. Any device designed to produce lift or thrust by passing it through the air is an airfoil. Airplane wings, propeller blades, and helicopter main and tail rotor blades are airfoils.



EXAMPLE OF AN AIRFOIL

1-4. CHORD

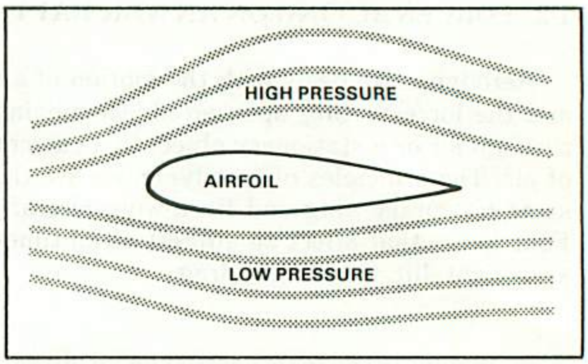
Chord is the distance or imaginary line between the leading and trailing edges of an airfoil. The amount of curve, or departure of the airfoil surface from the chord line, is known as camber. Upper camber refers to the upper surface. Lower camber refers to the lower surface. If the surface is flat, the camber is zero. The camber is positive if the surface is convex (curves outward from the chord line). The camber is negative if the surface is concave (curves inward toward the chord line). The upper surface of an airfoil always has positive camber, but the lower surface may have positive, negative, or zero camber.



AIRFOIL FEATURES

1-5. BERNOULLI'S PRINCIPLE

Bernoulli, an 18th century physicist, discovered that air moving over a surface would decrease the air pressure on the surface. As the speed of the air increases, the air pressure on the surface decreases accordingly. This applies to the flight of an aircraft. As the airfoil starts moving through the air, it divides the mass of air molecules at the leading edge. The distance across the curved top surface is greater than that across the relatively flat bottom surface. The air molecules which go over the top must therefore move faster than those going under the bottom in order to meet at the same time along the trailing edge. The faster airflow across the top surface will create a low pressure area above the airfoil. The air pressure below the airfoil will be greater than the reduced pressure above and will tend to push the airfoil up into the area of lower pressure. As long as air passes over the airfoil this condition will exist. This difference in pressure causes lift. When the movement of air is fast enough over a wing or rotor blade, the lift produced will match the weight of the airfoil and its attached fuselage. This lift can then support the entire aircraft. As the speed of air across the wing or rotor increases even more, the lift exceeds the weight of the aircraft and the aircraft will rise. All the air met by an airfoil is not used in lift. Some of it creates resistance or drag which hinders forward motion. Lift and drag increase and decrease together. They are therefore affected by the airfoil's angle of attack into the air, speed of airflow, air density, and shape of the airfoil or wing.



BERNOULLI'S PRINCIPLE

1-6. FACTORS AFFECTING LIFT AND THRUST

The amount of lift that can be develped by an airfoil depends on five major factors: area (size or surface area of the airfoil), shape (shape or design of the airfoil sections), speed (velocity of the air passing over the airfoil), angle of attack (angle at which the air strikes the airfoil), and density of air (amount of air in a given space).

a. Shape and Surface Area. The specific shape and surface area of an airfoil are determined by the aircraft manufacturer. An airfoil may be unsymmetrical or symmetrical, depending on the specific requirements to be met. A symmetrical airfoil is designed with an equal amount of camber above and below the airfoil chord line. A symmetrical airfoil has a greater amount of camber above the chord line. An airfoil with a smooth surface produces more lift than one with a rough surface. A rough surface creates turbulence that reduces lift and increases drag.

b. Speed. The speed of an airfoil can be changed by the speed of the engine or by the blade angle. The lift developed by an airfoil increases as speed is increased. However, there is a limit to the amount of lift because the drag (resistance) of the airfoil also increases with an increase in speed.

c. Angle of Attack. The angle of attack is the angle between the airfoil chord and direction of relative wind. Direction of airflow in relation to the airfoil is called relative wind. Lift increases as the angle of attack increases up to a certain point. If the angle of attack becomes too great, the airflow over the top of the airfoil tends to lose its streamlined path and will break away from the contoured surface and form eddies (burbles) near the trailing edge. When this happens, the airfoil loses its lift and stalls. The angle of attack at which this burbling takes place is called the burble point or stalling point.

d. Density of Air. The density (thickness) of the air plays an important part in the amount of lift an airfoil is able to make. The air nearest the Earth's surface is much denser than the air at higher heights. Therefore, an aircraft or helicopter can make more lift near the ground than at high altitude. While staying at the same speed and angle of attack, an airfoil will slowly make less lift as it climbs higher and higher.

1-7. FACTORS AFFECTING AIRFOIL STABILITY

a. Airfoil Center of Pressure. The resultant lift produced by an airfoil is the difference between the drag and lift pressures of the upper and lower surfaces. The point on the airfoil chord line where the resultant lift is effectively concentrated is called the center of pressure. The center of pressure of a symmetrical airfoil remains in one position at all angles of attack. When the angle of attack of an unsymmetrical airfoil changes, the center of pressure changes accordingly. That is, the center of pressure moves forward with an increase in angle of attack, and the center of pressure moves backward with a decrease in angle of attack.

b. Airfoil Aerodynamic Center. The aerodynamic center of an airfoil is the point along the chord line about which the airfoil tends to rotate when the center of pressure moves forward or backward between the leading and trailing edges.

c. Torque. Newton's third law of motion states, "To every action there is an opposite and equal reaction." As a helicopter main rotor or an airplane propeller turns in one direction, the aircraft fuselage tends to rotate in the opposite direction. This effect is called torque. Solutions must be found to counteract and control this torque during flight. In helicopters, torque is applied in a horizontal rather than a vertical plane. The reaction is greater because the rotor is long and heavy in relation to the fuselage, and forward speed is not always present to correct the twisting effect.

d. Gyroscopic Precession. If a force is applied against a rotating body, the reaction will be about 90° from the point of application, in the direction of rotation. This unusual fact is known as gyroscopic precession. It pertains to all rotating bodies. For example, if you push the 3-o'clock point on a clockwise rotating wheel, the wheel would move as if it had been pushed at the 6-o'clock point. The rotors on helicopters act as gyroscopes and are subject to the action of gyroscopic precession.

1-8. STRESSES

Stress is a force placed on a body and is measured in terms of force per unit area. Force is expressed in pounds and the unit of area in square inches. Aircraft design engineers plan the construction of an aircraft to meet, and even exceed, the strength requirements of military service. However, since Army aircraft are operated under combat conditions, they might exceed their designed limits. Maintenance personnel must constantly check for failures and for signs of approaching failure in the structural units of aircraft. Stress may be in the form of compression, torsion, tension, bending, and shear, or it may be a combination of two or more of these types of stress.

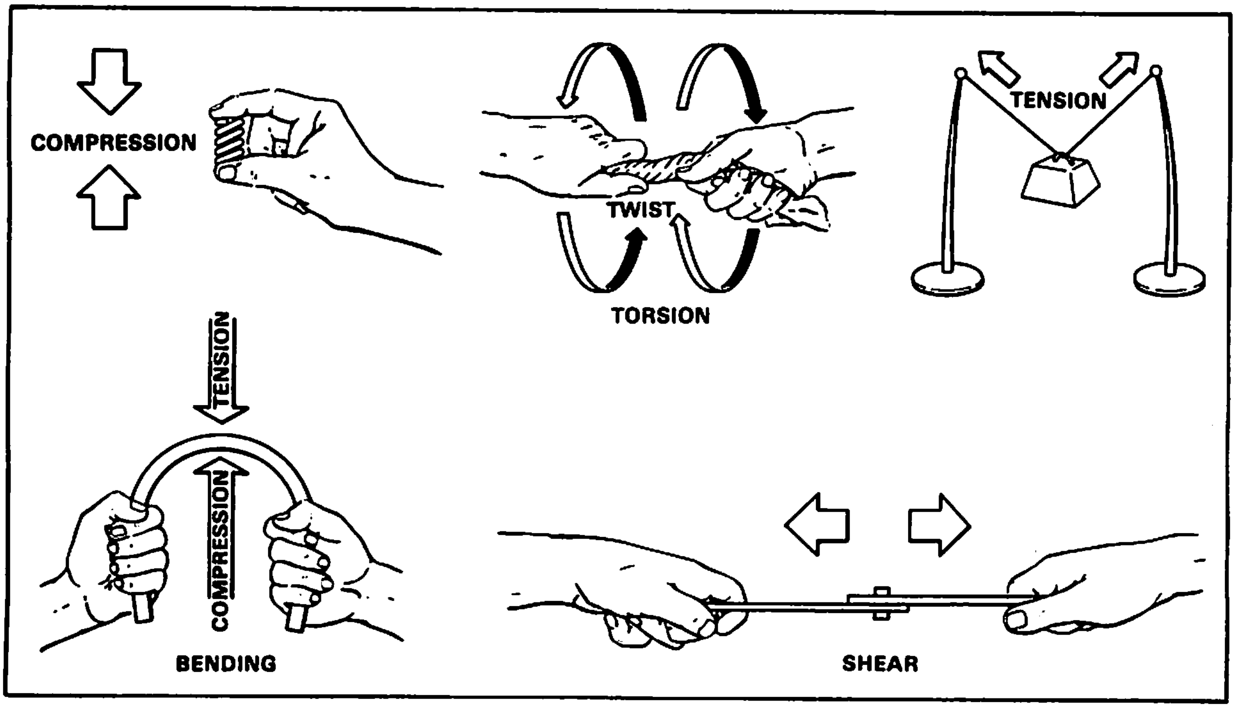
a. **Compression** is the resistance to being pushed together or crushed. This stress is produced by two forces pushing toward each other in the same straight line. The landing struts of an aircraft are under compression after landing.

b. **Torsion** is the resistance to twisting. A torsional force is produced when an engine turns a crankshaft. Torque is the force that produces torsion.

c. **Tension** is the resistance to being pulled apart or stretching. This stress is produced by two forces pulling in opposite directions along the same straight line. The pilot puts the cables of a control system under tension when he operates the controls.

d. **Bending** is a combination of tension and compression. The inside curve of the bend is under compression, and the outside curve is under tension. Helicopter main rotor blades are subjected to bending.

e. **Shear** is the stress exerted when two pieces of metal fastened together are separated by sliding one over the other in opposite directions. Two pieces of metal, fastened together by rivets or bolts, subject the rivets or bolts to shearing action when force is applied to the pieces of metal, tending to slide them across each other. This stress would cut off the bolt or rivet like a pair of shears. Generally, rivets are subjected to shear only but bolts may be stressed by shear and tension. There is internal shear in most bending elements and in the skin of sheet metal structures.

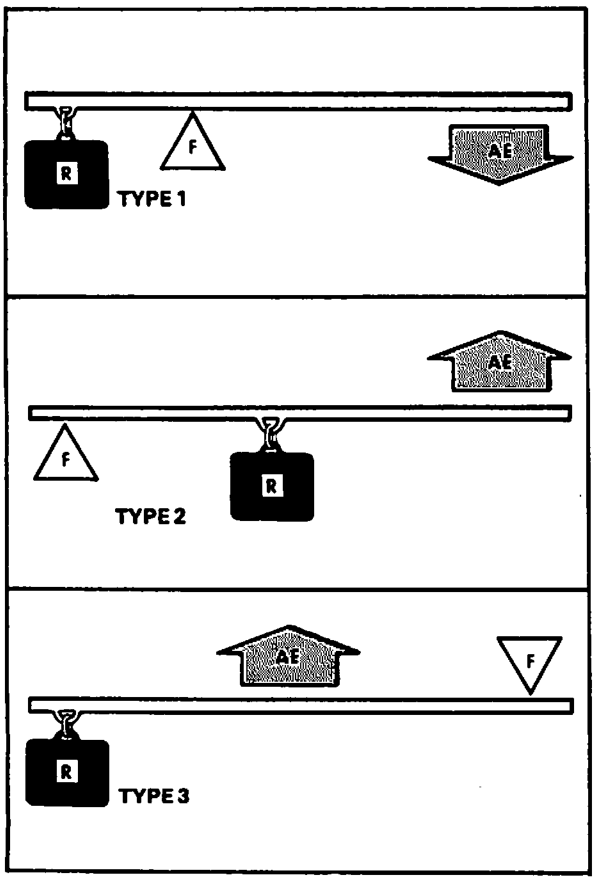


TYPES OF STRESSES

1-9. LEVERS AND MOMENTS OF FORCE

Levers are useful tools to the rotor repairer. They are used in tools such as jacks, shears, wrenches, and pliers. To use tools and balancing procedures correctly, the repairer must understand moments of force (amount of leverage).

a. **Types of Levers.** Levers are classified into three types according to the position of applied force, the resistance, and the fulcrum (the pivot point). Type 1 lever has the fulcrum located between the applied effort and the resistance. Type 2 has the resistance located between the fulcrum and the applied effort. Type 3 has the applied effort located between the resistance and the fulcrum.



TYPES OF LEVERS

b. **Mechanical Advantage of Levers.** Mechanical advantage is the ratio between the resistance and the effort applied to a lever. This is expressed in the following formula.

$$MA = \frac{R}{E}$$

MA = mechanical advantage

R = resisting force (weight moved)

E = effort (applied force)

Proper use of mechanical advantage enables a relatively small force to overcome a larger resisting force by applying the effort through a longer distance than the resistance is moved. For example, to lift a 4-pound weight (R) which is 2 inches from the fulcrum of a type 1 lever would require a 1-pound effort (E) applied 8 inches from the fulcrum. The mechanical advantage of this lever would be as follows:

$$MA = \frac{R}{E} = \frac{4}{1} = 4$$

Thus, the applied effort in the example would move through a distance 4 times greater than the distance the resistance would move.

c. **Moments of Force.** A moment of force is the product of a force or weight multiplied by a distance. To find a lever's moment of force, multiply the applied effort by the distance between the point of effort application and the pivot point (fulcrum). If the moment of force of the applied effort equals the moment of force of the resistance, the lever will balance. If an object to be balanced on a type 1 lever weighs 4 pounds and is located 2 inches from the fulcrum, it could be balanced by a 2-pound effort applied 4 inches from the fulcrum on the opposite side, or a 1-pound effort applied 8 inches from the fulcrum.

1-10. VIBRATIONS

Vibration pertains to any type of machine. Greater than normal vibration usually means there may be a malfunction. These malfunctions can be caused by worn bearings, out-of-balance conditions, or loose hardware. If allowed to continue unchecked, these vibrations can cause material failure and/or machine destruction. Aircraft, mainly helicopters, have a high vibration level due to the many moving parts. For this reason, designers have been forced to use many different methods of dampening and counteracting to keep vibrations at an acceptable level.

a. **Methods.** Some methods of keeping down vibrations are driving secondary parts at different speeds to reduce harmonic vibrations. This removes much of the vibration buildup. Mounting high-level vibration parts such as drive shafting on shock absorbent mounts is another method of reducing vibration. Installing vibration absorbers in high-level vibration areas of the airframe is still another way of keeping down vibration.

b. **Types.**

(1) *Lateral.* Lateral vibrations are felt as side-to-side swinging rhythms. An out-of-balance rotor blade causes this type of vibration. Lateral vibrations in helicopter rotor systems are quite common.

(2) *Vertical.* Vertical vibrations are felt as an up-and-down movement which produces a thumping feeling. An out-of-track rotor blade causes this type vibration.

(3) *High frequency.* High-frequency vibrations are felt as a buzzing feeling, and have a numbing effect on the feet and fingers. The high-frequency vibrations are caused by an out-of-balance condition or a high-speed, moving part that has been torqued incorrectly. The balance of high-speed parts is very important. Any buildup of dirt, grease, or fluid on or inside such a part (drive shafting for example) is produced as a high-frequency vibration. This type vibration is more dangerous than a lateral or vertical one because it causes a crystallization of metal which weakens the metal. It must be corrected before the equipment can be operated.

(4) *Ground resonance.* Ground resonance is the most dangerous and destructive of the vibrations discussed so far. Ground resonance can destroy a helicopter in a matter of seconds. It is a vibrating condition present in helicopters with articulated rotor heads. Ground resonance occurs while the helicopter is on the ground with rotors turning. It will not happen in flight. Ground resonance results when unbalanced forces in the rotor system cause the helicopter to rock on the landing gear at or near its natural frequency. Correcting this problem is difficult because the natural frequency of the helicopter changes as lift is applied to the rotors. With all parts working properly, the design of the helicopter landing gear, shock struts, and rotor blade lag dampeners will prevent the resonance building up to dangerous levels. Improper adjustment of the landing gear shock struts, incorrect tire pressure, and defective rotor blade lag dampeners may cause ground resonance. The quickest way to remove ground resonance is to hover the helicopter clear of the ground.

1-11. NONDESTRUCTIVE INSPECTIONS

Tests that are performed on an aircraft part to insure that the part is within serviceable limits are called nondestructive inspections. These tests place no additional wear or tear on the part. If no defects are found that would condemn the part, it may be returned to service. That's why these tests are called nondestructive inspections. Specific procedures for performing nondestruct tests are found in TM 43-0103.

CHAPTER 2

FUNDAMENTALS OF ROTORS

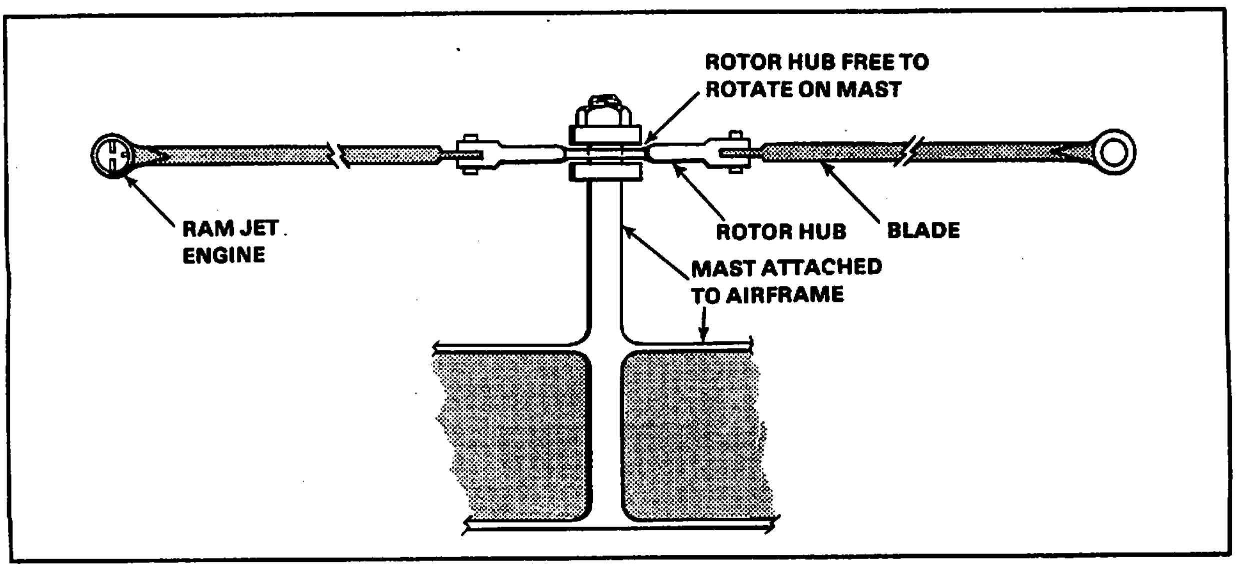
2-1. INTRODUCTION

Of all airfoils, the rotor blade on a helicopter is unique. It not only provides lift as most airfoils do, but it also provides thrust and directional control. This chapter contains information on the rotor system, forces acting on rotors, and rotor terminology.

2-2. ROTOR SYSTEM

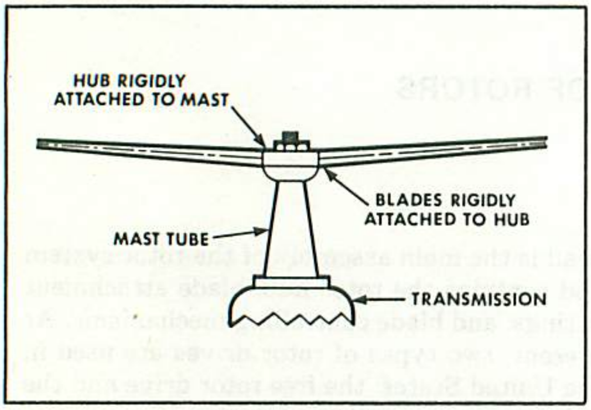
The rotor system produces the lift, thrust, and directional control needed for helicopter flight. It is composed of a rotor head, rotor blades, and control systems which drive and control the pitch angles of the blade. The rotor head is the main assembly of the rotor system and contains the rotor hub, blade attachment fittings, and blade controlling mechanisms. At present, two types of rotor drives are used in the United States: the free rotor drive and the hub drive.

a. **Free Rotor Drive.** In the free rotor drive the propulsion unit, usually a ramjet engine, is mounted to each end of the rotor blade. The rotor blades are attached to a rotor head or hub that is connected to a mast. The rotor head allows the self-propelled rotor blades to rotate on the stationary mast. The mast allows the lift and thrust of the blades to react on the airframe.



FREE ROTOR DRIVE

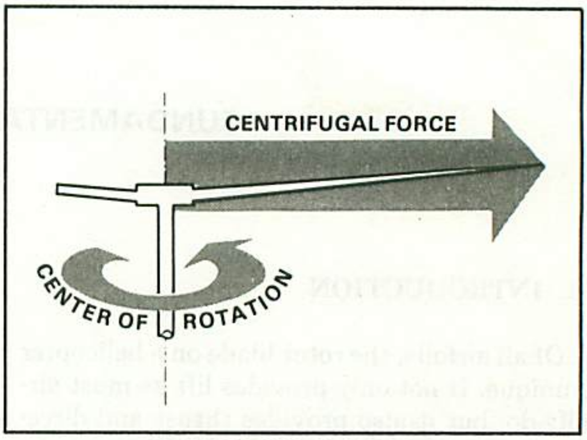
b. **Hub Drive.** In the hub drive the blades are attached to a rotor hub which is splined to the mast, which in turn rotates the rotor hub and blades. Currently, all the helicopters in the Army inventory use a hub drive system. Therefore, no further mention will be made of the free rotor drive system.



HUB DRIVE

2-3. FORCES ACTING ON ROTORS

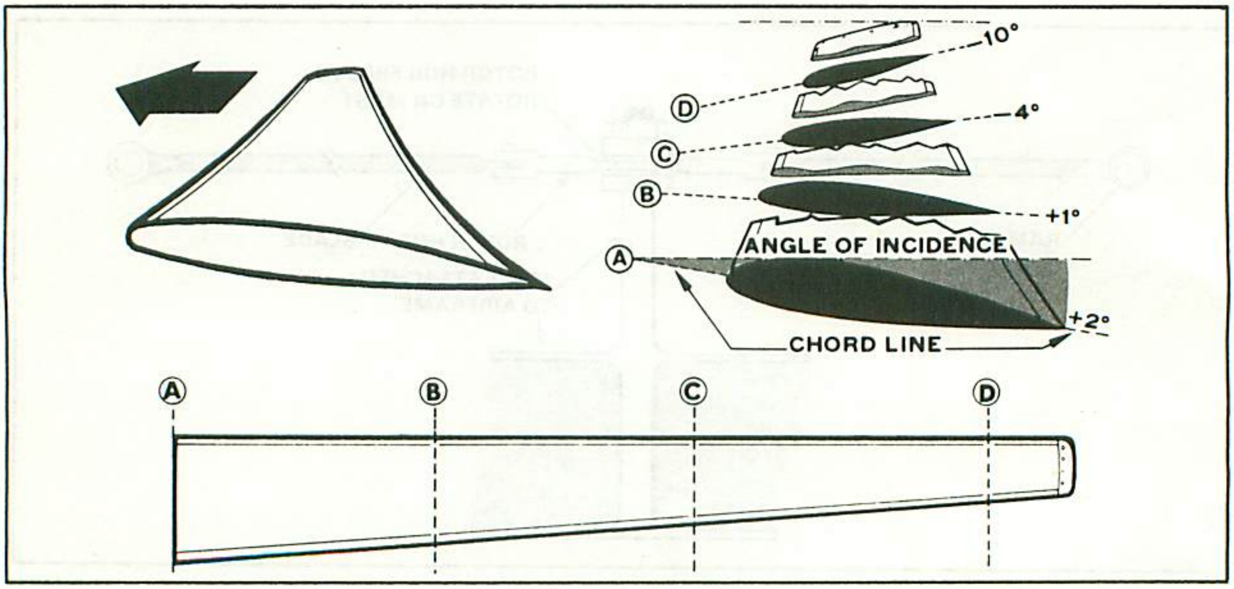
Since the rotor system of a helicopter provides both lift and thrust, it is exposed to all of the forces which act on aircraft wings and propellers. When applied to rotor blades, the thrust bending force which acts on propellers is called coning. Due to the large mass and weight of the rotating heads, it is important to consider the amount of centrifugal force that acts on the rotor blades. The centrifugal loads are the reason for allowing only slight damage to be repaired on certain portions of the rotor blades and hub assemblies of helicopters.



CENTRIFUGAL FORCE

2-4. ROTOR TERMINOLOGY

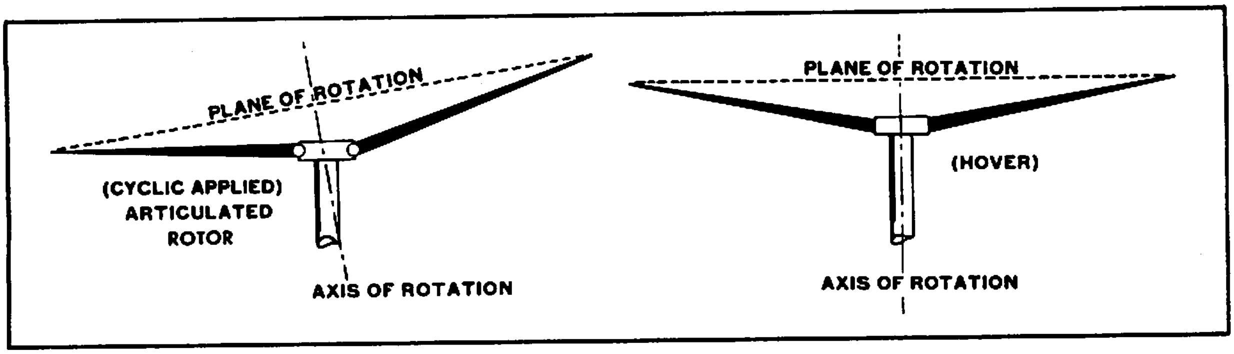
a. **Angle of Incidence.** The angular connection between a reference line on a rotor blade cuff, socket, or attachment point and the blade chord line at a specific blade station is called the angle of incidence. On most blades, this angle is determined during design and is not adjustable.



ANGLE OF INCIDENCE

b. **Plane of Rotation.** A plane formed by the average tip path of the blades is known as the plane of rotation. It is at a right angle to the axis of rotation.

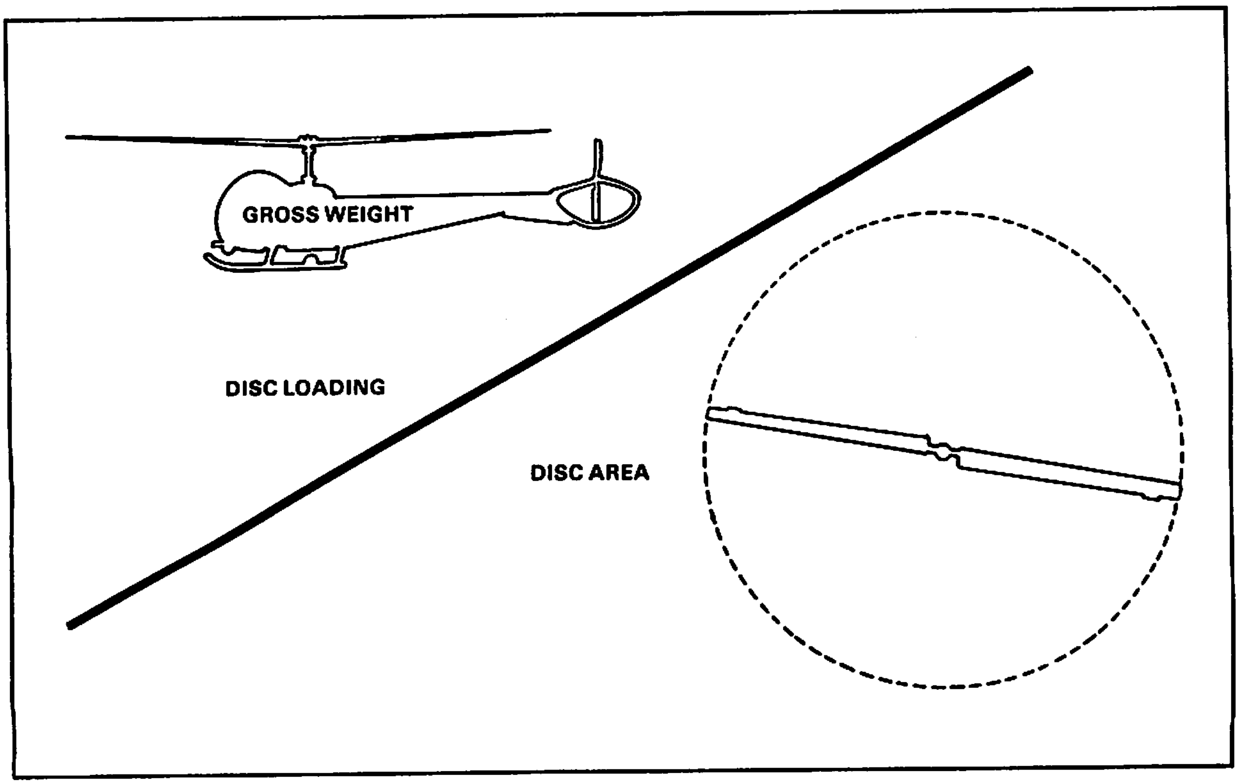
c. **Axis of Rotation.** An imaginary line that passes through a point on which a body rotates is called the axis of rotation. Its rotation is at a right angle to the plane of rotation.



AXIS OF ROTATION

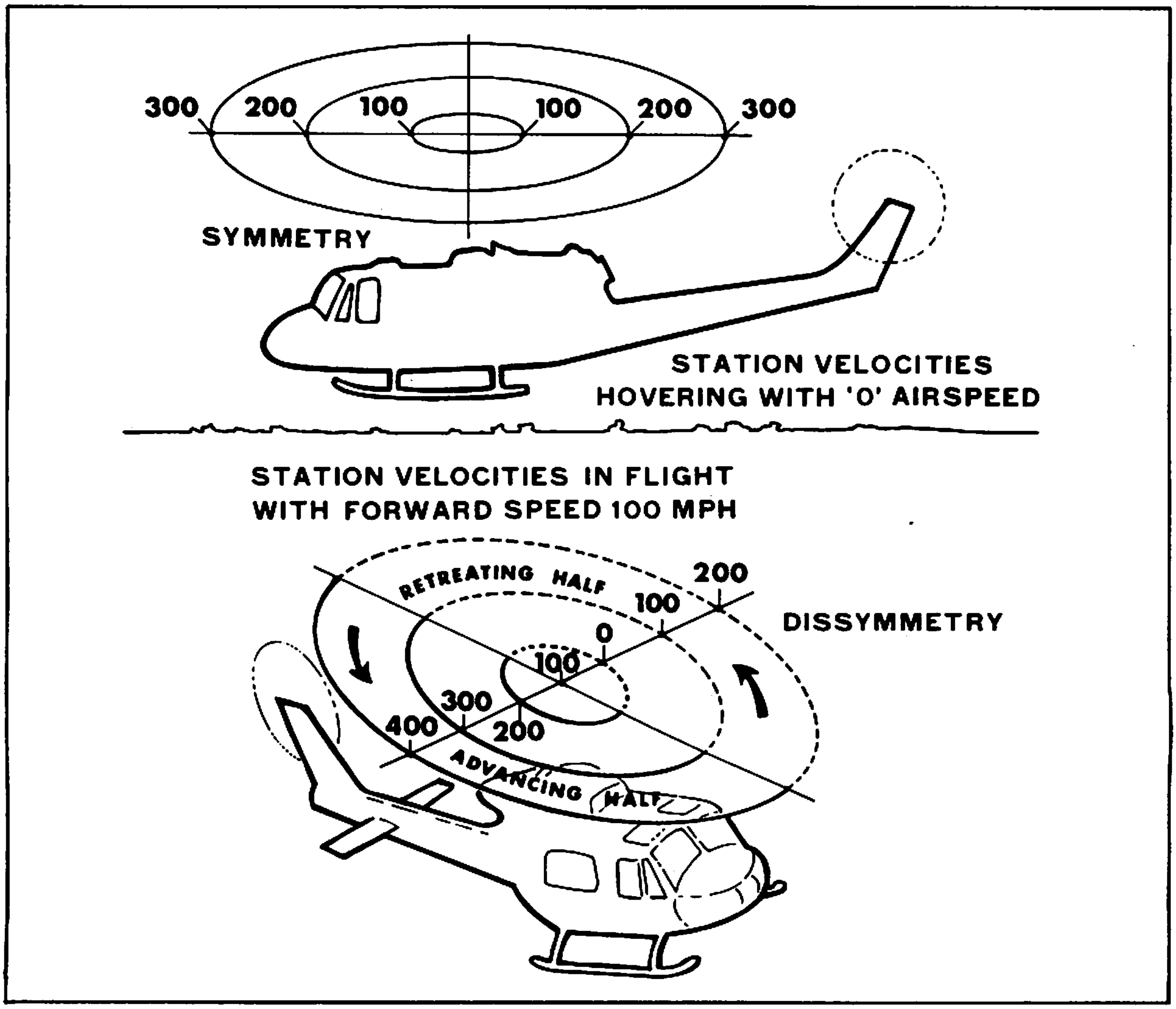
d. **Disc Area and Loading.** The disc area is the total space within the area of the circle formed by rotating rotor blades. The formula used to figure disc area is $A = TTR^2$ (A = area, TT = total, R = radius). Area equals 3.14159 multiplied by radius, then squared (multiplied by itself). The span length of one blade is used as the radius. The area of the hub in the disc area is not included since it doesn't make any lift. Disc loading is the ratio of aircraft gross weight to the disc area.

$$\text{Disc loading} = \frac{\text{gross weight of aircraft}}{\text{disc area}}$$



DISC AREA AND LOADING

e. **Symmetry and Dissymmetry of Lift.** Dissymmetry of lift is the difference in lift that exists between the advancing half of a rotor disc and the retreating half. Lift varies according to the square of the velocity (speed of blade and forward airspeed of aircraft). Symmetry and dissymmetry of lift are shown in the illustration. This example uses a blade tip speed of 300 miles per hour (mph). The blade speed varies from 300 mph at the tip station to 0 at the center of blade rotation on the hub. When a helicopter is hovering in a no-wind condition, there is symmetry of lift. The lift is equal on advancing and retreating halves of the rotor disc area because speed is the same on both halves. Dissymmetry of lift is created by forward movement of the helicopter. When the helicopter is moving forward, the speed of the advancing blade is the sum of the indicated airspeed of the helicopter plus the rotational speed of the blade. The speed of the retreating blade is the rotational speed of the blade minus the forward speed of the helicopter. The advancing half of the disc area has a blade tip speed of 300 mph plus the indicated helicopter speed of 100 mph, for a total blade tip speed of 400 mph. The total speed squared is 160,000. The retreating half of the disc has a blade tip speed of 300 mph minus the 100 mph indicated forward speed of 200 mph, and velocity squared is 40,000. In this example, the advancing blade creates four times as much lift as the retreating blade.

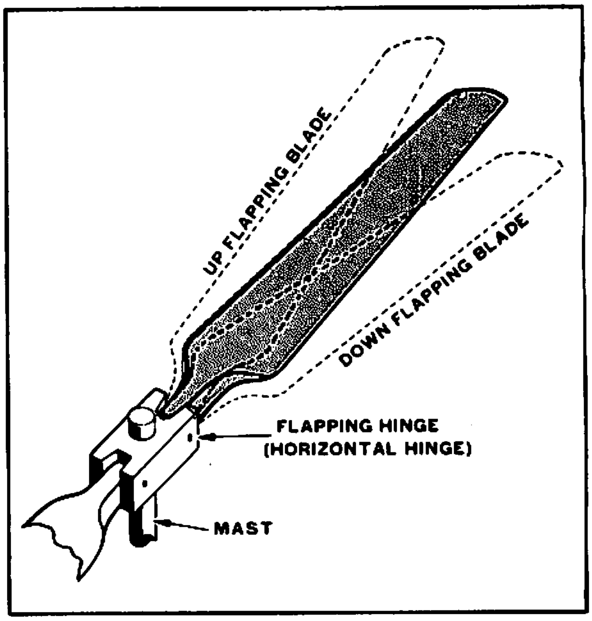


SYMMETRY AND DISSYMMETRY OF LIFT

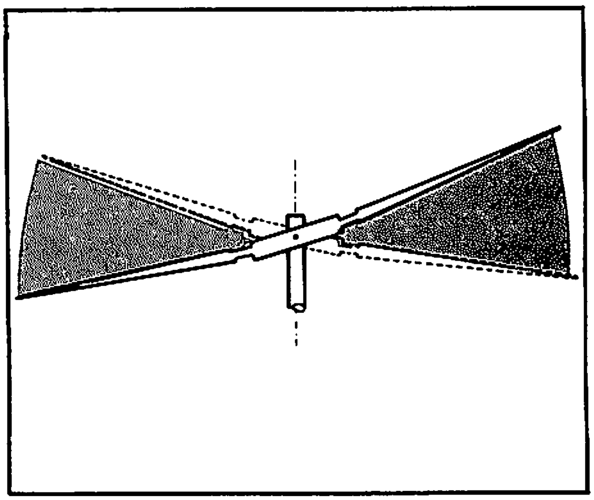
f. **Horsepower Loading.** Also called power loading, horsepower loading is often referred to in connection with fixed-wing and rotary-wing aircraft. It is the ratio of aircraft gross weight to maximum horsepower, or gross weight divided by available horsepower. The horsepower loading factor is used in determining rotor system design and testing.

g. **Flapping.** The up and down movement of rotor blades positioned at a right angle to the plane of rotation is referred to as flapping. This permits the rotor disc to tilt, providing directional control in flight. It also controls the required lift on each blade when in contact with dissymmetry of lift. Up and down flapping is limited by the centrifugal force acting against a smaller lifting force. Some hubs have droop stops to limit downward movement at low rotor speed.

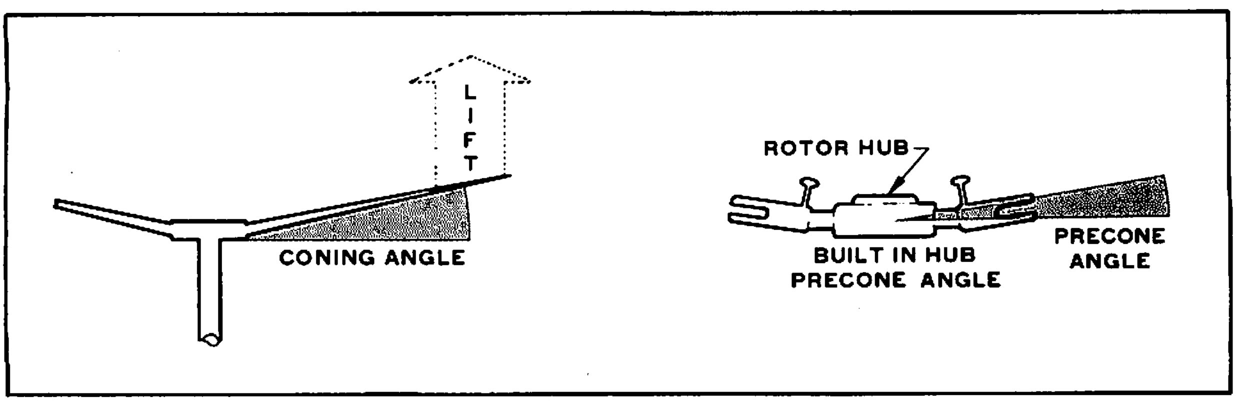
h. **Coning and Preconing.** Coning is the upward flexing of a rotor blade due to lift forces acting on it. Coning is the result of lift and centrifugal force acting on a blade in flight. The lift force is almost 7 percent as great as the centrifugal force which causes the blade to deflect upward about 3° to 4°. Coning is often expressed as an angle. Helicopter builders can determine the coning angle mathematically. They can build a precone angle into the rotor hub that is similar to the coning effect in normal flight. The preconed hub lets the blades operate at normal coning angles without bending. Therefore, stresses are reduced. It is not necessary to precone the articulated rotor hub because the blade can flap up on horizontal hinges to the correct coning angle.



FLAPPING, ARTICULATED HUB

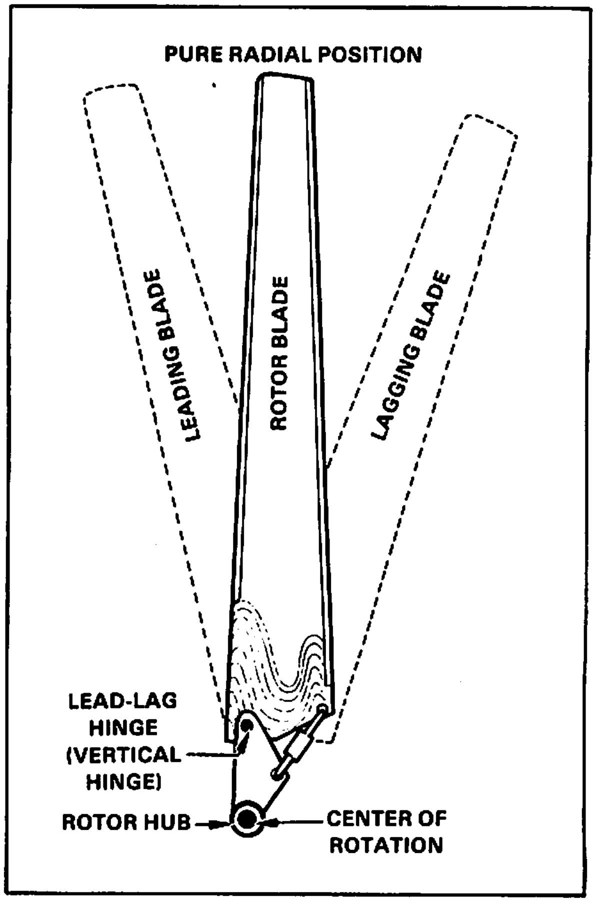


FLAPPING, SEMIRIGID HUB



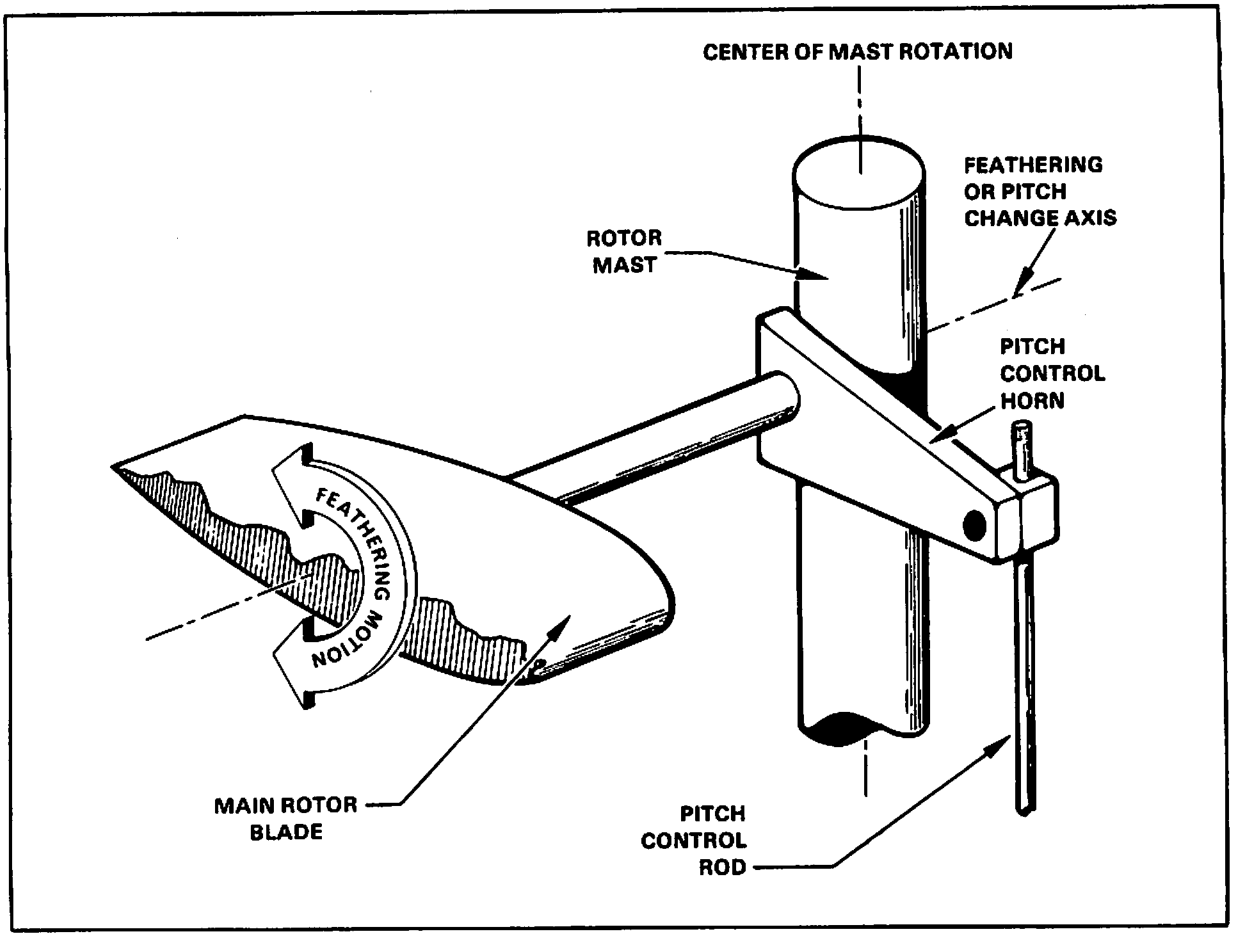
CONING AND PRECONING ANGLES

i. **Lead and Lag of Blades.** Leading and lagging (hunting) is the horizontal movement of the blades around a vertical pin. This is found only on fully articulated rotor heads. During starting the blades will resist rotational movement and will lag behind their (true radial) position. As centrifugal force reacts on the blade, the blade will gain momentum and find its own position of rotation. The blade will hunt about the vertical hinge close to a 5° range during normal operation. The movement of the blades about the vertical hinge is restricted by a hydraulic damper.



LEAD AND LAG

j. **Feathering Axis.** The spanwise axis about which a rotor blade rotates to change pitch is known as the feathering axis. The feathering action varies according to the position of the cyclic control in forward flight, the dissymmetry of lift, and the collective pitch control when the helicopter hovers.



FEATHERING AXIS

k. **Ground Effect.** When hovering near ground or water surfaces at a height of no more than one-half of the rotor diameter, the helicopter encounters a condition referred to as ground effect. It is more pronounced nearer the ground. Helicopter operations within ground effect are more efficient due to the reduction of rotor tip vortex and the flattening out of the rotor downwash. The benefit of ground effect is lower blade angle of attack, which results in a reduction of power requirements for a given load.

l. **Hover.** The versatility of a helicopter is due to its ability to hover at a point above the ground. This lets the helicopter rise from and come down vertically into small unimproved landing areas. When the main rotor angle of attack and engine power are adjusted so that lift equals weight, the helicopter will hover. Hover is considered an element of vertical flight. Assuming a no-wind condition exists during hover, the tip path plane of the rotor will remain horizontal with the earth. When the angle of attack of both blades is increased equally with blade speed remaining constant, more thrust will result and the helicopter will rise. By upsetting the lift-gravity balance, the helicopter will rise or come down depending on which force is the greater. Hovering takes a great deal of power because a large mass of air must be drawn through the rotor blades at high speeds.

CHAPTER 3

ROTOR SYSTEMS DESCRIPTION AND PRINCIPLES OF OPERATION

3-1. INTRODUCTION

There are many types of rotor systems. This chapter gives a general description of some rotor systems and the principles of operation.

3-2. PRINCIPLES OF OPERATION AND DESIGN FEATURES OF ROTOR SYSTEMS

It is important to know and understand the operation of rotor heads and how rotor blades are driven. An understanding of the rotor system is necessary to be able to troubleshoot the system in a logical manner. For a complete detailed description of a specific helicopter's rotor system, refer to the applicable aircraft multipart maintenance manual. Remember that if the components of the rotor system are not properly maintained, a malfunction may occur while in flight causing loss of life and equipment. Helicopter configurations or designs are classified as single, tandem, coaxial, and side by side. Only the single rotor and the tandem rotor configurations are used in Army helicopters.

a. **Single Rotor.** The configuration of a helicopter shows what type of rotor and power train system is used to power the helicopter. Helicopters designed to use a main and tail rotor system are referred to as single rotor helicopters. The main rotor provides lift and thrust while the tail rotor counteracts the torque made by the main rotor. This keeps the aircraft from rotating in the opposite direction of the main rotor. The tail rotor also provides the directional control for the helicopter during hovering and engine power changes. Power for operation of the main and tail rotor is supplied by the power train system. The single rotor configuration has the advantage of being simple, weighing less, and requiring less maintenance than the tandem rotor system. Since the tail rotor uses a portion of the available power, the single rotor system has a smaller center-of-gravity range.

b. **Tandem Rotor.** Normally used on large cargo helicopters, the tandem rotor configuration has two main rotor systems. One is mounted on each end of the fuselage. Each rotor operates the same as the main rotor on the single rotor helicopter, except for the direction of rotation of the aft rotor and the method of keeping directional control. The forward rotor turns in a counterclockwise direction viewed from below, and the aft rotor rotates in a clockwise direction. A separate antitorque system is not needed because the rotor systems rotate in opposite directions (counteract each other's torque). Advantages of the tandem rotor system are a larger center-of-gravity range, good longitudinal stability, and the fact that the counterrotating rotors do away with the need for an antitorque rotor. Because there is no antitorque rotor, full engine power can be applied for load lifting. Disadvantages of the tandem rotor system are a complex transmission and more drag due to its shape and excessive weight.

3-3. HELICOPTER FLIGHT CONTROLS

As a helicopter maneuvers through the air, its attitude in relation to the ground changes. These changes are described with reference to three axis of flight: lateral, vertical, and longitudinal. Movement about the lateral axis produces a nose-up or nose-down attitude. This is accomplished by moving the cyclic pitch control fore and aft. Movement about the vertical axis produces yaw — a nose swing (or change in direction) to the right or left. This is controlled by the directional control pedals. These pedals are used to increase or decrease thrust in the tail rotor of a single rotor helicopter and tilt the rotor discs in opposite directions on a tandem rotor helicopter. Movement about the longitudinal axis is called roll. This produces a tilt to the right or left. The movement is accomplished by moving the cyclic pitch control to the right or left. Some other helicopter flight controls are discussed as follows.

a. Cyclic Pitch Control. The cyclic pitch control looks like the control stick of a common aircraft. It acts through a mechanical linkage to cause the pitch of each main rotor blade to change during a cycle of rotation. To move a helicopter forward from a hovering height, the rotor disc must be tilted forward so that the main rotor provides forward thrust. This change from hovering to flying is called transition and is done by moving the cyclic control stick. Moving the cyclic control stick changes the angle of attack of the blades; this change tilts the rotor disc. The rapidly rotating rotor blades create a disc area that can be tilted in any direction respective to the supporting rotor mast. Horizontal movement is controlled by changing the direction of tilt of the main rotor to produce a force in the desired direction.

b. Collective Pitch Control. Collective pitch control varies the lift of the main rotor by increasing or decreasing the pitch of all blades at the same time. Raising the collective pitch control increases the pitch of the main rotor blades. This thereby increases the lift and causes the helicopter to rise. Lowering the control decreases the pitch of the blades, causing a loss of lift, and produces a corresponding rate of descent. Collective pitch control is also used in coordination with cyclic pitch control to regulate the airspeed of the helicopter. For example, to increase airspeed in level flight, the cyclic is moved forward and the collective raised at the same time.

c. Control Plate. Forces from the cyclic and collective pitch sticks are carried to the rotor by a control plate usually located near the bottom of the rotor drive. Control plates used by various builders are different in appearance and name, but they perform the same function. The control plate is attached to the rotor blades by push-pull rods, chains, and bell cranks. The collective pitch stick changes the pitch of the blades at the same time by a vertical deflection of the entire control plate. The cyclic pitch stick allows angular shifting of the control plate to be sent to a single blade. This causes flapping and small angles of pitch change to make up for unequal lift across the rotor disc. The direction of tilt of the control plate decides the direction of flight: forward, backward, left, and right.

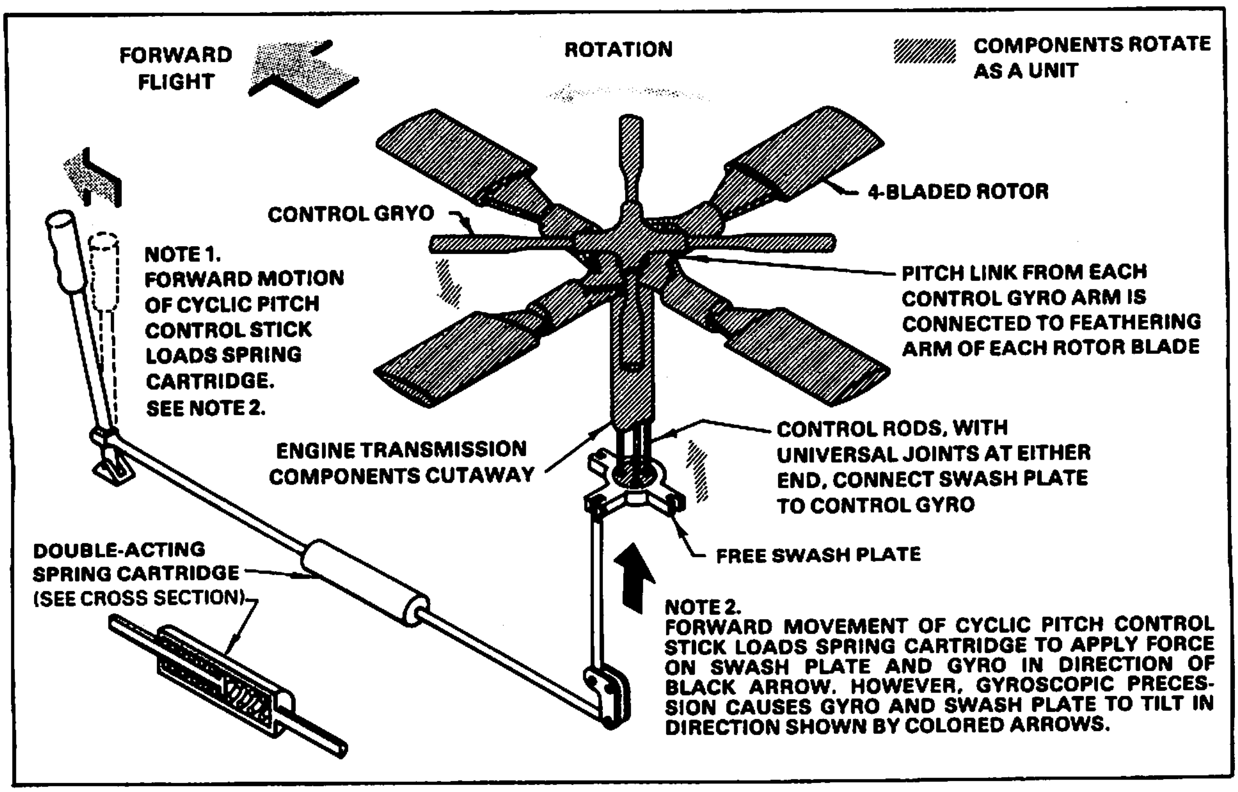
d. Throttle Control. By working the throttle control, the pilot can keep the same engine and rotor speed even if a change in blade pitch causes him to increase or decrease engine power. When the main rotor pitch angle is increased it makes more lift, but it also makes more drag. To overcome the drag and keep the same rotor rpm, more power is needed from the engine. This added power is made by advancing the throttle. The opposite is true for a decrease in main rotor pitch angle. The decreased angle reduces drag, and a reduction in throttle is needed to prevent a rotor overspeed. The throttle is mounted on the collective pitch grip and is operated by rotating the grip, as on a motorcycle throttle. The collective pitch stick is synchronized with the control of the carburetor so that changes of collective pitch will automatically make small increases or decreases in throttle settings. On turbine engine helicopters, the collective pitch stick is synchronized with the fuel control unit which controls the power and rotor rpm automatically.

e. **Torque Control.** In tandem rotor and coaxial helicopter designs, the main rotors turn in opposite directions and thereby neutralize or eliminate torque effect. In single rotor helicopters torque is counteracted by an anti-torque rotor called the tail rotor. It is driven by a power takeoff from the main transmission. The antitorque rotor runs at a speed in direct ratio to the speed of the main rotor. For this reason, the amount of thrust developed by the antitorque rotor must be changed as the power is increased or decreased. This is done by the two directional control pedals (antitorque pedals) which are connected to a pitch-changing device on the antitorque rotor. Pushing the left pedal increases the thrust of the tail rotor blades, swinging the nose of the helicopter to the left. The right pedal decreases the thrust, allowing the main rotor torque to swing the nose to the right.

3-4. MAIN ROTOR HEAD ASSEMBLIES

The main rotor head assembly is attached to and supported by the main gearbox shaft. This assembly supports the main rotor blades and is rotated by torque from the main gearbox. It provides the means of transmitting the movements of the flight controls to the blades. Three types of rotor heads used on Army helicopters are rigid, semirigid, and fully articulated.

a. **Rigid.** The rigid rotor head was among the first type of rotor heads to be designed and tested, yet it was the last to become operational. In the Lockheed rigid rotor concept, the rotor blades are cantilevered from the hub with freedom to rotate only about the feathering axis. When the pilot makes a cyclic control movement in a rigid rotor helicopter, the rotor and fuselage respond almost at the same time. In comparison, there is a time lag between cyclic movement and response on a helicopter equipped with a semirigid or fully articulated rotor head. The rotor tilts first, and the fuselage later assumes the new direction. This time-lagging pendular action is a direct result of the rotor blade hinges. Shown are the important parts of a rigid rotor system and the connected basic pitch controls.



RIGID ROTOR

(1) The engine and transmission are not shown in the illustration. However, everything above the swash plate is driven by the engine and rotates as a unit so that, whether rotating or not, the rotor, control gyro, and linkages keep the same positions. From the swash plate, control rods pass through the rotor hub and connect to the control gyro, which is connected by gimbals to the rotor mast. A pitch change link connects each control gyro arm to the feathering (pitch) operating arm on each blade of the rotor. Assuming the rotor assembly is not rotating, if the swash plate is tilted in any direction, the control gyro also tilts the same way and changes the pitch angles on each of the rotor blades. If the rotor assembly is rotating when the swash plate is tilted, each of the blades follows through an identical cycle in which the blade pitch results in more lift on one side of the rotor disc than the other. Assuming the rotor assembly is still stationary the plane of the control gyro would tilt down forward if the rear of the swash plate were pushed upward. However, this is not the case when the assembly is rotating, due to the laws of gyroscopic precession. Any upward force applied to the rear of the swash plate would result in the control gyro tilting down to the left. Thus, forward tilt movement of the cyclic control stick of the rotor disc is transmitted as an upward force to the left side of the swash plate. This force is transmitted from the swash plate to the control gyro which, due to precession, tilts upward 90° later in the direction of its rotation.

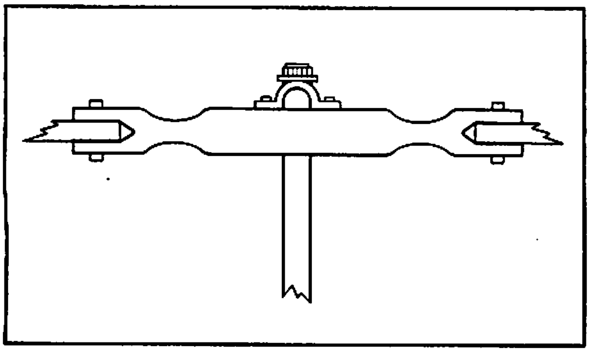
(2) It should be noted in the illustration that the movement of the control stick must not be directly transmitted to the swash plate, since the swash plate must be allowed to move in the same direction as the control gyro; that is, to tilt forward about the lateral axis. A spring cartridge is installed between the control stick and the swash plate to enable the desired force to be applied to the swash plate (but without moving it) while absorbing the control stick movement made by the pilot. The nose-down precession of the gyro changes the angle between the rotating planes of the control gyro and the rotor disc, which makes cyclic pitch changes in the blades of the rotor.

(3) Because the rotor disc is also a gyroscope, the pitch lines are connected to the rotor blades so that in cyclic pitch change the resultant force is applied upward on the left side of the rotor disc. Due to gyroscopic precession, the response to this force takes place 90° later, or under the rear of the rotor disc. This causes the rotor disc to tilt forward until the rotor plane is parallel to the control gyro. Cyclic pitch changing of the blades due to control movement then ceases and the lift over the rotor disc is equalized, but as a forward thrust component.

(4) When the pilot wants a roll response, the principle of operation and the control movements are similar to those just described for a pitch response. The exception is that a different set of control linkages from the cyclic pitch stick is used. This linkage is connected to the rear arm of the swash plate.

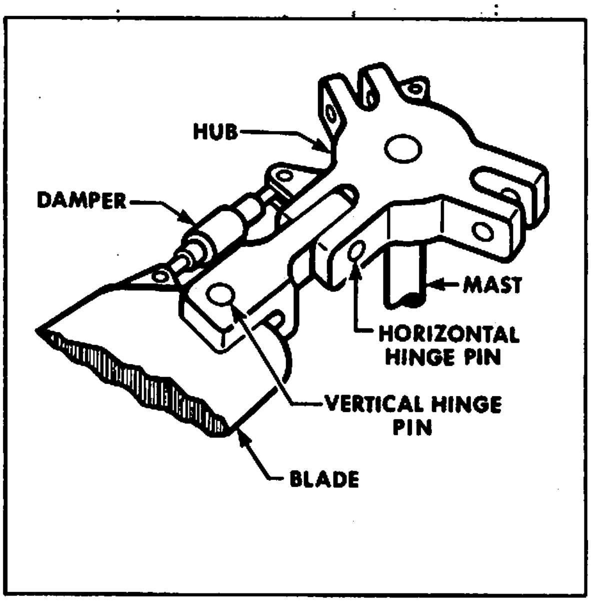
(5) External distrubances such as wind gusts have little effect on the rigid rotor helicopter. Gust forces must not only upset the helicopter's fuselage but must also at the same time overcome the inherent gyroscopic stabilizing characteristics of the cantilevered main rotor. In the event a strong gust of wind does upset the fueslage and rotor at the same time, the control, holding its plane of rotation as a gyroscope, automatically introduces damping through blade angle changes without any action being required by the pilot. The resulting displacement between the plane of the control gyro and the plane of the rotor changes the pitch of the rotor blades cyclically to restore the original attitude of the helicopter. Compensation for differential lift forces in translational flight is also achieved automatically by the rigid rotor system. As the rigid rotor helicopter gains horizontal speed, changes in lift over the rotor disc cause changes in the aircraft attitude. These changes are counteracted by the cyclic pitch change of the rotor blades initiated by the stabilizing control gyro.

b. **Semirigid**. The semirigid rotor head gets its name from the fact that the two blades are rigidly interconnected and pivoted about a point slightly above their center. There are no flapping or drag hinges such as appear on the articulating head. Since the blades are interconnected, when one blade moves upward the other moves downward a corresponding distance. The hubs are underslung to prevent any dissymmetry of lift and to let the plane of rotation tilt for directional control. The OH-13 helicopter rotor head is a typical teetering type of semirigid system. It consists primarily of trunnion, gimbal, yoke, grip assemblies, pitch horns, and connecting parts. The trunnion assembly is internally splined to provide for attachment to mast assembly. It has two spindles machined for attachment to the gimbal. The gimbal has two bores 90° from each trunnion spindle where bearing surfaces called "pillow blocks" are installed and attached to the yoke. The arrangement allows the hub assembly to see-saw spanwise on the trunnion spindles and to tilt or rock chordwise on the pillow block bearings. The yoke assembly has two threaded spindles located 180° apart where the blade grips are installed. Pitch horns, equalizer links, drag braces, and counterweights are attached to the grips. The pitch horns are the levers which twist the grips about the yoke spindles, thereby changing pitch angles. The equalizer links provide for interconnection of the two grips through the equalizer beams which are attached to each side of the yoke. The counterweights counteract the aerodynamic twisting force which tends to move the blades to a low-pitch angle.



SEMIRIGID ROTOR

c. **Fully Articulated.** A fully articulated rotor head gets its name from the fact that it is joined. Joining is made with vertical and horizontal pins. The fully articulated rotor head assembly has three or more blades, each acting as a single unit and capable of flapping, feathering, and leading and lagging. The assembly is made up primarily of an internally splined hub, horizontal and vertical hinge pins, extension links, pitch shafts, pitch housing, dampers, pitch arms, bearing surfaces, and connecting parts. The extension links are attached to the hub by the horizontal pins and to the forked end of the extension link. The pitch shafts are attached by the vertical pins. The pitch housing is fitted over and fastened to the pitch shaft by the tension torsion straps which are pinned at the inboard end of the pitch shaft and the outboard end of the grip housing. One end of the dampers is attached to a bracket on the horizontal pins, and the other end is fastened to the pitch housing.



FULLY ARTICULATED ROTOR

(1) *Flapping* of the rotor blades is permitted by the horizontal pin, which is the hinge or pivot point. Centrifugal force on the blades and stops on the head prevent excessive flapping.

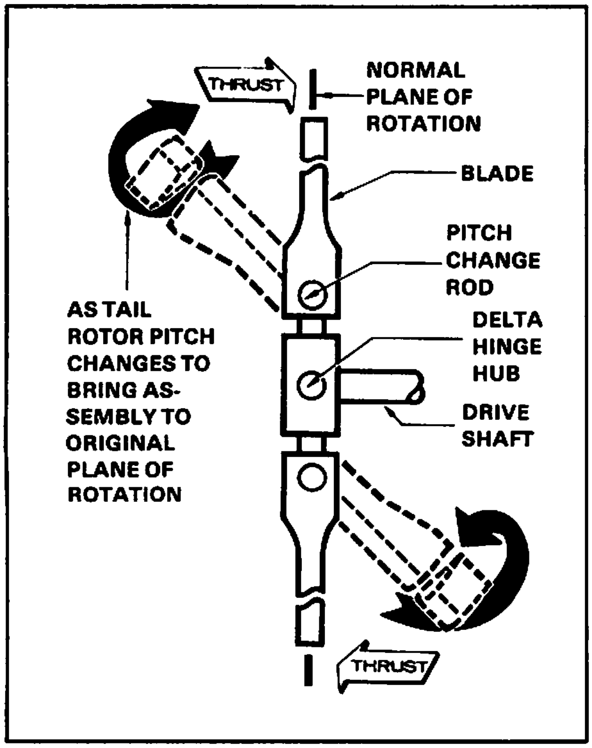
(2) *Feathering* is the controlled rotation about the longitudinal axis of the blades that permits the pilot to achieve directional control in either the horizontal or vertical plane. Feathering is permitted by a pitch change assembly on some helicopters and by a sleeve and spindle assembly on other types of helicopters.

(3) *Leading and lagging* is permitted by the vertical pin, which serves as a hinge or pivot point for the action. Excessive leading and lagging is prevented by the use of a two-way hydraulic damper in the system.

3-5. TAIL ROTOR HUBS

The tail rotor hub (antitorque rotor) is used as a centering fixture to attach the tail rotor blades so they will rotate about a common axis. It keeps the blocks against centrifugal, bending, and thrust forces. It accepts the necessary pitch-change mechanism to provide automatic equalization of thrust on the advancing and retreating blade, or equal and simultaneous pitch change to counteract torque made by the main rotor system. Hub design varies with the manufacturer. Typical configurations are the delta hinge, flapping hinge, and fully articulated.

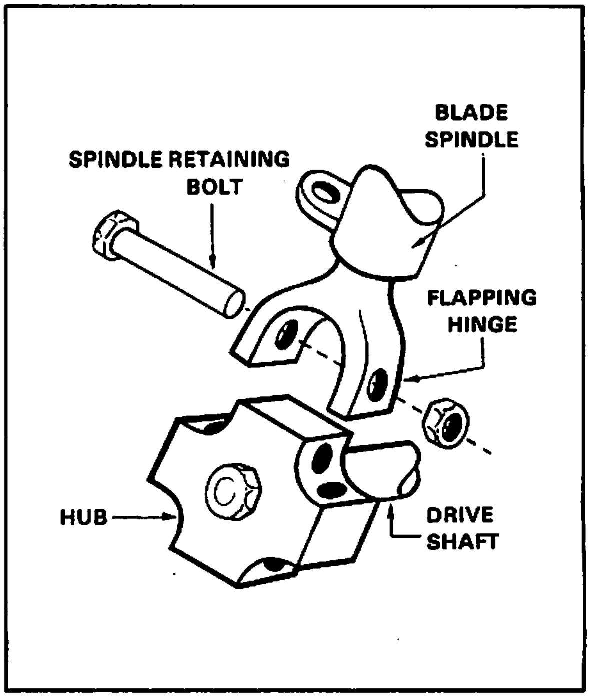
a. **Delta Flapping Hinge.** Observation helicopters use a delta type antitorque system where the trunnion is hinged to the hub at about 50° to 60°, with provisions for bearings.



DELTA HINGE TAIL ROTOR

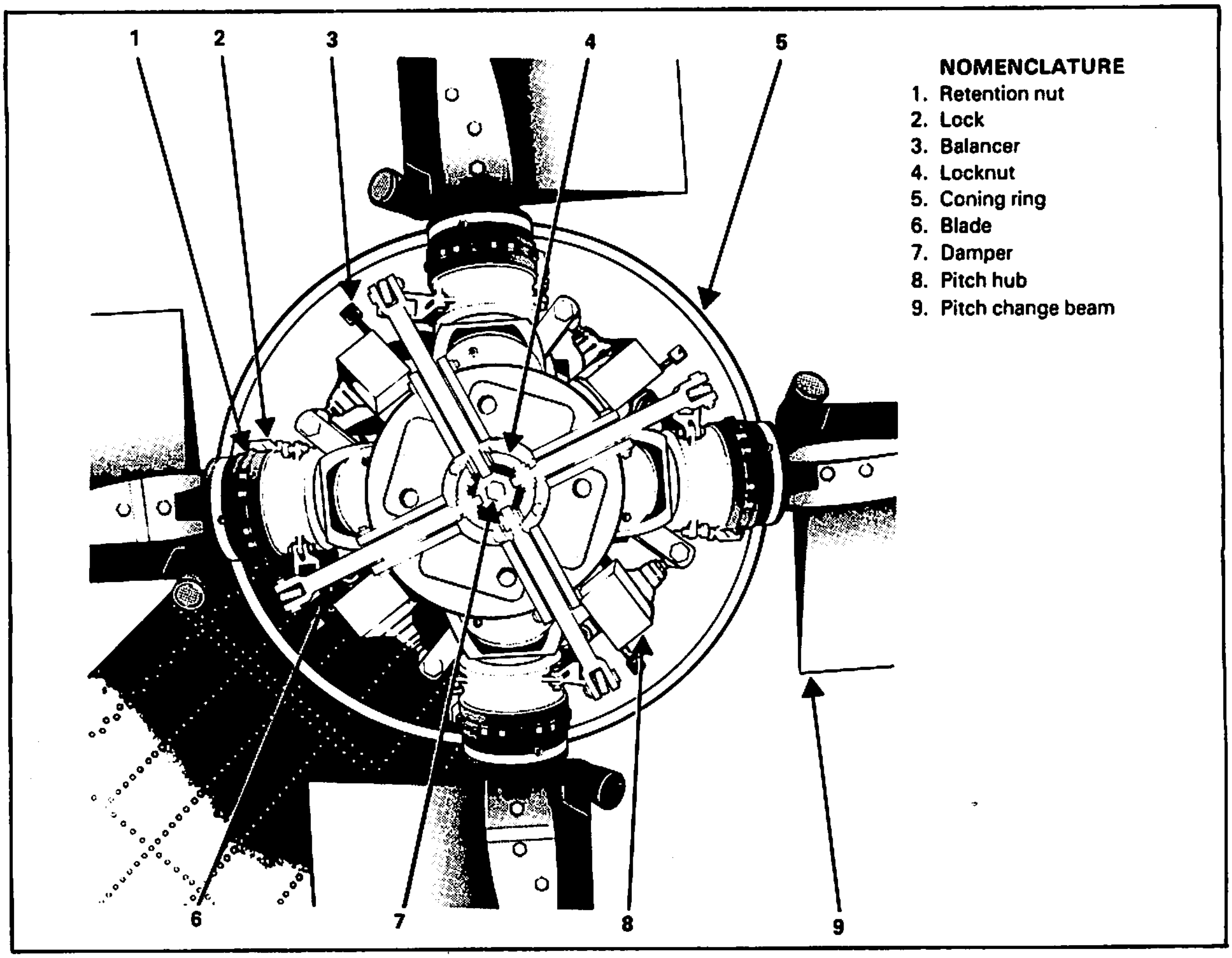
These bearings are needle type to resist the heavy loads imposed. The delta hinge design used with two-blade tail rotor configurations operates through pitch links attached to the blade roots. This causes automatic increase of pitch on one blade and corresponding decrease of pitch on the opposite blade, thus returning them to the original plane of rotation when disturbed. This action equalizes thrust when the helicopter is in forward flight, caused by advancing and retreating blades.

b. **Flapping Hinge.** The flapping action tail rotor, such as is found on cargo helicopters having four blades, has a hub rigidly attached to the drive shaft. The blades are attached to it by hinged blade spindles. Each blade flaps independently. This action against stationary pitch-change rods causes the blade pitch to increase or decrease, thus returning blade disc to original plane of rotation when disturbed.



FLAPPING HINGE TAIL ROTOR

c. **Fully Articulated.** The articulated tail rotor system counterbalances disturbing forces in a way that is the same as the flapping hinge rotor. The major difference is that the blades can individually lead and lag during rotation.



ARTICULATED TAIL ROTOR SYSTEM

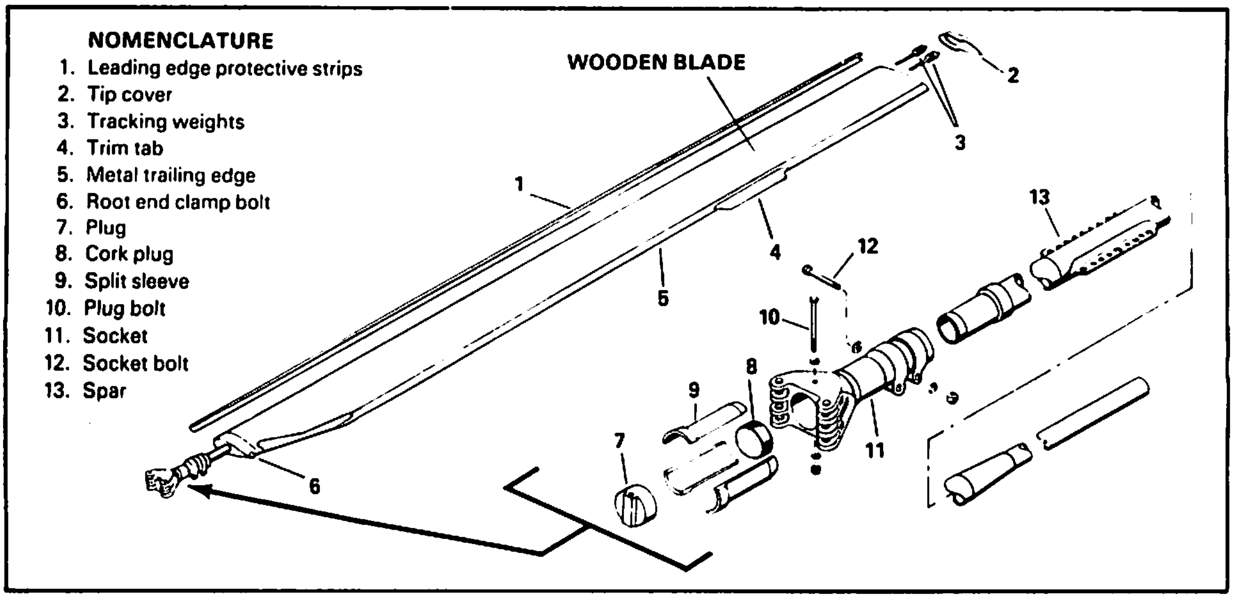
3-6. MAIN ROTOR BLADES

The rotor blade is an airfoil designed to rotate about a common axis to produce lift and provide directional control for a helicopter. It is often referred to as a rotary wing. The design and construction of a rotor blade vary with the manufacturer, although all strive to manufacture the most efficient and economical lifting device. The selected design of the helicopter places certain requirements on the main rotor blades. These requirements influence the design and construction features of the blades. Most rotor blades are designed as a symmetrical airfoil because it will produce a stable aerodynamic pitching characteristic. Aerodynamic stability is achieved by having the center of gravity, center of pressure, and blade feathering axis all acting at the same point. The blade is more stable in flight because these forces continue to act at almost the same point as the blade changes pitch. At present only one Army helicopter is equipped with an unsymmetrical airfoil. This unsymmetrical airfoil blade is capable of producing greater lift than a symmetrical airfoil blade of similar dimensions. Aerodynamic stability is achieved by building a 3° upward angle into the trailing edge section of the blade. This prevents excessive center-of-pressure travel when the rotor blade angle of attack is changed. A variety of material is used in the construction of rotor blades. Wood, aluminum, steel, brass, and fiberglass are most commonly used. The material will vary with the helicopter manufacturer's specifications.

a. **Types of Rotor Blades.**

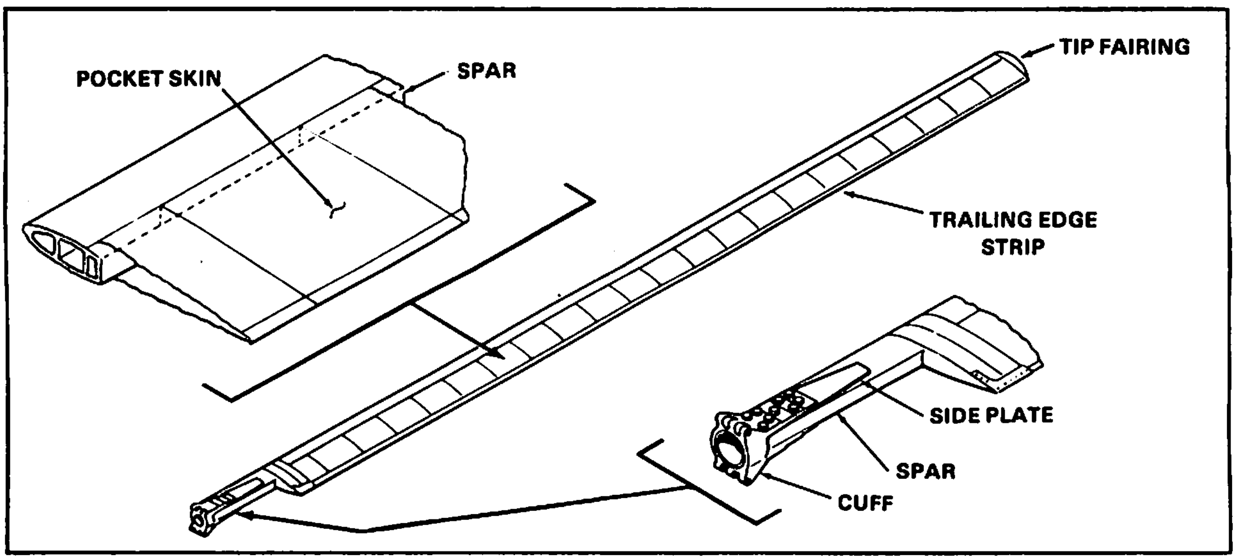
(1) *Wooden.* A typical wooden rotor blade consists of a steel spar, wooden contour ribs,

and a plywood cover. The leading edge is protected by a stainless steel cover. The trailing edge of the blade is reinforced by aluminum strips bonded to birch strips. These birch strips are bonded together and then bonded to the rotor blade. The blade tip is protected by a stainless steel cap. A number of vent holes are provided in the bottom cover of the rotor blade to relieve internal air pressure and to permit drainage of water.



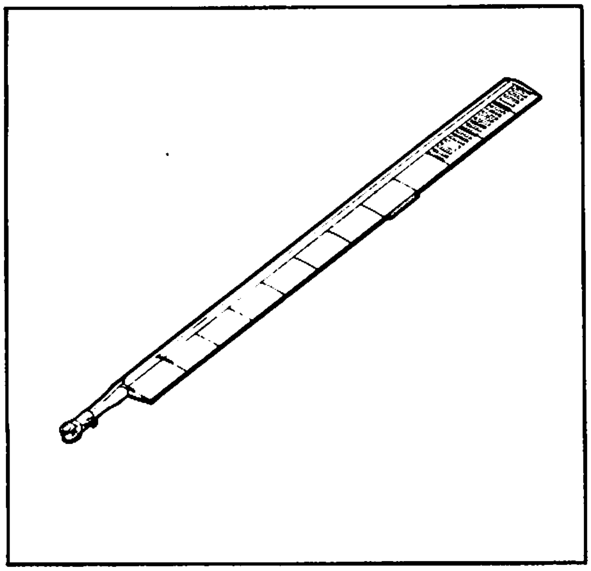
WOODEN ROTOR BLADE

(2) *Metal.* A typical metal blade consists of a hollow, extruded aluminum spar which forms the leading edge of the blade. Aluminum pockets are bonded to the trailing edge of the spar assembly to provide streamlining. An aluminum tip cap is fastened with screws to the spar and tip pocket. A steel cuff is bolted to the root end of the spar to provide a means of attaching the blade to the rotor head. A stainless steel abrasion strip is adhesive-bonded to the leading edge.



METAL ROTOR BLADE

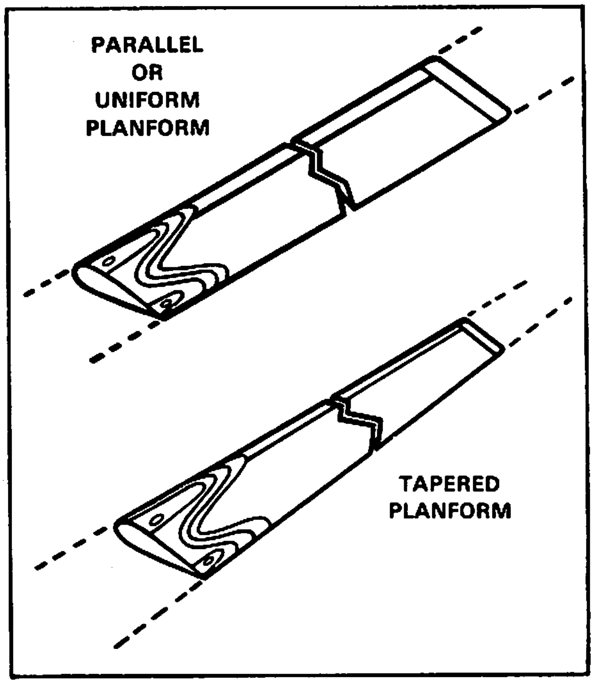
(3) *Fiberglass.* The main load-carrying member of a fiberglass blade is a hollow, extruded steel spar. The fairing or pockets are fiberglass covers bonded over either aluminum ribs or aluminum foil honeycomb. The fairing assembly is then bonded to the trailing edge of the spar. The trailing edge of the fairing is bonded to a stainless steel strip forming the blade trailing edge. Rubber chafing strips are bonded between the fairings to prevent fairing chafing and provide a weather seal for the blade fairings. A steel socket is threaded to the blade spar shank, thus providing an attaching point to the rotor head. A stainless steel tip cap is fastened by screws to the blade spar and blade tip pocket.



FIBERGLASS ROTOR BLADE

b. **Blade Nomenclature.**

(1) *Blade planform.* The blade planform is the shape of the rotor blade. It can be uniform (parallel) or tapered. Uniform planforms are most often selected by the manufacturer because they are easier to make, with all the ribs and other internal blade parts being the same size. The uniform blade requires only one stamping die for all ribs, thereby reducing blade cost. However, this design has a large blade surface area at the tip. It must therefore form a lot of negative tip twists to make a more uniform lift along the blade span. If the blade angle is the same for the length of the blade, the blade will make more lift toward the tip because this part moves at a higher speed than the blade root. This unequal lift will cause the blade to cone too much or bend up on the end. The tapered planform blade makes a more uniform lift throughout its length. However, few blade manufacturers use it because the manufacturing cost is too high due to the many different shaped parts required to fit the tapered airfoil interior.

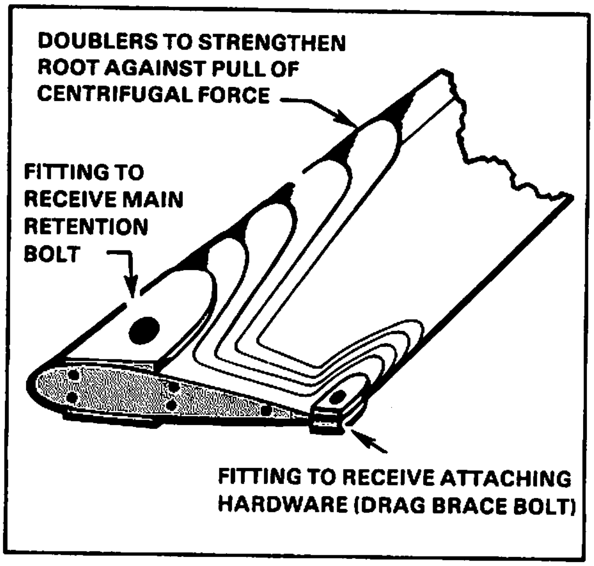


BLADE PLANFORM

(2) *Blade twist.* The blade-element theory applies to a rotor blade as well as a propeller. Therefore, most rotor blades are twisted negatively from root to tip to get a more even distribution of lift.

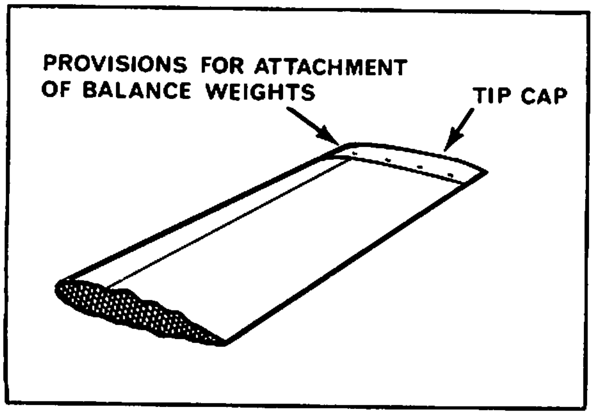
(3) *Blade skin.* The skin may be made of fiberglass or aluminum and consist of single or multiple layers. The skin is thin and can be easily damaged by careless handling on the ground. The three different blade coverings used when the rotor blades are being made are one piece wraparound aluminum alloy, single pocket (or fairing), and multiple pocket (or fairing). Most main rotor blades are made with either the single-pocket or the multiple-pocket construction.

(4) *Root.* The blade root is the section nearest the center of rotation which provides a means of attachment to the rotor head. It is made heavier and thicker to resist centrifugal forces.



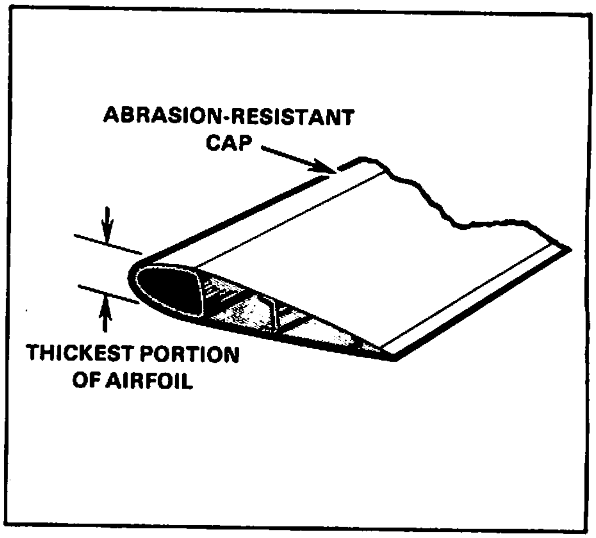
BLADE ROOT

(5) *Tip.* The tip is located furtherest from the center of rotation and travels at the highest speed during operation. The blade tip cap also has a means for attaching balance weights.



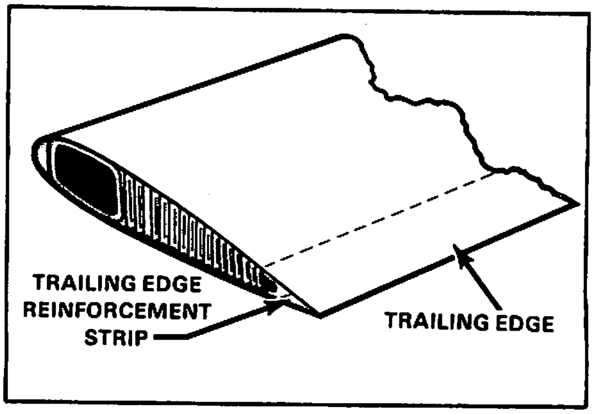
ROTOR BLADE TIP

(6) *Leading edge.* The part of the blade that meets the air first is the leading edge. For the edge to work correctly, the airfoils must have a leading edge that is thicker than the trailing edge. The leading edge of all blades is covered with a hard, abrasion-resistant cap or coating to protect against erosion caused by sand and dust.



ROTOR BLADE LEADING EDGE

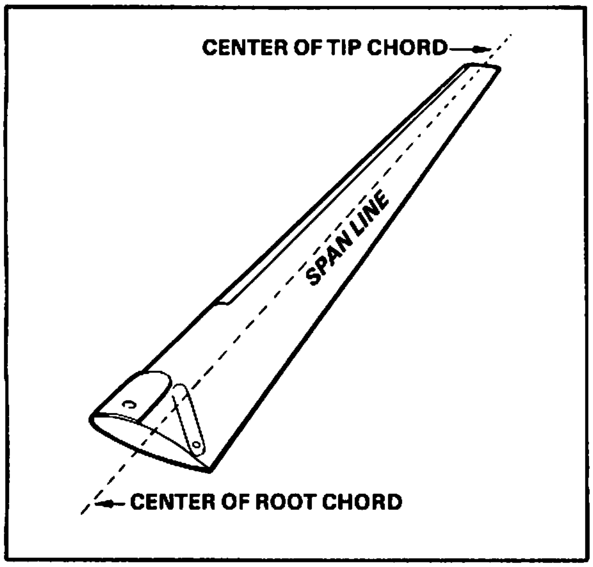
(7) *Trailing edge.* Trailing edge is that part of the blade that follows or trails the leading edge and is the thinnest section of the airfoil. The trailing edge is strengthened to resist damage, which usually happens during ground handling.



ROTOR BLADE TRAILING EDGE

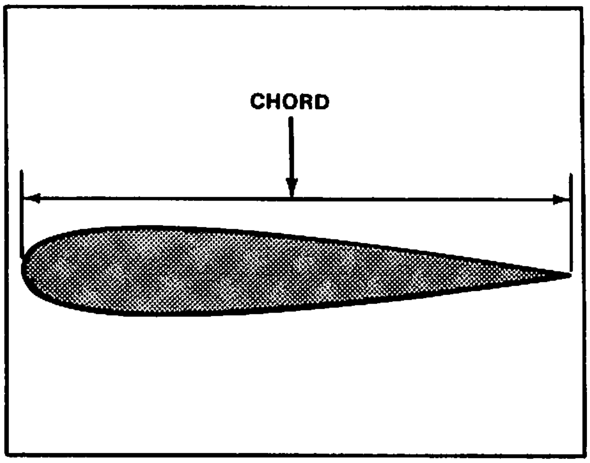
(8) *Span and span line.* The span of a rotor blade is the length from root to tip measured at its longest point. The span line is an imaginary line running parallel to the leading edge from the root of the blade to the tip. Blade span line is of importance to the blade repairer because damages are often located and classified according to their location in relation to the span

line. Defects paralleling the span line are usually less serious because stress lines move parallel to the span line and would pass the damage without interruption. Chordwise damages interrupt lines of stress.



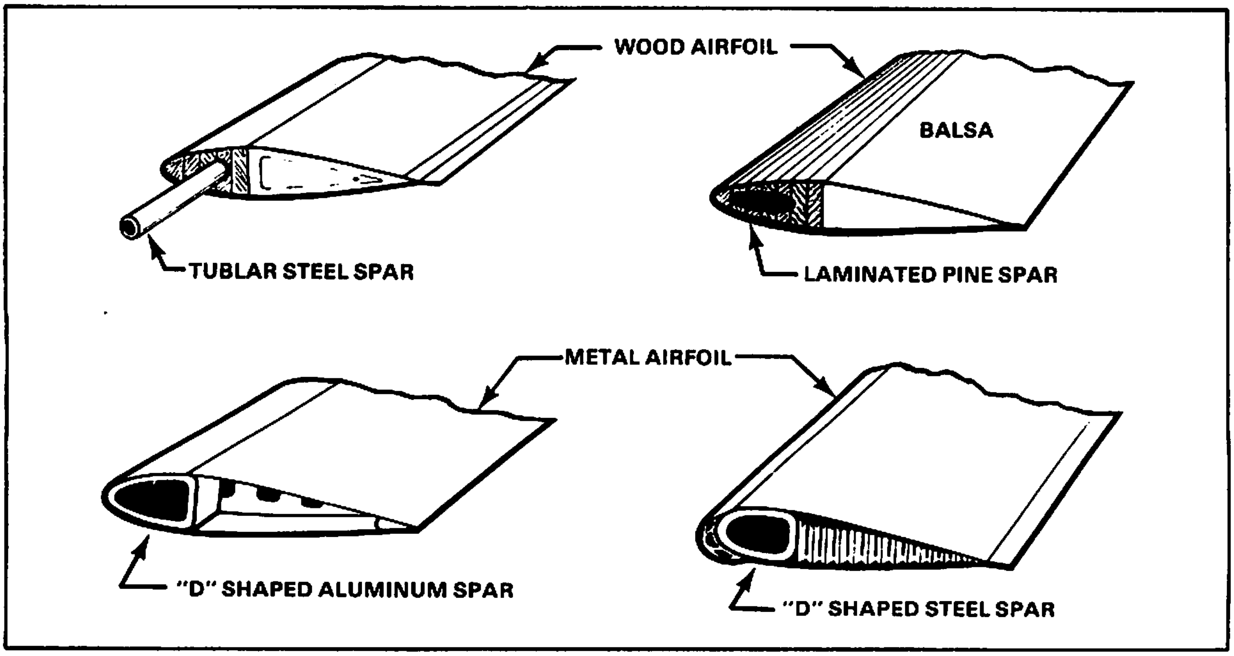
SPAN AND SPAN LINE

(9) *Chord and chord line.* The chord of a rotor blade is its width measured at the widest point. The chord line of a rotor blade is an imaginary line from the leading edge to the trailing edge, and perpendicular to the span line. Blade chord line is used as a reference line to make angular measurements.



CHORD OF ROTOR BLADE

(10) *Spar.* The main supporting part of a rotor blade is the spar. Spars are usually made of aluminum or steel and always extend along the spar of the blade. Often the spar is D-shaped and is made to form the leading edge of the airfoil. Spars are made in different shapes depending on the material of which the blades are made and how the spar fits into the blade airfoil.



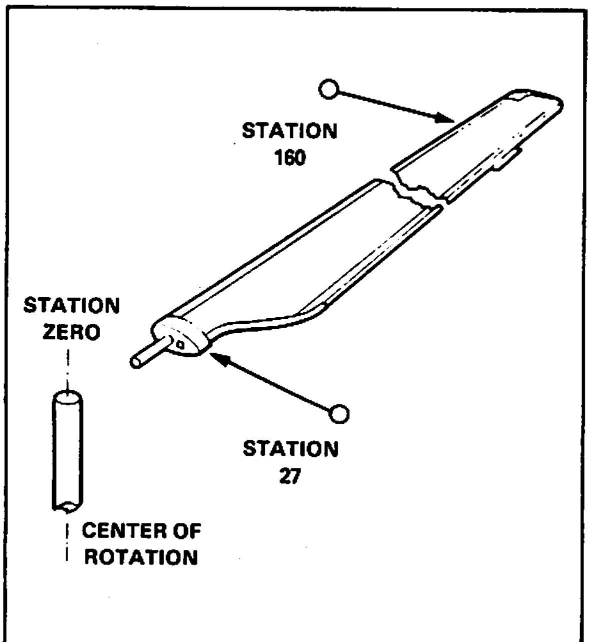
SPARS

(11) *Doublers.* Doublers are flat plates that are bonded to both sides of the root end of some rotor blades to provide more strength. Not all blades use doublers since some spars are made thick enough to provide the needed strength at the root end.

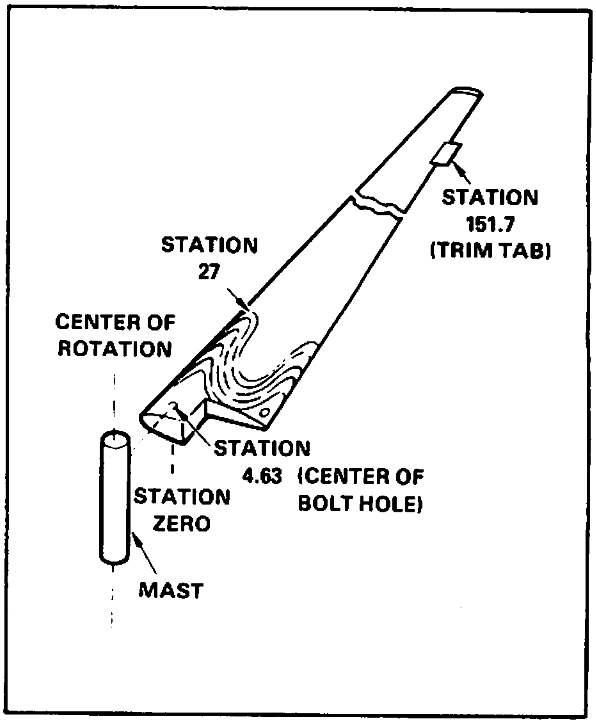
(12) *Top of blade.* The low-pressure side of the blade is the top. It is the blade surface which is viewed from above the helicopter. It is usually painted olive drab when the blade skin is plastic or metal, and gull gray if made of wood. A light-colored paint is used on wooden blades to reflect the sun's rays. This reduces heat absorption by the blade structure and it protects the bonding adhesive from deterioration.

(13) *Bottom of blade.* The high-pressure side of the blade is the bottom, and it is the blade surface which is viewed from the ground. It is always painted a lusterless black to prevent glaring light from reflecting off the blade and into crew compartments during flight.

(14) *Rotor blade stations.* Rotor blade stations are numbered in inches and are measured from one of two starting points. Some rotor blades are numbered from the center of rotation (center of the mast), which is designated station zero, and outward to the blade tip. Others are numbered from the root end of the blade, which is designated as station zero, and outward to the blade tip.



ROTOR BLADE STATIONS NUMBERED FROM CENTER OF MAST



ROTOR BLADE STATIONS NUMBERED FROM ROOT END

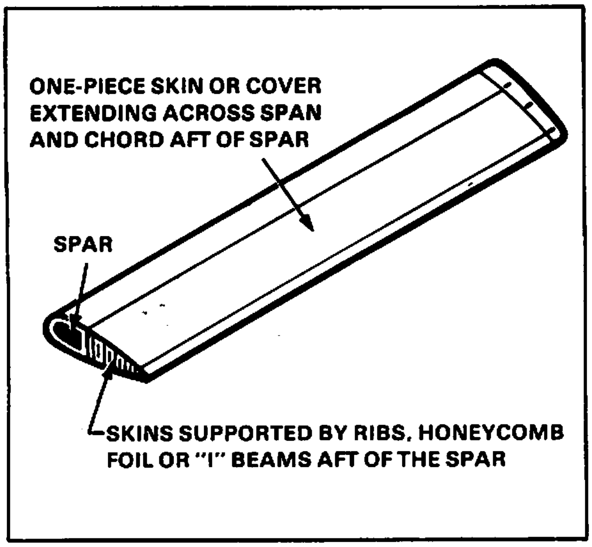
c. Blade Construction.

(1) *Single pocket or fairings.* The single pocket or fairing blade is made with a one-piece skin on top and one on the bottom. Each extends across the entire span and chord, behind the spar. This style was picked because it was simple and easier to make since a minimum number of pockets or fairings needed positioning and clamping during the process of bonding. However, minor damage to the skin often causes the blade to be thrown away since replacing the skin costs more than the blade itself.

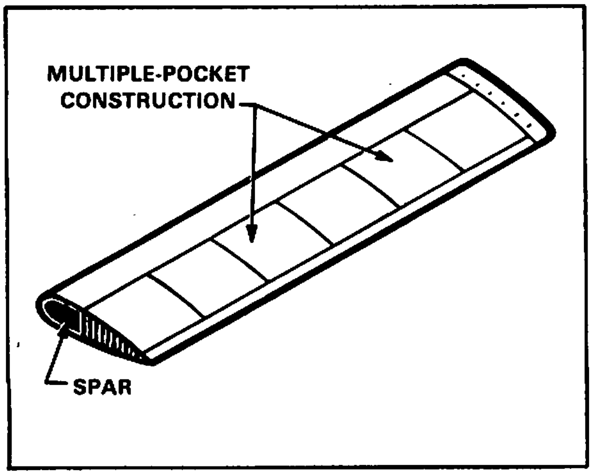
(2) *Multiple pockets or fairings.* Most of the large rotor blades built with the multiple-pocket or fairing shape behind the spar are costly. This type of blade is selected since damage to skin cover needs only pocket (or fairing) replaced. The high-cost blade then can be used over and over. The blade made this

way is more flexible across the span, cutting down blade vibrations.

(3) *Internal structural components.* Rotor blades have internal structural parts that help to support the blade skin. These parts are ribs, I-beams, spanwise channels, and aluminum honeycomb foil.

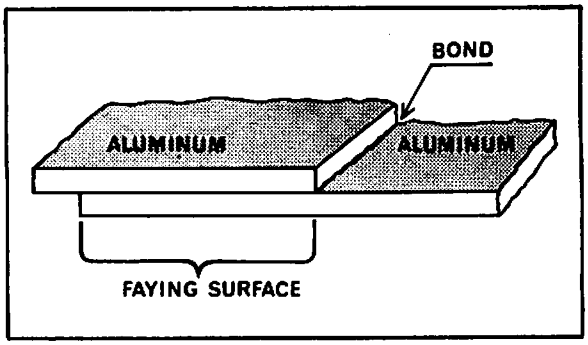


SINGLE-POCKET ROTOR BLADE COVER



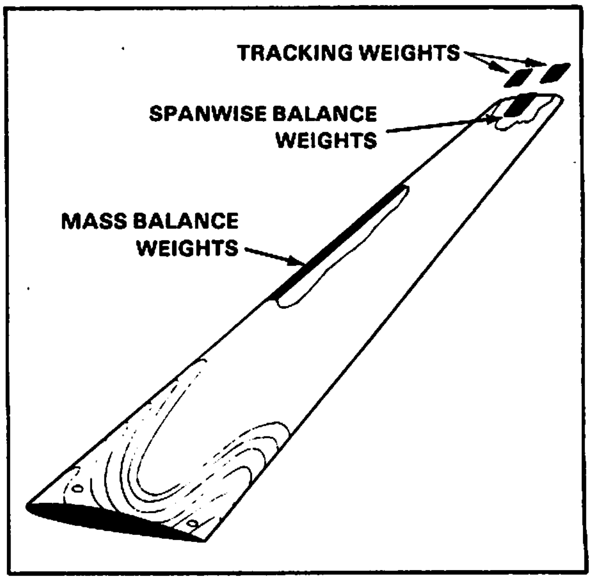
MULTIPLE-POCKET ROTOR BLADE COVER

d. **Bonds and Bonding.** Bonding is a method of putting two or more parts together with an adhesive compound. This will help to reduce the use of such hardware as bolts, rivets, and screws which would need holes and thus weaken the strength of the bond. To keep full strength, manufacturers never drill holes in load-carrying parts of the blade except at the inboard and outboard ends. However, the bonds react to chemical action of paint thinners and many cleaning solvents, and careless use of these solvents will dissolve bonded joints. The surface area where two objects are bonded together is known as the faying surface.



FAYING SURFACE

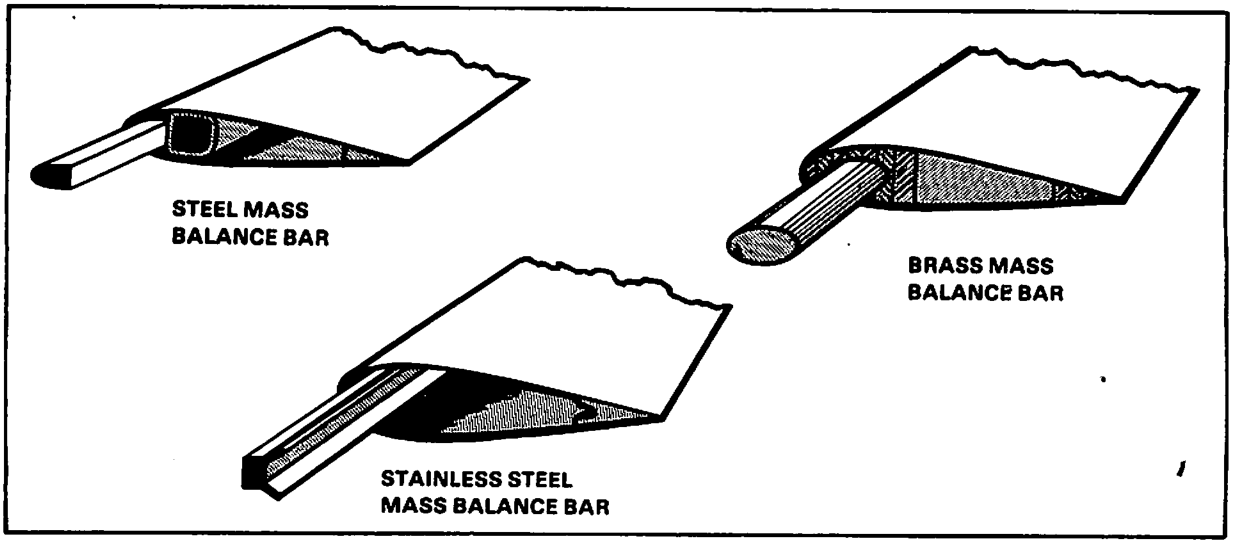
e. **Blade Balance.** Three types of weights to balance the blade are mass chordwise, spanwise, and tracking.



BLADE BALANCE WEIGHTS

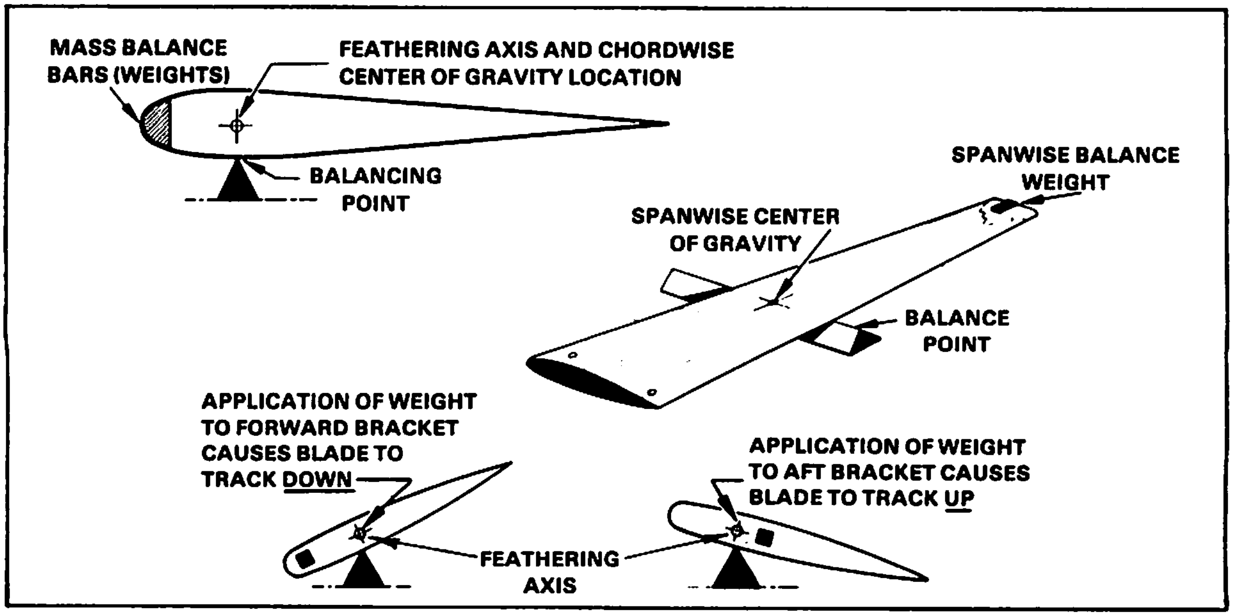
(1) *Mass balance weights* (bars) are placed into the leading edge of a blade while the blade is being made. This is to insure that correct chordwise balance is about 25 percent of chord.

The type of metal and its shape and location vary with the manufacturer. The repairer is not allowed to move the weights in most of the Army helicopter blades. When moving of weights is allowed, however, the repairer must remember that changing weights will move the center of gravity forward or backward.



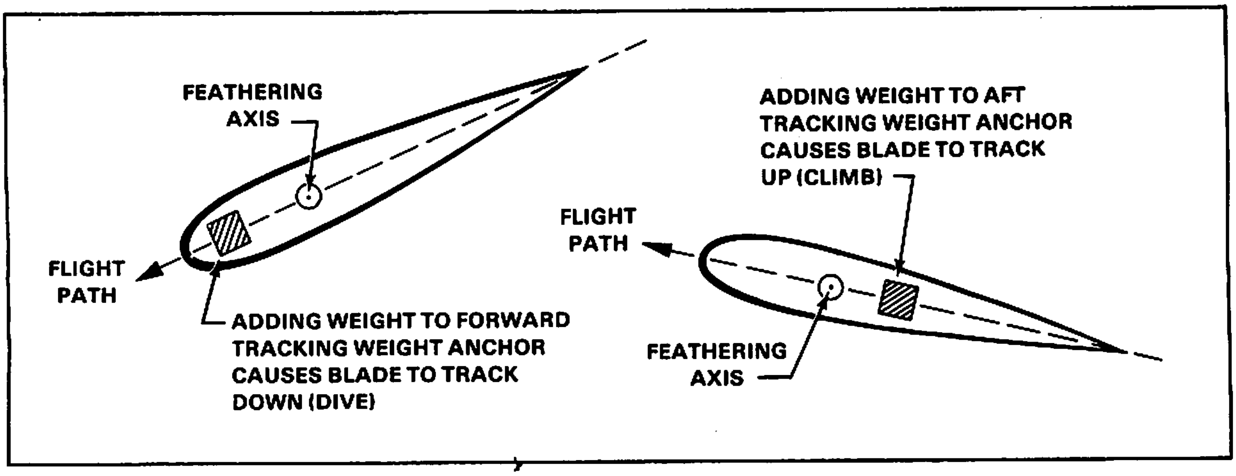
MASS BALANCE WEIGHTS

(2) *Spanwise balance weights* are at the tip of the blade, usually where they can be securely attached to the spar. These weights are usually installed in the blade while being built. The repairer is not always permitted to move these weights, but if he must, he should always remember that adding spanwise weight moves the center of gravity outward, thus subtracting the weight the center of gravity will move inward. When moving the spanwise weight is permitted, the weight change is computed by the repairer mathematically after the blade has been weighed on either two or three scales.



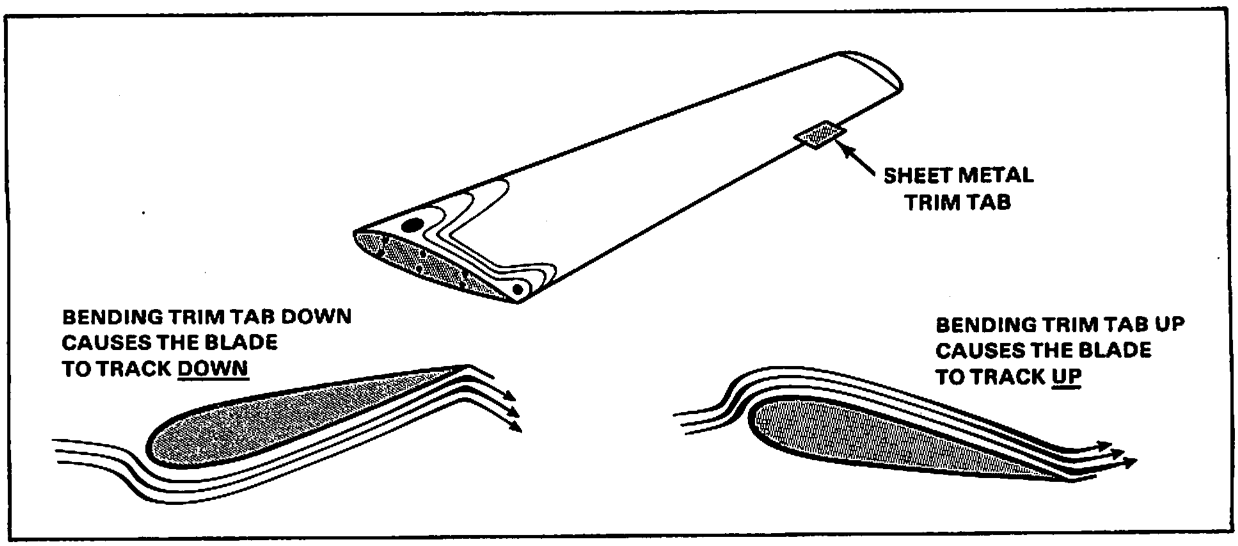
SPANWISE BALANCE WEIGHTS

(3) *To be efficient* and *vibration-free,* all rotating blades should track on about the same level or plane of rotation. Failure of blades to track correctly causes vibrations which can damage parts of the helicopter, reduce riding comfort, and cause a loss in blade performance due to the air turbulence made by the rotating blades. One way of keeping track is to attach tracking weights in front of and behind the feathering axis at the blade tips. By adding, removing, or shifting tracking weights, the repairer can move a blade track up or down to match the track of the other blade or blades and cause all blades to move in the same tip path plane.



TRACKING WEIGHTS

f. **Trim Tabs.** Another method used to align the rotor blade on the same plane of rotation is trim tabs. Due to added building costs involved when tracking weights are used, other cheaper methods are the next best thing. The same results may be achieved by putting a sheet metal trim tab on the trailing edge of the blade. The trim tab is usually located near the tip of the blade where the speed is great enough to get needed aerodynamic reaction. In tracking operations, the trim tab is bent up to make the leading edge of the rotor blade fly higher in the plane of rotation, or bent down to make it fly lower. The trim tabs are adjusted until the rotor blades are all flying in the same plane of rotation.



TRIM TABS

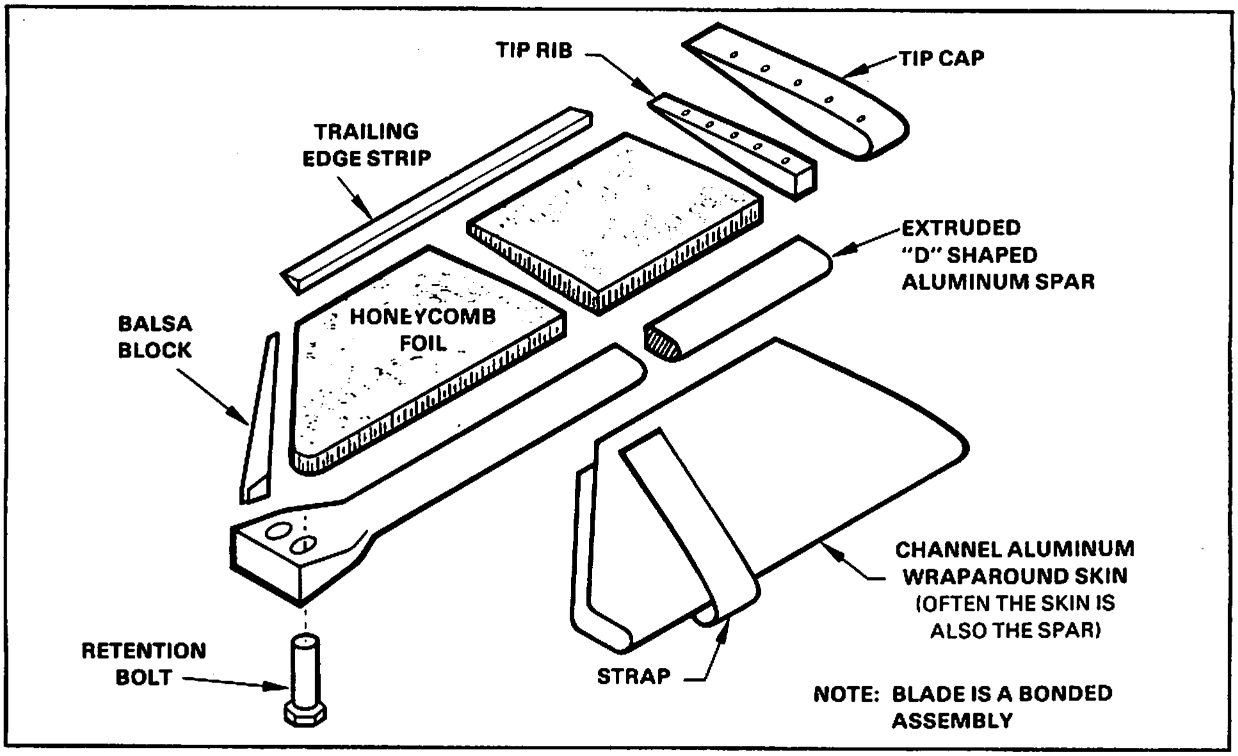
3-7 TAIL ROTOR BLADES

Tail rotor blades are used to provide directional control only. Made of metal or fiberglass, they are built similar to main rotor blades. Metal tail rotor blades are made of aluminum. The spars are made of solid aluminum extrusions, hollow aluminum extrusions, and aluminum sheet channels. Fiberglass rotor blades are made of fiberglass sheets. The spars are made of solid titanium extrusions.

a. **Construction.** The following illustration shows an example of the way a bonded tail rotor blade is assembled.

(1) *Metal.* The blade skins are formed around and bonded to the spars which in most cases form the leading edge of the blades. Metal blade skins are supported from the inside with aluminum honeycomb, ribs, and some smaller blades which have no bracing or support inside themselves.

(2) *Fiberglass.* The blade skins are formed around and bonded to H-shaped titanium spars. The blade skins are supported inside with aluminum honeycomb. The space around the spar is filled with foam plastic.



TAIL ROTOR BLADE CONSTRUCTION

b. **Blade Balance.**

(1) *Spanwise.* Spanwise balance is accomplished by adding or subtracting washers on the blade tip on some models. On others the washers are added to the blade cuff attaching bolts.

(2) *Chordwise.* On some models, blades are balanced chordwise by adding weights to the tips behind the spanwise balance screw. Other models are balanced by adding weights to the trailing edge of the blades near the cuff end.

(3) *Trammeling.* Fully articulated tail rotor systems must be trammeled before they are balanced. Trammeling consists of aligning the tail rotor blades an equal distance to one another with a 2° angle of lead to the blades.