

FM 1-514

**FUNDAMENTALS OF ROTOR AND  
POWER TRAIN MAINTENANCE—  
TECHNIQUES AND PROCEDURES**

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## FUNDAMENTALS OF ROTOR AND POWER TRAIN MAINTENANCE – TECHNIQUES AND PROCEDURES

### TABLE OF CONTENTS

	Page
<b>PREFACE</b> . . . . .	iii
<b>CHAPTER 1. PRINCIPLES OF HELICOPTER FLIGHT</b>	
Aerodynamics . . . . .	1-1
Bernoulli's Principle . . . . .	1-2
Lift and Thrust . . . . .	1-2
Airfoil Stability . . . . .	1-3
Stress . . . . .	1-3
Vibration . . . . .	1-5
Nondestructive Inspection . . . . .	1-5
<b>CHAPTER 2. FUNDAMENTALS OF ROTORS</b>	
Rotor System . . . . .	2-1
Forces Acting on Rotors . . . . .	2-1
Terminology . . . . .	2-1
<b>CHAPTER 3. ROTOR SYSTEM OPERATION</b>	
Single and Tandem Rotors . . . . .	3-1
Flight Controls . . . . .	3-1
Main Rotor Head Assemblies . . . . .	3-2
Tail Rotor Hubs . . . . .	3-4
Main Rotor Blades . . . . .	3-5
Tail Rotor Blades . . . . .	3-11
<b>CHAPTER 4. ALIGNMENT AND TRACKING PROCEDURES</b>	
Main Rotor Blade Alignment . . . . .	4-1
Unbalanced Semirigid Rotor Systems . . . . .	4-1
Vertical Vibrations . . . . .	4-2
Main Rotor Blade Tracking . . . . .	4-3
Vibrex Balancing Kit . . . . .	4-5
Preservation . . . . .	4-10
<b>CHAPTER 5. SINGLE-ROTOR POWER TRAIN SYSTEM</b>	
Main Drive Shaft . . . . .	5-1
Main Transmission . . . . .	5-4

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**FM 1-514**

Main Rotor Mast Assembly . . . . .	5-6
Tail Rotor Drive Shaft . . . . .	5-6
Intermediate Gearbox . . . . .	5-6
Tail Rotor Gearbox . . . . .	5-6
<b>CHAPTER 6. TANDEM-ROTOR POWER TRAIN SYSTEM</b>	
Engine Transmission . . . . .	6-2
Engine-Combining Transmission . . . . .	6-4
Forward Rotary-Wing Drive Transmission . . . . .	6-4
Aft Rotary-Wing Drive Transmission . . . . .	6-4
Drive Shafts . . . . .	6-10
<b>GLOSSARY</b>	
Abbreviations and Acronyms . . . . .	Glossary-1
Definitions . . . . .	Glossary-2
<b>REFERENCES</b> . . . . .	References-1
<b>INDEX</b> . . . . .	Index-1

## **PREFACE**

This manual is a guide for Army repairers on aircraft rotor and power train maintenance. It includes descriptions, construction features, operating principles, elementary repair procedures, and basic repair shop allied subjects.

Rotor and power train information presented herein is general. For detailed information and specific repair procedures on a particular aircraft, refer to the technical manual for that aircraft or component.

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## CHAPTER 1

## PRINCIPLES OF HELICOPTER FLIGHT

Basic flight theory and aerodynamics are considered in full detail when an aircraft is designed. The rotor repairer must understand these principles in order to maintain aircraft safely and to make repairs that are structurally sound and aerodynamically smooth.

## AERODYNAMICS

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

- Weight is the force exerted on an aircraft by gravity. The pull of gravity acts through the aircraft's 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.
- Lift is produced by air passing over the wing of an airplane or over the rotor blades of a helicopter. Lift is the force that overcomes the weight of an aircraft so that it can rise in the air.
- Thrust is the force that moves an aircraft through the air. In a conventional fixed-wing aircraft, thrust provided by the propeller moves the plane forward while the wings supply the lift. In a helicopter both thrust and lift are supplied by the main rotor blades.
- Drag is the force of resistance by the air to the passage of an aircraft through it. Thrust force sets an aircraft in motion and keeps it in motion against drag force.

Any device designed to produce lift or thrust when passed through air is an airfoil. Airplane wings, propeller blades, and helicopter main and tail rotor blades are all airfoils (Figure 1-1).

Chord is the distance, or imaginary line, between the leading and the trailing edge of an airfoil. The amount of curve, or departure of the airfoil surface from the chord line, is known as the camber. Upper camber refers to the upper surface; lower camber

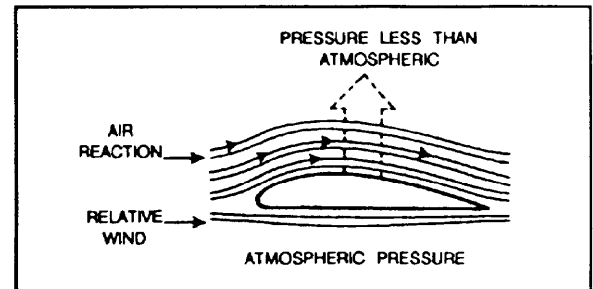


Figure 1-1. Example of an airfoil

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 (Figure 1-2).

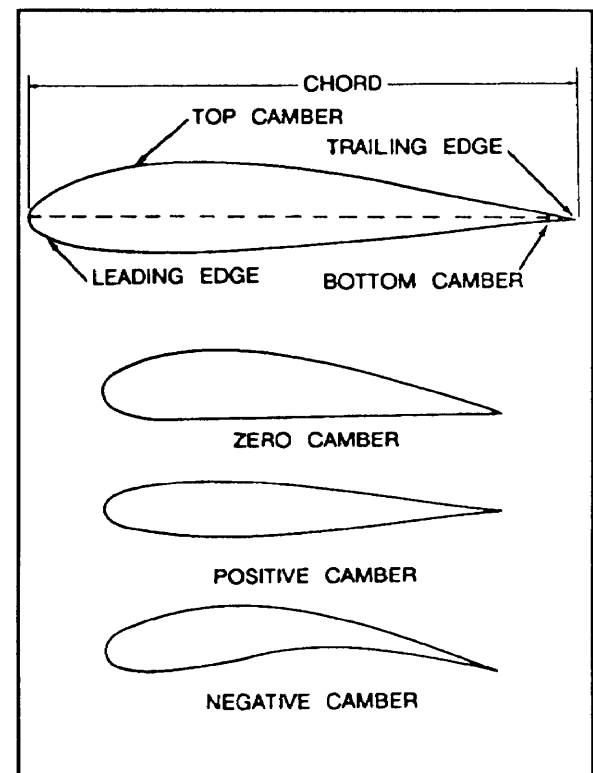


Figure 1-2. Airfoil features

## BERNOULLI'S PRINCIPLE

Bernoulli, an eighteenth century physicist, discovered that air moving over a surface decreases air pressure on the surface (Figure 1-3). As air speed increases, surface air pressure decreases accordingly. This is directly related to the flight of an aircraft. As an airfoil starts moving through the air, it divides the mass of air molecules at its leading edge. The distance across the curved top surface is greater than that across the relatively flat bottom surface. Air molecules that pass over the top must therefore move faster than those passing under the bottom in order to meet at the same time along the trailing edge. The faster airflow across the top surface creates a low-pressure area above the airfoil. Air pressure below the airfoil is greater than the pressure above it and tends to push the airfoil up into the area of lower pressure. As long as air passes over the airfoil, this condition will exist. It is the difference in pressure that causes lift. When air movement is fast enough over a wing or rotor blade, the lift produced matches the weight of the airfoil and its attached parts. This lift is able to support the entire aircraft. As airspeed across the wing or rotor increases further, the lift exceeds the weight of the aircraft and the aircraft rises. Not all of the air met by an airfoil is used in lift. Some of it creates resistance, or drag, that hinders forward motion. Lift and drag increase and decrease together. They are therefore affected by the airfoil's angle of attack into the air, the speed of airflow, the air density, and the shape of the airfoil or wing.

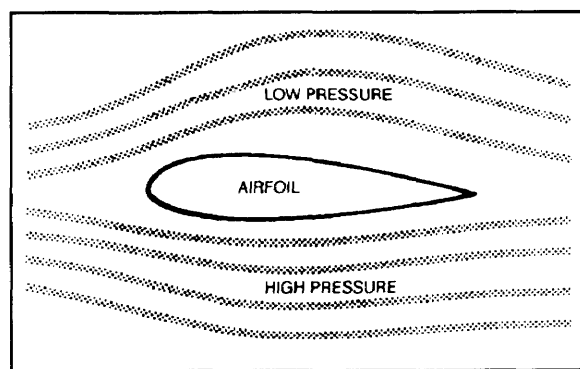


Figure 1-3. Bernoulli's principle

## LIFT AND THRUST

The amount of lift that an airfoil can develop 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).
- Air density (amount of air in a given space).

### Area and Shape

The specific shape and surface area of an airfoil are determined by the aircraft manufacturer. An airfoil may be symmetrical or unsymmetrical, depending on specific requirements. A symmetrical airfoil is designed with an equal amount of camber above and below the airfoil chord line. An unsymmetrical 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, which reduces lift and increases drag.

### Speed

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

### Angle of Attack

The angle of attack is the angle between the airfoil chord and the 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, airflow over the top of the airfoil tends to lose its streamlined path and break away from the contoured surface to form eddies (burbles) near the trailing edge. When this happens, the airfoil loses its lift, and it stalls. The angle of attack at which burbling takes place is called the critical angle of attack.

### Air Density

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 air at higher altitudes. Therefore, an aircraft or helicopter can achieve more lift near the ground than at a high altitude. While keeping at the same speed and angle of attack, an airfoil will slowly make less lift as it climbs higher and higher.

## AIRFOIL STABILITY

### Center of Pressure

The resultant lift produced by an airfoil is the difference between the drag and lift pressures of its 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: 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.

### 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.

### Torque

According to Newton's third law of motion, for every action there is an equal and opposite 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 torque during flight. In helicopters torque is applied in a horizontal rather than a vertical plane. The reaction is therefore greater because the rotor is long and heavy relative to the fuselage, and forward speed is not always present to correct the twisting effect.

### 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 therefore subject to the action of gyroscopic precession.

## STRESS

Stress is a force placed on a body measured in terms of force (pounds) per unit area (square inches). Aircraft design engineers design aircraft

to meet – even to exceed – strength requirements of military service. Since Army aircraft are operated under combat conditions, they might exceed these design limits. Therefore, maintenance personnel must check constantly for failures and for signs of approaching failure in aircraft structural units. Stress may take the form of compression, torsion, tension, bending, or shear or may be a combination of two or more of these forces (Figure 1-4):

- Compression is resistance to being pushed together or crushed. Compression 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.
- Torsion is resistance to twisting. A torsional force is produced when an engine turns a crankshaft. Torque is the force that produces torsion.
- Tension is resistance to being pulled apart or stretched. Tension is produced by two forces pulling in opposite directions along the same straight line. Pilots put the cables of a control system under tension when they operate the controls.
- 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.
- Shear is the stress exerted when two pieces of metal fastened together are separated by sliding one over the other in opposite directions. When force is applied to two pieces of metal fastened together by rivets or bolts, sliding them across each other, the rivets or bolts are subjected to shear. Stress will 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 all parts being bent such as the skin of sheet metal structures.

## LEVERS AND MOMENT OF FORCE

A lever is a useful device found in tools such as jacks, shears, wrenches, and pliers. To use tools and balancing procedures correctly, the repairer needs to understand moment of force (amount of leverage).

## FM 1-514

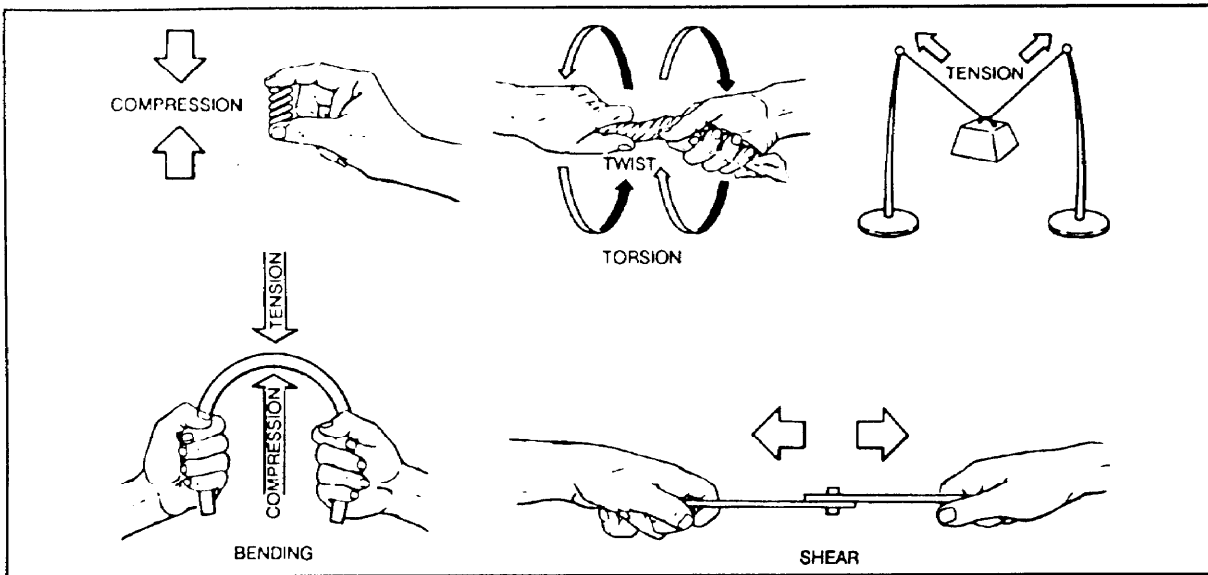


Figure 1-4. Types of stresses

## Levers

Levers are classified as three types according to the position of the applied force (effort), the resistance, and the fulcrum (the pivot point) (Figure 1-5). In Type 1 the fulcrum is located between the applied effort and the resistance. In Type 2 the resistance is located between the fulcrum and the applied effort. In Type 3 the applied effort is located between the resistance and the fulcrum.

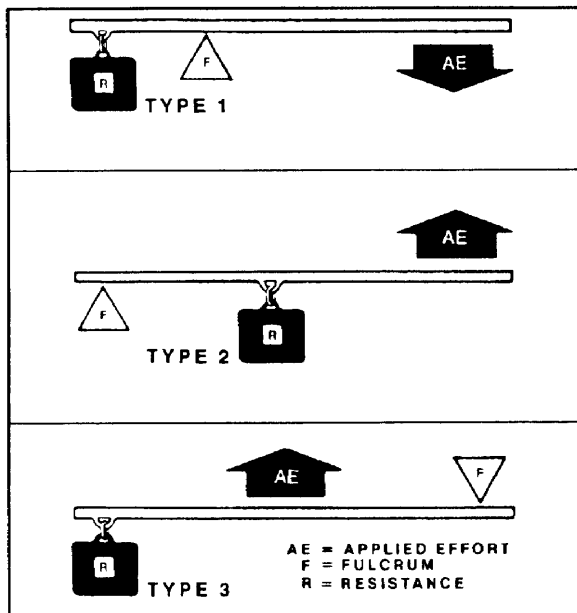


Figure 1-5. Types of levers

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 requires 1 pound of 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 that is four times greater than the distance the resistance would move.

## Moment of Force

A moment of force is the product of a force or weight and 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 by a 1-pound effort applied 8 inches from the fulcrum.

## VIBRATION

Any type of machine vibrates. However, greater than normal vibration usually means that there is a malfunction. Malfunctions can be caused by worn bearings, out-of-balance conditions, or loose hardware. If allowed to continue unchecked, vibrations can cause material failure or machine destruction. Aircraft – particularly helicopters – have a high vibration level due to their many moving parts. Designers have been forced to use many different dampening and counteracting methods to keep vibrations at acceptable levels. Some examples are —

- Driving secondary parts at different speeds to reduce harmonic vibrations; this method removes much of the vibration buildup.
- Mounting high-level vibration parts such as drive shafting on shock-absorbent mounts.
- Installing vibration absorbers in high-level vibration areas of the airframe.

### Lateral

Lateral vibrations are evident in 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.

### Vertical

Vertical vibrations are evident in up-and-down movement that produces a thumping effect. An out-of-track rotor blade causes this type vibration.

### High-Frequency

High-frequency vibrations are evident in buzzing and a numbing effect on the feet and fingers of crew members. High-frequency vibrations are caused by an out-of-balance condition or a high-speed, moving part that has been torqued incorrectly. The balancing of high-speed parts is very important. Any buildup of dirt, grease, or fluid on or inside such a part (drive shafting for example) causes a high-frequency vibration. This type vibration is more dangerous than a lateral

or vertical one because it causes crystallization of metal, which weakens it. This vibration must be corrected before the equipment can be operated.

### Ground Resonance

Ground resonance is the most dangerous and destructive of the vibrations discussed here. Ground resonance can destroy a helicopter in a matter of seconds. It is 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.

## NONDESTRUCTIVE INSPECTION

Nondestructive inspection (NDI) methods determine integrity, composition, physical/electrical/thermal properties, and dimensions without causing a change in any of these characteristics in the item being inspected. NDI includes —

- Liquid penetrant methods.
- Magnetic particle methods.
- Electromagnetic methods.
- Ultrasonic methods.
- Penetrating radiation.
- Harmonic bond testing.

NDI in the hands of a trained and experienced technician is capable of detecting flaws or defects with a high degree of accuracy and reliability. Maintenance engineering personnel should know the capabilities of each method. Equally important, they should recognize the limitations of each method. NDI is not a panacea for inspection ills – it is merely a means of extending the human senses. No NDI method should ever be considered conclusive. A defect indicated by one method must be confirmed by some other

## FM 1-514

method to be reliable. Further, NDI equipment is highly sensitive and capable of detecting discontinuities and anomalies which may be of no consequence to the particular service a component is used for. Limits for acceptance and rejection are thus as much apart of an inspection as the method itself. For

example, ultrasonic inspection equipment is fully capable of detecting normal grain boundaries in some cast alloys. Inspection criteria must be designed to overlook these "normal" returns and to discriminate in favor of those discontinuities that will affect the component in service.

## CHAPTER 2

## FUNDAMENTALS OF ROTORS

Of all airfoils the rotor blade on a helicopter is unique. Like most airfoils it provides lift, but it also provides thrust and directional control. The rotor system produces the lift, thrust, and directional control needed for helicopter flight.

## ROTOR SYSTEM

The rotor system includes a rotor head, rotor blades, and control systems that drive and control the pitch angles of the blade. The rotor head is the main assembly of the rotor system; it contains the rotor hub, blade attachment fittings, and blade controlling mechanisms. Currently, all helicopters in the Army inventory use a hub drive system (Figure 2-1). In the hub drive, blades are attached to a rotor hub that is splined to the mast, which, in turn, rotates the rotor hub and blades.

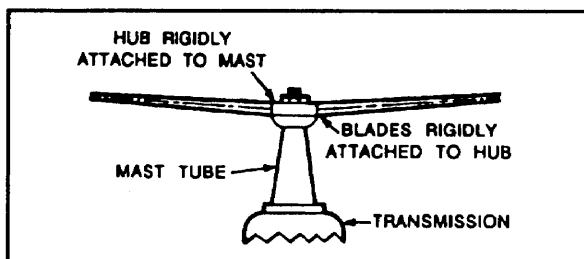


Figure 2-1. Hub drive

## FORCES ACTING ON ROTORS

Since the rotor system of a helicopter provides both lift and thrust, it is exposed to all of the forces that act on aircraft wings and propellers. When applied to rotor blades, the thrust-bending force that acts on propellers is called coning. Because of the large mass and weight of the rotating heads, the amount of centrifugal force (Figure 2-2) that acts on the rotor blades must be considered.

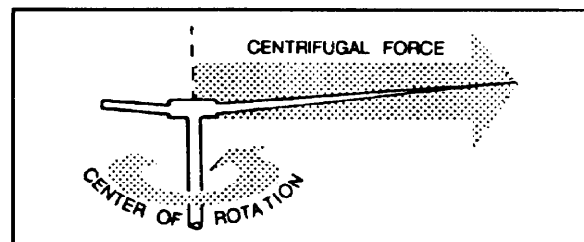


Figure 2-2. Centrifugal force

## TERMINOLOGY

## 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 (Figure 2-3). On most blades, this angle is determined during design and is not adjustable.

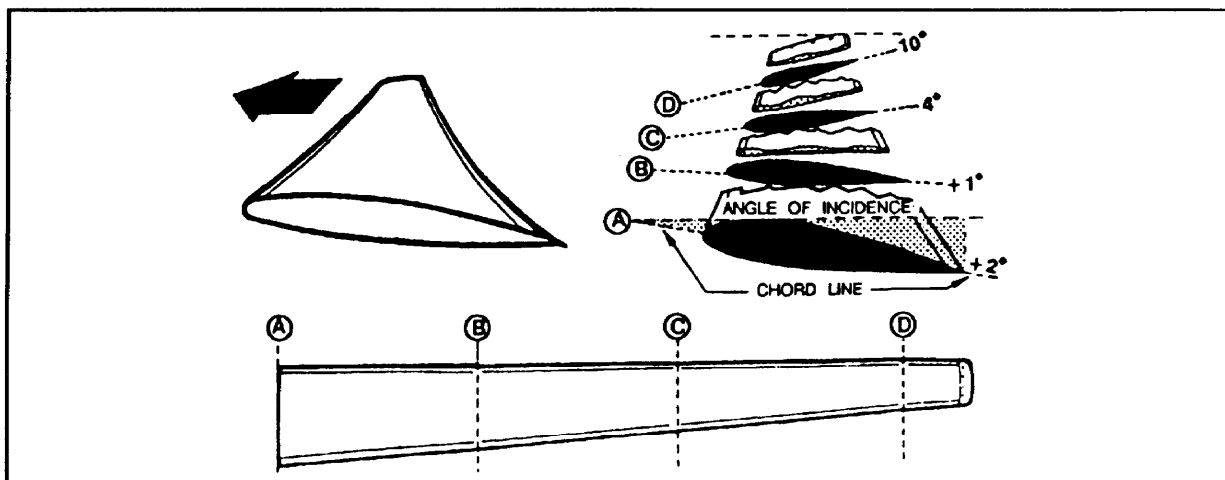


Figure 2-3. Angle of incidence

## FM 1-514

**Plane of Rotation**

A plane formed by the average tip path of the blades is known as the plane of rotation. The plane of rotation is at a right angle to the axis of rotation.

**Axis of Rotation**

An imaginary line that passes through a point on which a body rotates is called the axis of rotation (Figure 2-4). Its rotation is at a right angle to the plane of rotation.

Area equals 3.14159 multiplied by the 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:

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

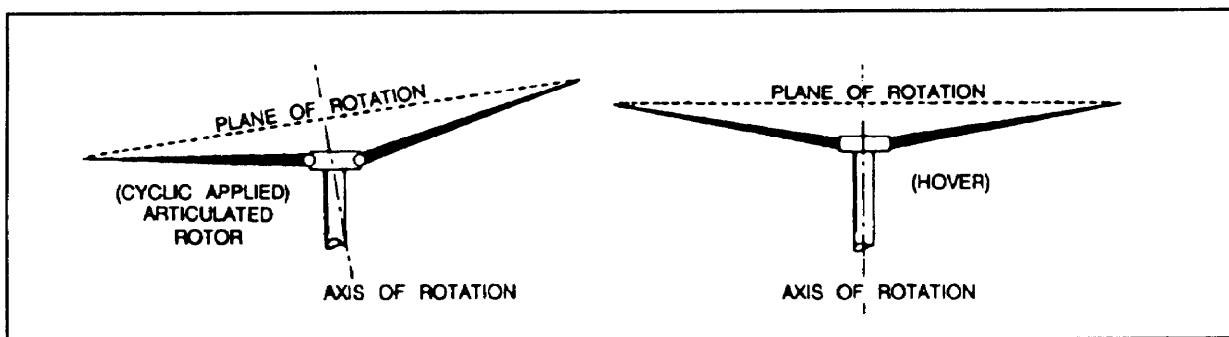


Figure 2-4. Axis of rotation

**Disc Area and Loading**

The disc area (Figure 2-5) is the total space in the area of the circle formed by the rotating rotor blades. The following formula is used to figure disc area:

$$A = TTR^2$$

A = area

TT = total

R = radius

**Symmetry and Dissymmetry of Lift**

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 Figure 2-6.

The example in the figure uses a blade tip speed of 300 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

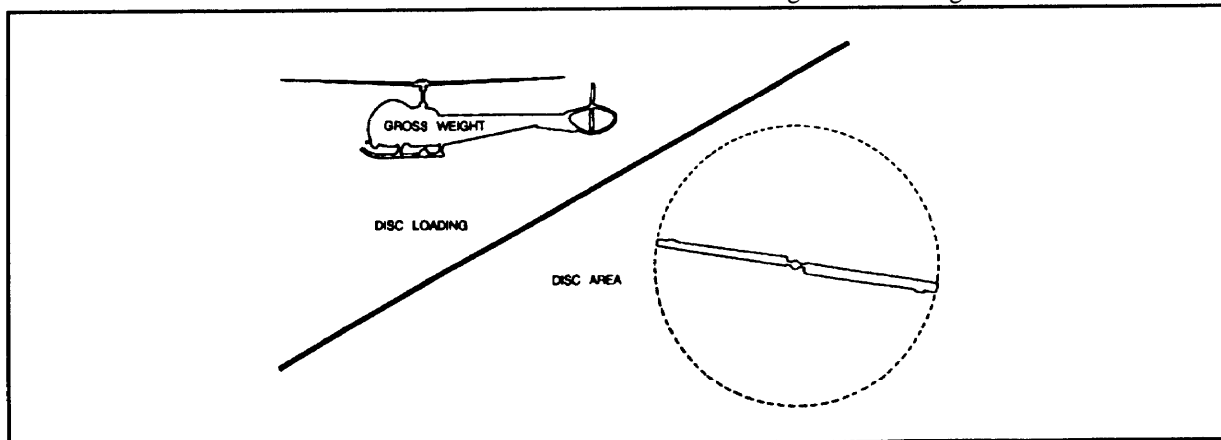


Figure 2-5. Disc area and loading

area because speed is the same on both halves. Dissymmetry of lift is the difference in lift that exists between the advancing half of a rotor disc and the retreating half. Dissymmetry 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 – 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.

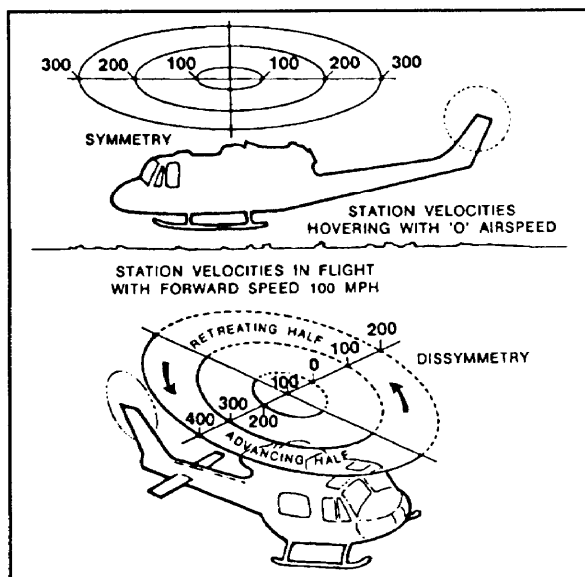


Figure 2-6. Symmetry and dissymmetry of lift

### Horsepower Loading

Also called power loading, horsepower loading is the ratio of aircraft gross weight to maximum horsepower (gross weight divided by available horsepower). The horsepower loading factor is used in determining rotor system design and testing.

### Flapping

The up-and-down movement of rotor blades positioned at a right angle to the plane of rotation is

referred to as flapping (Figures 2-7 and 2-8). 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.

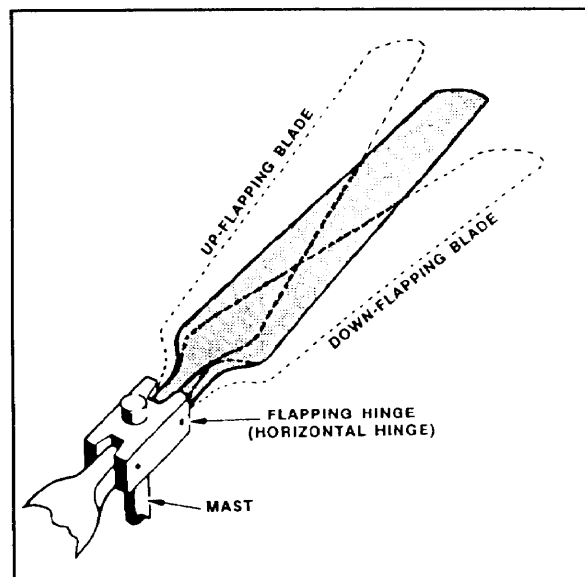


Figure 2-7. Flapping (articulated hub)

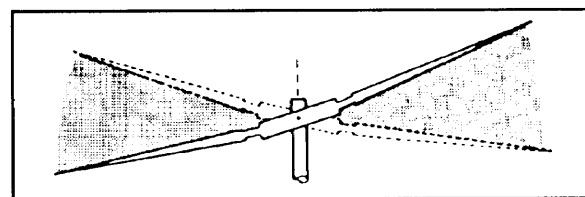
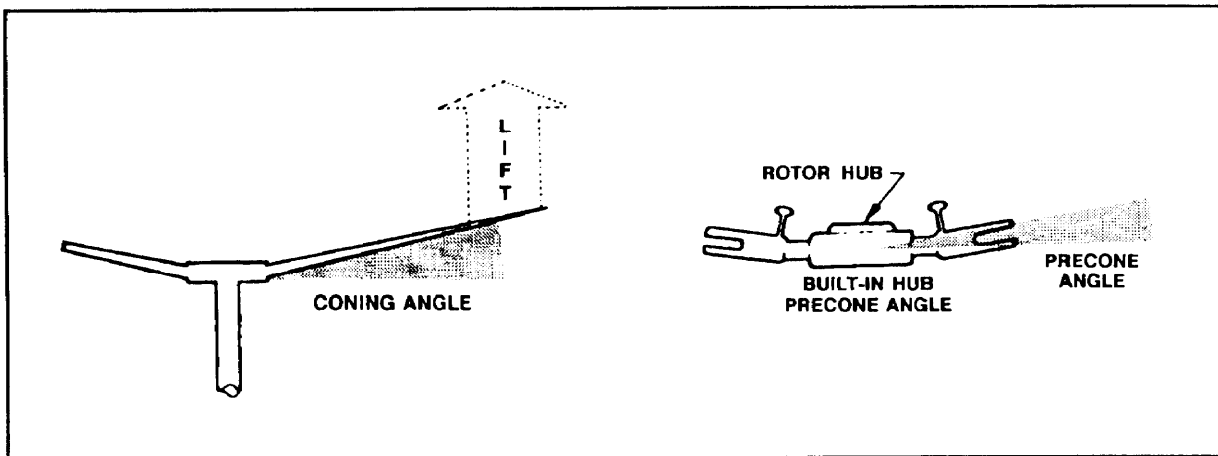


Figure 2-8. Flapping (semirigid hub)

### Coning and Preconing

The upward flexing of a rotor blade due to lift forces acting on it is called coning (Figure 2-9). 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 manufacturers determine the coning angle mathematically and build a preconed 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

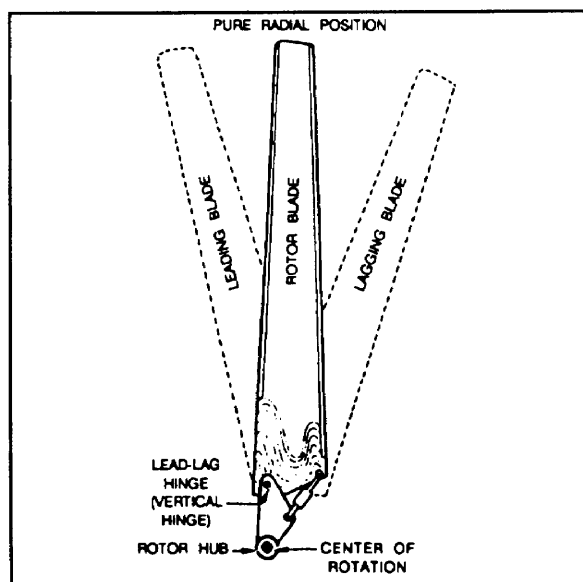


**Figure 2-9. Coning and preconing angles**

without bending, which reduces stress. It is not necessary to preconing the articulated rotor hub because the blade can flap up on horizontal hinges to the correct coning angle.

### Lead and Lag of Blades

The horizontal movement of the blades around a vertical pin is called leading and lagging (hunting) (Figure 2-10). 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



**Figure 2-10. Lead and lag**

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.

### Feathering Axis

The spanwise axis about which a rotor blade rotates to change pitch is known as the feathering axis (Figure 2-11). 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.

### Hover

The versatility of a helicopter is due to its ability to hover at a point above the ground. This lets the helicopter vertically rise from and descend to small, unimproved landing areas. When 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 while blade speed remains 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 greater. Hovering takes a great deal of power because a large mass of air must be drawn through the rotor blades at high speeds.

### Ground Effect

When hovering near ground or water surfaces at a height no more than one-half of the rotor diameter,

the helicopter encounters a condition referred to as ground effect. This condition is more pronounced nearer the ground. Helicopter operations within ground effect are more efficient due to reduction of

the 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.

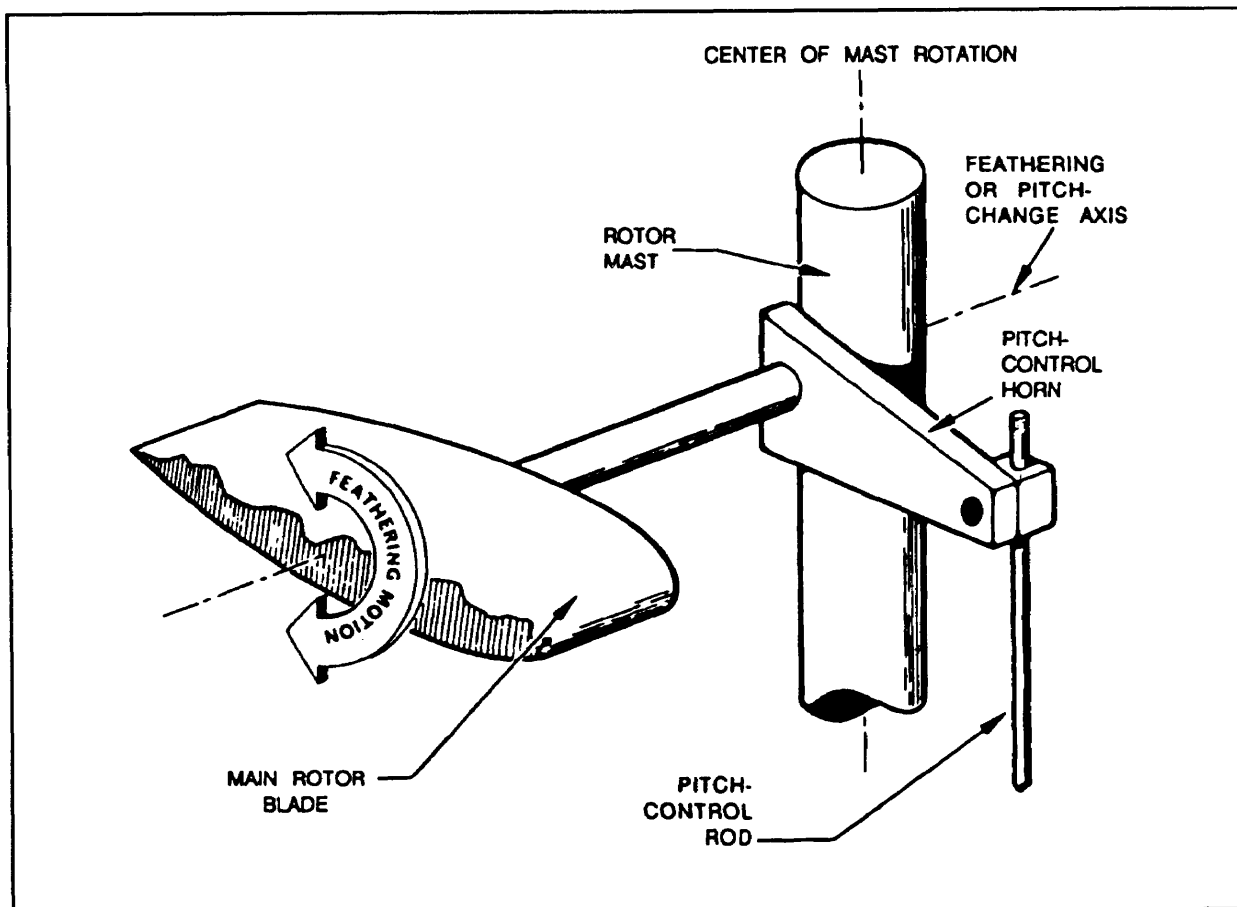


Figure 2-11. Feathering axis



## CHAPTER 3

### ROTOR SYSTEM OPERATION

An understanding of the rotor system is necessary to be able to troubleshoot it in an analogical manner. It is important to know and understand the operation of rotor heads and how rotor blades are driven. Remember that if the components of the rotor system are not properly maintained, a malfunction may occur while in flight causing possible loss of life and equipment. For a complete detailed description of a specific helicopter rotor system, refer to the applicable aircraft multipart maintenance manual.

#### SINGLE AND TANDEM ROTORS

Helicopter configurations are classified as single, tandem, coaxial, and side by side. The single- and tandem-rotor configurations are the only ones used in Army helicopters.

##### Single Rotor

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 to operate the main and tail rotors is supplied by the power train system. The single-rotor configuration has the advantage of being simpler and lighter than the tandem-rotor system, and it requires less maintenance. Since the tail rotor uses a portion of the available power, the single-rotor system has a smaller center-of-gravity range.

##### Tandem Rotor

Normally used on large cargo helicopters, the tandem-rotor configuration has two main rotor systems, one 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 and good longitudinal stability also, the counter-rotating rotors do away with the need for an antitorque rotor. Because there is no antitorque rotor, full engine power can be applied to load lifting. Disadvantages of the tandem-rotor system are a complex transmission and more drag due to its shape and excessive weight.

#### 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 axes 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 a nose swing (or change in direction) to the right or left; this movement is called yaw. 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 to 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 below.

##### 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 relative to



**FM 1-514**

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.

**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 increases the lift and causes the helicopter to rise. Lowering the control decreases the pitch of the blades, causing a loss of lift. This produces a corresponding rate of descent. Collective pitch control is also used in coordination with cyclic pitch control to regulate the airspeed. For example, to increase airspeed in level flight, the cyclic is moved forward and the collective is raised at the same time.

**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 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, or right.

**Throttle Control**

By working the throttle control, pilots can keep the same engine and rotor speed, even if a change in blade pitch causes them 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 obtained 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 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.

**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 antitorque 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.

**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. Two types of rotor heads used on Army helicopters are semirigid and fully articulated.

**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 (Figure 3-1). There are no flapping or drag hinges like those on the articulating head. Since the blades are interconnected, when one blade moves upward the other moves downward a corresponding distance. The main rotor hub is of a semirigid, underslung design consisting basically of the —

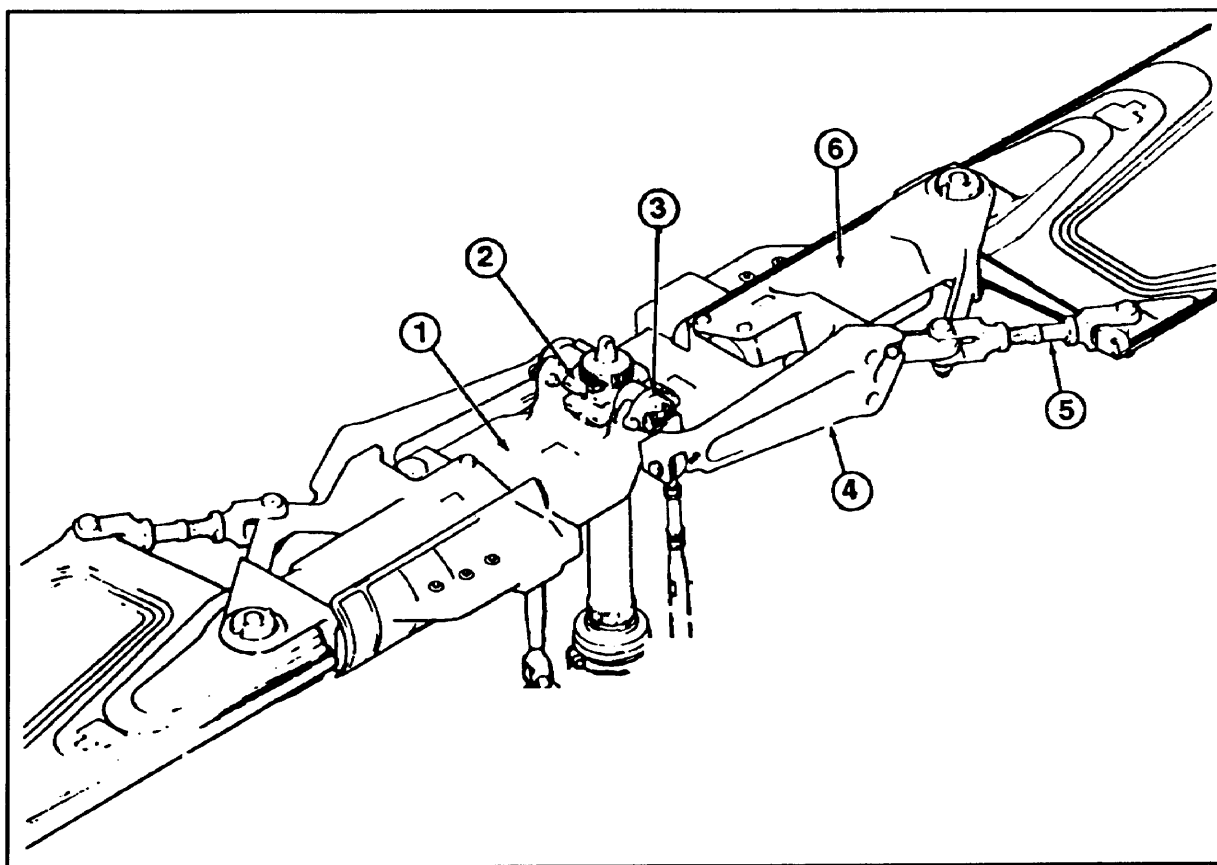
- Yoke (1).
- Trunnion (2).
- Elastomeric bearing (3).
- Yoke extensions.
- Pitch horns (4).

- Drag braces (5).
- Grips (6).

The yoke is mounted to the trunnion by elastomeric bearings which permit rotor flapping. Cyclic and collective pitch-change inputs are received through pitch horns mounted on the trailing edge of the grips. The grips in turn are permitted to rotate about the yoke extensions on Teflon-impregnated fabric friction bearings, resulting in the desired blade pitch. Adjustable drag braces are attached to the grips and main rotor blades to maintain alignment. Blade centrifugal loads are transferred from the blade grips to the extensions by wire-wound, urethane-coated, tension-torsion straps.

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.
- Connecting parts.

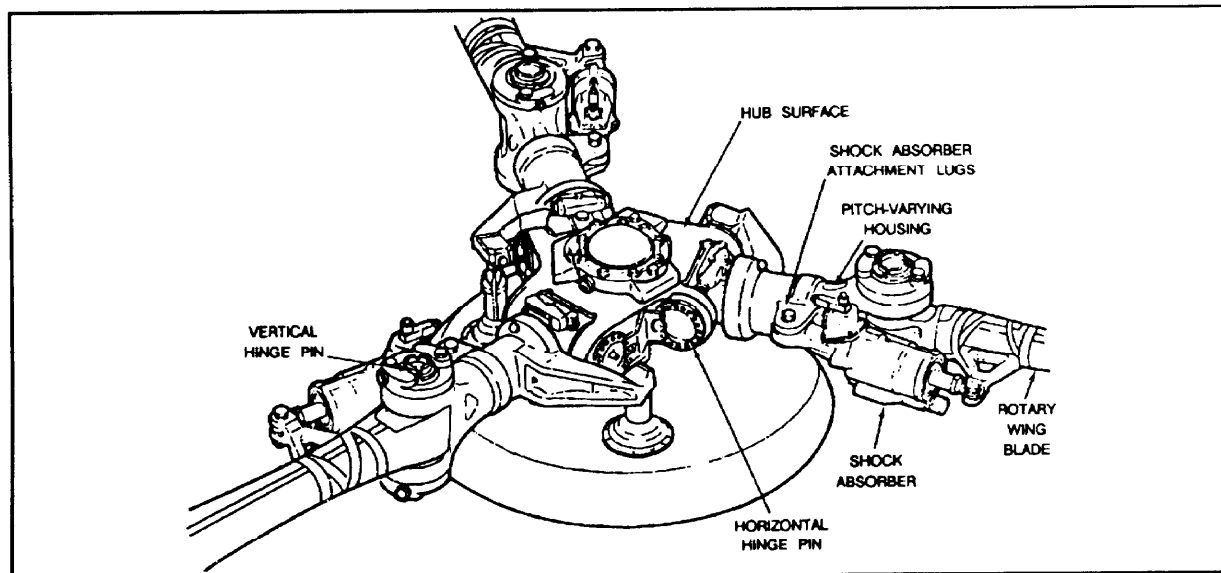


**Figure 3-1. Semirigid rotor system**

### Fully Articulated

A fully articulated rotor head gets its name from the fact that it is jointed (Figure 3-2). Jointing is made with vertical and horizontal pins. The fully articulated rotor head assembly has three or more blades,

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



**Figure 3-2. Fully articulated rotor system**

the outboard end of the pitch-varying housing. One end of the dampers is attached to a bracket on the horizontal pins; the other end is fastened to the pitch housing.

#### Flapping

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.

#### Feathering

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.

#### Leading and Lagging

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.

### **TAIL ROTOR HUBS**

The tail rotor hub (antitorque rotor) is used as a centering fixture to attach the tail rotor blades so that they rotate about a common axis. It keeps the blocks against centrifugal, bending and thrust forces. It accepts the necessary pitch-change mechanism to

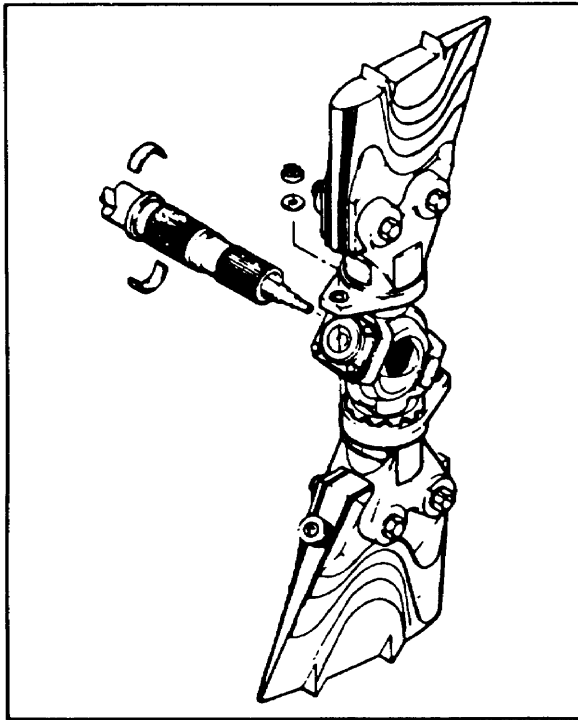
provide automatic equalization of thrust on the advancing and retreating blade, or equal and simultaneous pitch change to counteract torque made by the main rotor system. Hub design varies with the manufacturer. Typical configurations are the hinge-mounted, flex-beamed, and fully articulated types.

#### **Hinge-Mounted Type**

A single two-blade, controllable-pitch tail rotor is located on the left side of the tail rotor gearbox (Figure 3-3). It is composed of the blades and the hub and is driven through the tail rotor gearbox. Blades are of all-metal construction and attached by bolts in blade grips, which are mounted through bearings to spindles of the hub yoke. The tail rotor hub is hinge-mounted to provide automatic equalization of thrust on advancing and retreating blades. Control links provide equal and simultaneous pitch change to both blades. The tail rotor counteracts the torque of the main rotor and provides directional control.

#### **Flex-Beamed Type**

The tail rotor hub and blade assembly counteracts torque of the main rotor and provides directional control. It consists of the hub and two blades (Figure 3-4). The hub assembly has a preconed, flex-beamed-type yoke and a two-piece trunnion connected to the yoke by self-lubricating, spherical flapping bearings. The trunnion, which is splined to the tail rotor gearbox shaft, drives the blades and



**Figure 3-3. Hinge-mounted tail rotor system**

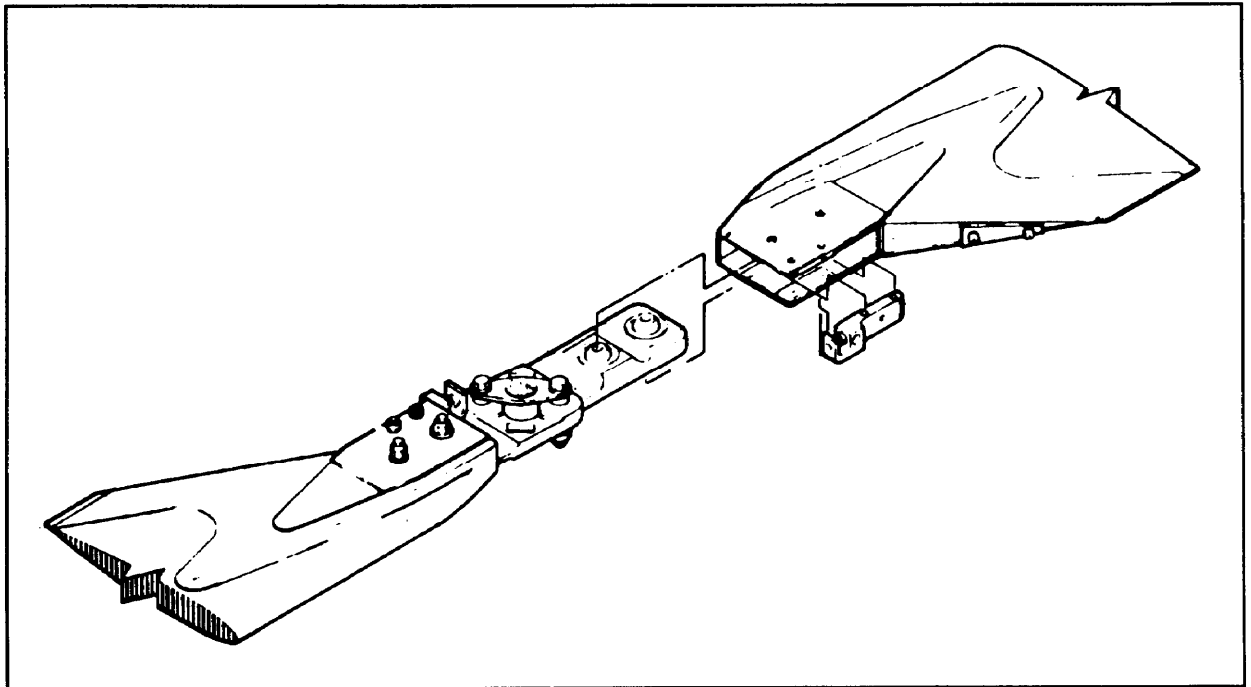
serves as a flapping stop for the tail rotor. The yoke has two self-lubricating, spherical bearings as attaching points for each rotor blade. Rotor pitch change is accomplished at these bearings.

### Fully Articulated Type

The articulated tail rotor system (Figure 3-5) counterbalances disturbing forces in the same way that the hinge-type rotor does. The major difference is that the blades can lead and lag individually during rotation.

### MAIN ROTOR BLADES

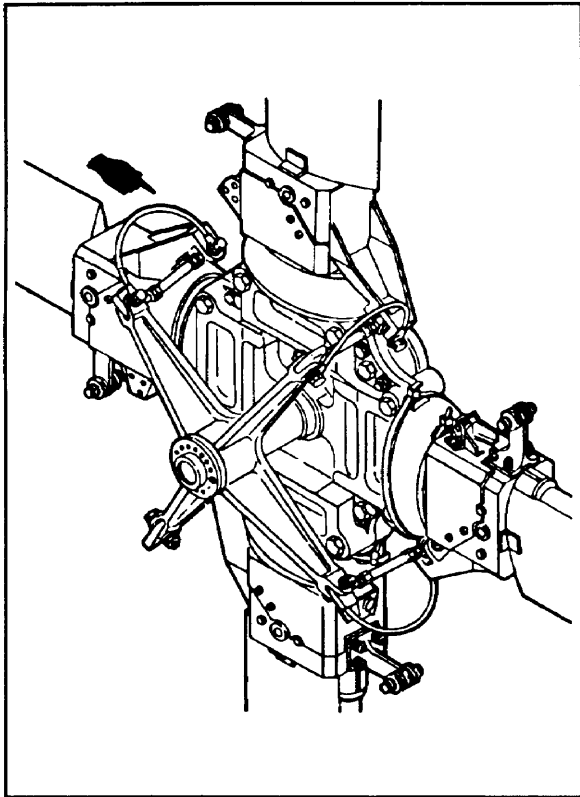
The rotor blade is an airfoil designed to rotate about a common axis to produce lift and provide directional control for a helicopter. It is often referred to as a rotary wing. The design and construction of a rotor blade vary with the manufacturer, although they all strive to manufacture the most efficient and economical lifting device. The particular helicopter design places certain requirements on the main rotor blades, which influence their design and construction. Most rotor blades are designed as symmetrical airfoils to produce a stable aerodynamic pitching characteristic. Aerodynamic stability is achieved when the center of gravity, center of pressure, and blade-feathering axis all act 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



**Figure 3-4. Flex-beamed-type tail rotor system**

## FM 1-514

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; aluminum, steel, brass, and fiberglass are most common.



**Figure 3-5. Fully articulated tail rotor system**

### Types of Rotor Blades

#### Metal

A typical metal blade has a hollow, extruded aluminum spar which forms the leading edge of the blade (Figure 3-6). Aluminum pockets bonded to the trailing edge of the spar assembly provide streamlining. An aluminum tip cap is fastened with screws to the spar and tip pocket. A steel cuff bolted to the root end of the spar provides a means of attaching the blade to the rotor head. A stainless steel abrasion strip is adhesive-bonded to the leading edge.

#### Fiberglass

The main load-carrying member of a fiberglass blade is a hollow, extruded steel spar (Figure 3-7). 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 threaded to the blade spar shank provides an attaching point to the rotor head. A stainless steel tip cap is fastened by screws to the blade spar and blade tip pocket.

### Blade Nomenclature

#### Planform

The blade planform is the shape of the rotor blade when viewed from above (Figure 3-8). It can be uniform (parallel) or tapered. Uniform planforms are most often selected by the manufacturer because, with all the ribs and other internal blade parts the same size, they are easier to make. The uniform blade requires only one stamping die for all ribs, which reduces blade cost. This design has a large blade surface area at the tip; it must therefore incorporate 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 produce more lift toward the tip because it 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. Few blade manufacturers use it, however, because the manufacturing cost is too high due to the many different-shaped parts required to fit the tapered airfoil interior.

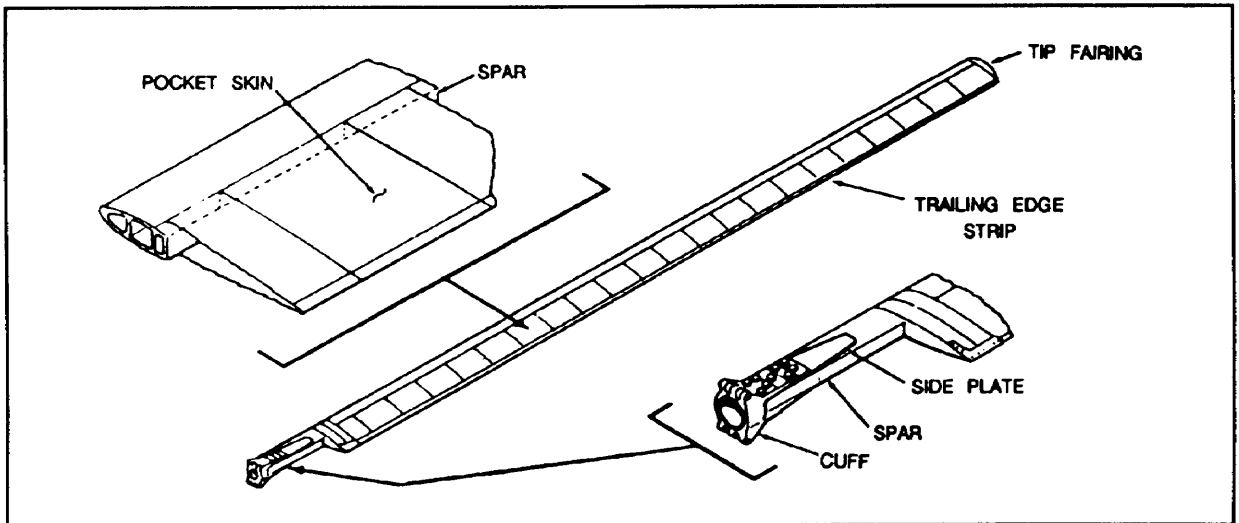
#### Twist

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

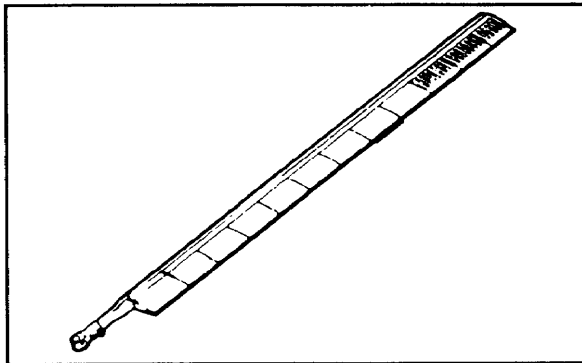
#### Skin

The skin may be fiberglass or aluminum and may consist of single or multiple layers. The thin skin can easily be damaged by careless handling on the ground. Three types of blade coverings are used: one-piece wraparound aluminum alloy, single pocket (or fairing), and multiple pocket

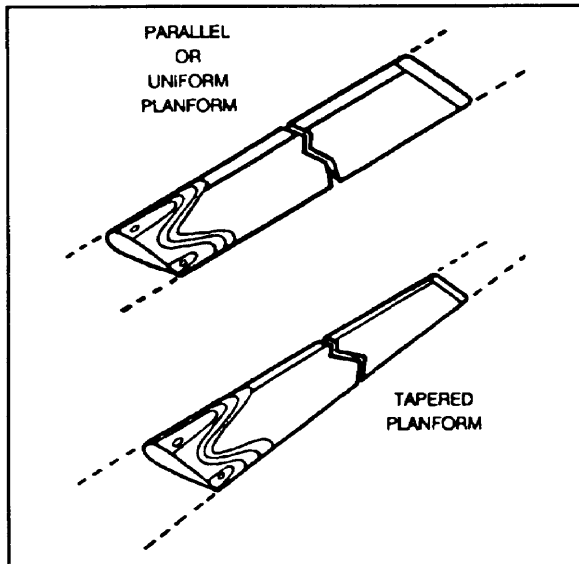




**Figure 3-6. Metal rotor blade**



**Figure 3-7. Fiberglass rotor blade**

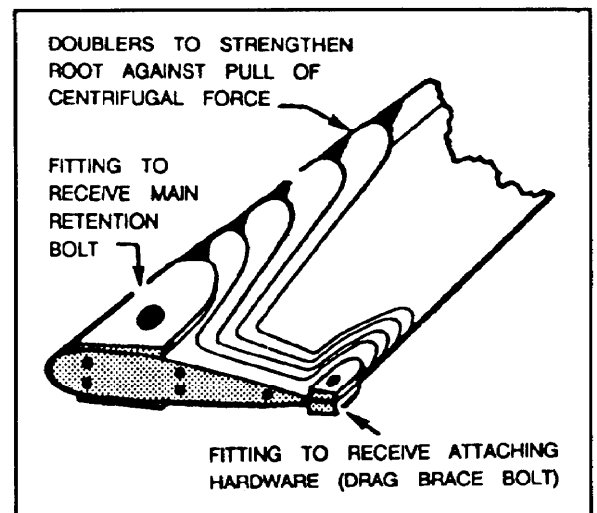


**Figure 3-8. Blade planform**

(or fairing). Most main rotor blades are of single-pocket or multiple-pocket construction.

#### Root

The blade root is the section nearest the center of rotation that provides a means of attachment to the rotor head (Figure 3-9). It is heavier and thicker than the rest of the blade to resist centrifugal forces.



**Figure 3-9. Blade root**

#### Tip

The tip is located furthest from the center of rotation and travels at the highest speed during operation (Figure 3-10). The blade tip cap also has a means for attaching balance weights.

FM 1-514

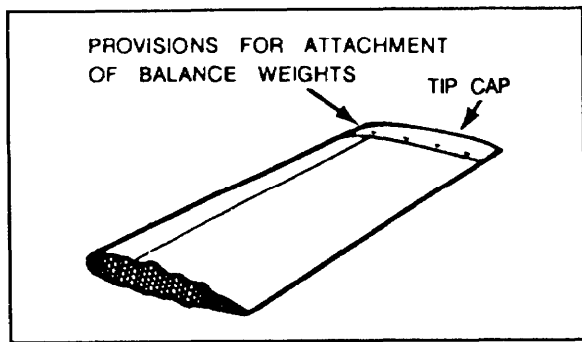


Figure 3-10. Blade tip

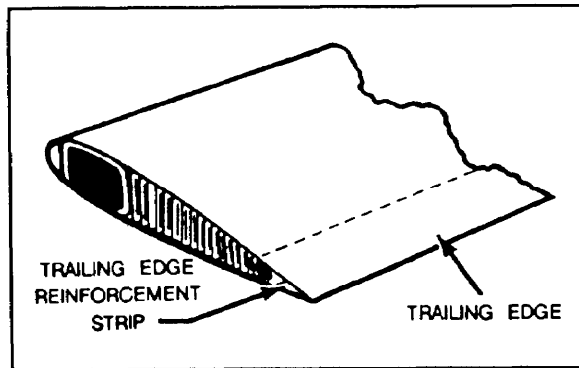


Figure 3-12. Blade trailing edge

### Leading Edge

The part of the blade that meets the air first is the leading edge (Figure 3-11). For the edge to work efficiently, 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.

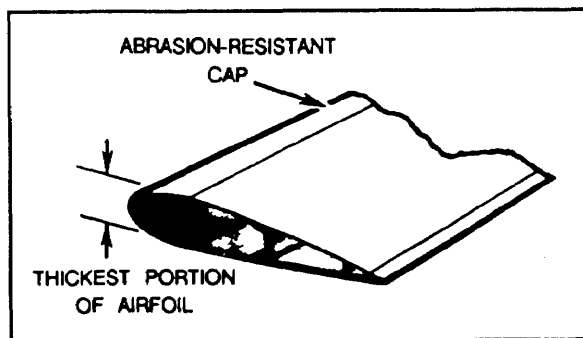


Figure 3-11. Blade leading edge

serious because stress lines move parallel to the span line and would therefore pass the damage without interruption. Chordwise damage interrupts lines of stress.

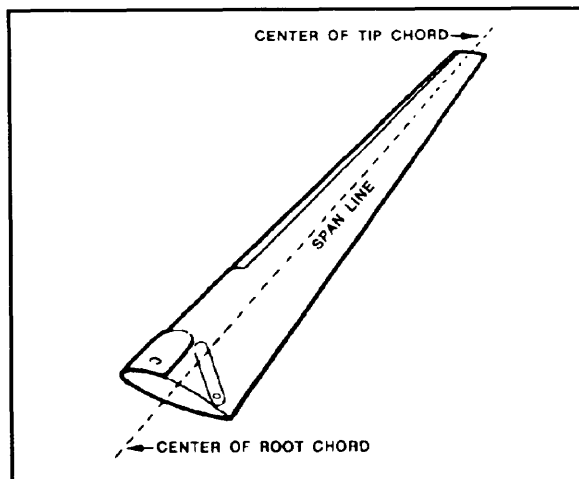


Figure 3-13. Span and span line

### 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 (Figure 3-12). The trailing edge is strengthened to resist damage, which most often happens during ground handling.

### Span and Span Line

The span of a rotor blade is its length from root to tip (Figure 3-13). The span line is an imaginary line running parallel to the leading edge from the root of the blade to the tip. Span line is important to the blade repairer because damages are often located and classified according to their relation to it. Defects paralleling the span line are usually less

### Chord and Chord Line

The chord of a rotor blade is its width measured at the widest point (Figure 3-14). The chord line of a rotor blade is an imaginary line from the leading edge to the trailing edge, perpendicular to the span line. Blade chord line is used as a reference line to make angular measurements.

### Spar

The main supporting part of a rotor blade is the spar (Figure 3-15). Spars are usually made of aluminum, steel, or fiberglass; they always extend along the span line of the blade. Often the spar is D-shaped and forms the leading edge of the airfoil. Spars are of

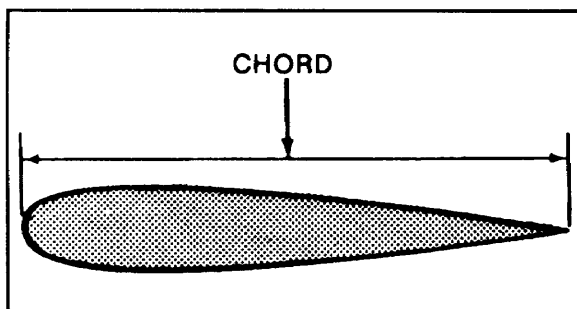


Figure 3-14. Rotor blade chord

different shapes, depending on the blade material and on how they fit into the blade airfoil.

#### 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.

#### Bottom

The high-pressure side of the blade is the bottom. The bottom is the blade surface which is viewed from the ground. It is always painted a lusterless black to prevent glare from reflecting off the blade and into crew compartments during flight.

#### 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, station zero, and outward to the blade tip (Figure 3-16).

#### Blade Construction

##### Single Pocket or Fairing

The single-pocket or fairing blade is made with a one-piece skin on top and bottom (Figure 3-17).

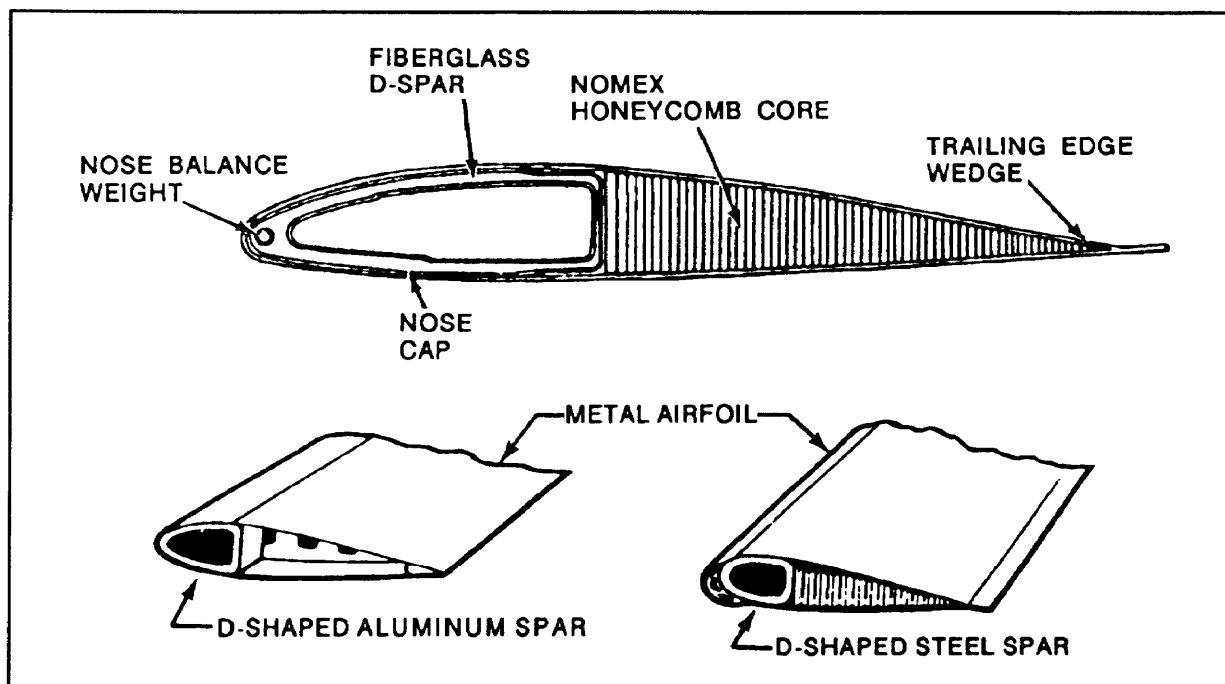


Figure 3-15. Spars

#### Top

The low-pressure side of the blade is the top. The top 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.

Each skin extends across the entire span and chord, behind the spar. This style is simple and easy to make because of the minimum number of pockets or fairings that need positioning and clamping during the bonding process. However, minor damage to the



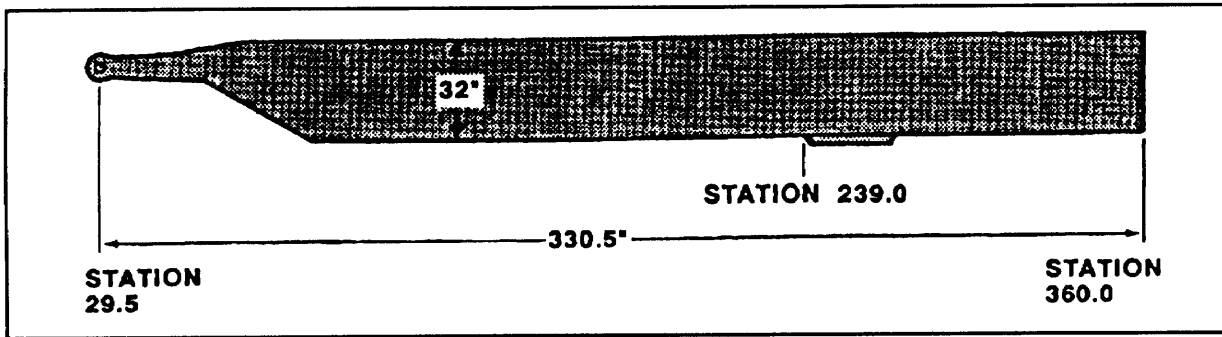


Figure 3-16. Rotor blade stations numbered from root end

skin often results in the blade being thrown away since replacing the skin costs more than replacing the blade.

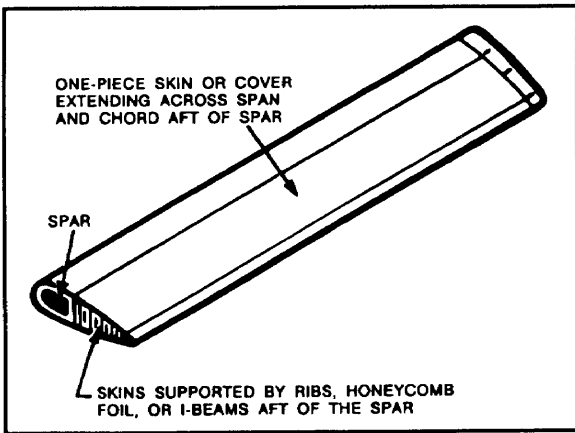


Figure 3-17. Single-pocket rotor blade cover

Multiple Pockets or Fairings

Most large rotor blades built with the multiple-pocket or fairing shape behind the spar are costly (Figure 3-18). This type of blade is selected since damage to the skin cover requires that only the pocket (or fairing) be replaced. The high-cost blade can then be used over and over. This type of blade is more flexible across the span, which cuts down on blade vibrations.

Internal Structural Components

Rotor blades have internal structural parts that help to support the blade skin – ribs, I-beams, spanwise channels, and aluminum honeycomb foil.

**Bonds and Bonding**

Bonding is a method of putting two or more parts together with an adhesive compound. Bonding helps

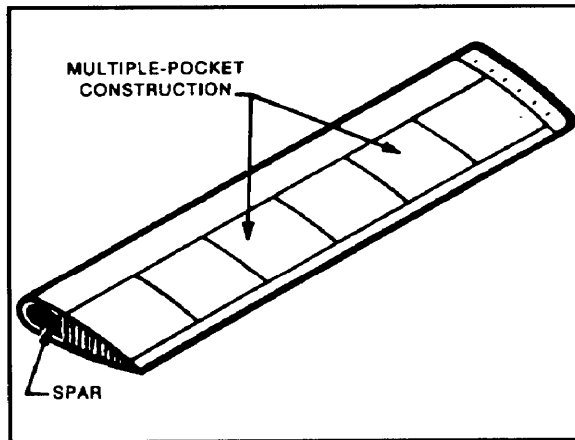


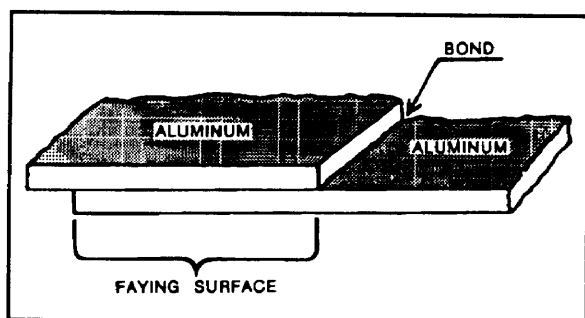
Figure 3-18. Multiple-pocket rotor blade cover

reduce the use of hardware like bolts, rivets, and screws that need holes and therefore weaken the strength of the bond. To ensure full strength, manufacturers never drill holes in load-carrying parts of the blade except at the inboard and outboard ends. However, bonds react to the chemical action of paint thinners and many cleaning solvents. Careless use of these solvents will dissolve bonded joints. The surface area where two objects are bonded together is known as the faying surface (Figure 3-19).

**Blade Balance**

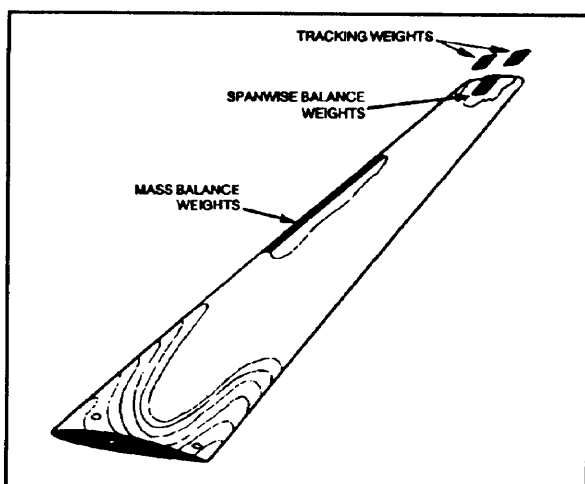
Three types of weights to balance the blade are mass chordwise, spanwise, and tracking (Figure 3-20).

Mass balance weights (bars) are placed into the leading edge of a blade while the blade is being made (Figure 3-21). This is to ensure that correct chordwise balance is about 25 percent of chord. The type of metal and its shape and location vary with the



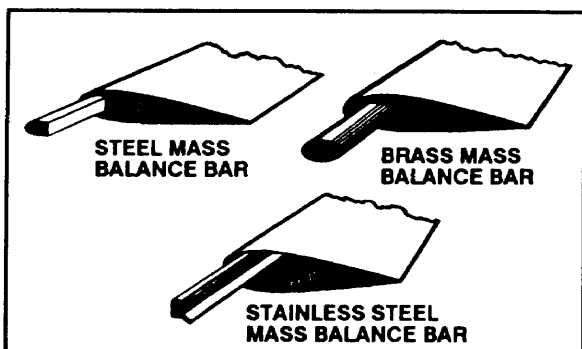
**Figure 3-19. Faying surface**

manufacturer. The repairer is not allowed to move the weights in most 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.



**Figure 3-20. Blade balance weights**

Spanwise balance weights are at the tip of the blade, usually where they can be attached securely to the spar (Figure 3-22). They are normally installed in the



**Figure 3-21. Mass balance weights**

blade during manufacture. The repairer is not always permitted to move these weights. When movement is necessary, the repairer should always remember that adding spanwise weight moves the center of gravity outward. Subtracting weight moves the center of gravity inward. When moving the spanwise weight is permitted, the weight change is computed by the repairer mathematically after the blade has been weighed.

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.
- Cause a loss in blade performance due to air turbulence made by the rotating blades.

One way of retaining track is to attach tracking weights in front of and behind the feathering axis at the blade tips (Figure 3-23). 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. This causes all blades to move in the same tip path plane.

### Trim Tabs

Another method used to align the rotor blade on the same plane of rotation is the use of trim tabs (Figure 3-24). Using tracking weights adds to building costs, but the same results may be achieved by cheaper methods; for example, 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 the 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 it is 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.

### TAIL ROTOR BLADES

Tail rotor blades are used to provide directional control only. Made of metal or fiberglass, they are built similarly 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

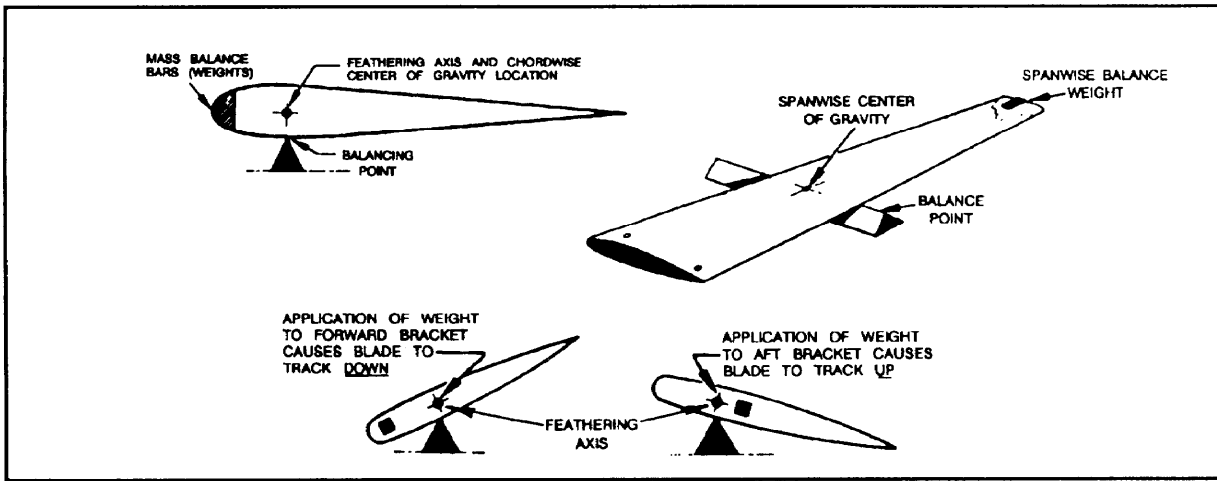


Figure 3-22. Spanwise balance weights

blades are made of fiberglass sheets; the spars are made of solid titanium extrusions. Refer to Figure 3-25.

**Metal Blades**

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.

**Fiberglass Blades**

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.

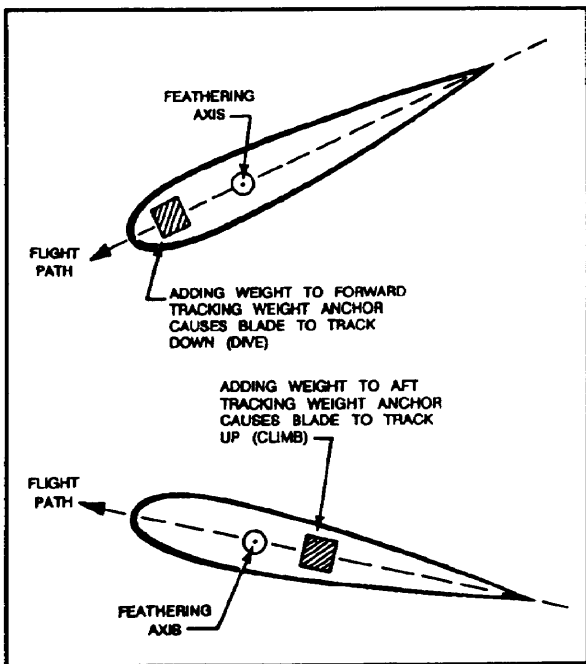


Figure 3-23. Tracking weights

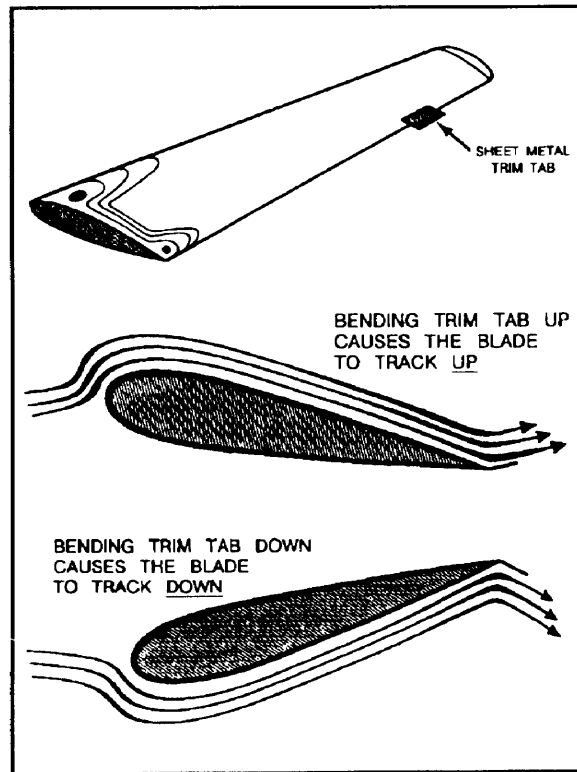


Figure 3-24. Trim tabs

## Blade Balance

### Spanwise

On some models spanwise balance is accomplished by adding or subtracting washers on the blade tip. On others the washers are added to the blade-cuff attaching bolts.

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.

### Trammeling

Fully articulated tail rotor systems must be trammed before they are balanced. Trammeling consists of aligning the tail rotor blades an equal distance to one another with a  $2^\circ$  angle of lead to the blades.

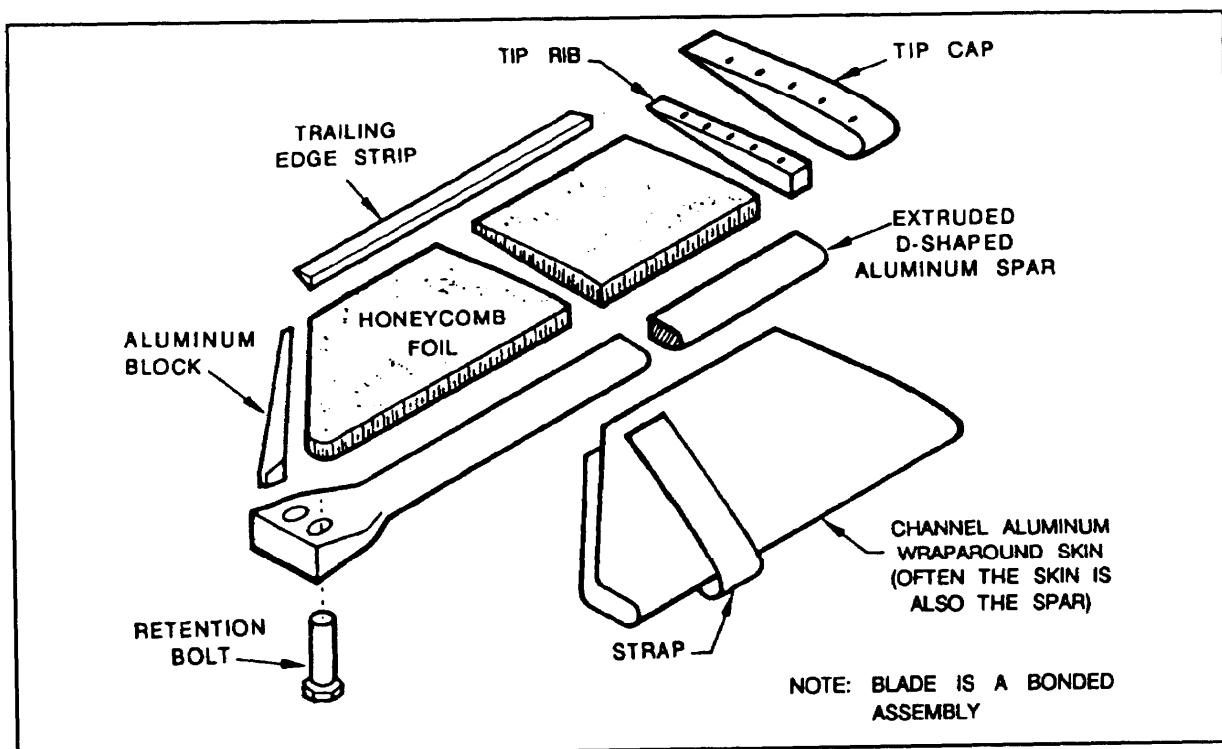


Figure 3-25. Tail rotor blade construction

## CHAPTER 4

## ALIGNMENT AND TRACKING PROCEDURES

This chapter discusses procedures required for alignment and balancing of rotor blades. Specific procedures for aligning blades vary with different types of helicopters. Prior to aligning blades, consult the appropriate technical manual for specific instructions and maximum allowable tolerance. This chapter also includes a description of the Vibrex balancing kit.

**MAIN ROTOR BLADE ALIGNMENT**

Main rotor blade alignment is the centering of the mass (distribution of weight) of the main rotor assembly across the center of rotation to balance it. The alignment of the rotor system has a distinct effect on balance because of the great weight and long arm involved. A greater weight on one side of the center of rotation will cause a lateral vibration. The requirement for manually aligning the main rotor blades applies to rigid and semirigid rotor systems only. The fully articulated rotor system automatically aligns itself as centrifugal force increases and pulls the blades into a pure radial position. The most common method of manually aligning main rotor blades is the telescope method.

A small bore rifle telescope is the basic tool used to align the main rotor assembly (Figure 4-1). A fixture to hold the telescope is fitted onto the hub directly over the center of rotation. A repairer should be concerned with the vertical cross hair only. Ignore the horizontal cross hair. Place a zeroed telescope in the holding fixture and sight the vertical cross hair on a reference point of the blade. The reference point normally used is a rivet in the skin at the tip of the blade in line with the feathering axis. Adjust a misaligned rivet by moving the blade in the hub to bring the rivet into alignment. Align the other (opposite) blade using the same procedure. Alignment of the main rotor assembly has been achieved when both blades have been adjusted so that the vertical cross hair of the telescope is positioned at the center of both rivets.

**UNBALANCED SEMIRIGID ROTOR SYSTEMS****Lateral**

When troubleshooting a semirigid main rotor system, the repairer must understand the basics of alignment and balance to act quickly yet skillfully. An unbalanced system causes the most problems in the field. The trouble that results is called lateral vibration. A few indicators of lateral vibration are worn parts and bearings, broken parts and bearings, loose parts and fittings, and cracked parts and fittings. The repairer must determine if the unbalanced condition is caused by chordwise or spanwise torque before it can be corrected.

**Chordwise**

To differentiate between a chordwise and a spanwise unbalanced condition, apply a strip of tape to the tip of one blade and hover the helicopter. If the lateral vibration decreases and then increases, this indicates that spanwise balance is okay but chordwise unbalance exists. To balance a rotor system chordwise, select a blade and sweep it to the rear by shortening the drag brace. Before making adjustments, matchmark all drag brace parts so that they can be returned to the same setting to regain alignment. Hover the helicopter. Should the lateral vibration increase, you have selected the wrong blade. Return the drag brace to the original alignment as matchmarked. Repeat drag brace sweeping on the opposite blade. Make small sweep corrections until the vibration stops. Secure and safety the drag braces.

**Spanwise**

To isolate spanwise balance, apply a strip of 2-inch tape to the tip of one blade. Hover the helicopter. Should the vibration increase, the wrong blade has been selected. Remove the tape and apply it to the opposite blade. Add the tape one strip at a time until the vibration is gone. Then replace the tape with

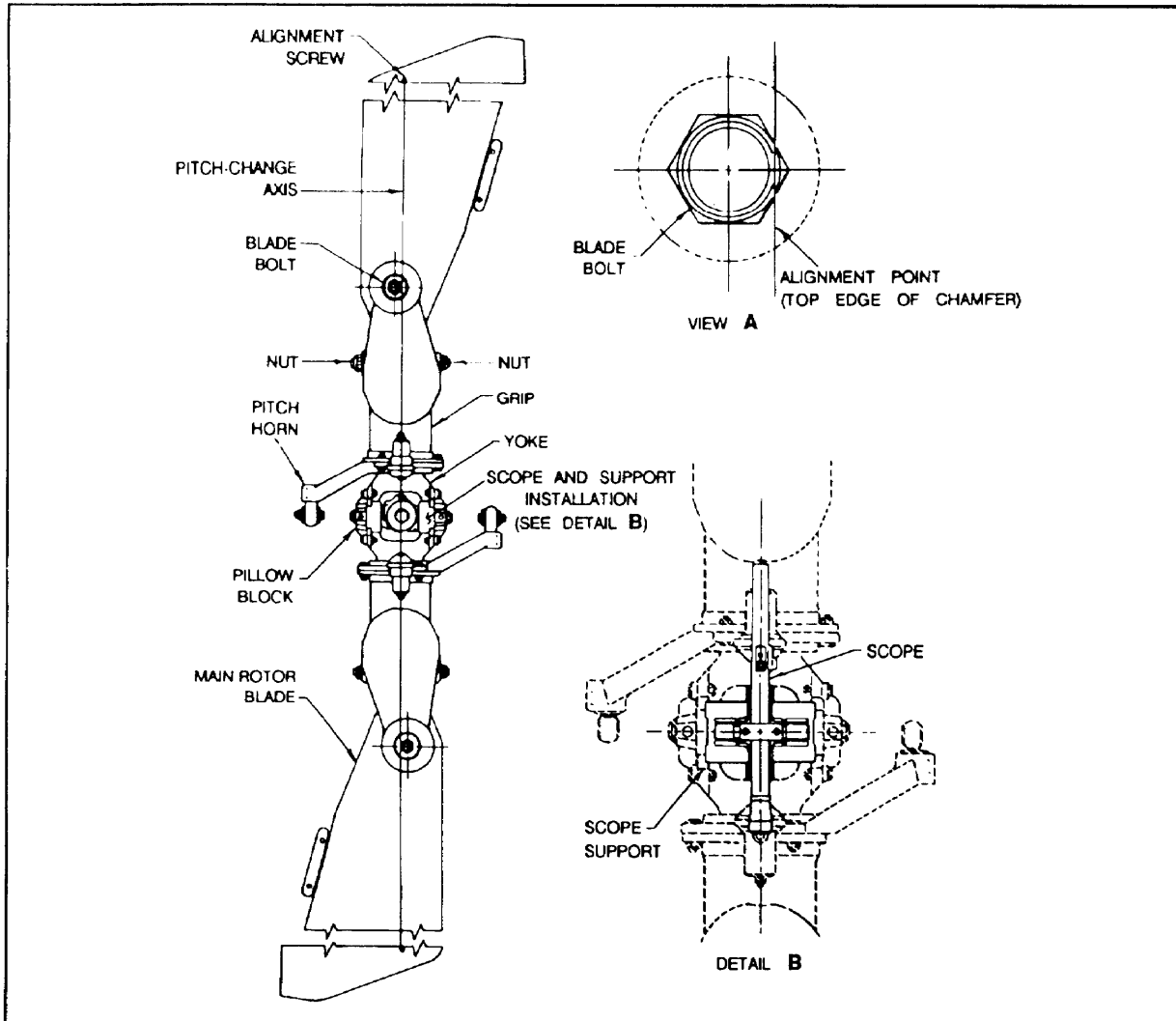


Figure 4-1. Telescopic method of alignment

equal weight or secure weight approximating equal moments at a specific location on the system. For example, apply a 3.1-ounce, lead-in retention bolt for each wrap of tape at the tip or as authorized in the applicable maintenance manual.

### Combined

It is not unusual for a combined chordwise-spanwise unbalance to exist in a main rotor system. When the unit is balanced spanwise, the chordwise unbalance becomes evident. In this case, each unbalance must be corrected separately. If the system cannot be balanced by the above operations, inspect it for loose, worn, or cracked parts and for frozen Teflon bearings or ratcheting roller or ball bearings.

### VERTICAL VIBRATIONS

Vertical vibrations – the bouncing of the helicopter up and down – are caused by a blade being out of track. Vibration is caused by a blade lifting the helicopter in one quadrant of rotation and suddenly losing lift in the remaining quadrant during cyclic travel. When present once during each revolution, this force is referred to as a one-per-revolution or 1-to-1 vibration. Two bounces of the fuselage is known as a two-per-revolution or 2-to-1 vibration.

Someone not familiar with the helicopter can determine vertical vibration by looking at the tips of the skids. A vertical vibration will cause the tip of the skid to bounce vertically against the ground. Depending on the shape of the main rotor and the



helicopter manufacturer, the vibration may be corrected. This is done by rolling the blade grips up or down using the pitch-change links or adjusting the trim tab to get a blade track that will stop the vibration. One method is to blade-track at low RPM using pitch-change links and at high RPM using trim tabs and links with power applied. The blades are tracked using a tracking flag or trackometer. The helicopter is then flown at cruise airspeed to see if blade crossover exists. Blade crossover occurs when blades are almost perfectly in track. During forward flight (cruise) dissymmetry of lift causes a blade to fly high through 180° of rotation and low in the remaining 180°. Corrections are made by adjusting either trim tab up or down to cause the blade to track high or low within limits. Crossover is corrected by the pressure exerted by the trim tab, which forces the blade up or down throughout 360° of rotation.

### Extreme Low Frequency

Extreme low-frequency vibration is essentially limited to pylon rock. Pylon rocking of two or three cycles per second is inherent with the rotor, mast, and transmission systems. To keep the vibration from reaching noticeable levels, transmission mount dampers are installed to absorb the rocking. The damper system may be checked by the pilot while at a hover. Moving the cyclic control forward and backward at about one movement per second will cause the pylon to start rocking. How long it takes for the rocking to die out after the motion of the cyclic is stopped indicates the condition of the damper system.

### Low Frequency

One-revolution and two-revolution vibrations are caused by the rotor. One-revolution vibrations are of two basic types: lateral and vertical. Low-frequency

vibration is started by a gust effect that causes a momentary increase of lift in one blade giving a one-revolution vibration. The momentary vibration is normal. However, if picked up by the rotating collective controls and fed back to the rotor causing cycles of one revolution, then it is undesirable. This condition is usually caused by too much differential tab in the blades. It can be corrected by rolling one blade at the grip and changing angular adjustment of the tab. Two-per-revolution (2/rev) vibrations are inherent with a two-bladed rotor system, and a low level of vibration is always present. When the 2/rev vibration rises to an unacceptable level, it is due to faulty vibration dampers or loose and worn hardware in the rotor system.

### Medium Frequency

Medium-frequency vibrations at four to six per revolution are inherent with most rotor systems. An increase in the level of vibration is caused by a change in the capability of the fuselage to absorb vibration due to loose hardware, structural damage, or load. Normally this vibration is caused by loose parts – either a regular part of the aircraft or the external load.

### High Frequency

High-frequency vibrations can be caused by anything in the ship that rotates or vibrates at a speed equal to or greater than that of the tail rotor. Unless the vibration is isolated to one part of the aircraft – under a shaft bearing, for example – the first step generally is checking the tail rotor track.

### MAIN ROTOR BLADE TRACKING

Blade tracking (Figure 4-2) is the procedure for measuring, recording, and adjusting the tip path plane of the rotor blades. The measurements taken

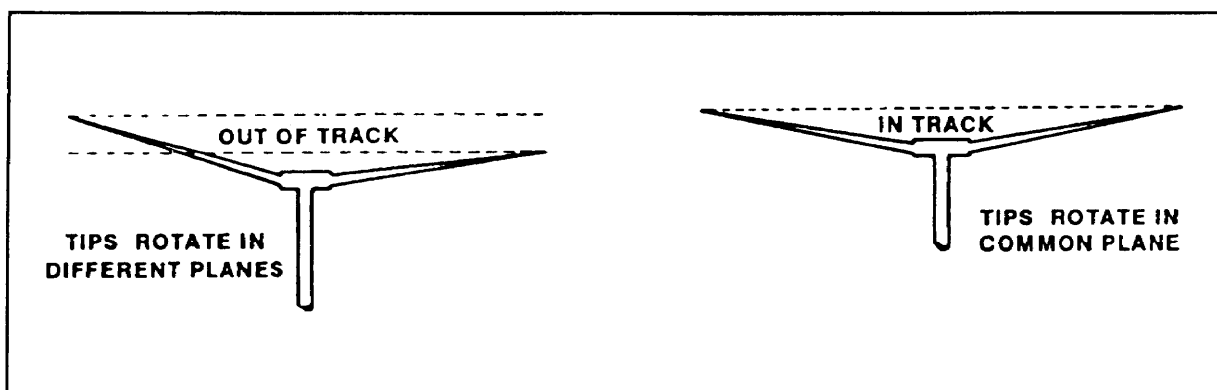


Figure 4-2. Blade tracking

## FM 1-514

while the blades are turning show the vertical position of the rotor blade tips in relation to each other. The positions of the blade tips must be kept within a certain tolerance, usually  $\pm.25$  inch. Tolerance for each helicopter will be listed in the applicable maintenance manual. Several methods used to track blades are —

- Electronic blade tracker.
- Reflector tracking.
- Strobe light.

### Electronic

Rotor blade assemblies may also be tracked with an electronic blade-tracking unit (Figure 4-3). The unit is made up of three major components:

- A phase detector with a magnetic pickup attached to the swash plate's stationary ring and a sweep attached to its rotating ring.

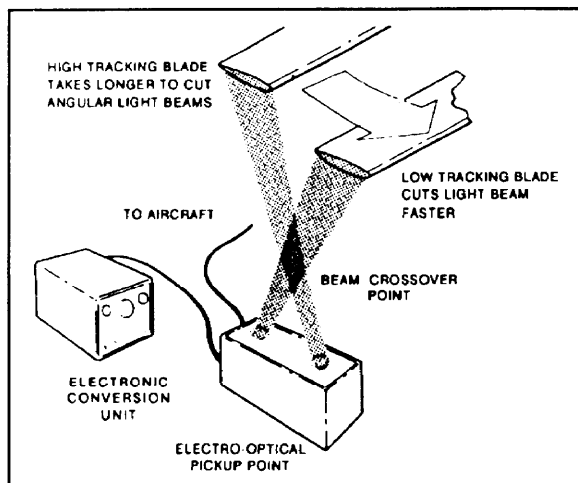


Figure 4-3. Electronic blade tracker

- A computer containing the electronic circuits, adjusting knobs, and meter.
- An electronic eye unit.

The electronic blade tracker unit permits blade tracking during adverse weather and at night. The electronic blade tracker is operated when the rotating rotor blades interrupt the electronic eye beam, sending a signal into the computer in conjunction with a signal from the phase detector. The computer then determines the blade tip path plane above an automatically selected reference plane. The meter shows the height in fractions of an inch of the rotor

blades in the set relative to the predetermined reference rotor blade. Refer to Figure 4-4 for an example.

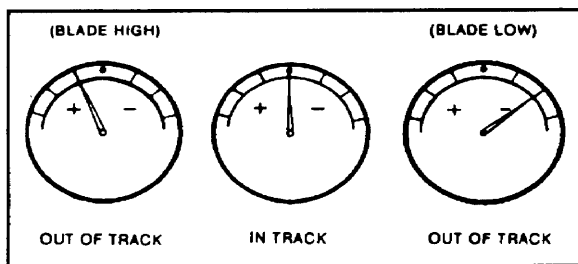


Figure 4-4. Electronic blade tracking — example

### Reflector

The reflector tracking method uses the principle of persistence of vision, which occurs when looking at a beam that is being intercepted by two light reflectors. One reflector is installed at the tip of each main rotor blade. The surface of one reflector is plain white, and the surface of the other is white with a horizontal black stripe painted across the center of the face. As the blades rotate and the light beam is intercepted by the reflectors, the observer will see two white bands and one black band. One white band will be above and the other below the black band. A perfect in-track condition exists when both white bands are the same width. If one reflector image moves vertically relative to the other, one white band will become larger than the other. All tracking should be done at engine-rated RPM to obtain the best track (or as specified in the applicable repair manual). Refer to Figure 4-5 for an example.

### Strobe Light

The strobe light blade-tracking system includes—

- A portable power supply.
- A hand-held strobe lamp.

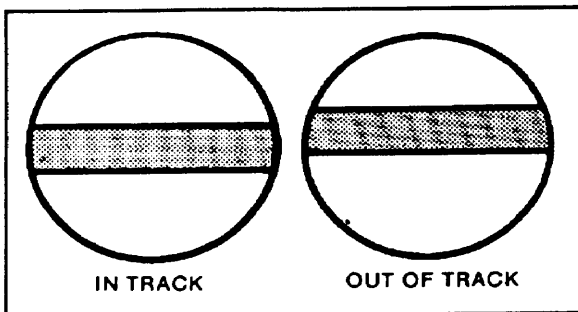


Figure 4-5. Reflector blade tracking — example



- Blade tip targets.
- Magnetic phase pickup.
- Pickup plates.

A concentrated parallel light beam from the strobe light is manually directed toward a predetermined spot on the rotor blade disc to strike the blade tip targets. The strobe light trigger switch is then depressed to allow strobing of the blade tip targets. The pulse signal for strobe effect is provided by the magnetic pickup unit mounted on the stationary swash plate ring. This strobe effect sends a pulse each time one of the pickup plates passes over the magnetic pickup unit. The pickup is mounted on each rotor blade pitch-change link lower attaching bolt. The strobe light targets are attached to the blade tips with patterns facing inboard. The targets have silver reflective tape with an identifying pattern for each blade (a straight line pattern on the red blade, a right-slanting pattern on the yellow blade, a left-slanting pattern on the green blade). When the single line of the master blade target is aligned axially with the centerline of the other blade targets, the system is in track. If one target image is displayed

vertically relative to the others, the colored lines of the affected blade target will become visible to the operator. Refer to Figure 4-6 for an example.

### VIBREX BALANCING KIT

The Vibrex balancing kit (hereinafter referred to as Vibrex) is used to measure and indicate the level of vibrations induced by the main and tail rotors of a helicopter. The Vibrex analyzes the vibration induced by out-of-track or out-of-balance rotors. Then by plotting vibration amplitude and clock angle on a chart, it determines the amount and location of rotor track or weight changes. The Vibrex is also used in troubleshooting to measure the RPM or frequency of unknown disturbances. DA Pam 738-751 prescribes forms, records, and reports to be used by maintenance personnel at all levels.

The Vibrex is housed in a carrying case; it consists of the components detailed in Figure 4-7. The main units of the Vibrex are the Balancer/Phazor, 177M6A; the Strobex tracker, 135M11; and the Vibrex tester 11. Three accelerometers, 4177B, and two magnetic pickups, 303AN, are the primary airframe-mounted components.

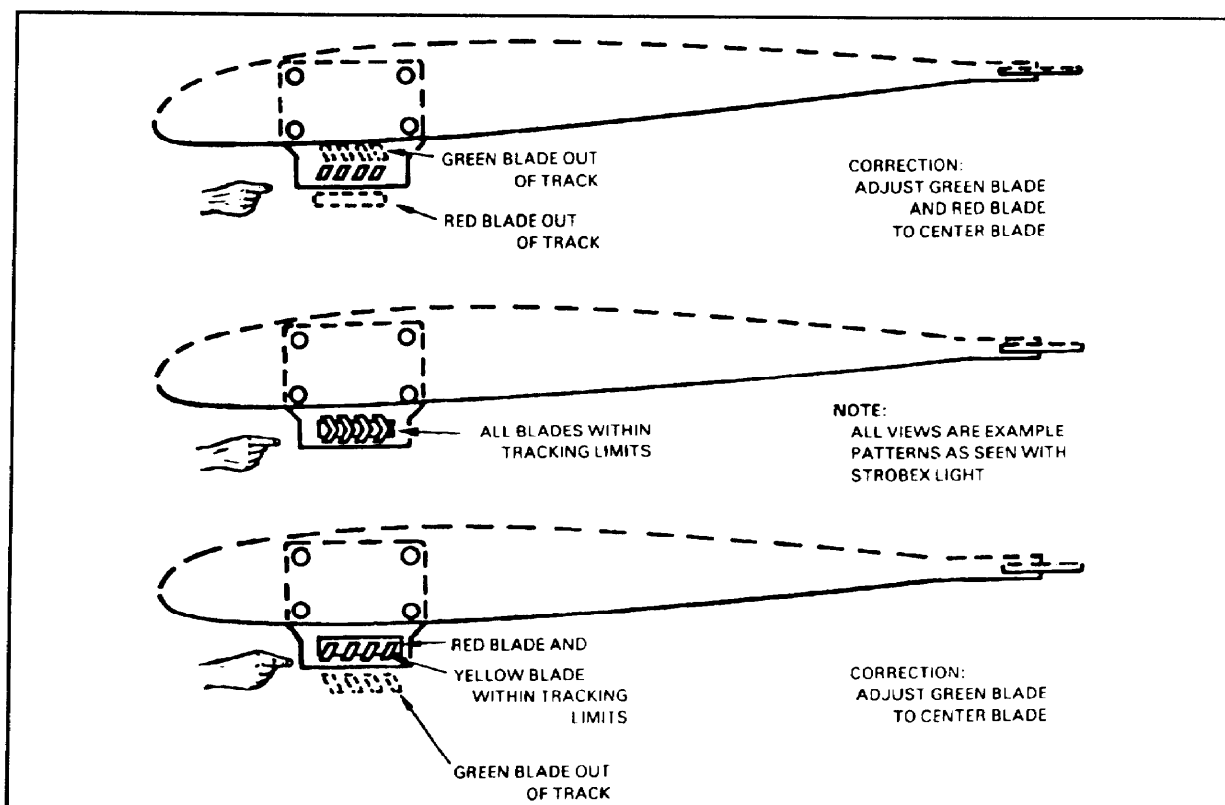


Figure 4-6. Strobe light blade tracking – example

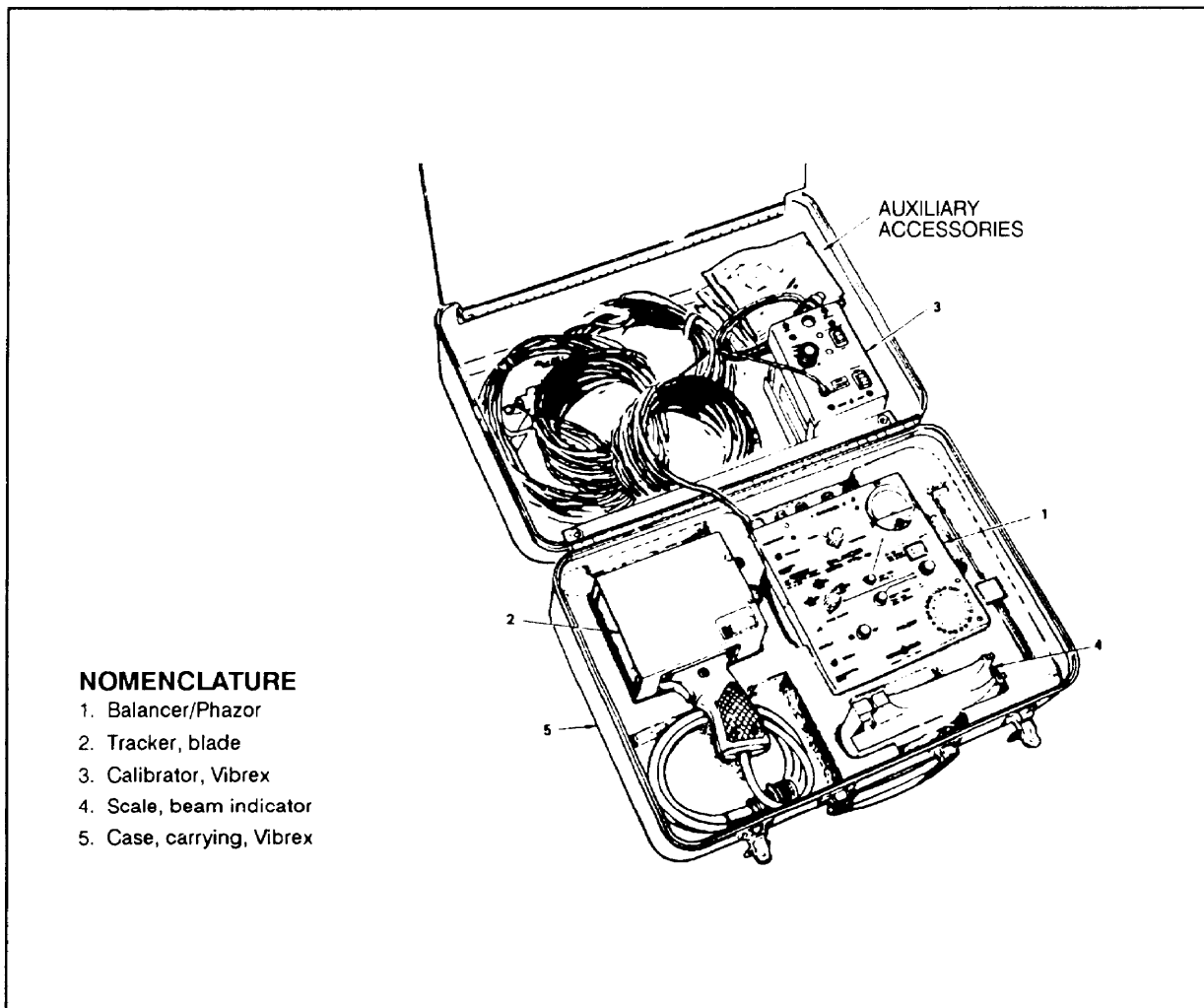


Figure 4-7. Vibrex balancing kit components

**CAUTION**

Use extreme care when operating the Vibrex test set. The unit contains delicate electronic components and assemblies that may easily be damaged if subjected to improper handling or physical abuse.

**Balancer/Phazor, 177M6A**

The key feature of the Balancer/Phazor (hereinafter referred to as a balancer) is a tunable, electronic hand-pass filter which is tuned to reject all but the one frequency or vibration under study (Figure 4-8). The meter reads the level of vibration at the rate (RPM) of concern, which indicates the amount of the required change (track or balance). The Phazor

section contains a phase meter that reads clock angle, or phase angle, between a one-per-revolution magnetic pickup azimuth signal from the rotor and a vibration signal from the accelerometer.

**Strobex Tracker, 135M11**

The Strobex tracker (hereinafter referred to as a Strobex) is a small hand-held, lightweight, combination power supply and strobe flash tube (Figure 4-9). It illuminates reflective targets on the tail rotor to measure tail rotor clock angle and on the main rotor to indicate rotor track and lead-lag.

**Vibrex Tester 11**

The Vibrex tester (hereinafter referred to as a tester) provides accurate calibration and a complete functional check of the Vibrex (Figure 4-10). The tester

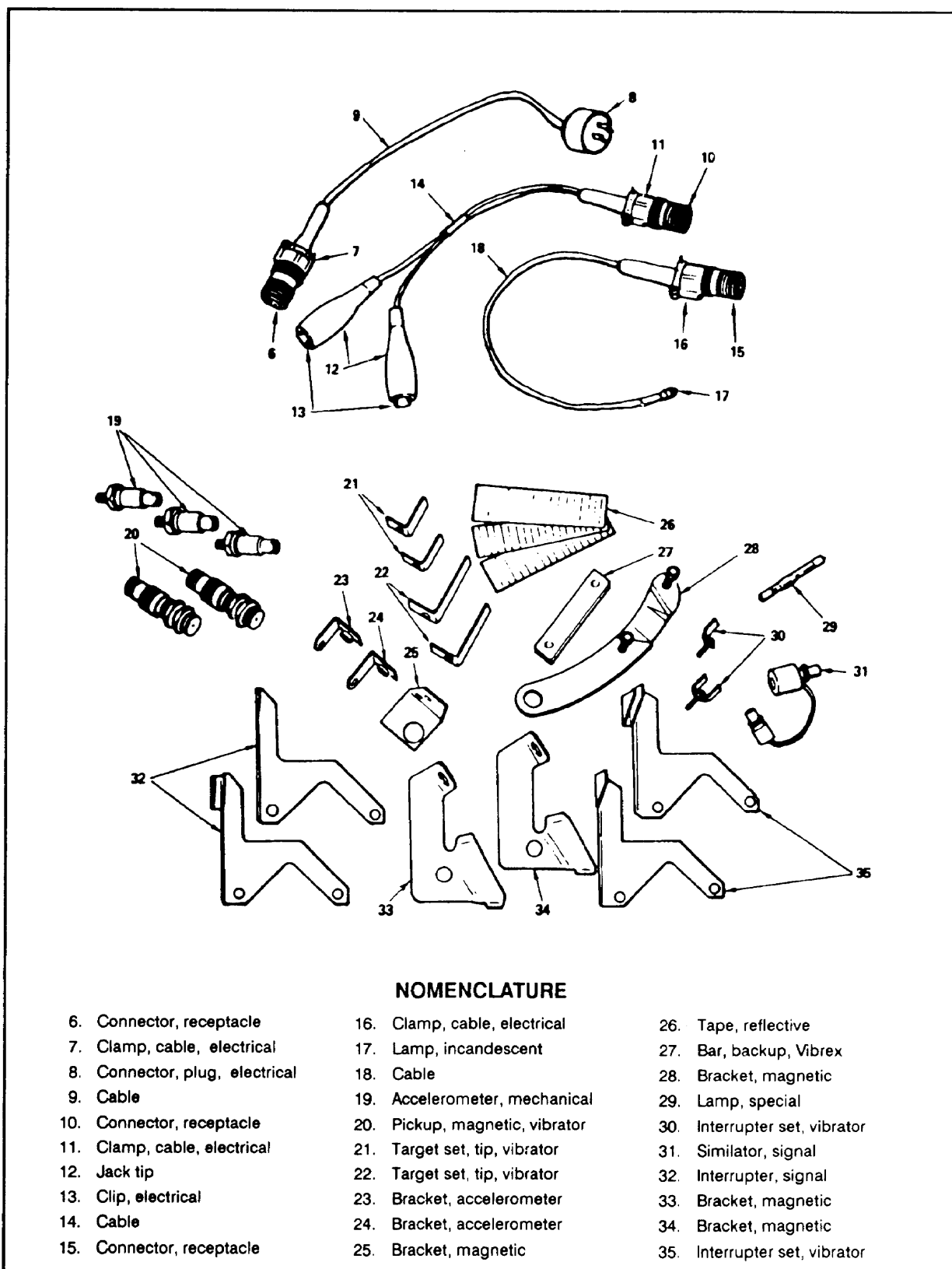


Figure 4-7. Vibrex balancing kit components (continued)

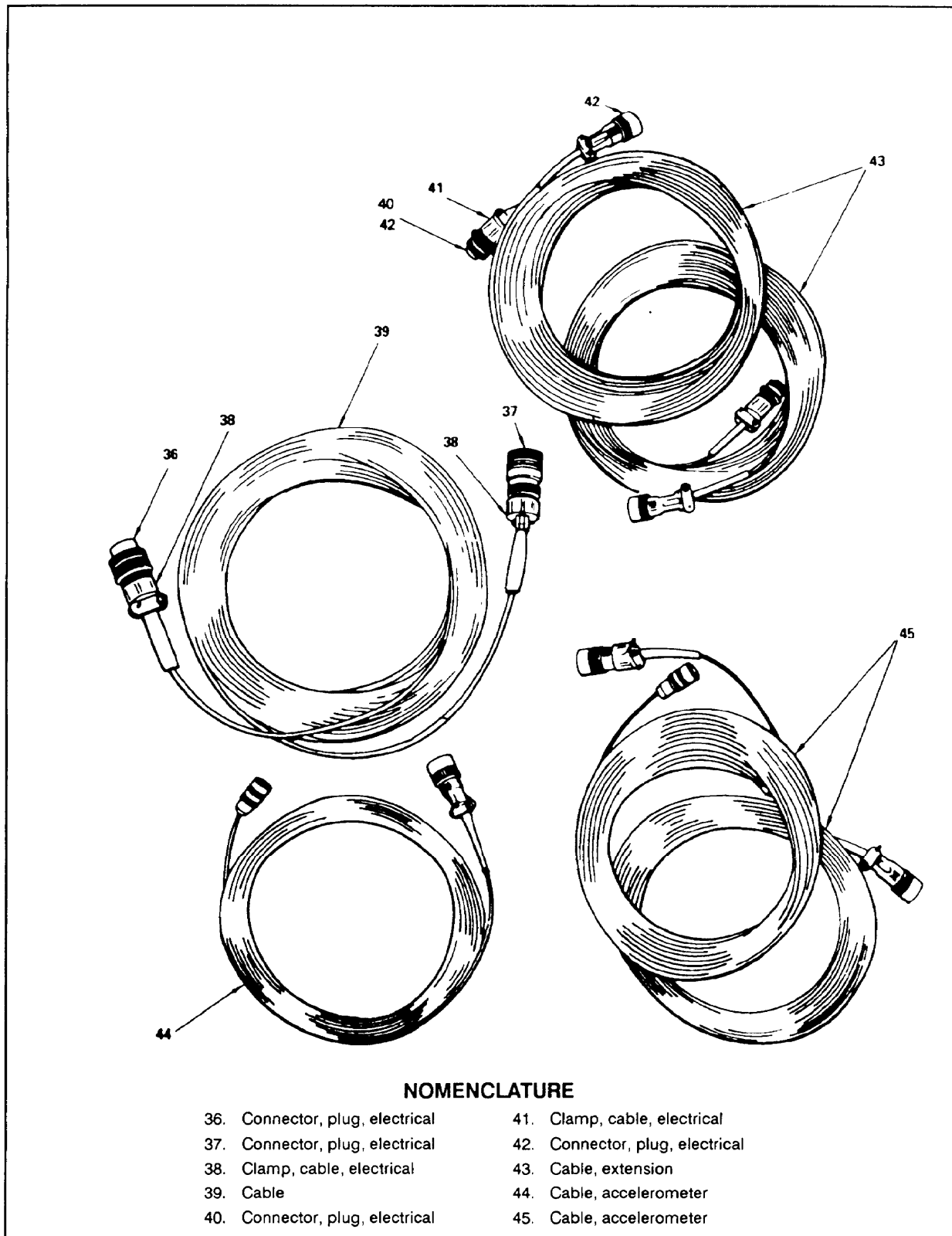


Figure 4-7. Vibrex balancing kit components (continued)

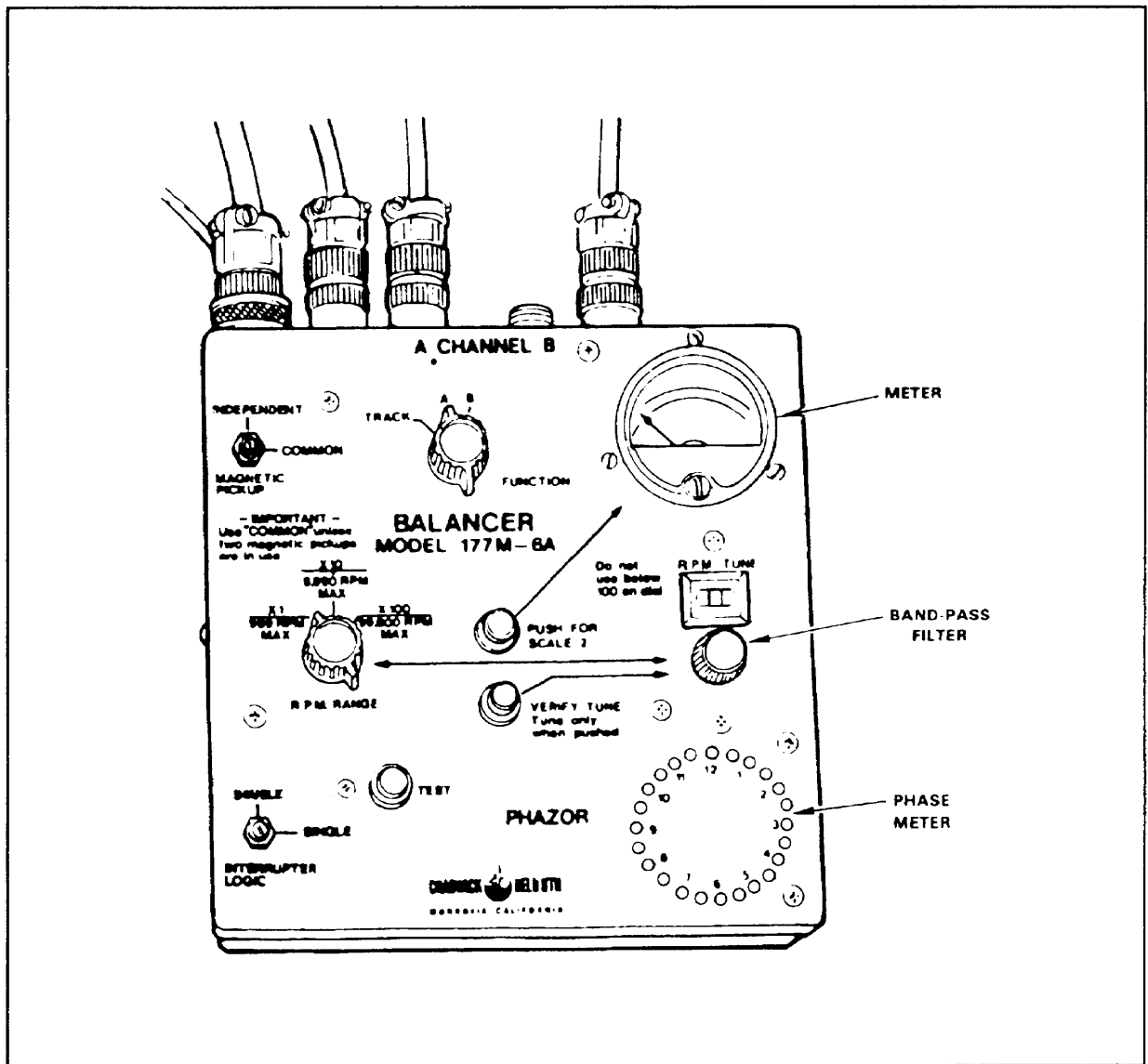


Figure 4-8. Balancer/phazor, 177M6A

shakes (vibrates) the accelerometer to measure vibration amplitude in inches per second (IPS) and rate (RPM) functions of the balancer. Phase or clock angle functions of the Phazor section are verified by a rotating interrupter plate and the magnetic pickup to provide double and single interrupter logic signals. The RPM dial of the Strobex is accurately checked against the known rotor speed of the tester motor.

#### Accessories

Following is a list of accessories that are used with the balancer, Strobex, and tester:

- Magnetic pickups and interrupter sets. These devices provide magnetic impulses from rotor to balancer. Magnetic pickups are located on stationary platforms; interrupter sets are located on rotating platforms.
- Accelerometers. Accelerometers provide the balancer with an electrical representation of the physical motion of the point to which it is attached.
- Reflective and tip target sets. These sets reflect Strobex flash pulses back to the Strobex operator.

## FM 1-514

- Balancer and tracking charts. These charts are used to calculate weight, sweep, pitch link, tab, and so forth to correct rotor problems.

**NOTE:** For further information on how to use the Vibrex, refer to TM 55-4920-402-13&P.

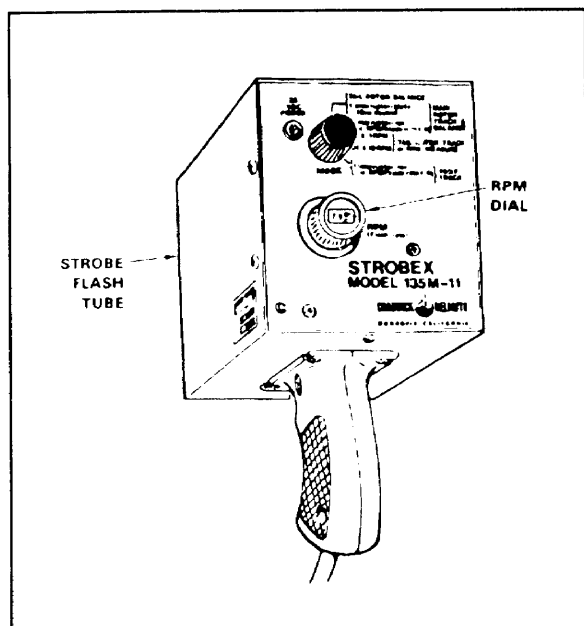


Figure 4-9. Strobex tracker, 135M11

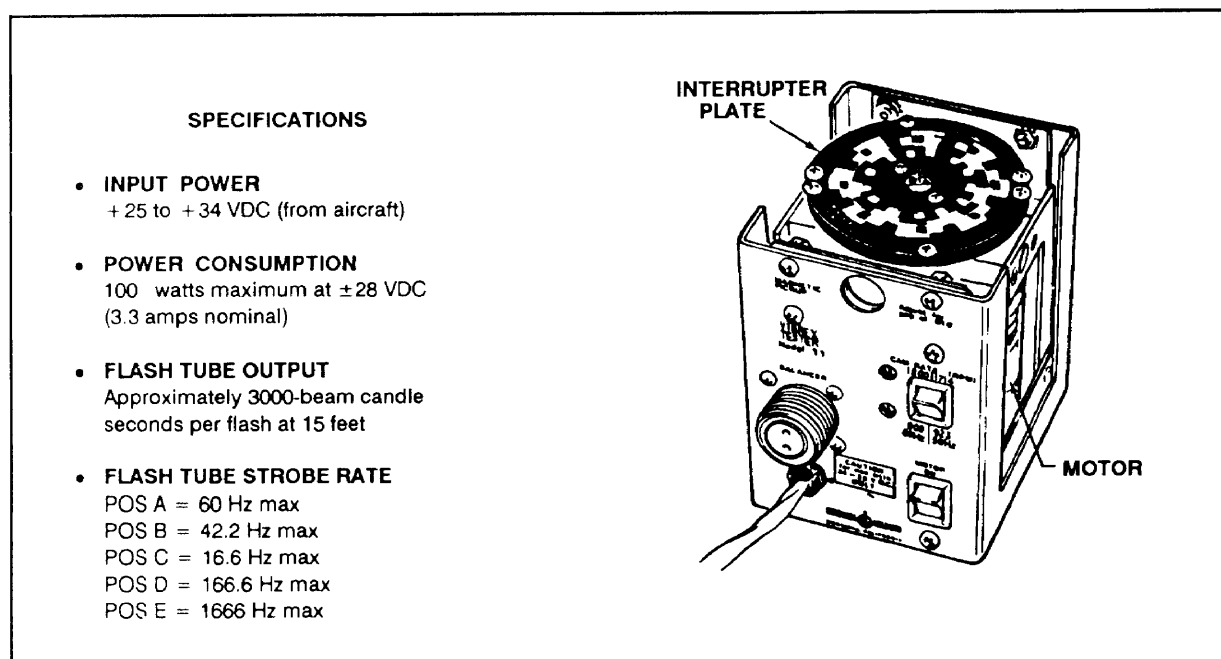
## PRESERVATION

Preservation is the term used for protection of equipment against deterioration due to exposure to atmospheric conditions during storage and shipment. The following items are needed for preservation:

- Mild soap and water.
- Solvent – PD-680.
- Moisture-absorbent cloth or filtered compressed air.
- Corrosion-preventive compound (CPC).
- Greaseproof paper.
- Desiccant bags.
- Padded contours (jute felt).
- Historical records.
- Parking and stenciling materials.

### Temporary Preservation and Storage

When rotor blades are removed from an aircraft and stored for any length of time, they must be properly preserved to remain in serviceable condition. Preservation procedures are the same for all rotor blades in the Army inventory. After the blades have been removed from the aircraft, clean painted surfaces with mild soap and water and unpainted surfaces with solvent, PD-680. Never use solvent on painted blade surfaces because it can



### SPECIFICATIONS

- **INPUT POWER**  
+25 to +34 VDC (from aircraft)
- **POWER CONSUMPTION**  
100 watts maximum at  $\pm 28$  VDC  
(3.3 amps nominal)
- **FLASH TUBE OUTPUT**  
Approximately 3000-beam candle  
seconds per flash at 15 feet
- **FLASH TUBE STROBE RATE**  
POS A = 60 Hz max  
POS B = 42.2 Hz max  
POS C = 16.6 Hz max  
POS D = 166.6 Hz max  
POS E = 1666 Hz max

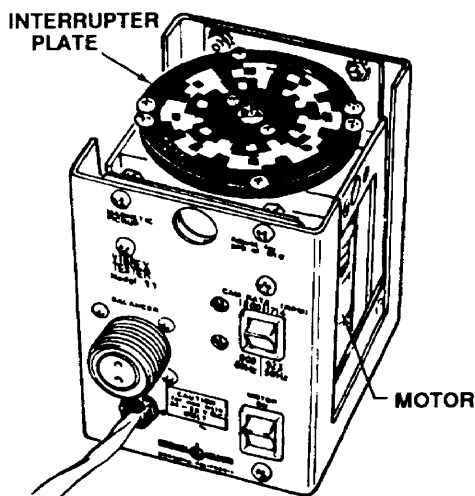


Figure 4-10. Vibrex tester

loosen the bonding. After cleaning dry rotor blades with a moisture-absorbent cloth or filtered compressed air, make sure all surfaces and contours are completely dry. Then apply a corrosion-preventive compound to the blades. CPC is a liquid; it should be spread only on the machined surfaces and only with a brush. Be careful to include the inside of all retention bolt holes. The painted surfaces should not be coated. If the blades are to be stored for no longer than 3 months, they may be placed in a slotted rack. Periodic inspection of stored blades is essential to prevent corrosion of machined surfaces and to keep painted surfaces clean. Blades are stored in slots with the leading edge down and the trailing edge up.

### **Shipment and Long-Term Storage**

When preparing a rotor blade for immediate shipment or long-term storage, use the procedures explained above to first clean, dry, and process it. Then prepare the blade for shipment in a container. Metal containers are used Armywide for shipment and storage of rotor blades.

After preserving the blade with a CPC, wrap the blade, sockets, cuffs, retention plates, and machined surfaces with greaseproof paper and tape them. This further protects the blade at these areas from moisture, condensation, and wear during shipment.

Place a bag of desiccant inside the container to aid in dehumidifying the interior. The desiccant (silica

gel) absorbs moisture. Jute felt padding comes with blade containers from the manufacturer. The padding is a plant fiber made to the shape of the blade and used to support the blade at different points along its span. Place the blade in the container with the jute felt padding supporting it.

Main rotor blades are secured inside containers at the root ends by either of two methods: by bolting a cuff fixture to the blade and its container wall, or by welding along bolt at one end of the container, which protrudes through the retention bolt holes and is secured with a nut.

Place the lid on the container and secure it. Make sure that the outside of the container is stenciled with the sender, receiver, and serial number of item being shipped. Remove the container's old serial number. A new center-of-balance line should also be stenciled on at this time.

Use DA Form 2402 (Exchange Tag) and DA Form 2410 (Component Removal and Repair/Overhaul Record) to ship rotor blades. Prepare two copies of DA Form 2402. Tie one to the item being shipped. Tape one on the outside of the shipping container or place it in the cylinder, which is used for historical records. Complete one copy of DA Form 2410 and place it in the cylinder. If blades are to be stored, the containers can be stacked on top of each other in a warehouse. Check stored blades periodically for corrosion and for forms required by TM 55-1500-344-23.



## CHAPTER 5

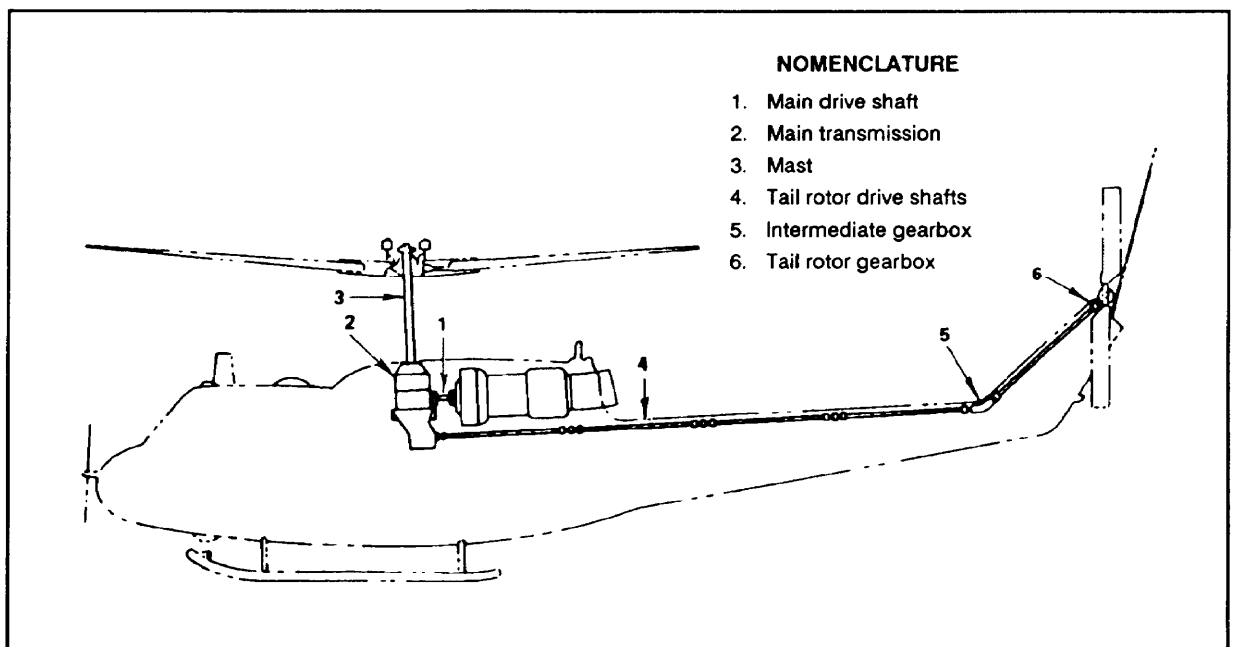
## SINGLE-ROTOR POWER TRAIN SYSTEM

A typical single-rotor power train system (Figure 5-1) consists of a main transmission (main gearbox), a main drive shaft, and a series of tail rotor drive shafts with two gearboxes. The main transmission includes input drive with freewheeling provisions if no clutch assembly is required, output drive, and main rotor mast. The main drive shaft between the engine and main transmission drives the main transmission. A series of tail rotor drive shafts with two gearboxes (transmissions) – intermediate and tail rotor – between the main transmission and tail rotor drive the tail rotor.

transmission input drive on the other end. The clutch assembly provides freewheeling (Figure 5-3). On systems not requiring a clutch assembly, the shaft is attached to an adapter on the engine output shaft on one end and to the freewheel coupling of the transmission input drive assembly on the other end.

**Clutch Assembly**

The clutch assembly allows for a smooth engagement of the engine to the power train system. The clutch is used to stop possible blade damage and shaft shearing due to sudden torque loading. Some



**Figure 5-1. Typical single-rotor power train system**

**MAIN DRIVE SHAFT**

The main drive shaft (Figure 5-2) transmits torque from the engine to the main transmission. The shaft is a hollow, statically balanced tube. In addition to required fittings, bolts, nuts, and washers are provided with flexible splined or rubber couplings for installation between the engine and transmission. On systems using a clutch assembly, the main shaft is attached to the clutch on one end and to the

clutches are designed to let the engine start and run without the rotor turning. This is very useful for warm-up and maintenance procedures. Due to the free power system in all gas turbine engines used by the Army, a clutch assembly is not needed on aircraft with gas turbine engines.

The centrifugal clutch assembly is used only with engines of low horsepower output. When the engine speed is increased, centrifugal force throws the



## FM 1-514

clutch shoe against the inner surface of a drum, completing the drive to the rotor. This type of clutch, because of its slippage at low and medium speeds, generates heat, which is harmful to the life of clutch parts.

### Freewheeling Unit

All rotary-wing aircraft have a freewheel unit located between the engine and the main rotor or rotors. Three basic types of freewheel units are roller, sprag clutch, and overrunning clutch. The purpose of the

freewheel unit is to free the power train drive system from the drag made by the dead or idling engine. By doing this the freewheel unit makes autorotation possible. This allows an aircraft to land safely without engine power. All types of freewheel units generally work in the same manner. They provide a positive lock of the power train drive system to the engine at any time engine speed equals rotor speed. When rotor speed is faster than engine speed, the freewheel unit unlocks the power train drive system from the engine.

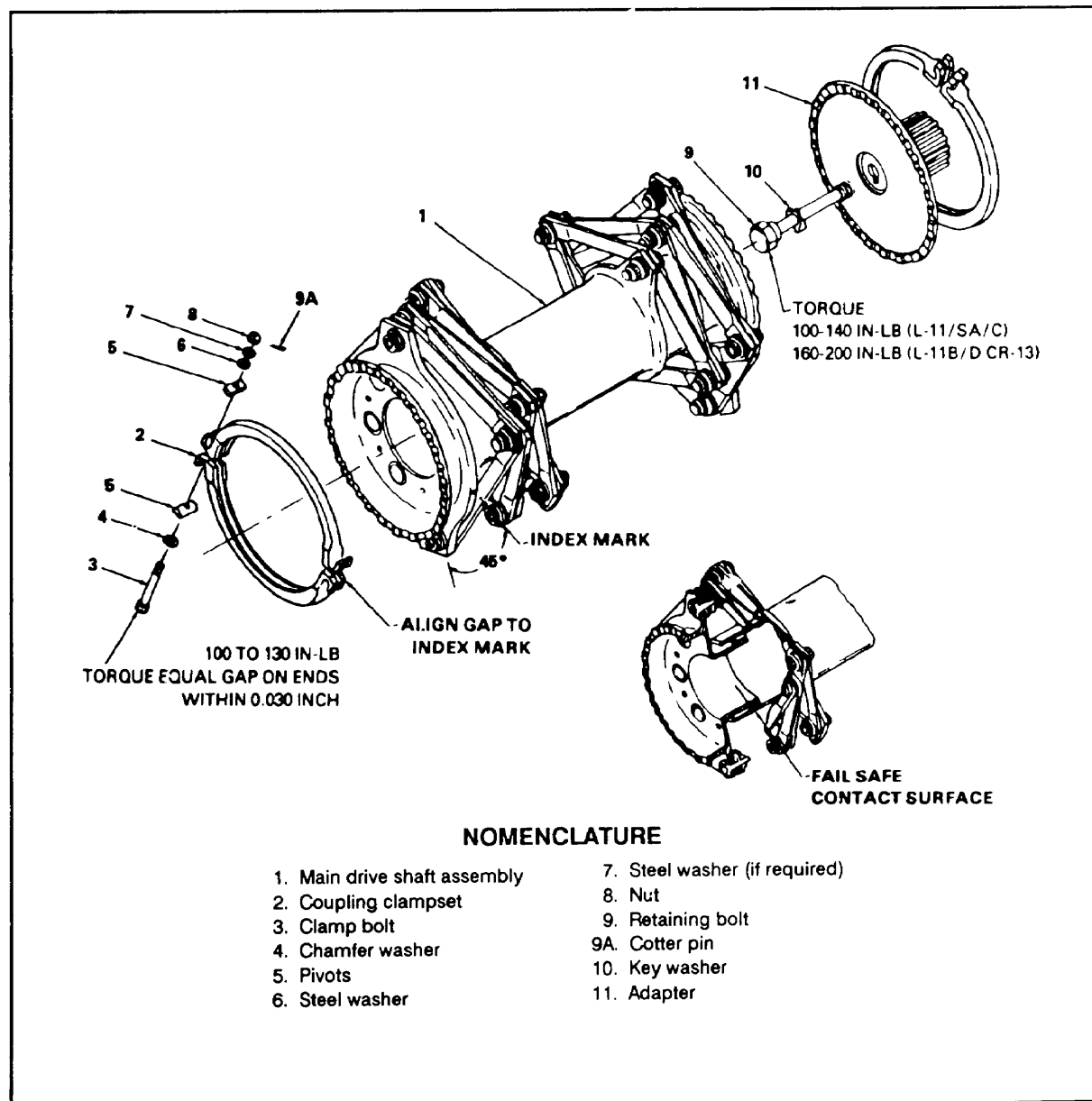


Figure 5-2. UH-1 main drive shaft, SKCP2281

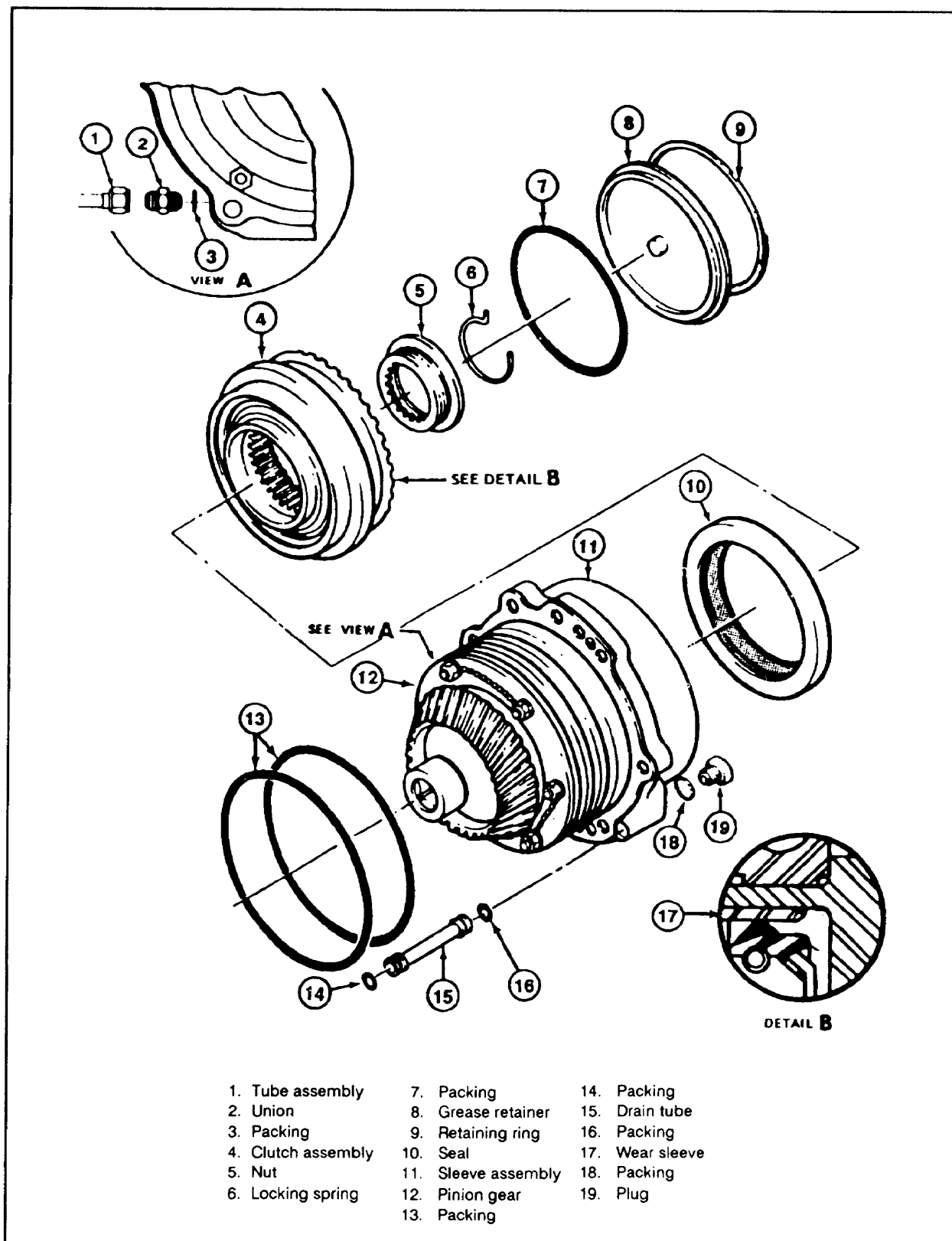


Figure 5-3. Centrifugal clutch assembly

## MAIN TRANSMISSION

A typical main transmission performs a number of functions (Figure 5-4). It—

- Drives the main rotor mast assembly.
- Changes the angle of drive from the engine to the main motor assembly.
- Provides RPM reduction through a train of spiral bevel gears and planetary gears.
- Provides a means of driving the tail rotor and the transmission accessories.
- Supports the main rotor assembly.

The main transmission is mounted in a variety of ways according to a particular manufacturer's design. Some transmissions contain a support case. The case is an integral part of the transmission mounted directly to the transmission deck. The transmission may be secured to the transmission deck by a system of tubular support assemblies. In one power train system, the transmission is secured to the main rotor mast support structure. In the power train system of a reciprocating-engine-powered, observation-type helicopter where neither shafting from engine to transmission nor drive angle change is necessary, the main transmission is mounted directly on the engine.

### Input Drive

Engine torque is transmitted through the main drive shaft to the input drive, which drives the main transmission gear trains. On systems not using a clutch assembly, a freewheel coupling is provided in the input drive assembly, which automatically engages to allow the engine to drive the rotor or disengages the idling engine during autorotational descent. On dual-engine, single-rotor power train systems, the transmission has two input drive assemblies.

### Tail Rotor Drive

The tail rotor is mounted on the end of the main transmission and is driven by the accessory gear train. A flexible splined coupling provides a means of attaching the tail rotor drive shaft.

### Generator Drive

The generator drive is driven by the main transmission accessory gear train. The generator is driven off the main transmission so that, when the helicopter goes into autorotation and the engine is idling or stopped, enough electrical power will be left to operate instruments, radio, and electrical fuel pumps.

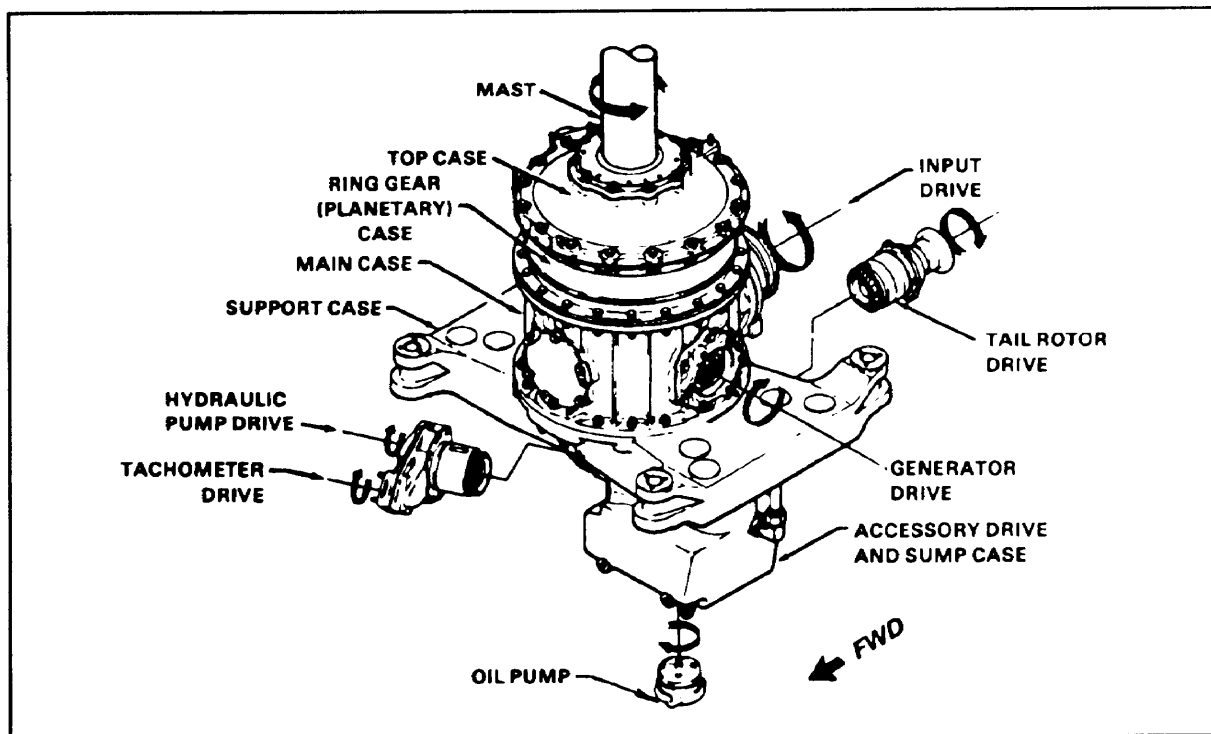


Figure 5-4. Typical main transmission

## Main Transmission Oil System

Most main transmissions are lubricated by a wet sump oil system which is separate from the engine oil system (Figure 5-5). However, the engine oil cooler and transmission oil cooler may be mounted close together so that they can use the same blower system to cool the oil. Oil supply from the transmission sump is circulated under pressure from a gear-driven pump through internal passages and a filter to the sump outlet. From this outlet external lines are routed to an oil cooler with a separate thermal bypass

valve, then to a manifold on the transmission main case. This manifold is equipped with a relief valve to regulate system pressure and distribute oil through jets and internal passages. This lubricates bearings and gears inside the transmission where the oil drains back to the sump.

Oil temperature and pressure gage readings are shown by a thermobulb and a pressure transmitter. Most transmission oil systems provide a heat switch and a pressure switch which will light caution lights on panels lettered XMSN OIL HOT and XMSN OIL

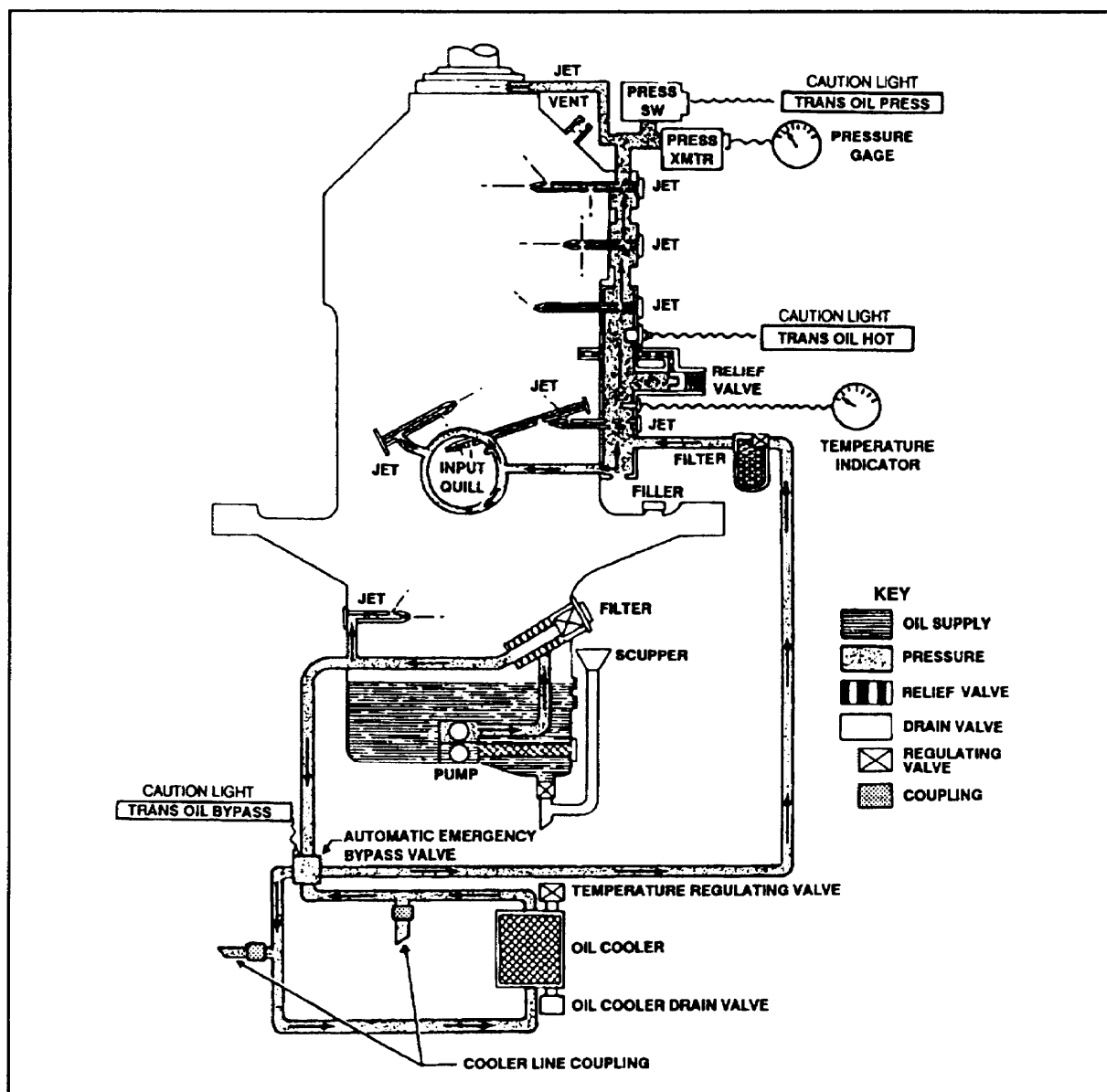


Figure 5-5. Typical main transmission oil system

## FM 1-514

PRESS (low pressure) if such conditions occur. Servicing and draining provisions are provided in the transmission oil system. Oil level sight gages are provided on most transmissions; others use the dipstick method. Chip detectors used in the transmission oil system are similar to those used on engines.

### Rotor Tachometer-Generator Drive

The rotor tachometer RPM indications are provided by the rotor tachometer-generator. The tachometer-generator drive is driven by the main transmission accessory gear train.

### Hydraulic Pump Drive

The hydraulic pump drive is driven by the main transmission accessory gear train. The hydraulic pump provides hydraulic pressure for the flight control servo system. Some helicopters use two separate flight control servo systems completely independent of each other. One system is the primary servo system; it gets hydraulic operating pressure from a hydraulic pump driven by the main transmission. A secondary servo system gets hydraulic operating pressure from a hydraulic pump driven by the engine.

### MAIN ROTOR MAST ASSEMBLY

The main rotor mast assembly is a tubular steel shaft fitted with two bearings which support it vertically in the transmission (Figure 5-6). Mast driving splints engage with transmission upper-stage planetary gear, providing counterclockwise rotation (viewed from above). The upper bearing retainer plate has an oil jet fed by an external oil hose. Splints on the upper portion of the mast provide mounting for main rotor arid control assemblies.

### TAIL ROTOR DRIVE SHAFT

The purpose of the tail rotor drive shaft is to transmit torque from the main transmission to the tail rotor gearbox (Figure 5-7). The shaft is made up of a series of hollow tubes with provisions for statically balancing and coupling attachments on each end. Flexibility in the shaft is provided by splined or rubber couplings. The tail rotor drive shaft is supported by a series of support bearings and support hanger assemblies.

### INTERMEDIATE GEARBOX

An intermediate gearbox is located on the tail boom of the helicopter (Figure 5-8). This gearbox provides

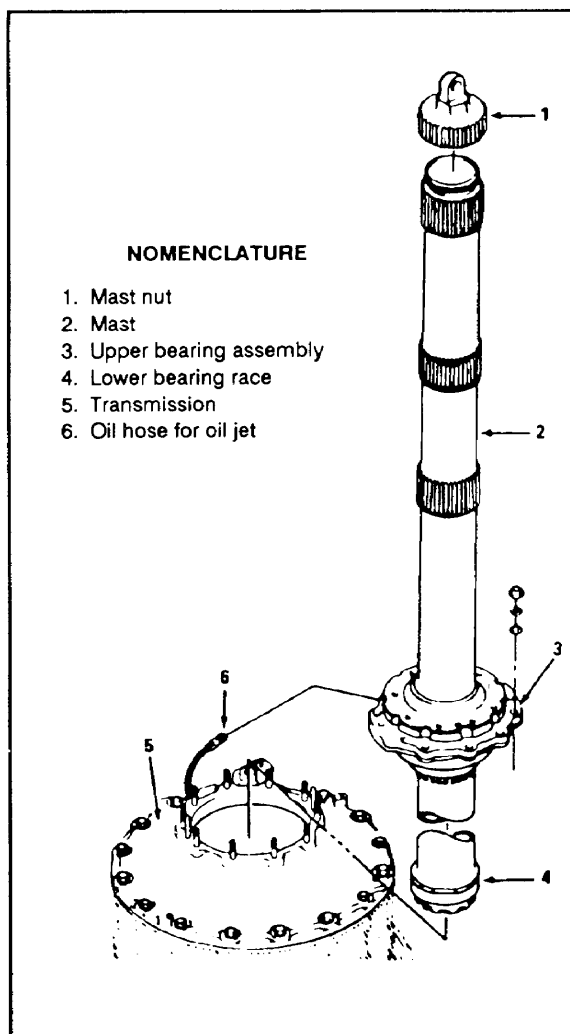


Figure 5-6. Typical main rotor mast assembly

a specific degree change in direction of the tail rotor drive shaft with no speed change. The gearbox assembly consists of a case with flexible coupling provisions for attaching onto the tail rotor shaft fore and aft. The gearbox is splash-lubricated, and the case is fitted with an oil filter cap, a vent breather, an oil level sight gage, and a drain plug equipped with a magnetic insert. The magnetic insert collects metal particles coming from inside the gearbox. When there is a requirement, the metal particles can be collected and analyzed to determine the condition of the gears and bearings in the gearbox.

### TAIL ROTOR GEARBOX

The tail rotor gearbox is located on the extreme aft end of the tail boom – in some cases on top of the tail

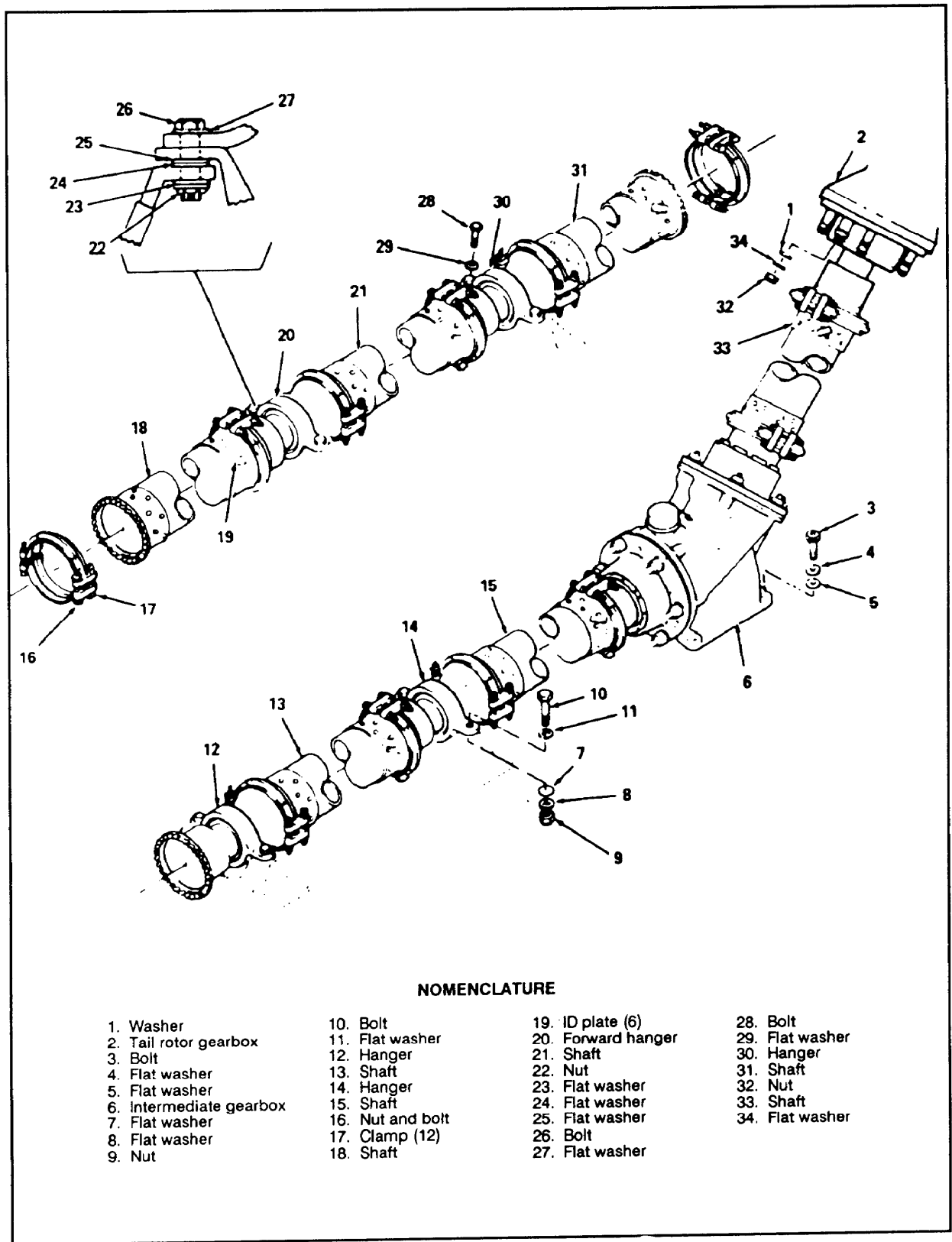


Figure 5-7. UH-1 tail rotor drive shaft



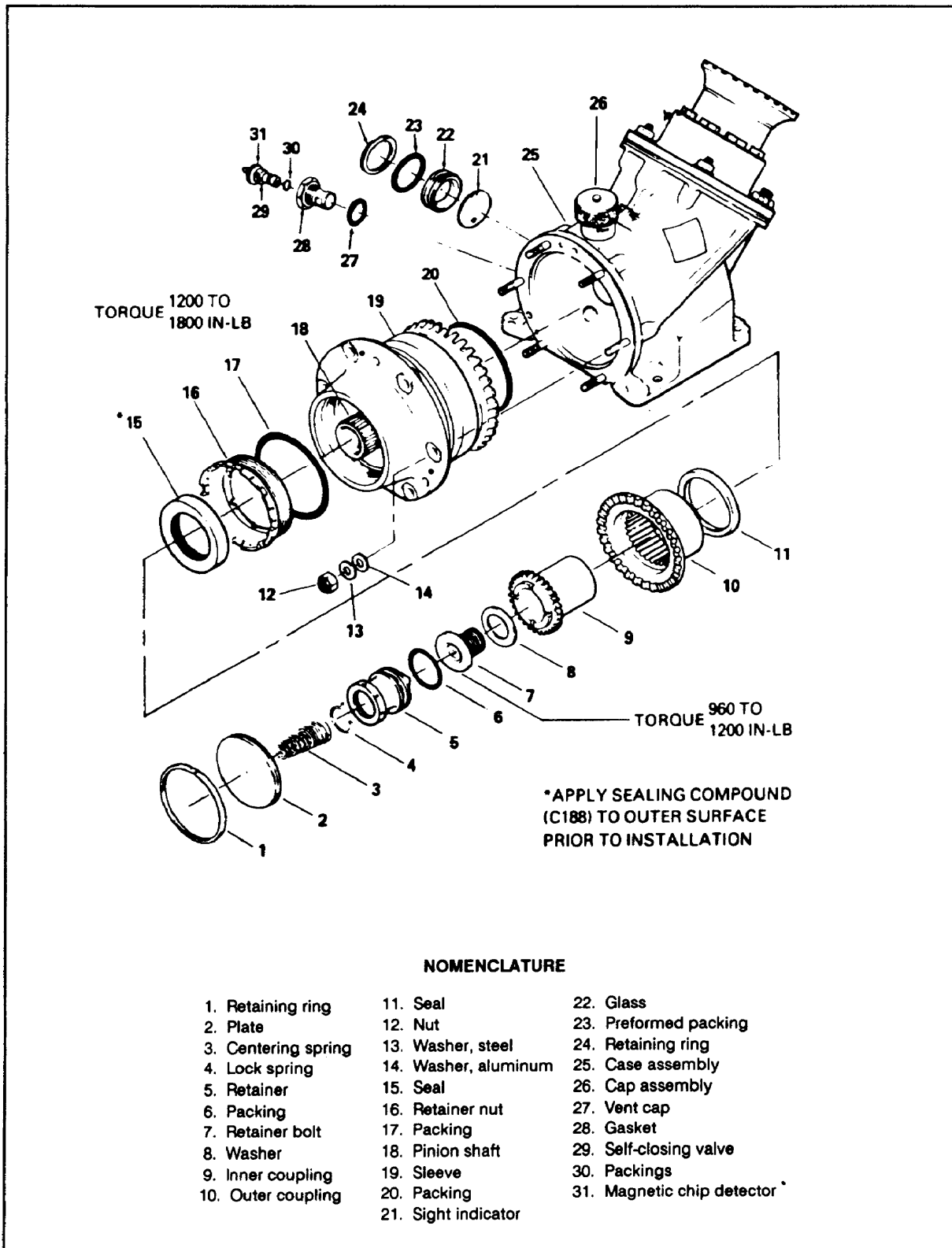


Figure 5-8. Intermediate gearbox (42°) (UH-1)

boom vertical fin (Figure 5-9). The gearbox is splash-lubricated. It consists of mating input and output gear assemblies set into a case provided with a vented oil filter cap, oil level sight gage, and a drain plug with a magnetic insert plug for collecting metal particles. By analyzing these metal particles, the condition of the gearbox gears and bearings can be determined. Flexible couplings are provided for attaching the tail rotor drive shaft onto the input end of the gearbox. The tail rotor gearbox provides a specific degree

change in tail rotor drive shaft direction and a specific speed reduction between input shaft and output shaft on which the tail rotor assembly is mounted.

#### CAUTION

**When troubleshooting or working on a specific single-rotor power train system or component, always refer to the applicable maintenance manual.**

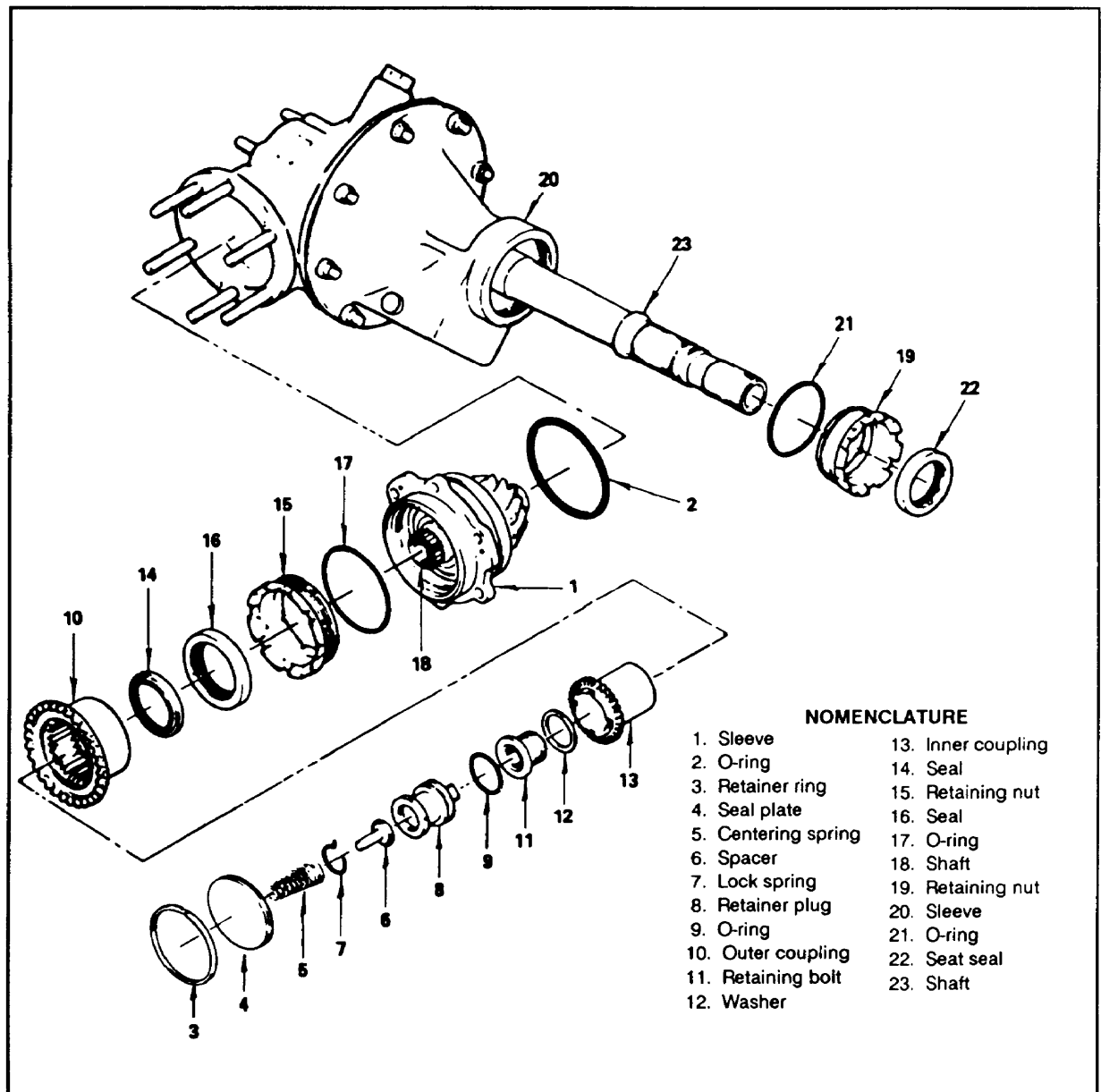


Figure 5-9. Tail rotor gearbox (90°) (UH-1)

## CHAPTER 6

## TANDEM-ROTOR POWER TRAIN SYSTEM

A typical tandem-rotor power train system consists of an engine transmission for each of the two engines and an engine-combining transmission (Figure 6-1). The system also includes a forward rotary-wing drive transmission (containing a rotary-wing drive shaft [mast]) and an aft rotary-wing drive transmission (containing a rotary-wing drive shaft [mast]). The drive shaft consists of an engine drive shaft assembly between each engine transmission and

the engine-combining transmission. This assembly is used by the engine to drive the engine-combining transmission. The drive shaft assembly also consists of a forward synchronizing drive shaft assembly through which the engine-combining transmission drives the forward rotary-wing drive transmission and an aft synchronizing drive shaft assembly through which the engine-combining transmission drives the aft rotary-wing drive transmission.

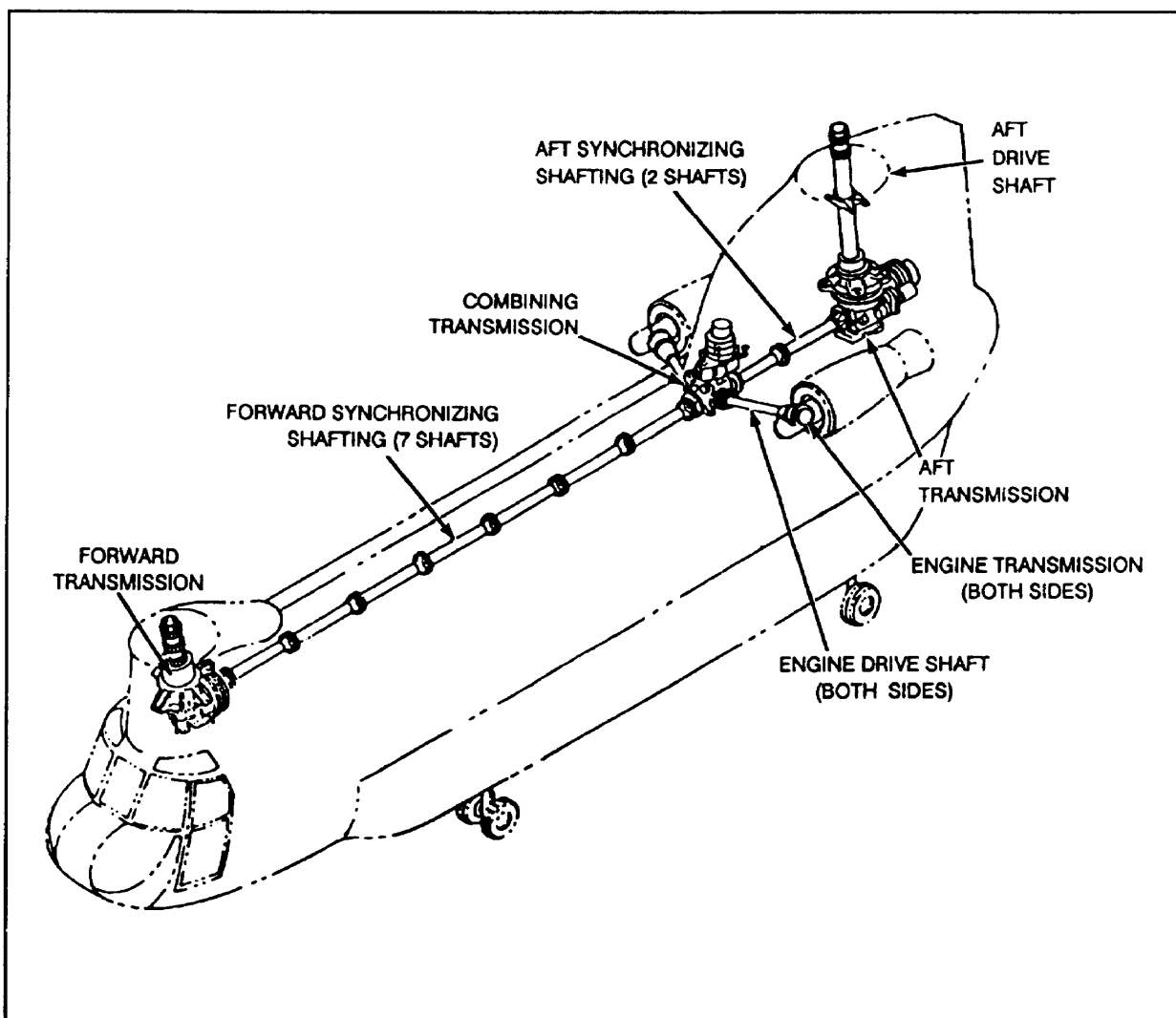


Figure 6-1. Tandem-rotor power train system

FM 1-514

## ENGINE TRANSMISSION

The two engine transmissions are identical assemblies. Minor rearrangement of transmission external parts provides interchangeability between right- and left-hand engine transmission installations. The transmissions are mounted directly on the engine being driven by the engine output shaft. The

transmissions provide angle of drive and RPM reduction in torque. Torque from the engine is transmitted by the engine transmission and engine drive shaft assembly to the engine-combining transmission. Freewheeling is provided in the output shaft of the engine transmissions. This permits the drive system to overrun the engine during failure, a sudden reduction of RPM, or autorotation. (See Figure 6-2.)

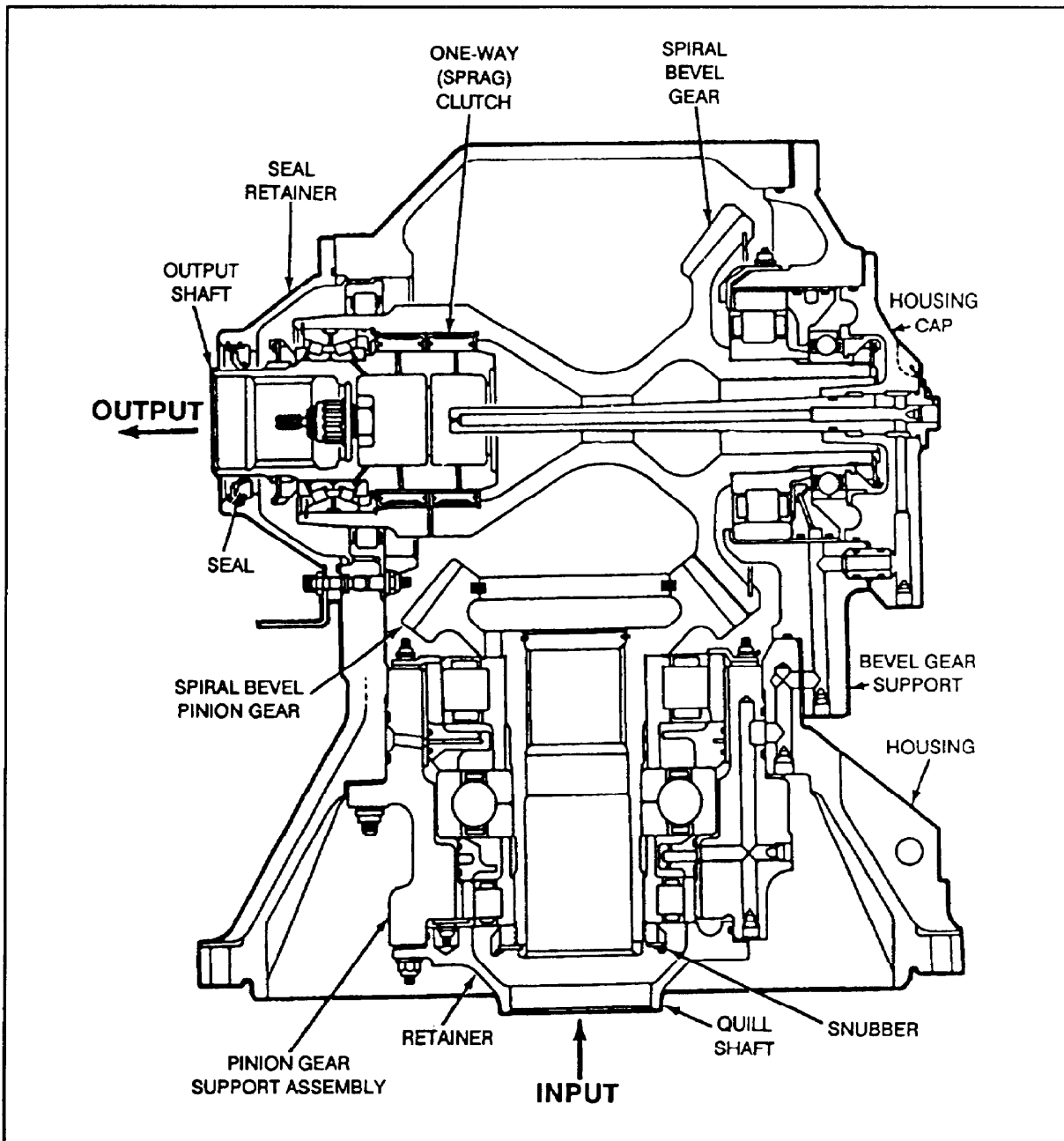


Figure 6-2. Sectional view of engine transmission

## Oil System Components

For each engine transmission there is a complete and separate oil system (Figure 6-3). The oil system is made up of the transmission sump, transmission lubrication jets, check valve, electrical chip detector, oil temperature transmitter (bulb), oil pump, oil pressure transmitter (transducer), filter and relief valve assembly, oil tank, and oil cooler. Although the oil systems of the engine transmission and engine-combining transmission are not interconnected, oil pressure and circulation for both types of transmissions are provided from a six-element oil pump mounted onto and driven by the engine-combining transmission.

the left-hand engine transmission, and one section for the engine-combining transmission. The oil filter and relief valve assembly for each of the engine transmissions and engine-combining transmission are mounted on the aft side of the oil tank. The oil cooler for the engine transmissions is mounted on top of the combining transmission. It receives cooling air from the fan assembly mounted on top of the combining transmission.

## Oil Circulation

Oil is circulated in each transmission lubrication system by two separate elements of the six-element lubrication pump in the combining transmission. Oil

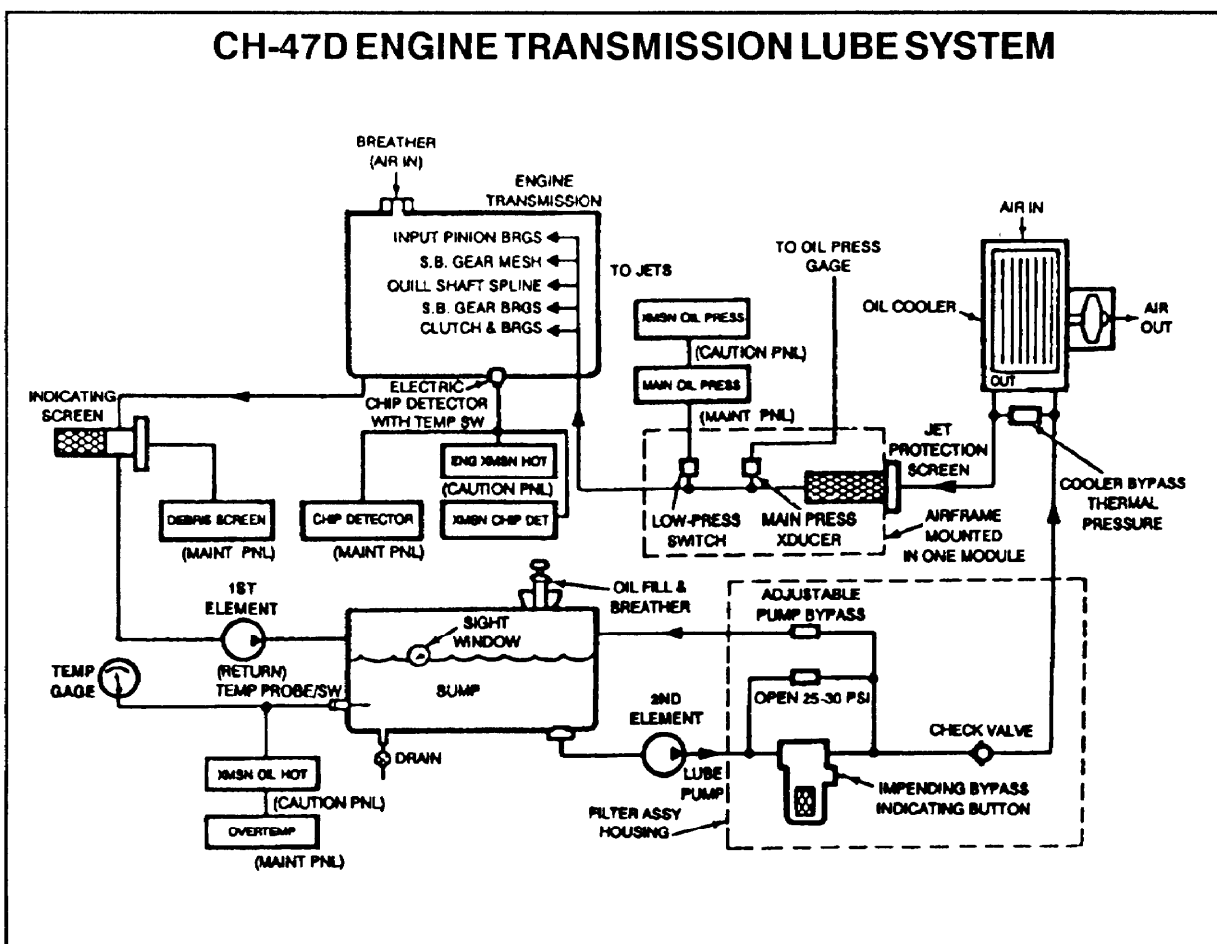


Figure 6-3. Engine transmission oil system

The engine-combining transmission is a three-section tank that is mounted onto and above the engine-combining transmission: one section for the right-hand engine transmission, one section for

flows from the oil tank through the pressure pump, through the filter and relief valve assembly, through the oil cooler, and through the check valve. Then the oil flows into the transmission where it is sprayed on

**FM 1-514**

the gears and bearings by various jets. Oil is scavenged from the sump by the scavenge section of the oil pump and returned to the oil tank.

**ENGINE-COMBINING TRANSMISSION**

The combining transmission is a central collection and distribution point for the drive system. The combining transmission is mounted in the lower forward section of the pylon. Torque from the engine transmission is transmitted by the combining transmission and the forward and aft synchronizing drive shafts to the forward and aft rotary-wing drive transmission. Speed reduction is also attained within the combining transmission. The output shaft drives the lubricated pump. The three-section oil tank (one section each for the combining transmission and each engine transmission) forms the uppermost portion of the combining transmission.

**Oil System Components**

The combining transmission oil system is a complete and separate oil system. The system includes the oil sump, oil temperature transmitter (bulb), oil pump, oil pressure transmitter (transducer), filter and relief valve, bypass valve, transmission lubricating jets, check valve, magnetic chip detector, oil tank, and oil coolers.

**NOTE:** The reservoir for the oil system is the center section of the three-section oil tank on the combining transmission. The three-section oil cooler and fan assembly is mounted on the top section of the transmission.

**Oil Circulation**

Oil is circulated by two separate elements: one pressure element and one scavenge element of the six-element oil pump in the combining transmission (Figures 6-4 and 6-5). Oil is routed from the oil tank through the filter and bypass valve and through an external line to the oil cooler. The oil is then routed by an external line through a check valve to the transmission. In the transmission oil is distributed through internal passages and jets and is sprayed on bearings and gears. Oil is scavenged from the sump through internal passages by the scavenge element of the oil pump. The pump then pumps the oil to the tank. A sight level gage is installed on the forward end of the oil tank.

**FORWARD ROTARY-WING DRIVE TRANSMISSION**

Torque is delivered to the forward rotary-wing drive transmission by the forward synchronizing drive shaft from the combining transmission (Figure 6-6). The forward rotary-wing transmission then changes the direction of torque from a horizontal plane to a vertical plane. This reduces the input shaft speed. The forward rotary-wing transmission transmits the torque through the rotary-wing drive shaft (mast) to the rotor head.

**Oil System Component**

The oil system serving the forward rotary-wing drive transmission is a complete, separate system. It is a wet-sump system, which includes the oil temperature transmitter (bulb), screens, oil pressure pump, oil pressure transmitter (transducer), relief valve, pressure filter, magnetic chip detector, oil cooler, and No. 1 flight control pump.

**Oil Circulation**

Oil from the sump flows through the screen to the inlet of the pressure pump. The pump pressurizes the system and pumps oil through the filter and cooler and then back to the transmission. Drilled and cored passages in the transmission distribute the oil to lubricators and oil jets. The lubricators and jets spray the oil into the transmission bearings and onto the rotating gears.

**AFT ROTARY-WING DRIVE TRANSMISSION**

Torque is delivered to the aft rotary-wing drive transmission by the aft synchronizing drive shaft from the combining transmission. The direction of torque changes from a horizontal plane to a vertical plane, and the aft rotary-wing transmission reduces input shaft speed (Figure 6-7). The aft rotary-wing transmission transmits the torque through the rotary-wing drive shaft (mast) to the rotor head. In addition to the reduction gearing, there are two accessory drive gears. One, driven by the input shaft, drives the transmission oil-cooling fan shaft and an oil scavenge pump. A second accessory gear drives the accessory gear section. The accessory gear section consists of gearing for driving the lubrication pump, one flight-control hydraulic pump, two AC generators, and a utility hydraulic pump. A one-way-drive clutch is united into one body in the accessory gear drive shaft for the accessory gear section. This type of clutch permits the accessory gears to overrun the



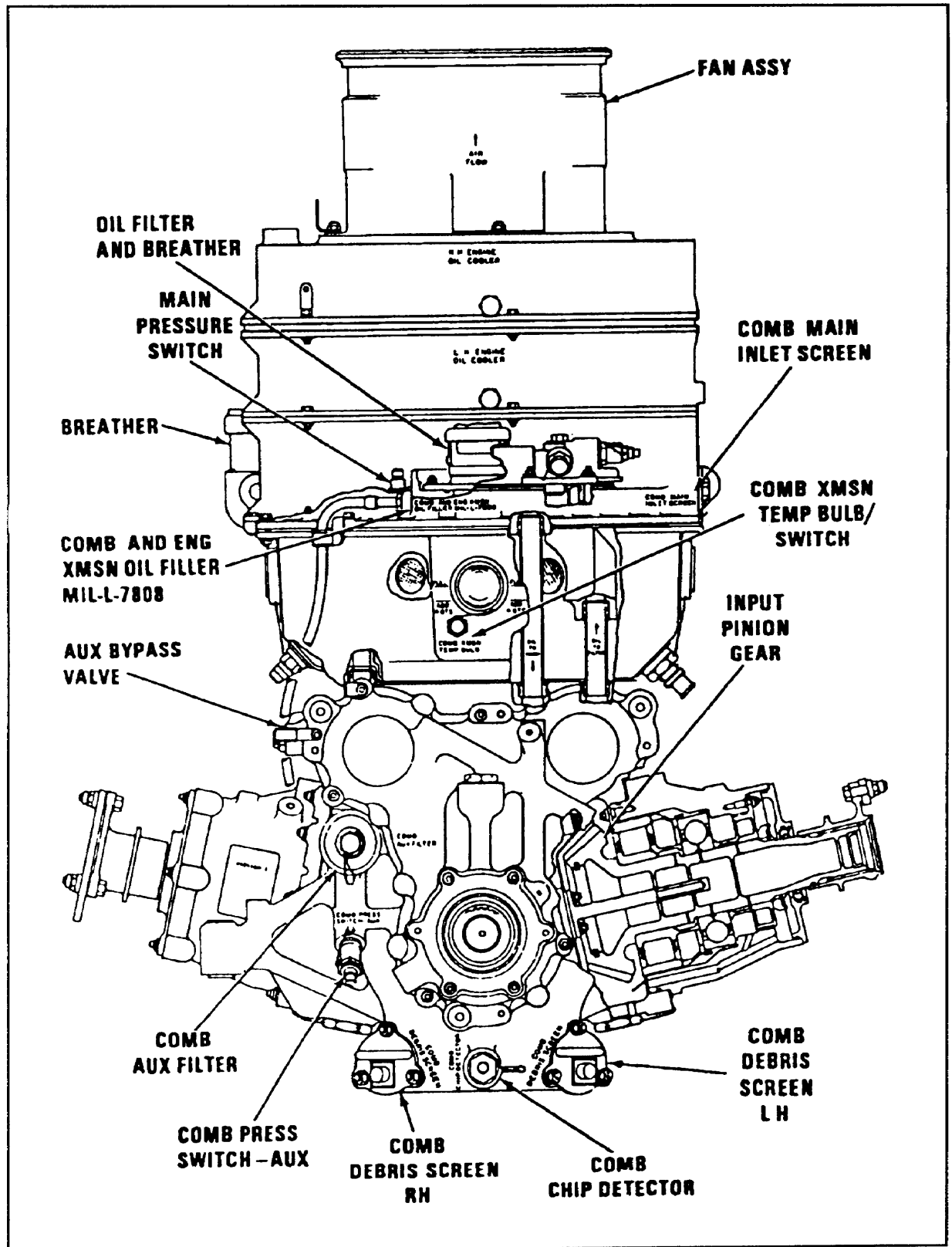


Figure 6-4. Combining transmission – sectional view

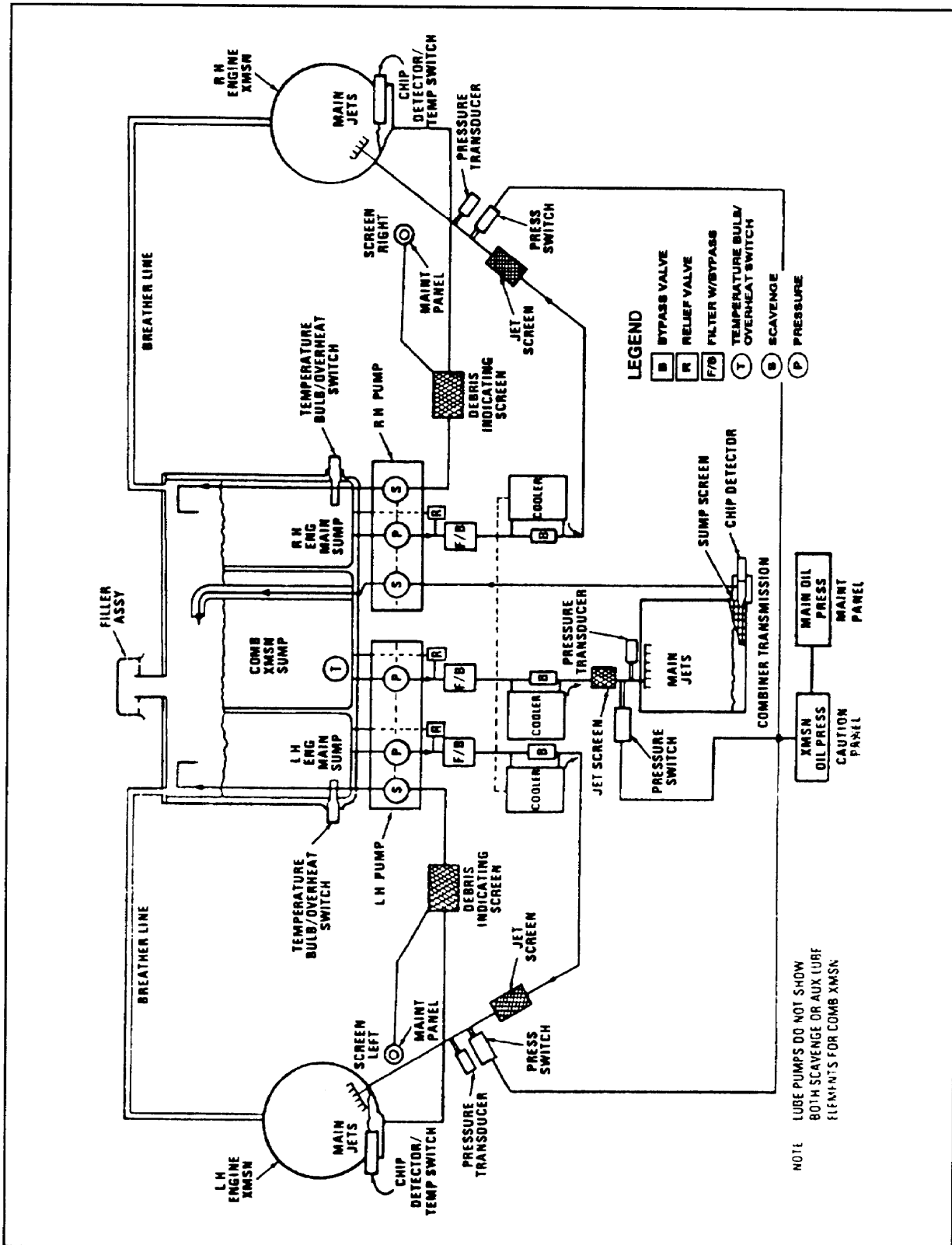
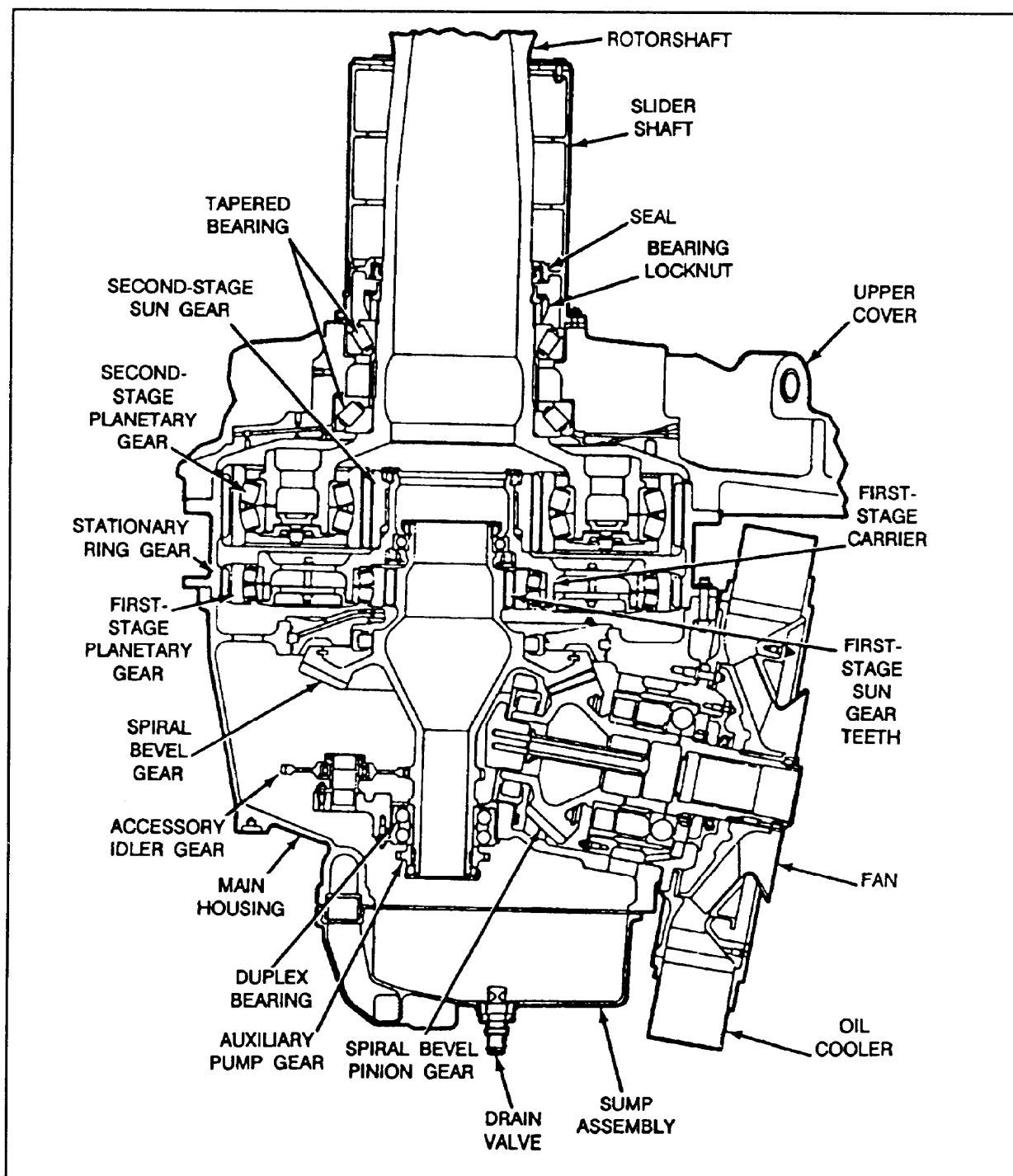


Figure 6-5. Combining transmission oil system – schematic diagram



**Figure 6-6. Sectional view of forward transmission**

transmission gears when the accessory gears are being driven by the hydraulic motor. In normal operation the accessory gears are driven by the bevel gear in the transmission through the clutch.

### Oil System Components

The oil system serving the aft rotary-wing drive transmission is a complete, separate system (Figure 6-8). It is a wet-sump system which includes

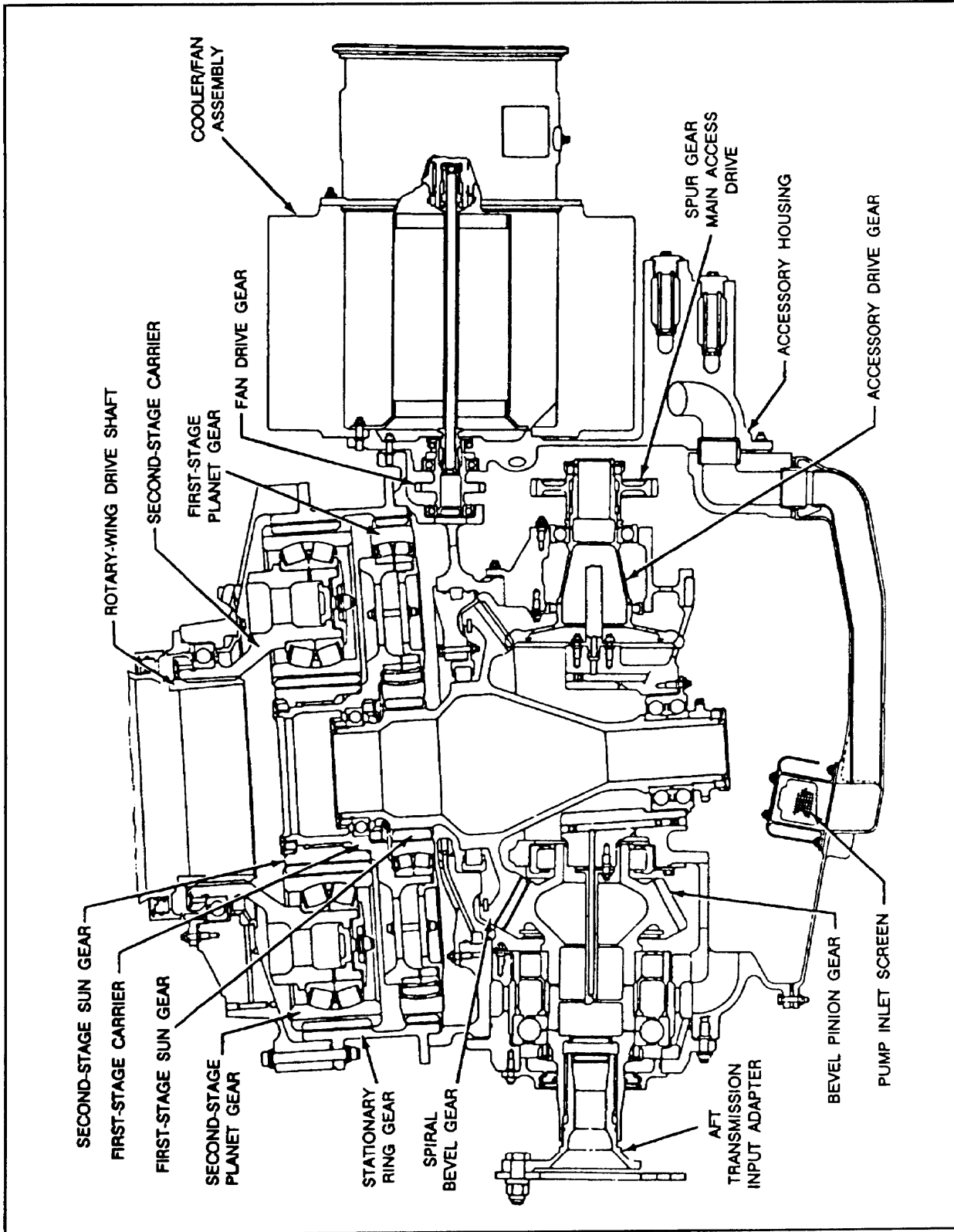


Figure 6-7. Sectional view of aft transmission

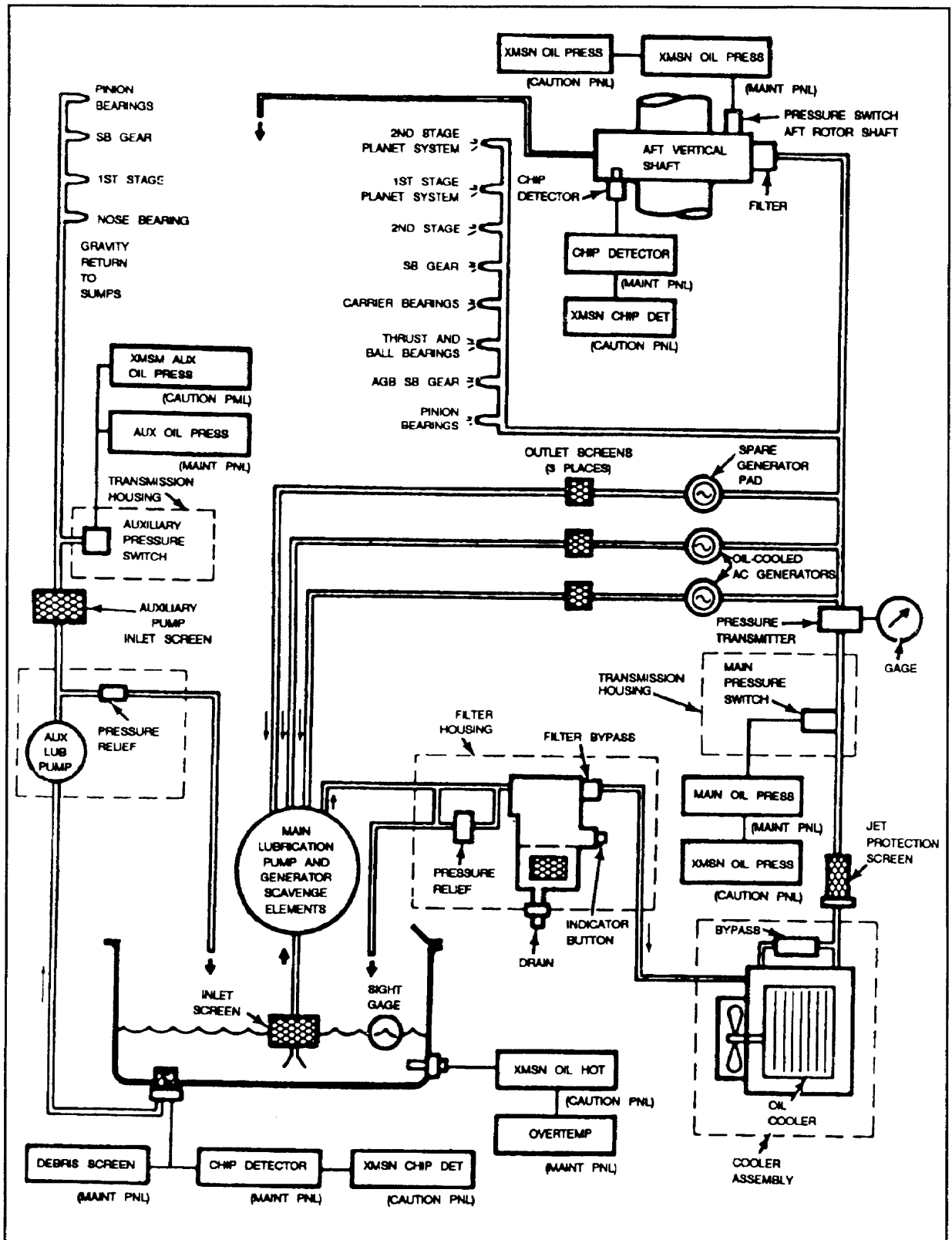


Figure 6-8. Aft transmission oil system – schematic diagram

## FM 1-514

the temperature transmitter (bulb), magnetic chip detector, screens, drain valve, oil level sight gage, oil pressure pump, oil pressure transmitter (transducer), relief valve, pressure filter, and oil cooler.

**NOTE:** The sump is the lower circular casting of the transmission. The fan drive shaft drives an oil scavenger pump in the fan drive housing. The pump returns scavenge oil which collects in the forward part of the transmission when the aircraft is in a nose-down attitude.

### Oil Circulation

Oil is drawn from the sump, through the screen to the inlet of the pressure pump. The pump pressurizes the system and pumps the oil through the filter and cooler and back to the transmission. Oil is supplied through external piping to the aft rotary-wing drive shaft (mast) thrust bearing. Drilled and cored passages in the transmission unit distribute oil to lubricators and jets. The lubricators and jets spray oil into the transmission bearings and onto the rotating gears. A scavenge pump in the fan drive housing

is driven by the fan drive shaft. The pump returns scavnged oil which collects in the forward part of the transmission when the aircraft is in a nose-down attitude.

## DRIVE SHAFTS

The purpose of drive shafting is to transmit torque from the engines to the transmissions and rotors. It also transmits torque to the fan assembly.

### Engine Drive Shaft

There are two engine drive shaft assemblies in each tandem-rotor power train system (Figure 6-9). The purpose of the engine drive shaft assembly is to transmit torque from each of the engine transmissions to the combining transmission. The shaft is a hollow, dynamically balanced tube. Each shaft is connected to the combining transmission and engine transmission by an adapter and plate assemblies, one on each end of the shaft. The adapter and plate assemblies provide flexibility in the shaft assembly.

### Forward Synchronizing Drive Shaft

The purpose of the forward synchronizing drive shaft is to transmit torque from the engine-combining transmission. It also keeps the forward and aft

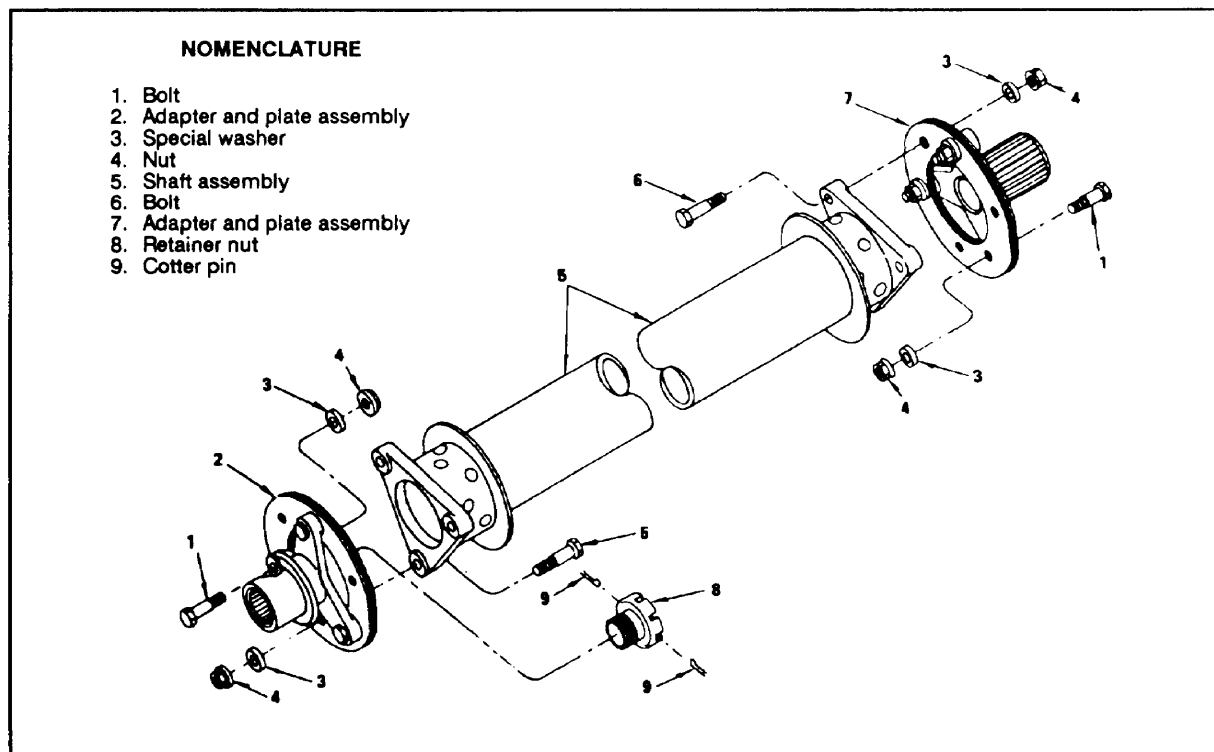


Figure 6-9. Engine drive shaft assembly



rotors mechanically connected and in phase with each other. The shafting assembly consists of a series of shafts, each of which is a hollow, dynamically balanced tube. Each shaft is interconnected to the other, to the combining transmission on the aft end, and to the forward rotary-wing drive transmission on the forward end by an adapter and plate assembly. The shaft is mounted and supported by bearings and support assemblies which contain shock mounts.

### Synchronizing Drive Shaft

The purpose of the aft synchronizing drive shaft is to transmit torque from the engine-combining transmission to the aft rotary-wing drive transmission (Figure 6-10). The aft synchronizing drive shaft is similar to and supported in the same manner as the forward synchronizing drive shaft assembly. The only difference is that the aft synchronizing shaft assembly contains fewer shaft units and fewer supports.

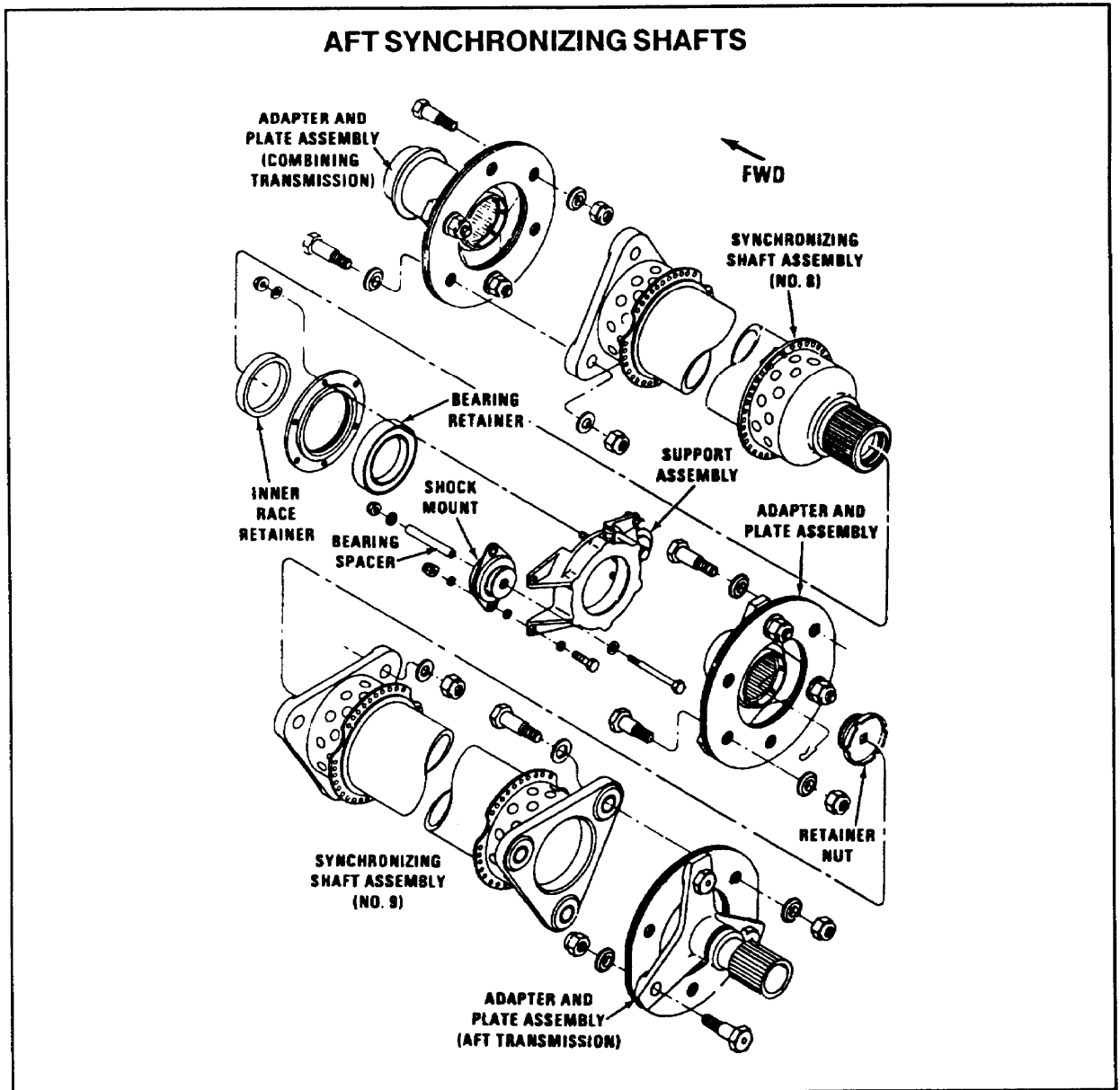


Figure 6-10. Synchronizing drive shaft

## GLOSSARY

## ABBREVIATIONS AND ACRONYMS

amp	ampere
assy	assembly
aux	auxiliary
brgs	bearings
byp	bypass
comb	combining
CPC	corrosion-preventive compound
det	detector
eng	engine
fwd	forward
Hz	hertz
ind	indicator
in-lb	inch-pound
ips	inches per second
LH	left hand
MA	mechanical advantage
maint	maintenance
max	maximum
MPH	miles per hour
NDI	nondestructive inspection
pnl	panel
pos	positive
press	pressure
psi	pounds per square inch
r	radius
RH	right hand
RPM	revolutions per minute
sw	switch
temp	temperature
trans	transmission
2/rev	two per revolution
v	velocity
VDC	voltage direct current
xducer	transducer
xmsn	transmission
xmtr	transmitter

**FM 1-514****DEFINITIONS**

Airfoil. Any surface such as an airplane wing, aircraft propeller, helicopter rotor blade or rudder, or aileron designed to obtain reaction from the air through which it moves. Any member or surface whose major function is to deflect airflow.

Airfoil profile. Outline of an airfoil section.

Airfoil section. Cross section of an airfoil parallel to the plane symmetry or to a specific reference plane.

Airworthy. Status of being in a condition suitable for safe flight.

Angle, blade. Acute angle between the chord of a section of propeller or rotor blade and a plane perpendicular to the axis of rotation.

Angle of attack. Acute angle measured between the chord of an airfoil and the relative wind.

Angle, pitch. Acute angle between the blade chord line and a referenced plane determined by the main rotor hub.

Aspect ratio. Ratio of the span to the airfoil; ratio of the span to the total area of the airfoil (span divided by chord).

Bending. Combination of tension and compression; inside curve is under compression and outside is under tension.

Blade feathering. Twisting movement of rotor blades about the pitch-change axis; the streamlining of propeller blades with the relative wind.

Blade leading and lagging. Sometimes called hunting, the movement of rotor blades in the plane of rotation when approaching and leaving the pure radial position (90° to the helicopter longitudinal axis on the advancing half of the rotor disc). Blades lead when moving away from the pure radial position; they lag when approaching pure radial position. Leading and lagging is caused by increase and decrease in drag on the blades. It is limited by hydraulic dampers on fully articulated rotor systems and by rigidity of blades on all other types.

Blade shank. Base end of a propeller blade, which must be thick to withstand bending and torque forces; usually cylindrically shaped.

Blade slip. Difference between effective and geometric pitch.

Blade station. Term used to identify specific areas of a propeller or rotor blade along the span. Most blade stations are numbered in inches from the center of rotation (station zero) and outward to the blade tip.

Blade tip. Portion of a propeller or rotor blade furthest from the center of rotation; least critical area of the blade.

Blade tracking. Procedures used to check a propeller or rotor system to determine the tip-path plane of each blade when rotating. Desired track is for all blades to rotate on the same tip-path plane.

Camber. Curvature of airfoil surfaces from the chord line; may be positive, negative, or zero.

Center of gravity. Point within an airplane or airfoil (blade) through which, for balance purposes, the total force of gravity is considered to act.

Center of pressure. Aerodynamic center of an airfoil; the point where all resultant forces act.

Centrifugal twisting moment. Force which tends to streamline rotating blades with the plane of rotation.

Chord. Distance between the leading and trailing edges of an airfoil.

Chord line. Imaginary line drawn between the leading and trailing edges of an airfoil.

Compression. The resistance to pushing together or crushing produced by two forces moving toward each other.

**Dissymmetry of lift.** Uneven distribution of lift in the rotor disc area normally encountered in forward flight of a helicopter; caused by the increased velocity of the advancing half of the rotor disc creating more lift, and the decreased velocity of the retreating half reducing lift.

**Drag, parasite.** Drag caused by any member or structure which does not contribute to lift; for example, engine cowlings.

**Drag, profile.** Friction resistance produced by a member moving through the air; in simple terms, the "stickiness" of air against the surface of an airfoil.

**Dynamic load.** Load on an aircraft due to a dynamic force.

**Effective angle of attack.** That part of a given angle of attack that lies between the chord of an airfoil and a line representing the resultant velocity of the disturbed airflow.

**Fatigue.** Weakening of metal or other material due to microscopic changes in molecular structures caused by vibration or exposure.

**Feedback.** Relay through the controls of aerodynamic forces exerted on control surfaces and felt by the pilot.

**Fillet.** Faired surface or piece that smoothes the flow of air at an internal angle, as at a wing root.

**Flapping.** Up-and-down motion of a rotor blade.

**Flapping angle.** Angle that measures the extent of flapping in a rotor blade.

**Ground effect.** Cushion or pushing effect of air compressed against the ground by a helicopter or airplane hovering or flying close to the ground.

**High lift blade.** Rotor blade designed to give greater lift than commonly used blades.

**Hub tilting.** Tilting of the rotor hub of a helicopter or autogyro.

**Hydromatic.** Pertaining to hydraulically operating mechanisms that function automatically.

**Induced angle of attack.** That part of any given angle of attack over and above the effective angle of attack.

**Induced drag.** That part of the total drag on an aircraft induced by the airflow about the lifting surfaces.

**Induced flow.** Downward flow of air induced through a rotor by the rotation of the rotor blades.

**In-plane motion.** Oscillating motion occurring in the plane of a rotor disc about the drag hinge.

**Lag angle.** Angle by which a rotor blade is displaced about its drag hinge; measured between the blade-span axis and a radial line taken across the rotor disc and containing the drag hinge and the axis of rotation.

**Leading edge.** Edge of an airfoil (wing, propeller, or stabilizer) that first meets or bites the air.

**Main rotor.** Main system of rotating airfoils on a helicopter; distinguished from tail rotor.

**Mean aerodynamic chord.** Chord of an assumed rectangular airfoil representing the mean chord of an actual airfoil.

**Mean blade-width ratio.** Ratio of the mean chord of a propeller to its diameter.

**Open storage.** Storage of certain material outdoors; material so stored.

**Plane of rotation.** Hypothetical reference plane described or occupied by rotating rotor blades of a helicopter or autogyro, assuming the blades remain perpendicular to their axis of rotation at all times.

**Plane of rotor disc.** Plane of rotation.

**Planform.** Form or shape of an object, as of an airfoil, as seen in plain view or from above.

Reduction gear. Gear assembly between a powered shaft and another shaft by which the latter shaft is driven at lower RPM than the powered shaft.

Retreating blade. Rotor blade moving 180° from upwind to downwind position.

Reverse-flow region. Place on a rotor disc where flow through the disc is opposite to normal direction of flow.

Rib. Chordwise structural member in an airfoil which gives it its form and transmits the load from the airfoil covering to the spars.

Rotary wing. Rotating lifting surface of a helicopter or autogyro.

Rotational speed. Speed at which a propeller, rotor, or some other rotating part rotates, measured in revolutions per minute.

Rotor blade area. Planform area of a given rotor blade, equal to its length times its mean chord.

Rotor disc. Space occupied or described by the rotating blade of a rotor.

Span. Maximum dimension of an airfoil from tip to tip or from root to tip.

Spar. Any principal structural member in an airfoil, running from tip to tip or root to tip.

Static balanced surface. Surface that is in balance about its hinge axis.

Swash plate. Rotating member, usually circular, set on a shaft and acting like a cam.

Tip-path plane. Plane in which rotor blade tips travel when rotating.

Tip speed. Rotative speed of a propeller or rotor at its blade tips.

Trailing edge. Edge of an airfoil over which the airflow passes last.

Translational lift. Lift force exerted on the rotor blades of a helicopter when increased speed is imparted to the blades or when their angle of attack is changed going from one type of flight to another, such as from hovering to forward flight.

Unfeather. To change the blade angle of a propeller.

Vertical axis. Axis of the conical surface described by the rotating blades of a rotary wing.

Volatile. Easily passing away by evaporation; explosive.

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## INDEX

- Air density, 1-2
- Airfoil, 1-1 thru 1-3, 3-5, 3-8, Figure 1-1. *See also*
  - Leading edge; Trailing edge
  - aerodynamic center of, 1-3
  - shape of, 1-2 thru 1-3
  - speed of, 1-2
- Angle of attack, 1-2 thru 1-3, 2-4, 3-1
- Angle of incidence, 2-1, Figure 2-3
- Axis of rotation, 2-2, Figure 2-4
- Balancer (Balancer/Phazor), 4-6 thru 4-10, Figure 4-8
- Bernoulli's principle, 1-2, Figure 1-3
- Blade balance, 3-10 thru 3-11, 3-13, Figures 3-20 thru 3-25
  - mass chordwise weights for, 3-10
  - spanwise weights for, 3-11, 3-13
  - tracking weights for, 3-11
  - trammeling for, 3-13
  - trim tabs for, 3-11
- Blade construction, 3-9 thru 3-10, Figures 3-17 and 3-18
  - internal structural components in, 3-10
  - multiple pockets (fairings) in, 3-10
  - single pocket (fairing) in, 3-9
- Blade nomenclature, 3-6 thru 3-9, 3-11, Figures 3-8 thru 3-16
  - bottom, 3-9
  - chord and chord line, 3-8
  - doublers, 3-9
  - leading edge, 3-8
  - planform, 3-6
  - root, 3-7
  - skin, 3-6
  - span and span line, 3-8
  - spar, 3-8
  - stations, 3-9
  - tip, 3-7
  - top, 3-9
  - trailing edge, 3-8, 3-11
  - twist, 3-6
- Bonds, 3-10, Figure 3-19
- Camber, 1-1 thru 1-2, Figure 1-2
- Centrifugal force, 2-1, 2-3 thru 2-4, 4-1, 5-1, Figure 2-2
- Chord, 1-1 thru 1-3. *See also* Blade nomenclature
- Collective pitch control, 3-2
- Coning, 2-1, 2-3 thru 2-4, Figure 2-9
  - angle of, 2-3 thru 2-4
- Control plate, 3-2
- Cyclic control stick, 3-1 thru 3-2
- Cyclic pitch control, 3-1 thru 3-2
- Disc area, 2-2 thru 2-3, Figure 2-5
- Drag, 1-1 thru 1-3, 3-2, 5-2
- Drag brace, 4-1, 6-4
- Eddies (burbles), 1-2
- Electronic tracking. *See* Rotor blade (main)
- Faying surface. *See* Bonds
- Feathering. *See* Rotor head assemblies
- Feathering axis, 2-4, Figure 2-11
- Flapping, 2-3, Figures 2-7 and 2-8. *See also* Rotor head assemblies
- Freewheeling unit. *See* Power train (single-rotor)
- Ground effect, 2-5
- Gyroscopic precession, 1-3
- Horsepower loading, 2-3
- Hover, 2-4
- Intermediate gearbox. *See* Tail rotor system
- Lateral axis, 3-1
- Leading and lagging, 2-4, Figure 2-10. *See also* Rotor head assemblies
- Leading edge, 1-1 thru 1-2, 3-8, 3-11
- Levers, 1-4, Figure 1-5
  - for applied force (effort), 1-4
  - for fulcrum (pivot point), 1-4
  - for mechanical advantage, 1-4
  - for resistance, 1-4
- Lift, 1-1 thru 1-3, 2-1 thru 2-4, 3-1, Figure 2-6
  - dissemmetry of, 2-2 thru 2-4
  - symmetry of, 2-2
- Longitudinal axis, 3-1, 3-4
- Long-term storage, 4-11
- Moment of force, 1-3 thru 1-5
- Multiple pockets (fairings). *See* Blade construction
- Nondestructive inspection (NDI), 1-5 thru 1-6
- Oil circulation. *See* Power train (tandem-rotor)
- Oil system. *See* Power train (single-rotor); Power train (tandem-rotor)
- Phazor, 4-7 thru 4-9
- Plane of rotation, 2-2, 3-11
- Planform, 3-6, Figure 3-8
- Power loading. *See* Horsepower loading
- Power train (single-rotor), 5-1 thru 5-4, 5-6, Figures 5-1 thru 5-6
  - clutch assembly of, 5-1
  - components of, 5-1
  - freewheeling unit of, 5-2
  - generator drive of, 5-4
  - hydraulic pump drive of, 5-6

## FM 1-514

- input drive of, 5-4
- main drive shaft of, 5-1 thru 5-2
- main rotor mast assembly of, 5-6
- main transmission of, 5-4 thru 5-6
- oil system of, 5-5
- rotor tachometer-generator drive of, 5-6
- tail rotor drive of, 5-4
- Power train (tandem-rotor), 6-1 thru 6-4, 6-7 thru 6-8, 6-10 thru 6-11, Figures 6-2 thru 6-10
  - aft rotary-wing drive transmission of, 6-7, 6-10
  - components of, 6-1
  - engine-combining transmission of, 6-4
  - engine drive shaft of, 6-10
  - engine transmission of, 6-2 thru 6-4
  - forward rotary-wing drive transmission of, 6-3 thru 6-4
  - forward synchronizing drive shaft of, 6-10 thru 6-11
  - oil circulation of, 6-3, 6-4, 6-10
  - oil system of, 6-3, 6-4, 6-7, 6-10
  - synchronizing drive shaft of, 6-11
- Pressure, center of, 1-3
- Reflector tracking. *See* Rotor blade (main)
- Relative wind, 1-2
- Resistance. *See* Drag
- Roll (longitudinal axis), 3-1
- Rotation, center of, 4-1
- Rotor blades, 3-5 thru 3-6, Figures 3-6 and 3-7
- Rotor blade (main), 4-1 thru 4-5, Figures 4-1 thru 4-6
  - alignment of, 4-1 thru 4-2
  - tracking of, 4-3, 4-4
- Rotor head assemblies, 2-1, 3-2 thru 3-4, Figures 3-1 and 3-2
  - fully articulated, 3-3 thru 3-4
  - semirigid, 3-2
- Rotor mast assembly (main). *See* Power train (single-rotor)
- Rotor, single, 3-1
- Rotor system, 2-1, Figure 2-1
- Rotor, tandem, 3-1
- Servo system (flight control), 5-6
- Shipment, 4-11
- Single pocket (fairing). *See* Blade construction
- Skin, 3-9
- Span and span line. *See* Blade nomenclature
- Spanwise, 3-11, Figure 3-22
- Spar, 3-9, 3-11, Figure 3-15
- Stress, 1-3, Figure 1-4
- Strobe light tracking. *See* Rotor blade (main)
- Strobex, 4-6, 4-9, Figure 4-9
- Tail rotor system, 3-2, 3-4 thru 3-5, 3-11 thru 3-13, 5-6 thru 5-9; Figures 3-3 thru 3-5, 3-25, 5-7 thru 5-9
  - antitorque pedals of, 3-2
  - blades, fiberglass, of, 3-11 thru 3-12
  - blades, metal, of, 3-11 thru 3-12
  - drive shaft (power train, single-rotor) of, 5-6
  - gearbox (power train, single-rotor) of, 5-6 thru 5-9
  - hub of, 3-4 thru 3-5
  - trammeling of, 3-13
- Temporary storage, 4-10 thru 4-11
- Throttle control, 3-2
- Thrust, 1-1, 2-1, 3-1 thru 3-2
- Torque, 1-3, 3-1 thru 3-2, 3-4, 5-1, 5-4, 5-6, 6-2, 6-4, 6-10
- Tracking flag, 4-3
- Trailing edge, 1-1 thru 1-2, 3-6, 3-8, 3-11
  - of fairing, 3-6
  - of spar, 3-6
- Transmission (main). *See* Power train (single-rotor)
- Vertical axis, 3-1
- Vibration, 1-5, 4-1 thru 4-3
  - extreme low frequency, 4-3
  - ground resonance, 1-5
  - high frequency, 1-5, 4-3
  - lateral, 1-5, 4-1, 4-3
  - low frequency, 4-3
  - malfunctions, 1-5
  - medium frequency, 4-3
  - tracking flag for, 4-3
  - vertical, 1-5, 4-2 thru 4-3
- Vibrex, 4-5, 4-6, 4-9 thru 4-10, Figures 4-7 and 4-10
  - accessories for, 4-9
  - components of, 4-5
- Weight, 1-1, 2-4
- Yaw, 3-1

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