This manual contains active content, you must "trust" this document or select "play" to view the active content.
If you can read this warning, you may not have yet activated this document.

CHAPTER 8

AUTOMATIC FLIGHT CONTROL AND STABILIZATION SYSTEMS

Aircraft fly under many conditions. External conditions can alter the desired flight characteristics of the aircraft. To maintain the desired characteristics of the aircraft, the pilot moves the control surfaces either manually or automatically.

You have already learned about indicating systems and instruments that supply the pilot with information on the performance of the aircraft. The pilot must be able to see and interpret each of these indicators and then react to get the desired performance. In high-performance aircraft, especially single-piloted aircraft, other flight duties require much of the pilot's time. Navigation, communication, radar, and other special equipment are severely limited if the pilot has to work continually on the physical manipulation of the controls.

In high-performance aircraft capable of supersonic flight, aircraft speed is so great that the pilot's normal response time is far too slow. For example, by the time the pilot reacts to an indicator to position a control surface, the aircraft may already be out of control.

Automatic flight control and stabilization systems ease the pilot's workload and provide aircraft stability at all speeds. The information now flows directly to a flight control computer rather than to an indicator. This action lessens the time required to start a control movement to nearly zero. The result is increased stability. These systems also provide command controls by which the computer can control the aircraft in nearly any desired flight condition. Some automatic flight control systems are capable of flying the aircraft by radio navigation aids, correcting for wind, and making pilot-unaided landings.

The term Automatic Flight Control System (AFCS) is used instead of the older term, automatic pilot, or the shortened version, autopilot. A reliable AFCS is necessary because pilots have duties other than moving the flight controls. However, regardless of how sophisticated the AFCS computer may be, the reasoning power of the pilot cannot be duplicated.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Explain the principles of flight for both fixed- and rotary-wing aircraft.
2. Recognize functions, operating principles and modes, including air data, flap position information and coordination inputs.
3. Identify AFCS components.

PRINCIPLES OF FLIGHT

To understand automatic flight control and stabilization systems, you must study the effects that the various controls have on the aircraft. *Airman*, NAVEDTRA 14014, contains a basic introduction to the principles of flight and flight controls. You should review this text before proceeding with this chapter.

An airfoil is any part of an aircraft designed to produce lift. Obviously, a wing is the primary airfoil on an aircraft, but propeller blades, tail surfaces, and even the fuselage itself are important airfoils. The design of a specific airfoil is determined by its job. All airfoils have the basic elements shown in *Figure 8-1.*

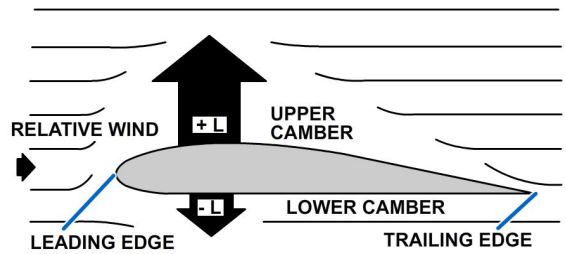


Figure 8-1 — An airfoil.

An airfoil consists of two nearly parallel surfaces, with one surface being more rounded than the other. As air passes over these two surfaces, the air passing over the rounded surface has farther to travel than the air passing over the flat surface. However, two particles of air leaving the airfoil's leading edge at the same instant, one going over the rounded surface and one over the flat, arrive at the trailing edge at the same time. Therefore, you can infer that air passing over the rounded surface travels at a higher velocity than air passing over the flat surface.

Bernoulli's theory concerning the behavior of fluids, E = VxP, explains how pressure is changed and lift is produced. Here, E is the total energy produced by the airfoil passing through the air, V is velocity energy, and P is pressure energy. An airfoil that passes through air at a velocity of 50 feet per second and exerts a pressure of 10 pounds per square inch on the flat surface produces a total energy of 500 foot-pounds per square inch per second.

$$E = VxP = 50x10 = 500 \text{ foot-pounds inch}^2\text{/sec}$$

If the airflow velocity over the rounded surface is increased to 60 feet per second, and the total energy is unchanged, it exerts a pressure of 8.33 foot-pounds per square inch per second on the rounded surface.

$$P = \frac{E}{V} = \frac{500}{60} = 8.33 \text{ foot-pounds inch}^2\text{/sec}$$

The difference in the pressure between the rounded surface and the flat surface of the airfoil is called lift.

In actual practice, the flat surface is not perfectly flat and causes some decreased pressure. The decreased pressure is negative lift. Negative lift is compensated for by the creation of high pressure on the flat surface. Air packed beneath the airfoil (dynamic lift) causes the high pressure. The true measure of lift remains the difference in pressure between the rounded and flat portions of the airfoil.

Increased lift is the result of a larger pressure difference between the surfaces. The difference can be produced in two ways—by increasing the forward movement of the airfoil through the air *(Figure 8-2)*, or by changing the angle of attack. Angle of attack is the acute angle between the chord line of an airfoil and its direction of motion relative to the air.

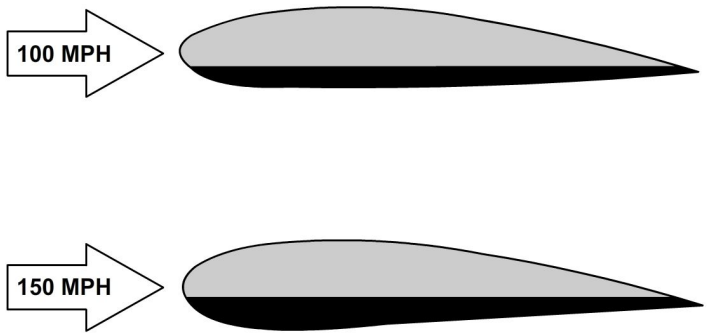


Figure 8-2 — Lift increases as velocity increases.

The chord of an airfoil is an imaginary straight line drawn from the leading edge to the trailing edge of the airfoil *(Figure 8-3)*. As the angle of attack increases, the air strikes the leading edge closer to the flat portion of the airfoil. The distance air must flow over the rounded portion becomes even greater in relation to that flowing over the flat portion. This action causes a larger pressure difference and develops more lift.

If the angle of attack increases too much, airflow over the airfoil's rounded portion separates from the surface and becomes turbulent. Turbulence causes the pressure on both surfaces to become nearly equal, and the airfoil is said to stall.

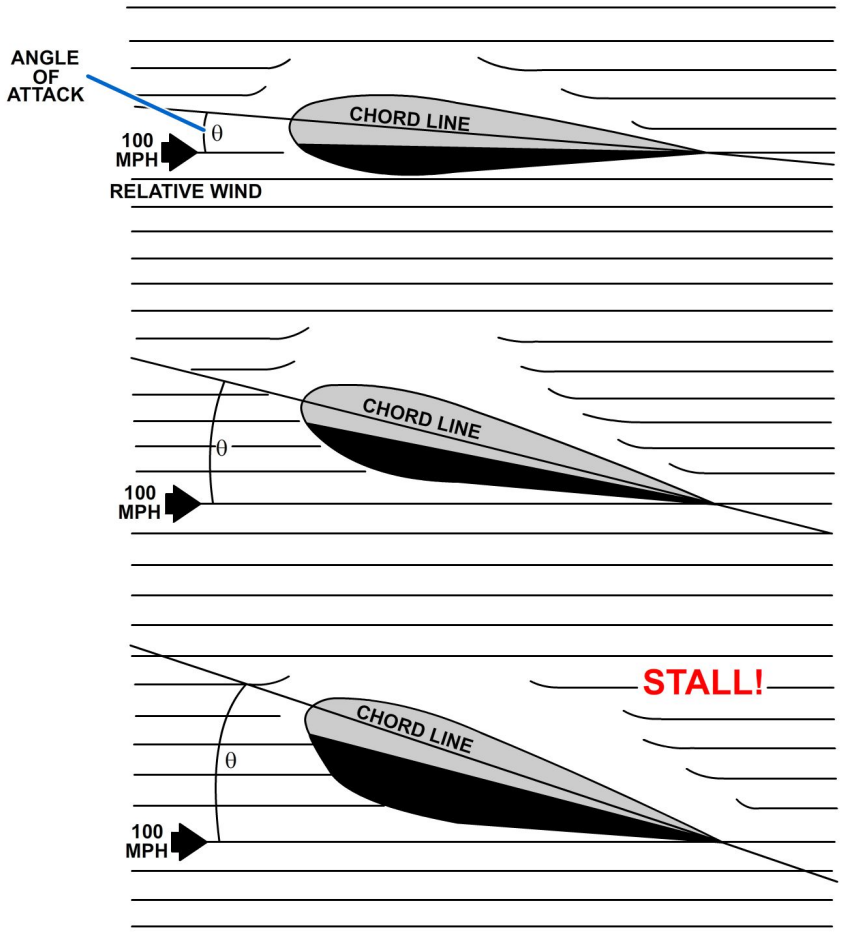


Figure 8-3 — Constant velocity versus increasing angle of attack.

When producing lift, a secondary effect called drag is also produced. Drag produced by a lifting surface or airfoil is called induced drag *(Figure 8-4)*. Induced drag develops in direct proportion to lift—when lift increases, induced drag also increases.

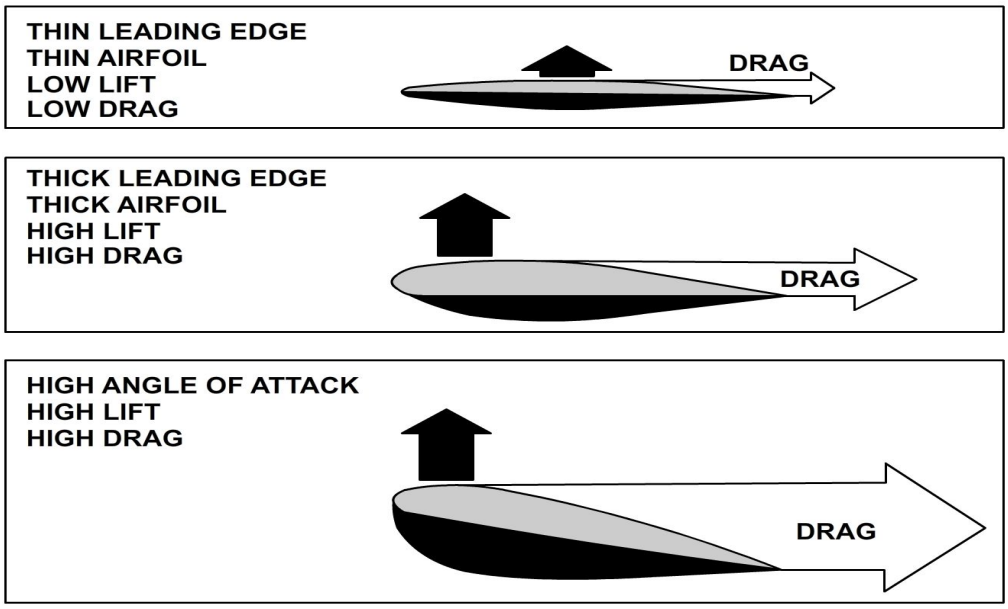


Figure 8-4 — Induced drag.

At a given speed and angle of attack, a thick airfoil produces more lift and drag than does a thin airfoil. It follows that large, subsonic aircraft have thick wings to produce a great amount of lift at slow speeds. Supersonic aircraft must have very thin wings to decrease drag at high speeds.

Many airfoils have devices attached to them to increase or decrease lift in various flight conditions or attitudes. These devices may mount on the leading edge, trailing edge, rounded surface, or flat surface. If the device attaches to the trailing edge by a hinge and has controls to move the trailing edge, you control lift by changing the angle of attack *(Figure 8-5)*. When the trailing edge moves into the higher pressure air on the airfoil's flat side, the angle of attack is effectively increased. This angle increase causes more lift and drag. Conversely, if the trailing edge moves into the airfoil's low-pressure side, the angle of attack decreases. Lift and drag decrease accordingly.

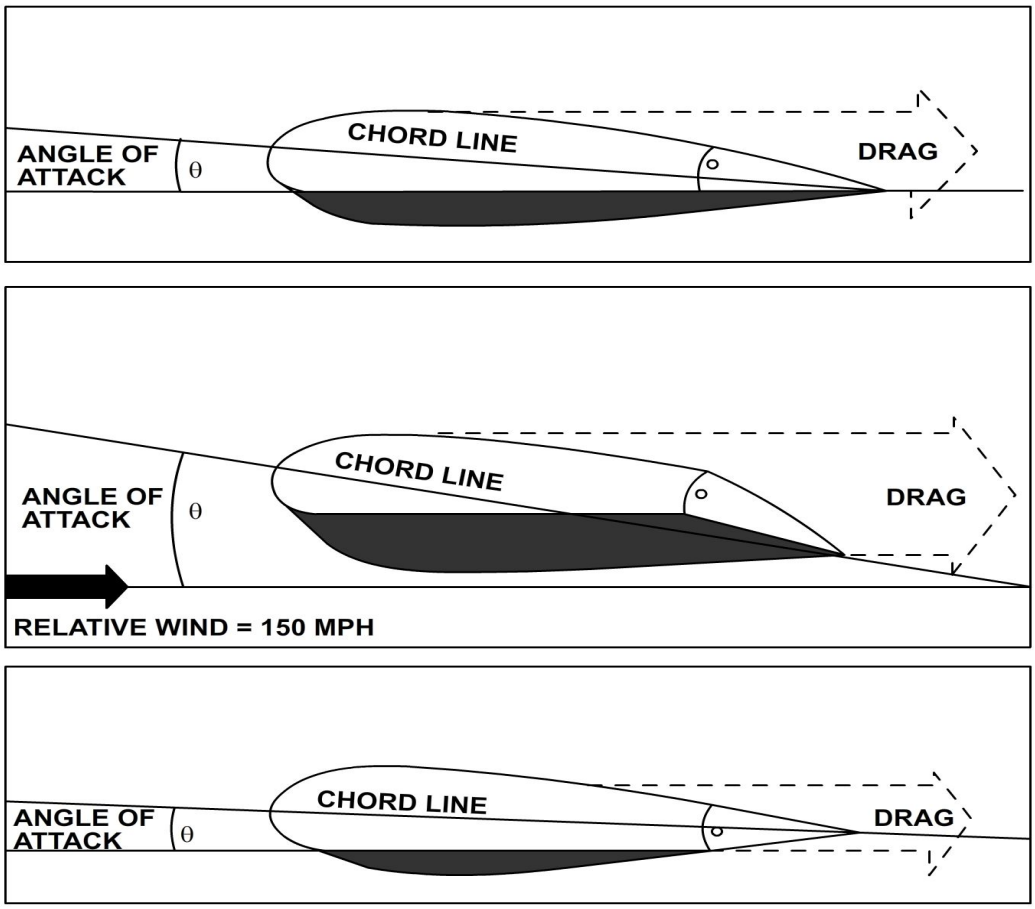


Figure 8-5 — Lift and drag change proportionately with the shape of the airfoil.

In flight, each aircraft has certain forces acting upon it *(Figure 8-6).* To sustain flight at a constant altitude, the total lift of all airfoils must equal the aircraft weight. To change altitude you must change the total lift. If the aircraft weighs 10,000 pounds, 10,001 pounds of lift causes the aircraft to climb; 9,999 pounds of lift causes the aircraft to descend.

To fly at a constant airspeed, the forces of thrust and drag must be equal. When one force is greater than the other, the aircraft accelerates or decelerates.

Figure 8-6 — Forces on an aircraft.

To turn, place the aircraft in a bank angle *(Figure 8-7).* The lift developed by the airfoils can then be broken down into components of horizontal and vertical lift. The horizontal component of lift pulls the aircraft around in the turn. The vertical component of lift must be equal and opposite to gravity for the aircraft to remain at a constant altitude. (Note that total lift must be increased to prevent a loss in altitude.)

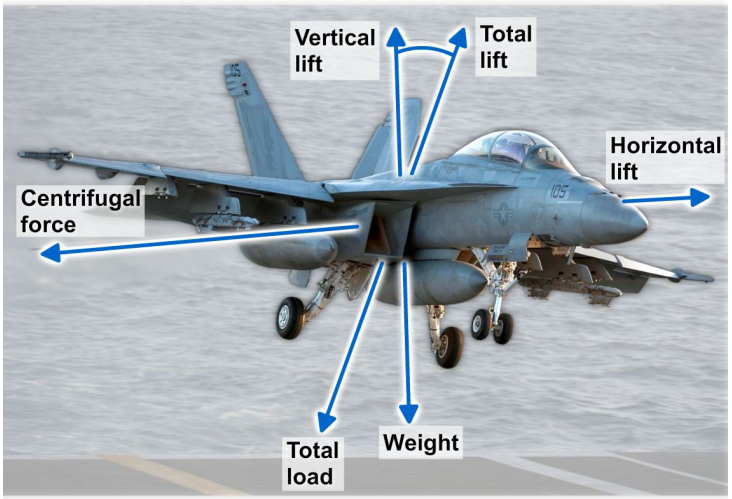


Figure 8-7 — Forces in a turn.

When centrifugal force equals horizontal lift, the aircraft is in a constant-rate turn. For a faster rate of turn, increase horizontal lift by increasing the bank angle. When all lift is vertical to gravity, any turning motion is called a skid.

FIXED-WING AIRCRAFT

A fixed-wing aircraft is one in which the main lifting surface remains stationary with respect to the rest of the aircraft. Today's fixed-wing aircraft are mostly electronically operated and have certain fixed surfaces or airfoils—wings, vertical stabilizers and Leading Edge Extensions (LEX)—that provide stability *(Figure 8-8)*. In addition, these aircraft have movable control surfaces, one each per side—ailerons, Leading Edge Flaps (LEF), Trailing Edge Flaps (TEF), horizontal stabilizers and rudders. These surfaces permit the pilot to control the aircraft through a sophisticated integrated electronic flight control system.

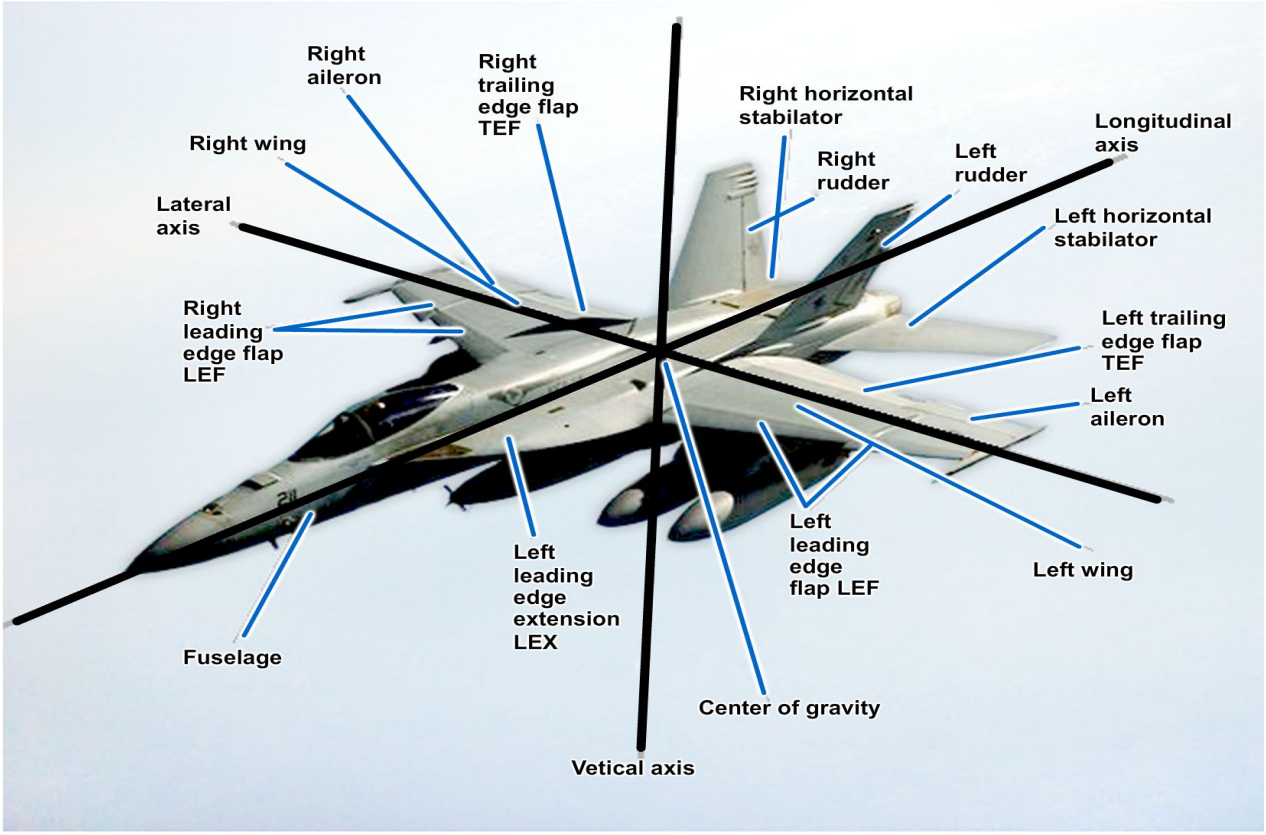


Figure 8-8 — Fixed-wing aircraft controls.

Movement about the lateral axis of the aircraft (the axis that extends from wing to wing through the center of gravity) is pitch. To control pitch you use the horizontal stabilizers. Pitch is controlled by symmetrical deflection of the horizontal stabilizers. If the operator desires a nose-up attitude, apply an aft motion on the aircraft controller grip assembly (control stick). This causes the horizontal stabilizer's leading edge to move down. Rotation about the lateral axis then causes the nose to lift, due to air on top of the wing to move faster than air on the bottom of the wing. Conversely, if you want to lower the

aircraft nose, apply a forward motion on the aircraft controller grip assembly. This causes the horizontal stabilizers leading edge up. Rotation about the lateral axis then causes the nose to lower. Movement of the aircraft about the longitudinal axis (from nose to tail) is known as bank or roll. Roll is controlled by differential deflection of the LEFs, TEFs, ailerons, and horizontal stabilizers working simultaneously. Per side; the TEFs, ailerons and horizontal stabilizers deflect in the same direction and the LEF deflect in the opposite direction. Moving the aircraft controller grip assembly left or right produces the required differential deflections for the present angle of attack, altitude, and airspeed. For the aircraft to enter a left bank, the angle of attack of a portion of the right wing must increase. You accomplish this by symmetrically lowering the right aileron, right TEF, and right horizontal stabilizer to increase the lift on that wing. The left aileron, TEF and left horizontal stabilizers deflect asymmetrically from the right side and rise to decrease the lift on that wing. The aircraft then rotates about its longitudinal axis until the ailerons and horizontal stabilizers are neutralized in some angle of bank. The rudders are symmetrically deflected to minimize sideslip during roll maneuvers. The aircraft remains in that bank angle until you again move the ailerons.

Refer to *Figure 8-7*. Whenever the aircraft is in a bank, lift developed by the wings is displaced from the vertical position. If you do not increase lift, its vertical component is insufficient to maintain the aircraft at a constant altitude. A change in pitch attitude to increase the angle of attack of the wings is used to prevent a loss in altitude. A few degrees of bank angle require an imperceptibly small pitch change. A 90-degree bank in level flight (no altitude change) is theoretically impossible because of the absence of vertical lift. As the bank angle changes, coordination between ailerons, horizontal stabilizers and TEFs are necessary to prevent a loss in altitude. Notice in *Figure 8-7*, the LEFs are canted downward; not level with the fuselage and the left aileron is full down providing lift and the right is streamlined as the aircraft prepares to land on the deck.

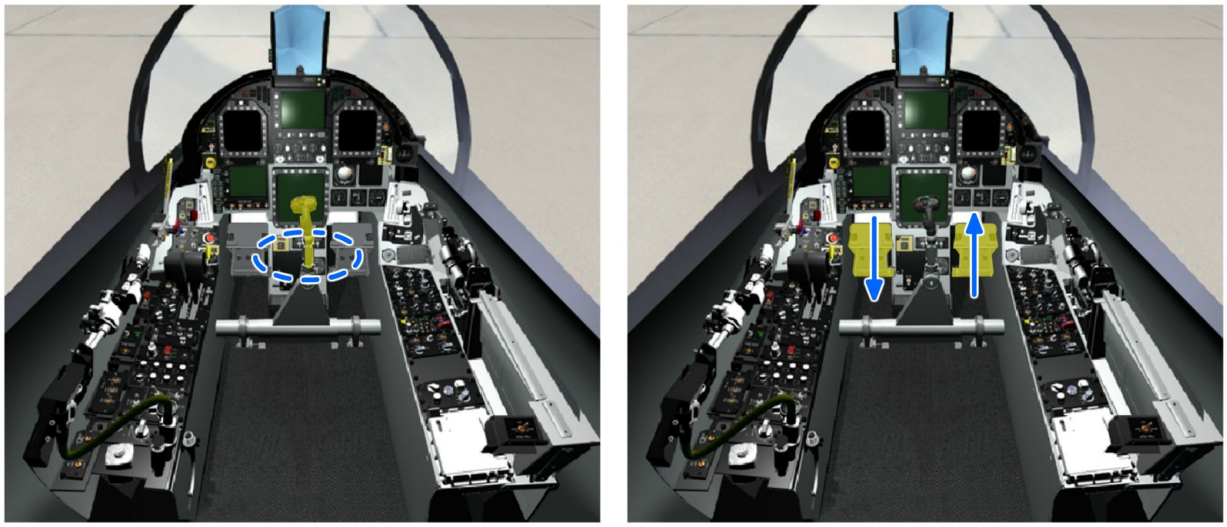
To return to level flight, increase lift on the left wing by lowering its aileron into the higher pressure area beneath the airfoil. Reduce lift on the right wing by raising its aileron into the lower pressure area at the top of the airfoil. As the wings become level, neutralize the ailerons.

Movement about the vertical axis is *yaw.* Usually this movement is undesirable in an aircraft. Use the rudder to correct any tendency of the aircraft to yaw. The rudder is NOT used to turn the aircraft (change heading).

When placing the ailerons into the airstream, the aircraft has a tendency to yaw. When banking to the right, the aircraft produces more lift and drag on the left wing, and less lift and drag on the right wing. Even though the intention is to turn to the right by going into a right bank, the initial tendency is for the nose of the aircraft to go to the left. This movement happens because of the increased drag on the left wing and decreased drag on the right wing. This effect is adverse yaw; you compensate for it by displacing the rudder in the same direction as the intended turn.

If an aircraft in a turn tends to slip into the inside of the turn or skid to the outside of the turn, this is also yaw. You also compensate for it by using the rudder. Many other things may cause yaw, such as the engines on one wing of a multiengine aircraft producing more power than the engines on the other wing.

You can see, then, when you place a fixed wing aircraft in a bank angle, coordination between all three controls—ailerons, horizontal stabilizers, and rudder—is necessary. The pilot accomplishes control of horizontal stabilizers, ailerons, and rudder through the use of a control stick and rudder pedals *(Figure 8-9)*. To operate the ailerons, move the control stick right or left in the direction of the intended turn *(Figure 8-9, view A).* Aft force on the control stick raises the trailing edge the horizontal stabilizers and causes the nose to pitch up. Forward pressure on the control stick lowers the trailing edge of the horizontal stabilizers and causes the nose to pitch down. You use your feet to operate the rudder pedals *(Figure 8-9, view B)*. Pressure on either rudder pedal causes rudder deflection in that direction.



(A) **(B)**

Figure 8-9 — Flight controls: (A) Horizontal stabilizer and aileron, (B) Rudder.

Weight distribution in an aircraft varies for many reasons. For example, fuel may be used faster from one wing tank than from the other, allowing that wing to become lighter. In large aircraft where crew members or passengers walk around, the balance point, called the Center of Gravity (CG), shifts whenever someone changes position in the aircraft. As fuel is used, the aircraft gross weight reduces. The pilot must reduce the angle of attack of the wings to lessen lift and prevent a gain in altitude.

The pilot must use control pressures to compensate for these unbalanced flight conditions. Several methods are used to reduce these control pressures and to ease the pilot's workload. In newer aircraft, the most common method is the setting autopilot. Look at *Figure 8-8*. The figure shows aircraft control surfaces. Setting autopilot is desirable on this particular aircraft because flight computers and the air data system compensate for unbalanced conditions and automatically adjust flight surfaces.

When pilots must exert a force on the control stick, they can use the trim control to relieve that force. For instance, when they must hold left rudder pressure to prevent yaw movement to the right, they can move the rudder trim control to the right. The airflow on the vertical stabilizer strikes the rudder and moves the complete rudder a little to the left. Since the rudder trim control now supplies the required rudder pressure, the pilot no longer has to hold pressure on the rudder pedals.

ROTARY-WING AIRCRAFT

An aircraft that derives its main lifting force from a horizontally driven propeller device (rotor) is a rotary-wing aircraft. The most common rotary-wing aircraft is the helicopter. For lift to happen there must be relative motion between an airfoil and an air mass. Therefore, the major advantage of a rotary-wing aircraft is its ability to maintain zero or very low airspeed while the wings (rotors) are still creating lift.

Forces acting on a rotary-wing aircraft are identical to those acting on a fixed-wing aircraft *(Figure 8-6).* You must also control the rotary-wing aircraft about the vertical, longitudinal and lateral axes, as shown in *Figure 8-8.*

In the conventional helicopter, the main and tail rotors are engine driven. Remember the earlier discussion on airfoils. You increase lift either by increasing the speed of the airfoil through the air or by increasing the angle of attack of the airfoil. In helicopters, the airfoil's angle-of-attack is known as blade pitch. When the rotor speed is constant, the pilot maintains complete control of the aircraft by varying the pitch of the rotor blades.

Figure 8-10 shows helicopter flight controls. The pilot operates collective control with the left hand, cyclic control with the right hand, and rudder control with the feet. The collective and cyclic controls command the main rotor. Operation of the rudder control changes the blade angle of the tail rotor.

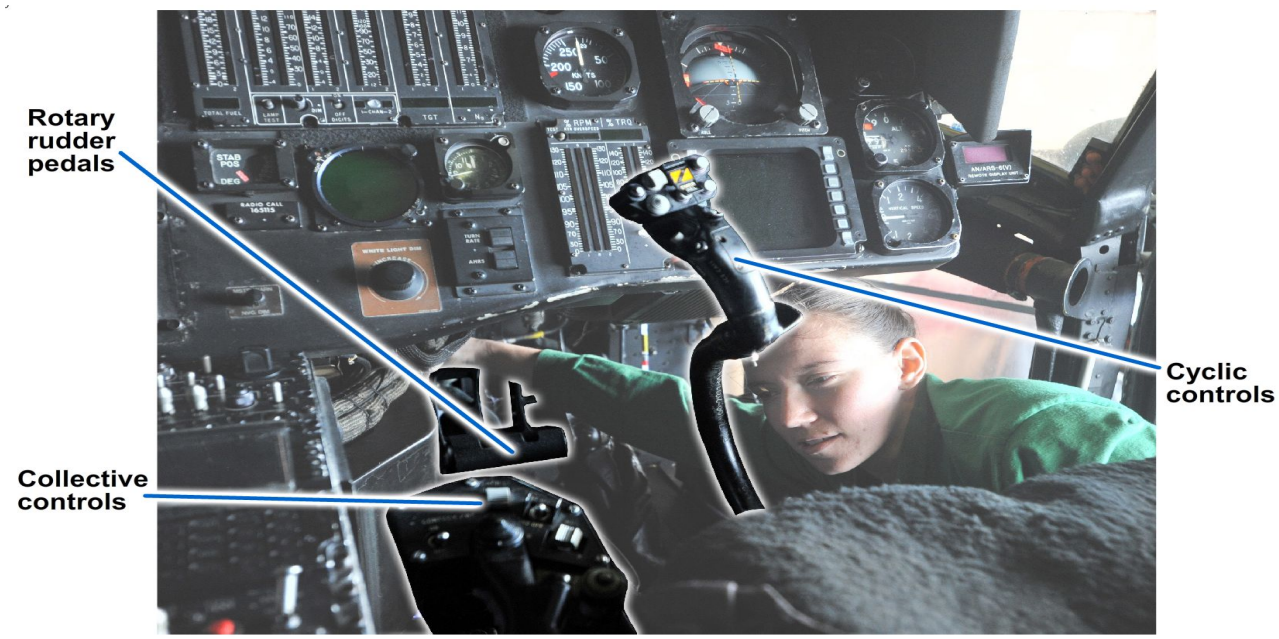


Figure 8-10 — Helicopter flight controls.

In helicopter flight (except hovering flight), the main rotor provides altitude, bank, and directional control through use of the collective and cyclic controls. The tail rotor prevents the main body of the helicopter from spinning (yawing) with the torque of the main rotor. It prevents yaw in a similar way as the fixed-wing aircraft rudder.

Collective control maintains or changes altitude. Moving the collective control causes an equal change in pitch (angle of attack) of all main rotor blades. Also, through a

mechanical mixer, collective control automatically changes tail rotor pitch to compensate for increases or decreases in main rotor torque.

Since the rotor blades are somewhat flexible, the more collective control applied, the more an action called coning takes place. As the blades rotate, they take the shape of a cone *(Figure 8-11)*. The speed and pitch of the blade tips determine the coning angle. With a constant pitch, the faster the rotor blades turn, the more horizontal the blades become because of centrifugal force. As the blade pitch increases, lift also increases, and the coning angle increases because of the load on the blades.

Figure 8-11 — Coning angle increases as load increases.

In hovering flight, cyclic controls contain pitch and roll, which create forward and sideward motion, respectively. The collective controls maintain altitude and the rudder pedals control heading.

The cyclic stick provides pitch and directional control of the helicopter. When the pilot applies pressure to the cyclic stick, each blade moves to a specific pitch angle as it passes a certain point in its rotation *(Figure 8-12, frame 1)*.

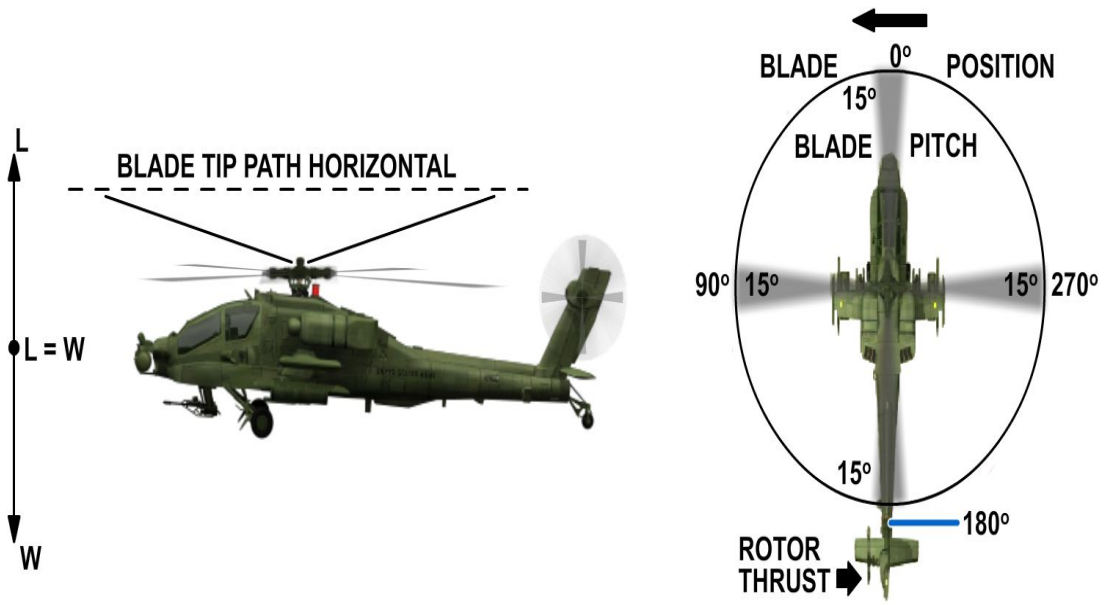


Figure 8-12 — Flapping angle creates horizontal lift: (Frame 1) Hovering flight; (Frame 2) Forward flight.

During forward flight, the blade pitch is greatest as it passes the 90-degree position. The blade pitch is least at the 270-degree position, and equal at the 0-degree and 180-degree positions. To turn the aircraft, lateral motion of the cyclic stick causes blade pitch to be greatest at 0 and 180 degrees, and least at 90 and 270 degrees. Since the blades form a spinning mass, the gyroscopic principle of precession occurs 90 degrees in the direction of rotation from where the lifting force is applied.

The coning angle remains the same. However, the cone tilts in the direction of the desired flight path, creating what is called the flapping angle. You can again break down lift into its vertical and horizontal components. Look at *Figure 8-12, frame 2*. To maintain altitude, the vertical lift is increased until it is equal to gravity. With the cone at a flapping angle, the helicopter accelerates in the desired direction until drag is equal to horizontal lift.

To accelerate the helicopter in a forward direction, move the cyclic control stick forward. You also must make a corresponding increase in collective control to maintain altitude. As the collective control increases, torque on the main rotor blade increases. This action makes the helicopter tend to rotate in the direction opposite to the rotor blade rotation

Interaction Available

(nose right). A mechanical mixer automatically changes the pitch of the tail rotor to overcome the right turning tendency (skid).

To turn the helicopter (change heading), place the cyclic control stick to the right or left. Flapping action of the main rotor blades causes the cone to tilt in the direction of the desired turn (*Figure 8-12, frame 3)*. As with the fixed-wing aircraft, the pilot must maintain coordination in a turn by using the rudder pedals to prevent skid or slip. Also, the pilot must adjust collective control to prevent a loss in altitude. In hovering flight, the pilot uses the rudder pedals only to turn the helicopter, thus producing a skid.

AUTOMATIC FLIGHT CONTROL SYSTEMS (AFCSs)

In the human body, signals to move us from place to place start with our five senses as they reference outside conditions. The brain processes these signals and sends them through the nerves to the muscles. The body then does its required movement by muscle power. Similarly, most AFCSs have their component parts divided into three major groups—sensors (information inputs), amplifier/ computer, and output units.

The sensors originate the signals as they are acted upon by outside references. They only sense changes and do not have sufficient power to make corrections.

The amplifier and computer are the brains for the AFCS. They receive the weak signals from the sensors, which in most cases are synchros, and determine how much and in which direction correction is necessary. The synchro signals are usually in millivolts, but the correct strength needed is in volts. Therefore, the amplifier increases the weak signal to a workable voltage. The value of the synchro signal depends on the amount of rotor displacement with respect to the stator from the null position. The direction of rotor displacement from the stator determines the direction of the correction. Most amplifiers have at least two stages of voltage amplification—one stage of phase discrimination, and another stage where power amplification takes place. Other types of amplifiers control the voltage to control valves in hydraulic servos.

The output unit is the muscle of the AFCS. It consists of an electro/hydraulic booster package. There is a booster package for each control surface—rudder, aileron, and elevator. The boosters also assist the pilot in manual control of the aircraft.

Summing up the major groups, the sensors send a small signal to the amplifier/computer when a displacement occurs. The amplifier/computer amplifies the weak signal to a workable voltage and sends it to the output unit. The output unit changes the electrical energy to mechanical displacement. It then moves the control surfaces by an amount commanded by the sensor signal.

AFCS COMPONENTS

The AFCS consists of many controls, sensors, and electromechanical components. To understand the entire system, you need to know what each component of the system does. In this section, you will read about the components that make up the AFCS.

Electrical/Electronic Components

The electrical/electronic components make AFCSs work. The control panel is used to program any pilot-desired maneuver that is within the capability of the system. Originally, AFCS systems were very limited. They supplied only one-channel operation to the ailerons to keep the wings level. Newer aircraft receive signals from other aircraft systems. Radar and barometric altimeter signals couple with the AFCS to maintain the aircraft at a constant altitude. Some aircraft use signals from data-link systems to fly the

aircraft during approaches and landings. Some fighters have the fire control system tied in so the aircraft can fly automatically to an enemy aircraft. Fighter bombers with a weapons control system tie-in can fly automatically to the target and release their weapons at the proper time. Long-range patrol aircraft have their Anti-submarine Warfare (ASW) systems tied into their AFCS. The AFCS operates the rudder, the elevator, and the ailerons by using various sensors and electrically controlled hydraulic servos. Before engagement, the AFCS is synchronized with the flight control surfaces to prevent sudden or violent maneuvers.

The system senses deviation from the reference flight condition and causes the aileron control to maintain either a reference bank angle or a heading. It also causes the elevator control to maintain either a reference pitch angle or an altitude. Additionally it makes the rudder control coordinate turns and provides automatic yaw damping.

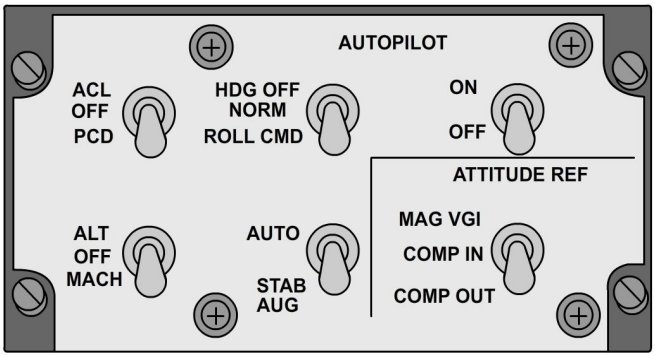


Figure 8-13 — AFCS control panel.

CONTROL PANEL—The AFCS control panel contains all the switches and controls necessary for the pilot to select/control the autopilot modes. Control panels are designed for the particular type and mission of the aircraft. Some control panels are simple, while others are complex. *Figure 8-13* is an example of an AFCS control panel. Here, the switches serve as manually operated interlocks in setting up the circuitry to engage the various AFCS modes of operation. This control panel has six switches. They are labeled as follows: ACL/OFF/PCD, ALT/OFF/MACH, HDG OFF/NORM/ROLL CMD, AUTO/STAB-AUG, ON/OFF, and ATTITUDE REF.

The ACL/OFF/PCD, ALT/OFF/MACH, and HDG OFF/NORM/ROLL CMD switches are solenoid-held toggle switches. Each has a lever-lock toggle feature that prevents accidental engagement in the operate position. The AUTO/STAB-AUG and ON/OFF switches are solenoid-held, spring-loaded switches. When not engaged or when no power applied, the switches return to the STAB-AUG and OFF positions, respectively. The ATTITUDE REF switch is a miniature, positive-break, aircraft-type toggle switch.

AIR NAVIGATION COMPUTER (ANC)—All operating functions of the AFCS channel through the air navigation computer. It is sometimes called the amplifier computer, and it is the heart of the entire system.

The ANC modifies the combined signals supplied by various sensors and command controls to develop output signals. The output signals control the aircraft's ailerons, rudder, and elevators. By use of these flight controls, the aircraft automatically maintains a reference attitude, heading, and altitude. Also, it can maneuver in a coordinated manner in response to turn and pitch control settings on the control panel.

The physical appearance of the ANC depends on the type and mission of the aircraft. *Figure 8-14* shows two types of ANC.

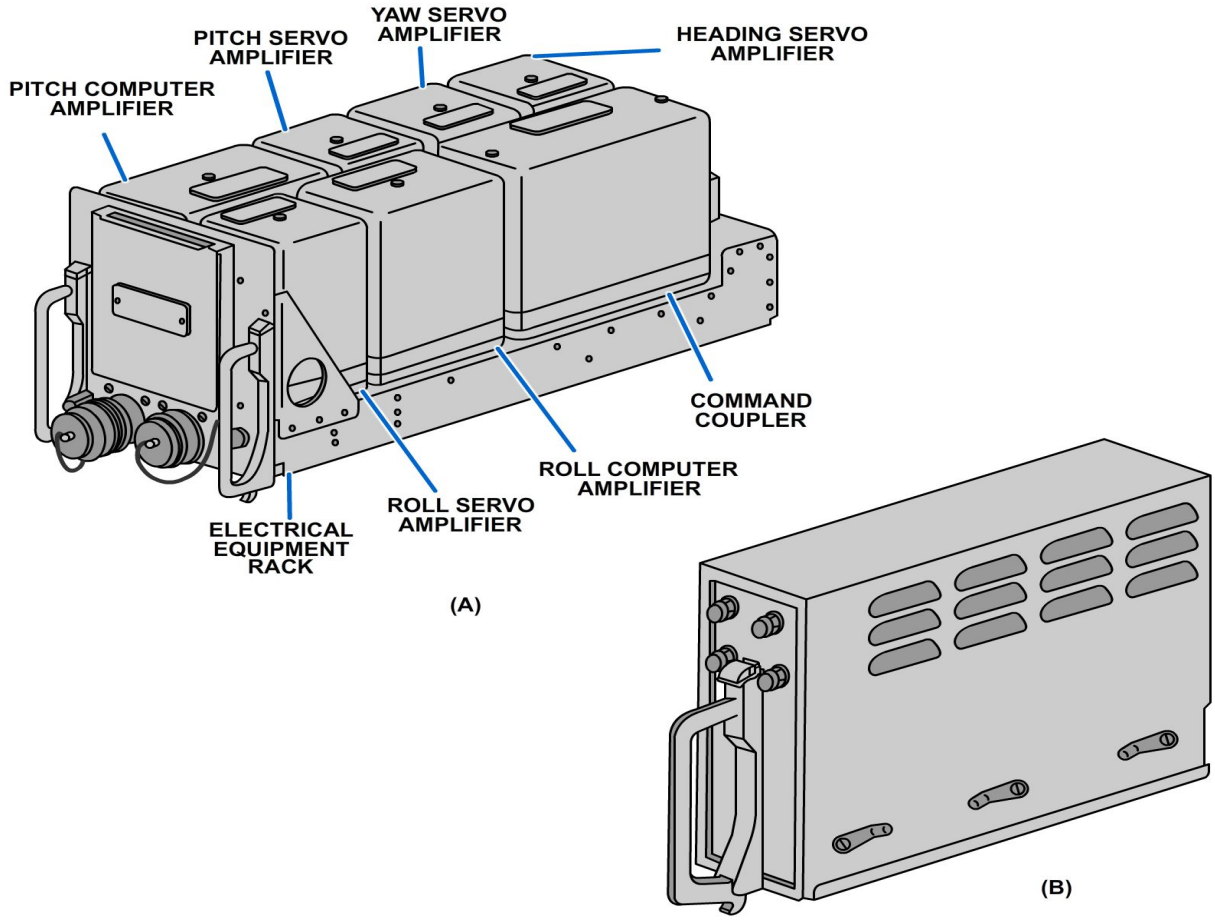


Figure 8-14 — (A) Air navigation computer; (B) One-channel amplifier/computer.

Figure 8-14, view A, shows an ANC that consists of an equipment rack and seven amplifier modules, which are listed below.

1. Roll servo amplifier
2. Pitch servo amplifier
3. Yaw servo amplifier
4. Roll computer amplifier
5. Pitch computer amplifier
6. Heading computer amplifier
7. Command coupler

Each of the seven modules contains subassemblies and sub-subassemblies. Some of these are interchangeable between modules. The roll, pitch, and yaw servo amplifiers are identical. The other modules have individual differences. The computer, through an interlocking relay arrangement in conjunction with the control panel mode selection

switches, controls signal switching operations. A calibration board on the front of the ANC provides gain adjustments of the major system parameters.

Figure 8-14, view B shows a one-channel amplifier/computer. Normally, this particular type of autopilot computer consists of three individual amplifier/computer modules (one for each control surface)—aileron channel (roll), rudder channel (yaw), elevator channel (pitch).

This one-channel computer accomplishes analog computations by using servomechanisms. These servomechanisms consist of electromechanical computer cards and electronic amplifier cards mounted in the amplifier/computer. In addition, a transformer board and a resistor board provide summing networks. The networks combine the various signals supplied to and generated within the unit. An interlocking relay arrangement is included to perform most of the switching control in the AFCS.

CONTROL STICK—Control stick or control wheel steering is used on some aircraft to control the aircraft electronically through the AFCS. On fighters, the signals are generated in a unit such as the one labeled "motional pickup transducer" in *Figure 8-15*.

When the AFCS is on and the control stick is moved left or right, pressure on the roll force switch momentarily disengages the roll channel of the AFCS. The pilot then controls the roll attitude of the aircraft through regular stick control. When the pilot releases stick pressure, the force switch opens, allowing the AFCS to reengage roll. If the bank angle is above a given angle (for example, 5 degrees), the AFCS will maintain the bank angle. If the bank angle is below the given angle, the AFCS automatically returns to wings level.

The pitch force switches close when a fore or aft pressure is on the control stick. This action momentarily disengages the AFCS. The stick pressure also couples a signal through the E pickoff transformer that is labeled "force sensor," as shown in *Figure 8-15*. The signal couples with the AFCS pitch channel. Depending on the direction of the stick pressure (fore or aft), the aircraft either climbs or dives.

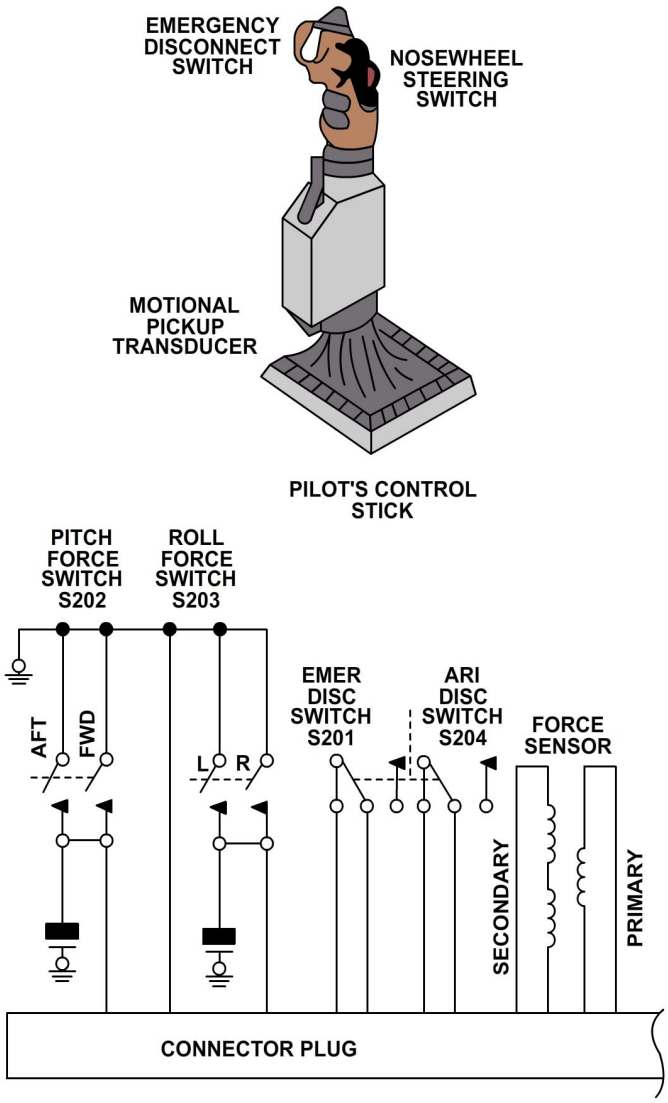


Figure 8-15 — Control stick steering components.

Electrical/Electronic Sensors

Many electrical and electronic sensors provide input to the AFCS. This section of the Rate Training Manual (RTM) includes a review of the sensors already discussed, and it introduces you to other sensors in the AFCS.

SIGNAL GENERATOR PICKOFF (SYNCHRO)—*Figure 8-16* illustrates the principal of operation for a signal generator pickoff. The pickoff consists of a stator and rotor. The stator is ring-shaped and has four poles. Each pole has a primary and secondary winding. The rotor has no windings. It serves to change the reluctance of the magnetic flux path between the stator poles. The primary and secondary windings are connected so the voltages induced into the secondaries are of opposite polarity on adjacent poles. However, opposite poles have the same polarity.

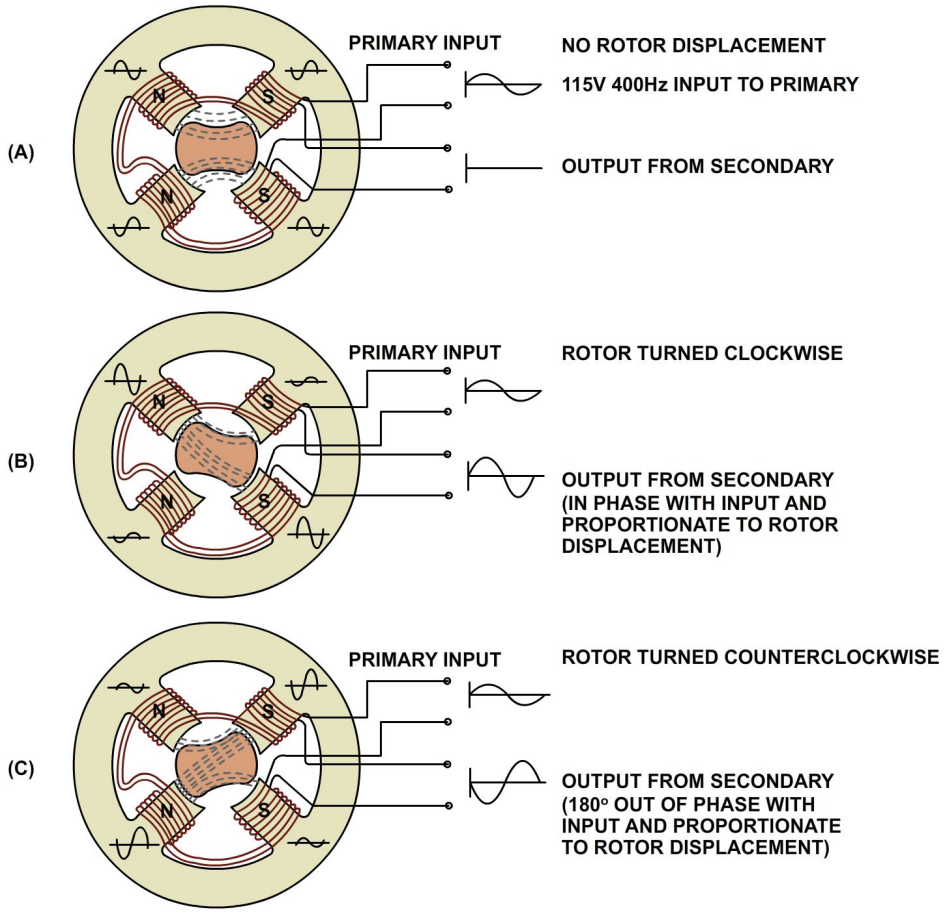


Figure 8-16 — Signal generator pickoff operation.

The voltage output of the secondary is zero if the rotor is in its neutral position *(Figure 8-16, view A)*. Repositioning the rotor *(Figure 8-16, views B and C)* makes a stronger magnetic field on a single pair of poles. This results in a voltage output on the secondary winding. The amplitude of the output voltage is proportional to the amount of rotor displacement—the greater the displacement, the greater the amplitude. The direction of rotor movement determines the polarity of the output voltage. The polarity will be either in phase with the input voltage or 180 degrees out of phase with it.

Synchro construction allows for more accurate voltage production than angle signal, effective through 360 degrees of rotation. For more information about synchros, servos, and gyros, you should refer to Navy Electricity and Electronics Training Series (NEETS), Module 15, *Principles of Synchros, Servos, and Gyros*.

GYROS—There are several different gyros used with the AFCS. You have already learned about most of them earlier in the RTM. The following paragraphs provide a review of gyros and how they specifically affect the AFCS.

Vertical Gyro—The vertical gyroscope *(Figure 8-17)* is an electrically driven gyro that provides pitch and bank attitude references for the AFCS. It can also provide pitch and bank attitude references for servo indicators and other systems of the aircraft. It has enough signal load capacity to sustain several systems at the same time.

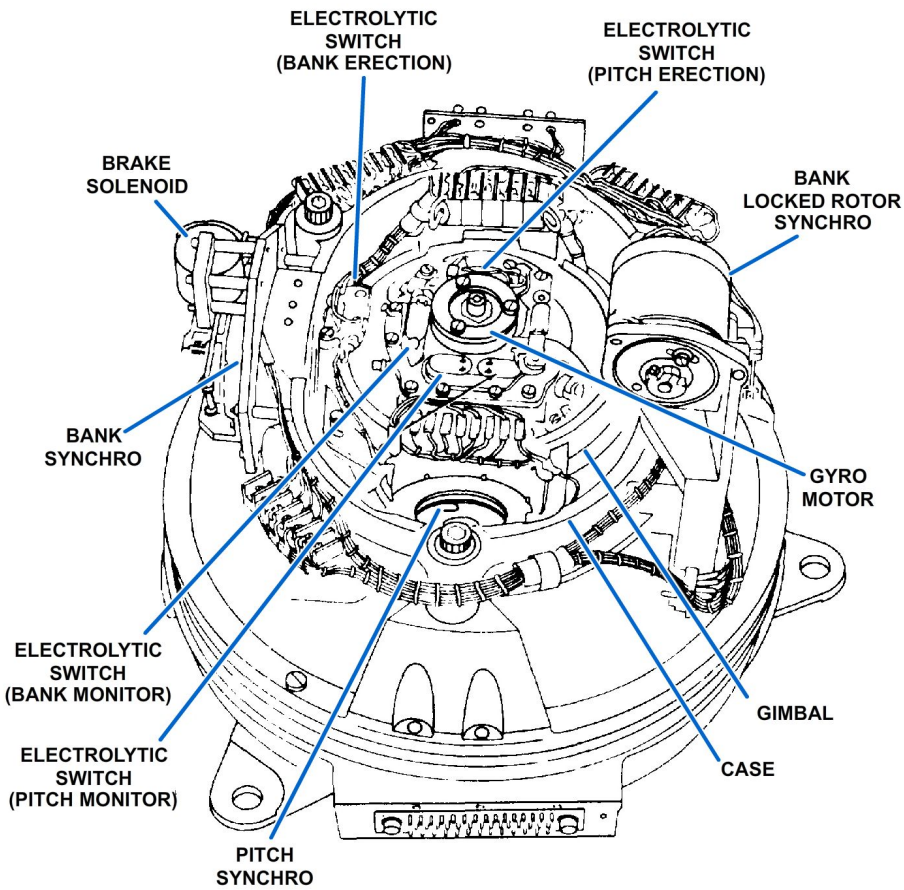


Figure 8-17 — Vertical gyro components.

The vertical gyro is a two-degree-of-freedom gyro. This gyro is termed the vertical gyro because it is continuously erect with its spin axis vertical to the surface of the earth. The spin axis provides a vertical reference for measurement of aircraft bank angle and pitch angle. Pitch and roll gimbals isolate the gyro from its housing and the aircraft. Thus, the aircraft can bank or pitch while the gyro remains vertical because of gyroscopic action *(Figure 8-18).* A pitch synchro, mounted on the vertical gyro's pitch pivot, continuously senses the relative pitch angle between gyro and aircraft. Similarly, a bank synchro, mounted on the vertical gyro's bank pivot, continuously senses the relative bank angle between gyro and aircraft.

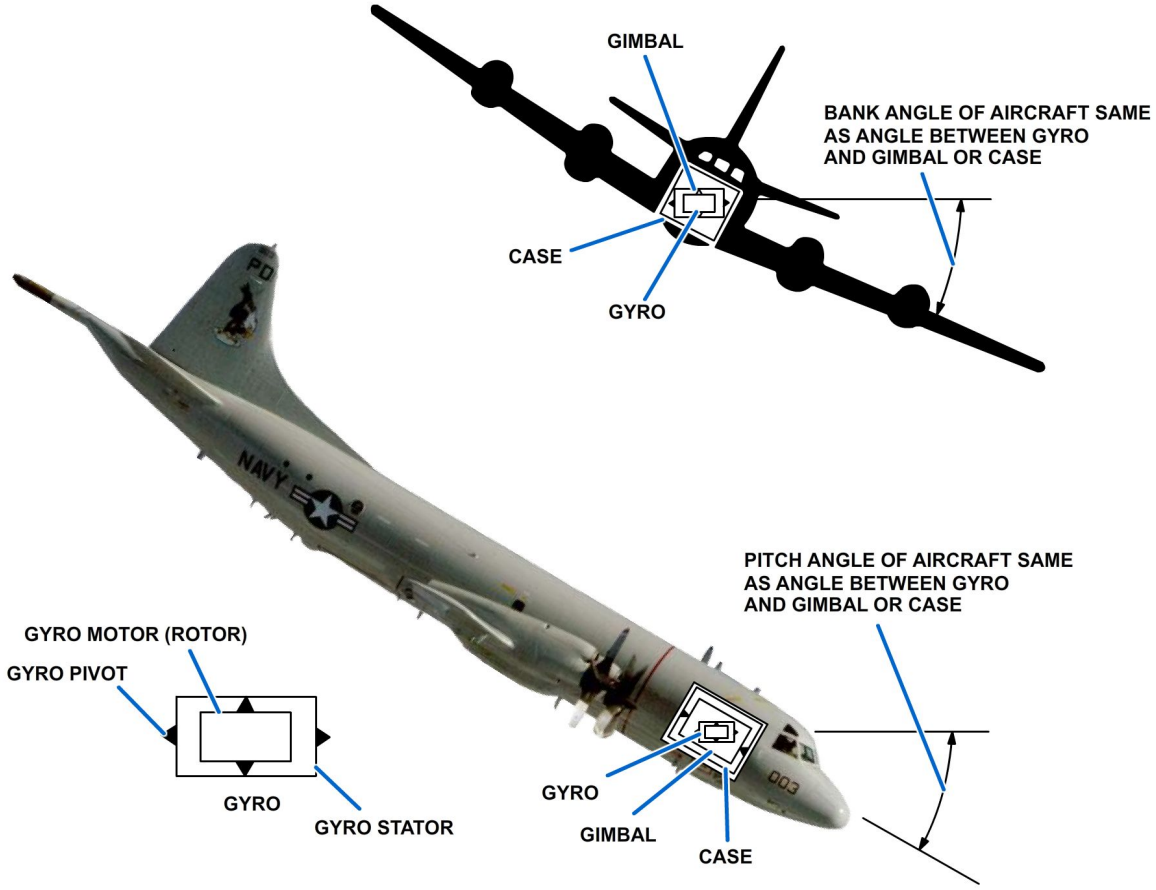


Figure 8-18 — Vertical pitch and roll reference.

The gyro motor rotates at a speed of about 20,000 RPM. A solenoid-operated friction brake prevents tilting and tumbling when the gyro motor is idle and during the initial starting torque.

Synchros mounted on the gyro detect motion between the gyro, the gyro gimbal, and the gyro case. A synchro generates a weak signal when its rotor is displaced from its stator. The pitch synchro mounts with its rotor on the gyro pivot and its stator on the gyro gimbal. Thus, the synchro measures the displacement angle between the gyro and the gimbal. This is the pitch displacement angle from the vertical reference. The bank synchro mounts with its rotor on the gyro gimbal pivot and its stator on the gyro case. Thus, the synchro measures the displacement angle between the gimbal and the case. This is the bank displacement angle from the vertical reference.

As the pitch attitude of the aircraft changes, the gyro case and gimbal turn about the gyro rotor. The pitch synchro rotor is held rigid in space by the gyro. The gyro motor generates voltages in the pitch synchro proportional to the aircraft's pitch angle with respect to the surface of the earth. During changes in pitch attitude, the bank synchro remains at null since the gyro gimbal is not free to rotate with respect to the case in pitch. Therefore, it tilts with the case.

As the bank attitude of the aircraft changes, the bank synchro stator turns about the bank synchro rotor. The gimbal is held rigid in space by the gyro because it is not free to rotate with respect to the gyro in bank. Thus, the bank synchro generates voltages proportional to the bank angle between the aircraft and the surface of the earth.

When the aircraft yaws, the case, the gimbal, and the gyro stator turn about the rotating gyro motor. This has no significant effect upon the relative positions between the gyro and the case. As a result, there are no pitch and bank synchro output voltages in response to changes in yaw.

Three-Axis Rate Gyro—Rate gyros sense the rate of movement of an aircraft about its vertical, lateral, or longitudinal axis. They provide synchro signal outputs representing yaw rate, pitch rate, or roll rate to the air navigation computer. These units are sometimes very similar in appearance to the rate switching gyro, but they provide entirely different information to the system. Physically, rate gyroscopes are the same. They differ only in respect to calibration, alignment, range, sensitivity, and natural frequency. Each gyro measures angular rate. It uses the proportional precessional torque generated by the rate of movement about the gyro-sensitive axis *(Figure 8-19)* to make these measurements.

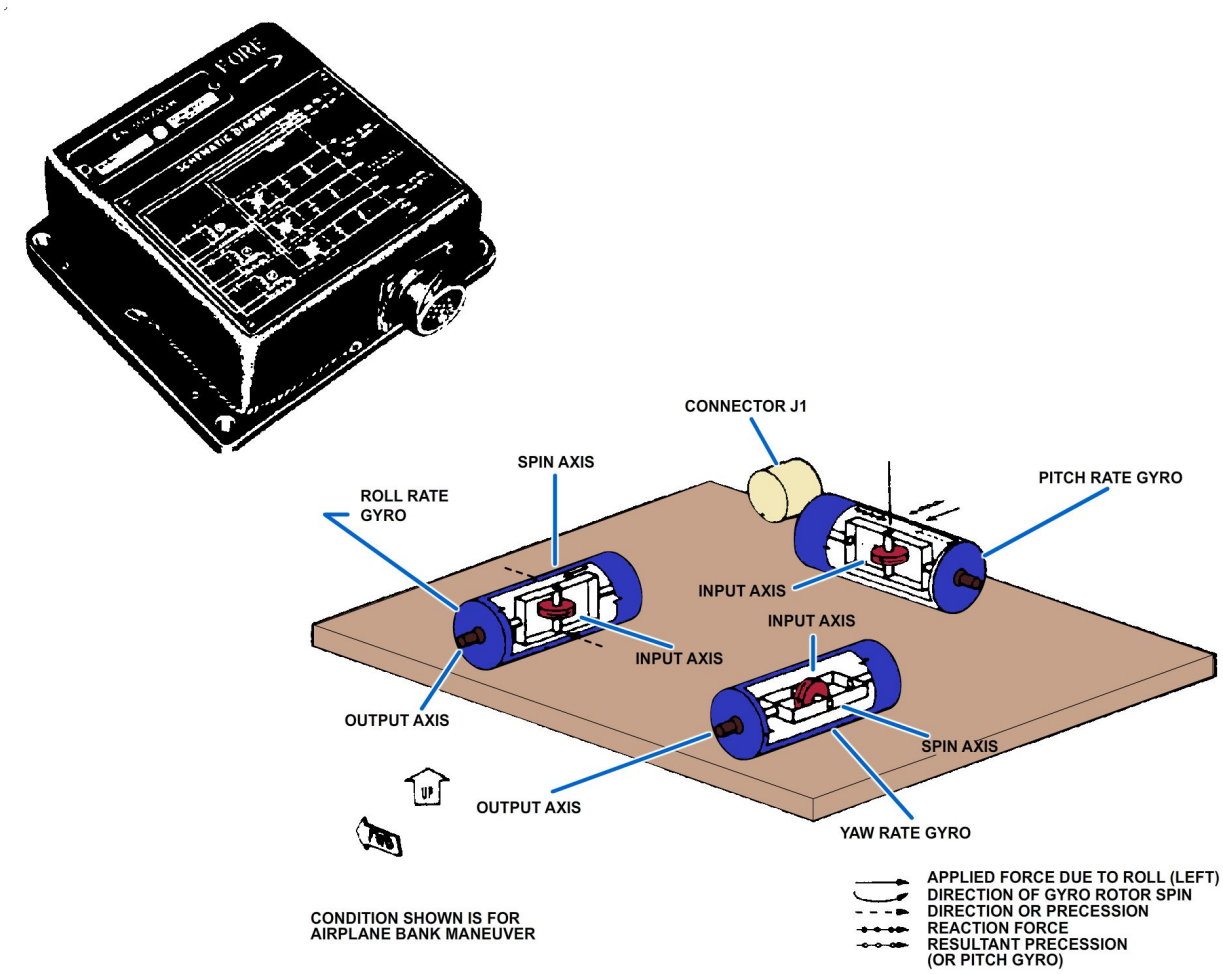


Figure 8-19 — Three-axis rate gyro orientation diagram.

Internally, each rate gyro consists of a small viscous-damped, single-degree-of-freedom gyro with a differential transformer pickoff *(Figure 8-20)*. The gyroscopic element of each gyro is the rotor of a synchronous motor. The rotor mounts in a gimbal frame and spins at high speed about its spin axis. The gimbal is flexible and free to rotate about an output axis. This axis is perpendicular to both the spin axis and the input axis. A torsion-restoring spring that couples the gimbal to the case limits the rotational freedom about

the output axis. The gyro gimbal carries the pickoff rotor on an extension along its output axis. The pickoff rotor senses the relative angular displacement of the gimbal and case.

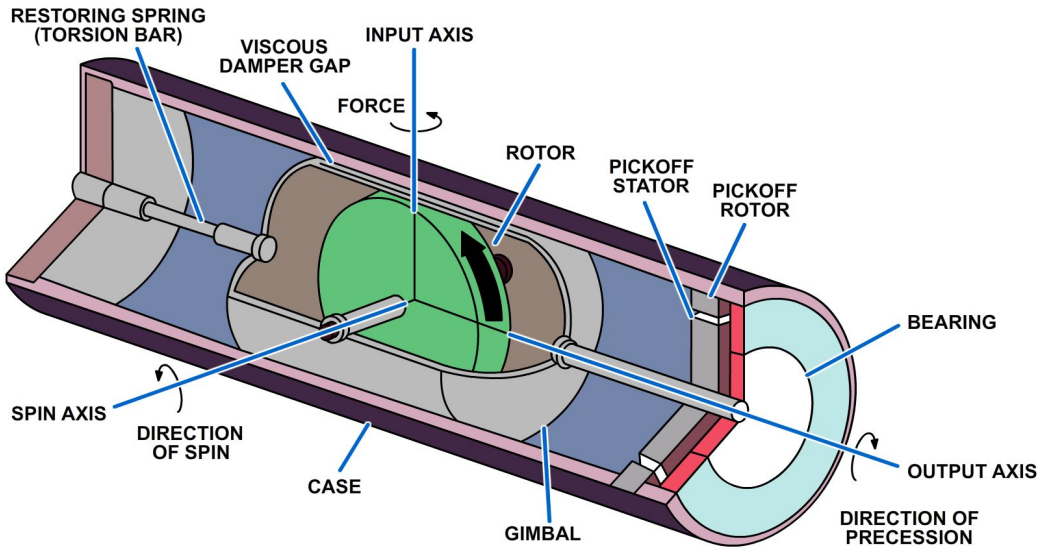


Figure 8-20 — Rate gyro axis orientation.

With the pickoff rotor in its zero or neutral position, the mutual inductance is zero. The current flowing in the pickoff primary causes essentially no voltage in the secondary (output) winding. As the pickoff rotor is turned one way or the other about its output axis by gyro gimbal deflection, a proportional mutual inductance is introduced. The polarity of the inductance (positive or negative) depends upon the direction of deflection from the neutral position. Hence, the current flowing in the primary produces a voltage proportional to this mutual inductance in the pickoff secondary. The output voltage is proportional to the aircraft's angular velocity input to the gyro in the particular axis.

COMPASS INFORMATION—Normally, compass information for the AFCS is supplied by the aircraft compass system or the Inertial Navigation System (INS). However, some compass information is developed for the AFCS.

The compass system/INS incorporates a gear train to drive several synchros. The gear train is driven by a motor generator unit that aligns to aircraft heading. Of the several synchros, one provides heading information to the pilot's compass indicator. Another synchro, which is attached to the gear train through a clutch, provides a clutched heading. When the AFCS is not engaged, the clutch remains deenergized, with its rotor spring loaded to an electrical null condition. When the pilot engages the AFCS, the clutch engages the engaged heading to establish a reference heading for the system. If the aircraft drifts off heading, the gear train drives against the spring tension on the rotor, generating an electrical signal. This signal goes to the aileron channel, much like the signal generator pickoff operation *(Figure 8-16)*. Limiters in the AFCS prevent the bank angle from becoming excessive when large heading errors are detected.

Another type of compass information is derived from the heading indicator in the flight station. The pilot selects a desired heading on the face of the indicator. The difference between the selected heading and the actual heading becomes an error signal to the AFCS. This error signal causes the aircraft to turn to the desired heading.

A radio navigation aid can also supply heading information to the AFCS. If the pilot desires to fly to a selected ground station, the radio receiver develops a signal to produce the desired ground track directly to the station.

AIR DATA INFORMATION—Changes in the speed of an aircraft also affect the effectiveness of the control surfaces. At a given altitude, slow speeds require more control surface movement than high speeds require to accomplish the same maneuver. The pilot maintains (or changes) the altitude by referencing the altimeter. The AFCS can also maintain a constant altitude. To accomplish this task the AFCS uses altitude data supplied by an air data sensor or Air Data Computer (ADC) as the reference altitude.

Airspeed—Control surface signals are modified by a gain control unit to compensate for changes in airspeed. This unit uses the difference between ram pressure and static pressure. A mechanical schematic of the gain control unit is shown in *Figure 8-21*. Here, you can see that as airspeed increases (ram air pressure increases), the bellows cause the spring to become more compressed. This compression allows the armature to move each potentiometer's sliding arm to modify the control surface signals an amount representative of the change in airspeed of the aircraft. When airspeed decreases, the armature moves to the right, selecting a different amplifier gain. The opposite occurs for increases in airspeed.

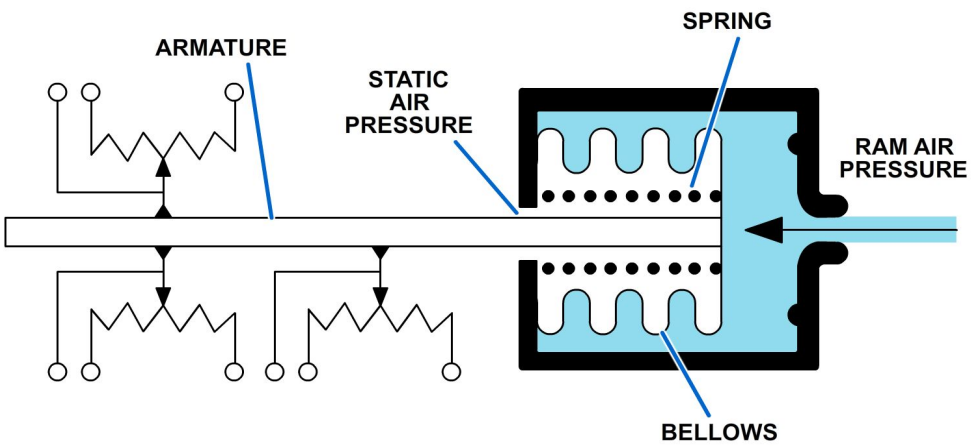


Figure 8-21 — Mechanical schematic of a gain control unit.

Altitude—The AFCS includes an altitude control feature to maintain the aircraft at a fixed altitude. The altitude controller consists of an aneroid, a mechanism for transmitting and magnifying the motion of the aneroid, and a solenoid-operated clutch. It also includes a synchro transmitter and a centering device for returning the synchro transmitter rotor to the null or no-signal position. Some aircraft do not use an altitude controller. In place of an altitude controller, the AFCS uses signals from the ADC.

Figure 8-22, view A, shows a three-quarter view of a barometric altitude control. The outside appearance of controls of this type varies, depending upon the manufacturer; however, the working parts are similar. *Figure 8-22, view B*, shows the internal parts of a barometric altitude control, and *view C* shows a simplified mechanical schematic.

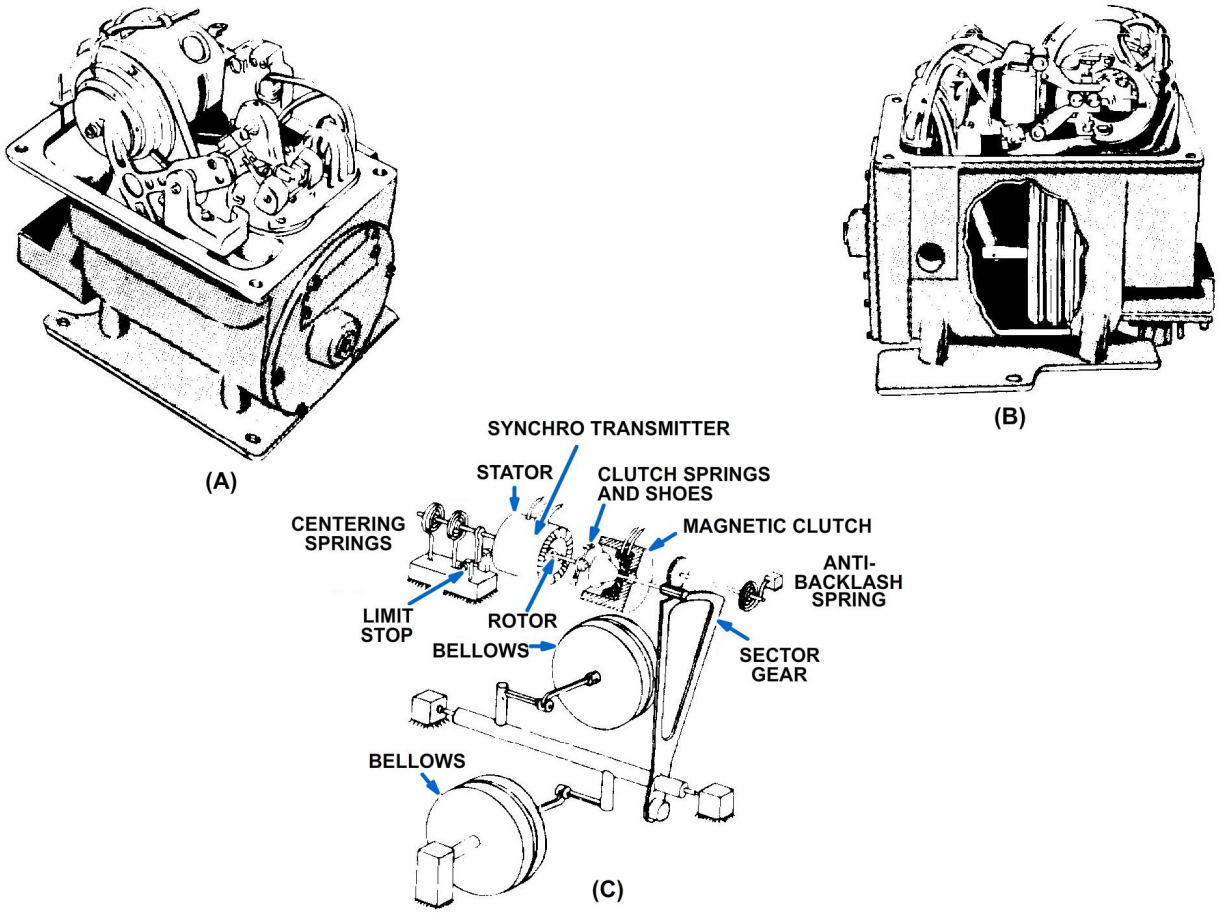


Figure 8-22 — (A) Barometric altitude control; (B) Internal parts; (C) Simplified schematic.

The aneroid consists of two diaphragms sealed internally at standard (sea level) barometric pressure. The two diaphragms connect in tandem to a single pushrod and are mounted in an airtight case *(Figure 8-22, view B)*. A tube connects the case to a source of static air pressure. The diaphragm pushrod mechanically links to one of the clutch plates. This linkage consists of a lever, a pivoted shaft to which a sector gear is attached, and a pinion gear.

When the aircraft deviates from the barometric pressure altitude to which the altitude control switch is set, the aneroid diaphragms move. This motion is transmitted through the linkage to displace the rotor of the synchro transmitter. This displacement generates a signal in the synchro transmitter stator. The signal is applied to the elevator channel to return the aircraft to the pressure altitude indicated by the aneroid. When the aircraft reaches the correct altitude, the synchro transmitter signal becomes zero, and normal AFCS operation resumes.

When the altitude control switch is off, the magnetic clutch and the centering device actuating coil deenergizes. The deenergizing of the coils opens the clutch to disengage the synchro transmitter rotor from the aneroid mechanism. The centering yoke, by spring action, closes on the synchro transmitter rotor shaft lever to return the rotor to the null or no-signal position. In this way, the synchro transmitter rotor is always at the no-

signal position when altitude control is not selected. Since the clutch is disengaged, the aneroid is free to move. This allows the pilot to engage the altitude control at any time. Regardless of the aneroid position, the altitude that it senses is the one used as the reference altitude. It is not necessary to wait for synchronization or alignment.

FLAP POSITION INFORMATION—When the flaps are lowered on some aircraft, the increased lift causes the aircraft to gain altitude (normally called ballooning). Ballooning is undesirable, and it is counteracted by using nosedown pressure on the flight control. When the AFCS is engaged and the flaps are lowered, automatic nosedown force is applied to the elevator. Flap position is detected by the use of a flap position transmitter.

The flap position transmitter consists of two synchro transmitters with a single input shaft *(Figure 8-23).* The synchro transmitters supply flap position information to the AFCS elevator channel and the external flap position indicator.

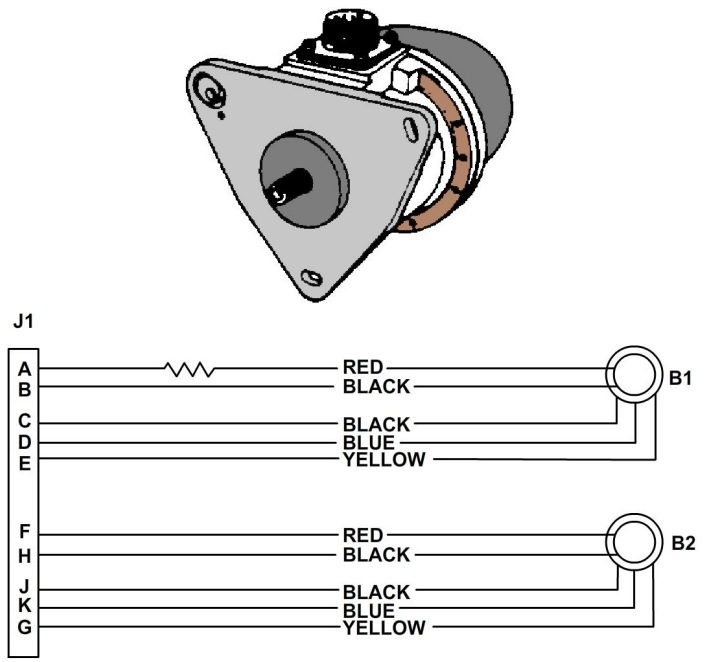


Figure 8-23 — Flap position transmitter and schematic.

ACCELEROMETER TRANSMITTER—The normal accelerometer *(Figure 8-24, view A)* generates a signal proportional to normal vertical acceleration. This signal is used for altitude or Mach hold vertical path damping and as the g-command reference. The unit consists of a cast housing assembly, a sensitive element assembly, bellows, and calibration resistors (R51, R52, and R53). The sensitive element assembly has an E pickoff, an armature and armature support, flexure springs, and a backplate.

When assembled, the sensitive element assembly and bellows are sealed inside the housing, which is filled with damping fluid. The metal bellows allow the volume of the damping fluid to change with temperature and pressure variations. The damping fluid provides viscous damping during motion of the armature.

The sensitive element is mechanically biased to produce zero output when mounted in the correct position and subjected to the normal gravity force of 1 g.

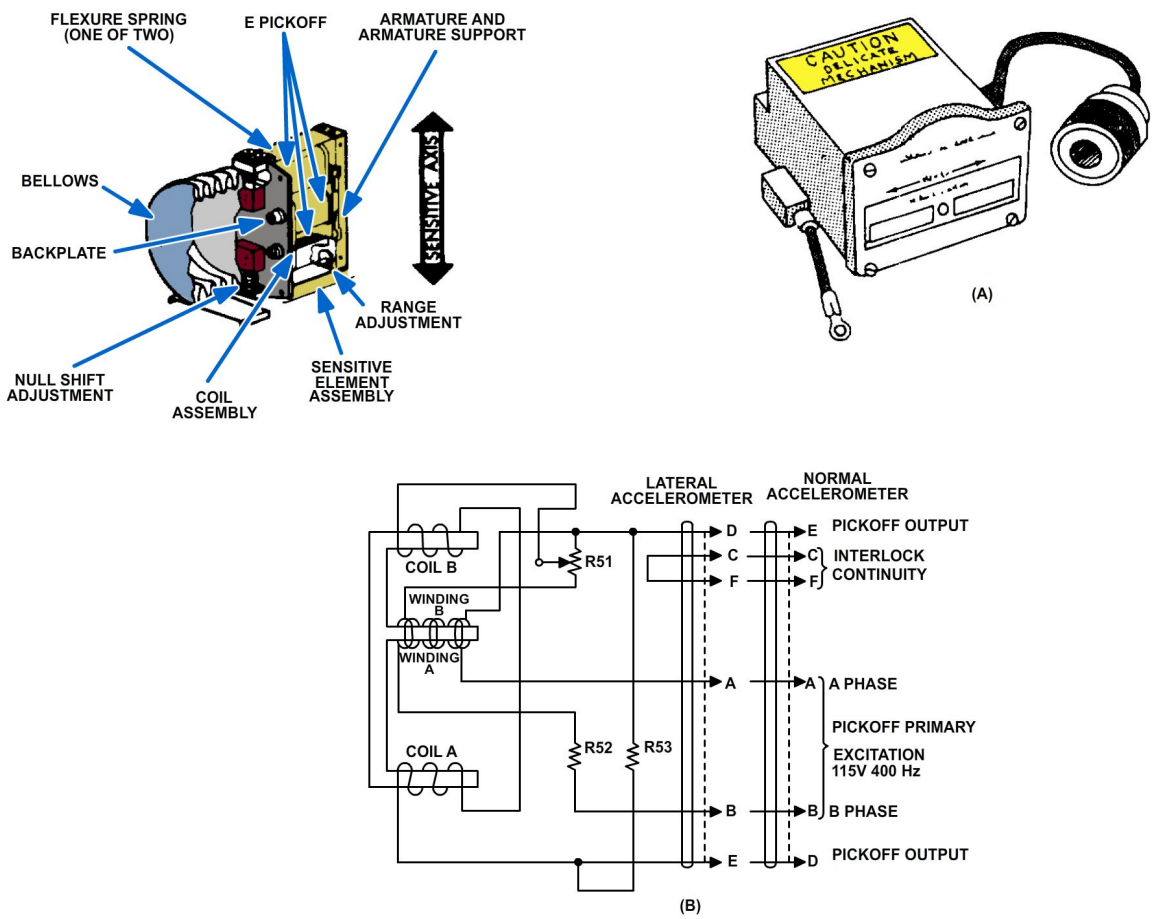


Figure 8-24 — Accelerometer transmitter.

While you read this section, refer to *Figure 8-24*. As the aircraft accelerates in the sensitive vertical direction, the suspended armature tends to remain behind due to its inertia. This reaction varies the reluctance of the magnetic circuit set up by the E pickoff windings and armature (*view B*). The armature completes the magnetic circuit through a small air gap. The relative motion between the armature and E pickoff varies the reluctance through the signal output windings. This variation results in a signal that is proportional to acceleration. When operating, the output voltage is either in phase or 180 degrees out of phase with the excitation, depending on the direction of acceleration.

COORDINATION INPUT—In some aircraft, a dynamic vertical sensor detects lateral accelerations (slip or skid) of the aircraft. The sensor supplies a signal to position the rudder to correct the slip or skid, coordinating the turn. The signal is proportional to the amount of the aircraft deviation from the vertical axis of the aircraft. In other aircraft, a horizontally mounted accelerometer aligned with the lateral axis of the aircraft provides the same information. Only the dynamic vertical sensor is covered in this RTM.

The dynamic vertical sensor consists of a viscous-damped pendulum mechanically connected to the rotor shaft of a transmitter synchro. The cutaway view of the sensor *(Figure 8-25)* shows the mechanism assembly, which includes a synchro transmitter with a pendulum and vane assembly attached to the rotor. The vane moves in an oil-filled chamber. The damping effect of the fluid gives a long-term sensing characteristic that makes the unit relatively insensitive to transient oscillations. The damping chamber also limits displacement of the pendulum to 10 degrees either side of the center position.

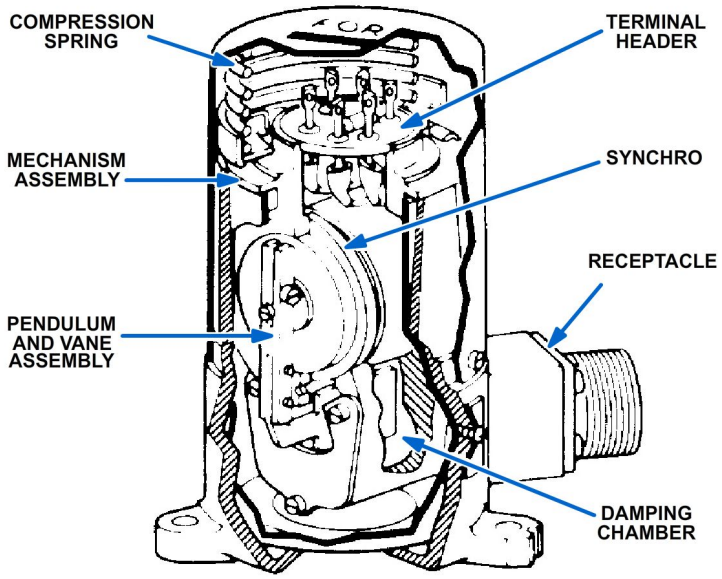


Figure 8-25 — Cutaway view of a dynamic vertical sensor.

A pin in the housing fits into a slot in the mechanism shell. This positions the mechanism to align the synchro rotor with the longitudinal axis of the aircraft when installed.

The sensor functions in the same manner as the ball in a turn-and-bank indicator. The ball gives a visual indication of slip or skid resulting from lateral acceleration. The sensor provides a signal output of this condition. *Figure 8-26* shows a diagram of the forces acting on the aircraft in a turn. Refer to this figure as you read this section. In a coordinated turn, the vertical and lateral forces resolve into a vector perpendicular to the span of the aircraft. When the aircraft is turning with the two forces in balance, the ball is centered; the pendulum in the sensor gives a null output.

When the aircraft bank angle is too large for the turn rate, the balance is upset *(Figure 8-26, view B)*. The ball moves away from the center toward the inside of the turn, and the pendulum moves the synchro rotor from the center null position. The rotor displacement produces a signal with magnitude proportional to the displacement angle and signal polarity corresponding to the direction of displacement. The unbalanced condition results from a sideways accelerating force, causing the aircraft to slip toward the inside of the turn.

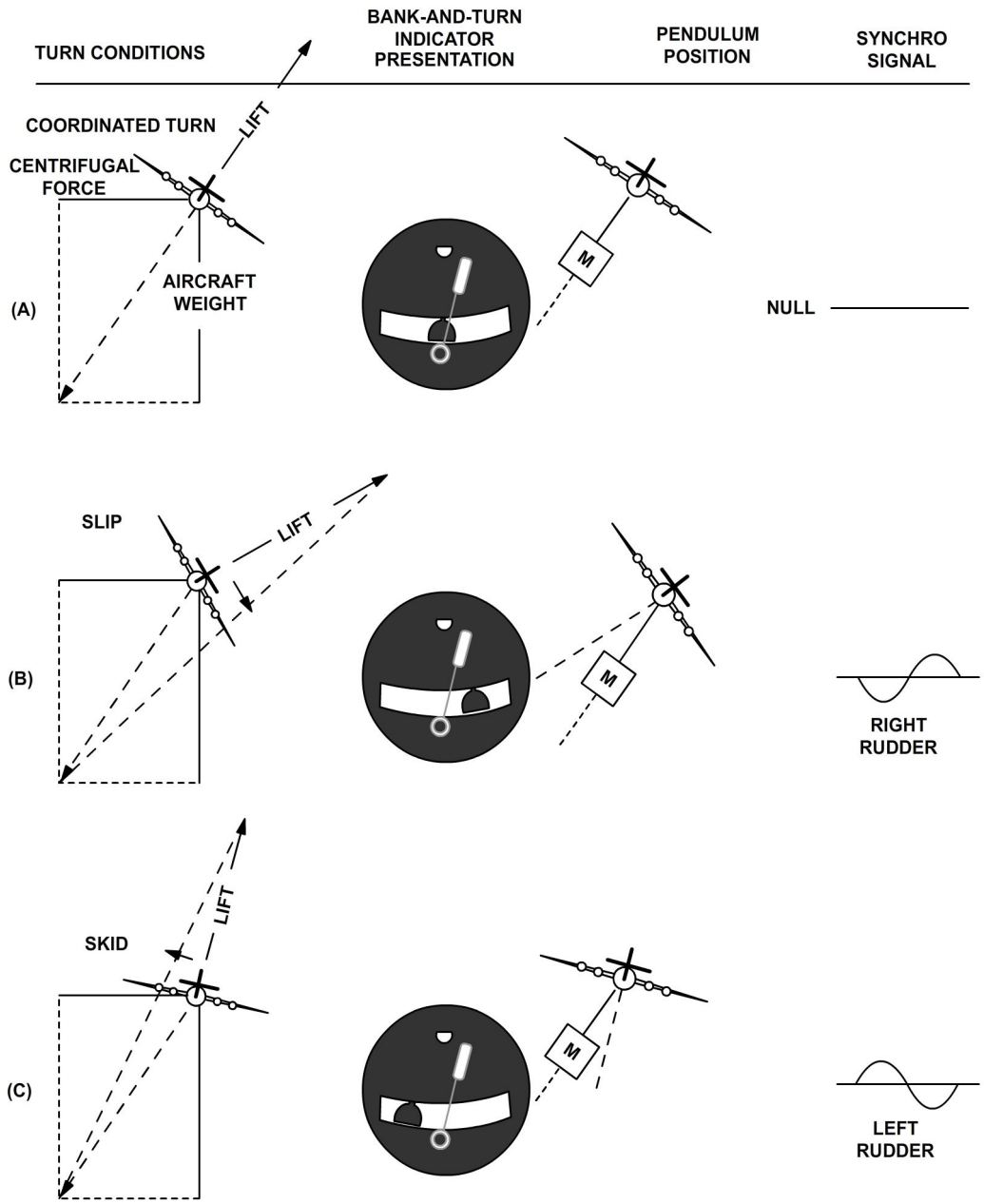


Figure 8-26 — Dynamic sensor pendulum positions: (A) Coordinated turn; (B) Slip; (C) Skid.

When the aircraft is insufficiently banked for the turn, an acceleration acts toward the outside of the turn *(Figure 8-26, view C)*. The ball in the turn-and-bank indicator moves from the center, and the pendulum in the dynamic vertical sensor is displaced from null in the direction corresponding to the ball. This gives a signal whose polarity is opposite to that of the signal when the aircraft was in a slip. The signal is fed to the rudder channel for the right or left rudder to coordinate the turn. Since the pendulum is unaffected by transients, the rudder adjustment is on a comparatively long-term basis.

Hydraulic Components

Hydraulic systems provide the physical power to move the flight control surfaces. All electrohydraulic (AFCS) actuators work in the same manner. A brief discussion of electrohydraulics is presented in the following paragraphs.

ELECTROHYDRAULIC SERVO ACTUATORS — Electrohydraulic servo actuators (hydraulic booster packages) are discussed in chapter 4 of this RTM. Modern aircraft use several types of actuators, with each booster actuator having at least two modes of operation—manual mode and electrical signals.

The first mode is the manual mode. Its primary purpose is to aid the pilot in manually positioning the control surfaces. Control surfaces on large aircraft are much too large to move unaided. On smaller, high-speed aircraft, the high air pressure makes it nearly impossible to move the controls unaided. In the manual mode of operation, the hydraulic booster package is connected between the pilot's control stick and the control surface. It provides hydraulic assistance to the pilot in a similar manner that power steering aids the driver of a car or truck.

The second mode of the hydraulic booster package uses electrical signals from the AFCS to move the flight control surfaces. In this mode, the booster package connects the AFCS to the control surface and provides the power to move the surface. Synchro devices on the boost package provide feedback signals to the AFCS *(Figure 8-27)*.

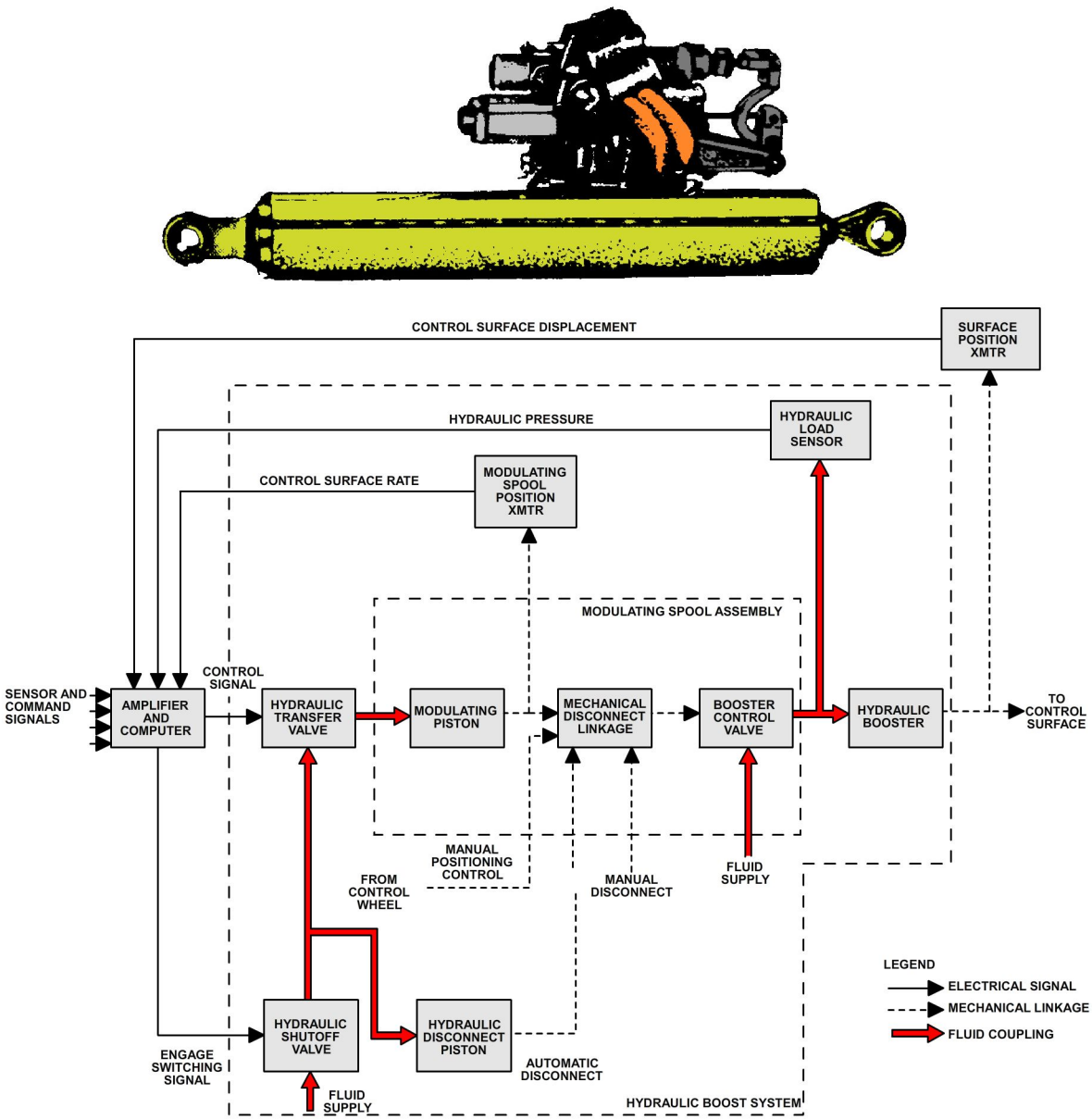


Figure 8-27 — Hydraulic booster block diagram.

The surface position transmitter sends the AFCS a signal representing the amount and direction of control surface displacement from the streamline position. This signal acts as a follow up to prevent overshoot of the controls. Also, it returns the control surface to the trimmed condition as the original signal returns to zero.

The modulating piston is displaced only when the control surface is in motion. The position of the modulating piston is monitored to sense the control surface rate of movement. This action generates a signal to damp control surface movement.

Hydraulic load sensors determine the amount of pressure the AFCS is applying to the control surface so the pilot can properly trim the aircraft before disengaging the AFCS. If the aircraft is not properly trimmed and the control pressure is suddenly relieved, the control surface moves rapidly, causing sudden aircraft movement.

Some aircraft use both manual and AFCS modes simultaneously. Aircraft stabilization is provided from the AFCS, while the pilot manually controls the aircraft. All flight control systems have a method of disconnecting the booster package. This method gives the pilot manual control of the flight control surfaces if the booster malfunctions or failure of the hydraulic system occurs.

AUTOMATIC TRIM—Some AFCS systems incorporate automatic trimming. When a signal is present in the control channel, there is an unbalance in fluid pressure at the input to the hydraulic booster. The hydraulic load sensor *(Figure 8-28)* detects this unbalance. Its signal is amplified and drives the trim servomotor. The engagement clutch engages when the AFCS is operating and the automatic trim system is functioning properly. The slip clutch allows the pilot to override the automatic trim in case of a malfunction. Most AFCSs use auto trim in the pitch channel; however, it can be used for yaw and roll as well.

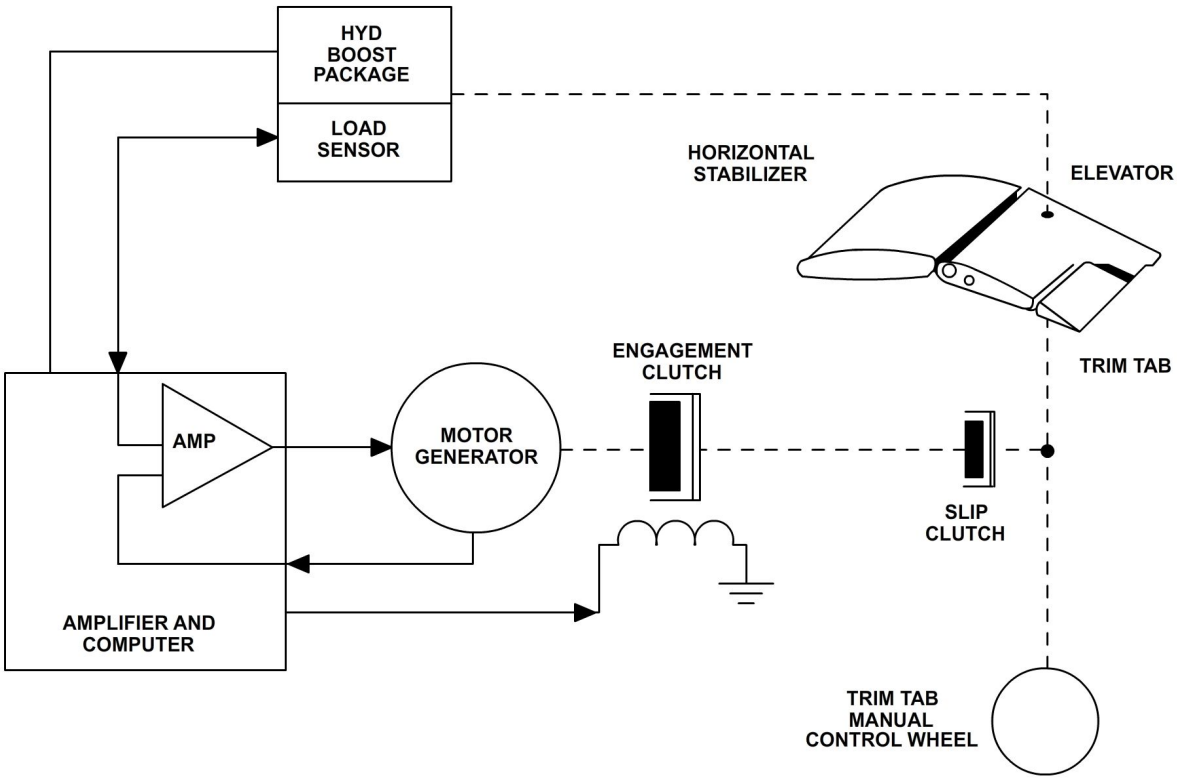


Figure 8-28 — Automatic pitch trim block diagram.

THEORY OF OPERATION

The AFCS has three main control channels to control movement of the aircraft about its axis. These channels control the yaw (rudder), roll (aileron), and pitch (elevator). Each of the control channels has similar functional equipment groupings. The groupings include controls, sensors, signal coupling circuits, AFCS servo loops, and aircraft flight controls.

Each channel of the AFCS supplies control signals to the flight controls and receives error signals from the sensors. The sensors and the signal coupling circuits in use in each control channel depend on the mode of operation. The AFCS servo loops and the aircraft flight control system provide the final amplifying link to move the flight control surfaces.

Look at *Figure 8-29*. Each AFCS control channel is basically the same; however, its design depends on the type and mission of the aircraft.

NOTE

The AFCS channel shown in Figure 8-29 represents the basic design of the channel and is for instructional use only. For further study of the AFCS, you should refer to the Maintenance Instruction Manual (MIM) for your particular aircraft.

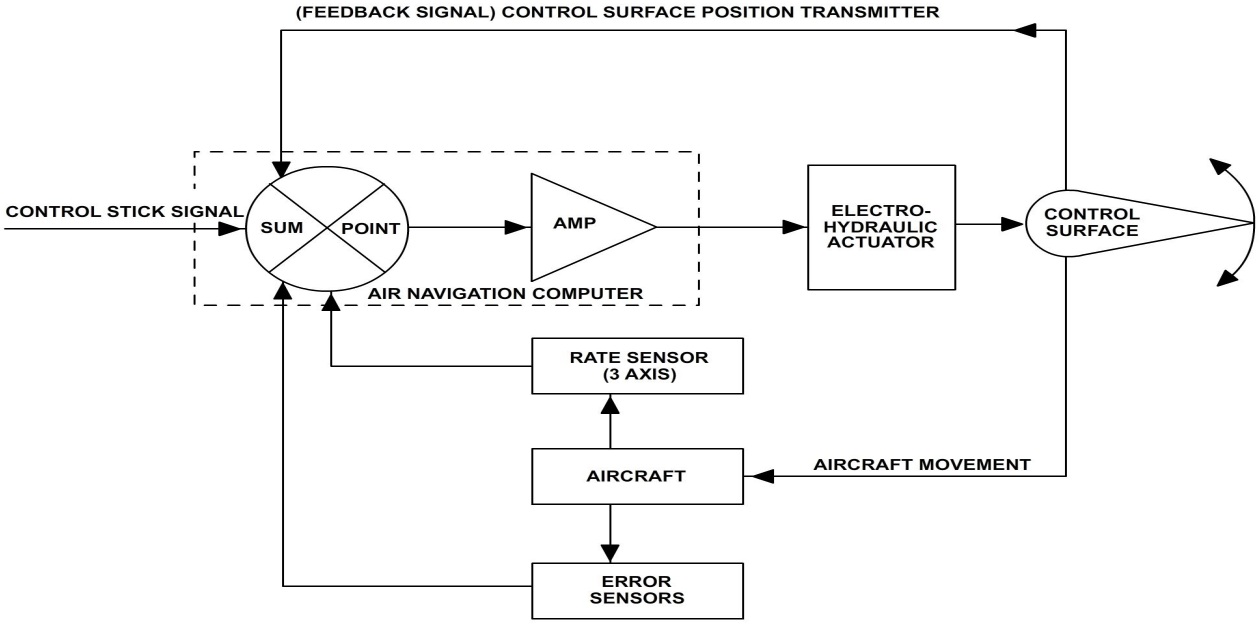


Figure 8-29 — Basic AFCS control channel.

The Air Navigation Computer (ANC) receives various error and control signals. These weak signals are coupled (summed), modified, and amplified to develop the control surface command signal to drive the electrohydraulic actuators. The actuators move a certain direction for a specific distance, depending on the command signal's polarity and magnitude.

The flight control surfaces (rudder, aileron, and elevator) are mechanically linked to the electrohydraulic actuators. As the control surface moves, a position transmitter synchro develops a feedback signal having the opposite polarity to the error signal. The magnitude of the feedback signal increases as the control surface displacement increases. When the error signal and feedback signal are equal and opposite in magnitude and polarity, the control surface will no longer move.

Movement of the control surface causes the aircraft to displace about its axis (or reference). This movement corrects the original error signal as sensed by the sensors. Without any error signal inputs to the control channel of the amplifier/computer, only the feedback signal is present. The feedback signal is opposite in polarity and magnitude to the original error signal. This drives the electrohydraulic actuator an equal distance in the opposite direction and brings the control surface back to the null or reference position.

AFCS MODES

This part of the chapter contains a brief description of the various modes available in a typical AFCS. The pilot selects one of these modes on the AFCS control panel by moving the control stick or using knobs on some instruments. Because the circuitry is complex and varies among the different weapons systems, no specific mode will be diagramed.

Stability Augmentation Mode

The stability augmentation (STAB AUG) mode provides improved control of the aircraft by automatically damping oscillations about the pitch, roll, and yaw axes. Signals from rate gyroscopes command control surface movement through electrohydraulic actuators. In some high-speed aircraft, STAB AUG is considered critical to safe flight. For this reason, the STAB AUG engagement switch connects in series with all other modes of the AFCS. This arrangement ensures that STAB AUG is engaged before any other mode of the AFCS.

Attitude Hold

The attitude hold mode is the basic, hands-off mode of operation. With attitude hold mode engaged, the AFCS maintains aircraft attitude at the time of engagement in pitch and roll. This particular mode is governed by the actual degrees of bank or pitch of the aircraft. For example, a typical attitude hold mode will release when the aircraft exceeds ±60 degrees in pitch or ±70 degrees in roll.

Altitude Hold

With altitude hold engaged, the aircraft will maintain the altitude at the time of engagement. If the aircraft is climbing or diving at engagement, the aircraft returns to the altitude that existed at engagement. The AFCS receives control signals for this mode from the ADC.

Heading Hold

With heading hold engaged, the AFCS maintains aircraft heading at the time of engagement. If the pilot is flying a heading of 180 degrees and engages the heading hold, the AFCS maintains the heading of 180 degrees.

Control Stick Steering/Control Wheel Steering

The control stick steering/control wheel steering mode lets the pilot manually (moving the stick/wheel) change the attitude of the aircraft with the AFCS engaged without disengaging it. After achieving the new attitude, the pilot releases the stick/wheel, and the AFCS resumes control of the aircraft.

Heading Select

In the heading select mode, the aircraft will automatically turn to a course selected by the pilot. Upon engagement, the aircraft will assume a fixed maximum roll and turn to the selected heading.

Mach Hold

The Mach hold function maintains the Mach number existing at the time of Mach hold engagement. In this mode, the ADC commands a pitch-up or pitch-down when airspeed is above or below the selected mach number.

Automatic Carrier Landing System (ACLS)

In the Automatic Carrier Landing System (ACLS) mode, the pilot can make a “hands-off” carrier landing. The aircraft follows command signals generated by the data link receiver.

Ground Control Bombing

Similar to ACLS, the aircraft follows command signals from personnel on the ground.

HELICOPTER AFCS

In many respects, the helicopter differs radically from conventional fixed-wing aircraft. However, rotary-wing aerodynamics are very similar to fixed-wing aerodynamics. A review of *Airman*, NAVEDTRA 14014, will help you understand the material in this discussion.

The AFCS is an electrohydromechanical system. It provides inputs to the flight control system to aid the pilot in maneuvering and handling the helicopter. The AFCS consists of three major subsystems—the Stability Augmentation System (SAS), the Stabilator System, and the Digital Automatic Flight Control System (DAFCS). All engagement controls for the three subsystems are on the AFCS and stabilator control panels. Each subsystem operates independently of the other two subsystems, and they complement one another. The pilot engages autopilot functions by pushing the AUTO PLT push button on the AFCS CONTROL panel. The AFCS system provides the following features:

- Pitch, roll, and yaw stability augmentation
- Stabilator control
- Cyclic, collective, and pedal trim
- Pitch and roll attitude hold
- Airspeed hold
- Heading hold
- Barometric altitude hold
- Radar altitude hold
- Pitch and roll hover augmentation/gust alleviation
- Turn coordination
- Maneuvering stability
- Automatic approach to hover
- Hover coupler
- Automatic depart
- Crew hover
- Longitudinal stick gradient augmentation (pitch bias actuator)
- Blade-fold assist
- Automatic preflight check

- Diagnostics (mode failure display)

AFCS Control Panels

The pilot controls the AFCS from the AFCS CONTROL panel and the stabilator control panel *(Figure 8-30* and *Figure 8-31)*. The stabilator control panel contains all the operating controls for the stabilator. All the other AFCS controls are on the AFCS CONTROL panel. All detectable AFCS mode failures, except the stabilator, illuminate the AFCS DEGRADED light on the caution/advisory panel. They will also illuminate the appropriate mode failure capsule on the failure advisory section of the AFCS CONTROL panel. Stabilator failures illuminate the STABILATOR caution light on the caution/advisory panel and generate an aural warning tone in the pilot's and copilot's headsets.

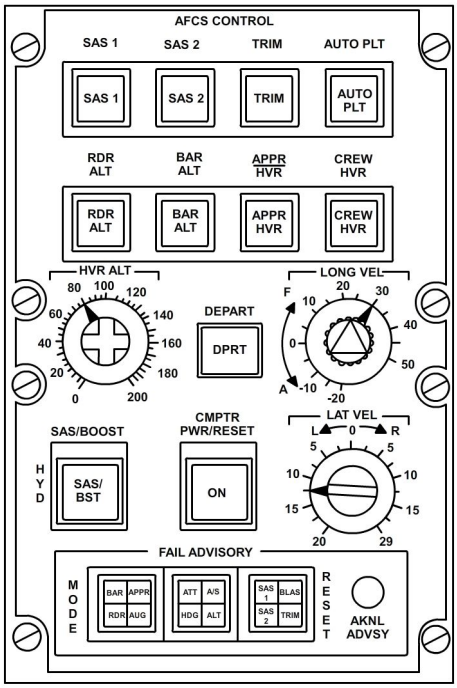


Figure 8-30 — Helicopter automatic flight control system panel.

The AFCS CONTROL panel has switches to electronically engage the SAS 1, SAS 2, and SAS/BOOST HYD switch. The SAS/BOOST HYD switch controls pressure application to SAS actuators and pitch boost servos.

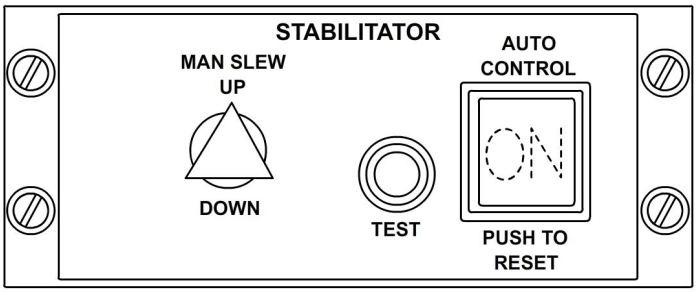


Figure 8-31 — Stabilator control panel.

AFCS Failure Monitoring

During AFCS failures, a trip of the fault circuit depends on airspeed, which disengages automatic mode when a fault occurs. As a result, the driver supply voltage to both amplifiers is removed. This deenergizes the auto engage relays in the stabilator control panel and turns off the AUTO CONTROL-PUSH TO RESET lighted pushbutton switch ON legend. The stabilator control panel applies an automatic mode disengagement signal to the primary and backup computers to turn on the STABILATOR legend on the mission displays. The automatic mode disengagement signal also energizes the audible warning signal unit that generates a beeping warning tone in the pilot's and copilot's headsets. The MASTER CAUTION PRESS TO RESET capsules on the pilot's and copilot's master warning panels will also go on when automatic mode is disengaged. Pressing either MASTER CAUTION PRESS TO RESET capsule will cause the pilot's and copilot's MASTER CAUTION PRESS TO RESET capsules and the audio warning tone to go off. The STABILATOR caution legend will remain on. Reengagement of the automatic mode can be attempted by pressing the AUTO CONTROL-PUSH TO RESET pushbutton switch. This applies an AUTO CONTROL RESET signal to each stabilator amplifier to initiate automatic mode engagement. If the fault has not been corrected, automatic mode will not engage.

The Advanced Flight Control Computer (AFCC) continuously monitors AFCS operation by comparing sensor input signals, by testing program functions, by checking output signals, and by checking servo response to output signals. Should a malfunction be detected, the AFCC automatically disables any function affected. The AFCC also provides fail advisory output signals to the FAIL ADVISORY legends on the AFCS control panel and to the primary and backup computers.

The AFCC checks SAS servo valve flapper valve coils by comparing the return current flow from the coil to the output drive current. Any difference will indicate an open or shorted valve solenoid. The AFCC will turn on the affected SAS 1 or SAS 2 FAIL ADVISORY legend on the AFCS control panel and in the case of SAS 2, disable the affected SAS 2 channel (pitch, roll, or yaw).

The pitch, roll, yaw, and collective trim servos each contain a position sensor that indicates trim position. If the sensor feedback to the AFCC does not follow the trim drive voltage, a malfunction is indicated. The AFCC will disable the affected channel and turn on the TRIM FAIL ADVISORY legend on the AFCS control panel.

Each FAIL ADVISORY legend will flash to indicate a malfunction. This, in turn, will flash the AFCS DEGRADED legend on the mission display panel and the MASTER CAUTION PRESS TO RESET capsule on the master warning panel. By pressing the AKNL ADVSY pushbutton on the AFCS control panel, the flashing FAIL ADVISORY legend will stop flashing, and go on steady. This allows a reset of the MASTER CAUTION PRESS TO RESET capsule by pressing the MASTER CAUTION PRESS TO RESET capsule. Pressing any of the MODE RESET switches resets the malfunctioned AFCC mode. If reset has occurred, the affected FAIL ADVISORY legend on the AFCS control panel and the AFCS DEGRADED legend on the Caution Advisory Panel will go off. *Table 8-1* provides a listing of AFCS control panel FAIL ADVISORY legends and the conditions they indicate.

Table 8-1 — AFCS control panel fail advisory legends

Legend	Condition
A/S	Airspeed hold is lost.
ALT	Barometric or radar altitude hold is lost or degraded, dependent upon which is selected.
ATT	Pitch or roll autopilot attitude hold is lost. If TRIM legend is also on, both pitch and roll attitudes have been lost or are malfunctioning. If pitch attitude failure occurs, the A/S legend will also go on, indicating airspeed hold is also not available.
AUG	Hover augmentation is lost. A/S, ATT, or SAS 1 and SAS 2 legends may also be on.
BIAS	Provisional.
CH	Loss of crew hover mode.
CORD	Turn coordination is lost. AUG, SAS 1 and SAS 2, or A/S legend may also be on.
CPLR	Approach/hover coupler capability is lost. ATT, A/S, or ALT legend may also be on.
HDG	Heading hold is lost or degraded.
SAS 1	A malfunction has occurred, causing improper pitch, roll, or yaw SAS 1 operation.
SAS 2	SAS 2 pitch and/or roll failure has occurred. Affected axis is automatically disabled.
TRIM	Cyclic stick pitch or roll trim, pedal yaw trim, or collective stick trim is lost or malfunctioning.

The AFCC monitors the AFCS while in flight. Malfunctions detected by the AFCC are stored in nonvolatile memory Flight Bite Code (FBC). Predefined malfunctions have preassigned codes to identify that particular problem. FBCs can be stored. If there are more than five problems, the first four and the last occurring FBC is stored. Upon landing, the FBCs are read out one at a time on the AFCC display by actuating the CODE ADV switch. FBCs can be cycled through and read out any number of times. FBCs can be cleared from memory with the CLR BITE switch.

The AFCC also has the capability of performing an AFCS test on the ground. A system test is initiated by setting the GND INIT/CODE ADV switch to GND INIT. The AFCC then proceeds to check sensors, exercise servos and actuators, and check internal functions. Malfunctions are recorded as a 3-digit numeric Ground Bite Code (GBC) and an 8-character alpha series of messages. Predefined malfunctions have preassigned codes to identify that particular problem. GBCs are cycled through by actuating the CODE ADV switch and can only be read out one time. Removing power from the AFCC will erase the GBCs.

Stability Augmentation System (SAS)

The SAS 1 system provides electrical control signals proportional to sensor inputs to the pitch, roll, and yaw servo valves. The servo valves convert electrical control signals into hydraulic commands for the SAS actuators. The SAS actuators respond to the hydraulic commands and produce mechanical movement of the flight control linkages without moving the cyclic sticks and pedals. The flight control linkages direct changes in main rotor and tail rotor pitch.

With both SAS 1 and SAS 2 engaged, the SAS actuators each have 10 percent authority of flight control movement. Each SAS system has 5 percent authority. With only SAS 1 engaged, the gain of the SAS amplifier is double, but the control authority remains at 5 percent. The AFCS control panel provides a signal to the SAS amplifier to indicate SAS 2 engagement.

The SAS 1 pitch channel provides dynamic stability for the helicopter's pitch axis. The No. 1 pitch rate gyro senses changes in pitch rate and applies this rate to the No. 1 stabilator amplifier. The No. 1 stabilator amplifier filters this pitch rate signal and applies it to the SAS amplifier. The SAS amplifier processes the pitch rate signal to remove long-term rate signals and applies a correction signal to the pitch SAS servo valve. The servo valve controls hydraulic pressure to the SAS actuator. The SAS actuator provides mechanical movement of the flight controls, producing rotor head movement opposing the sensed pitch rate.

The SAS 1 roll channel provides dynamic stability and limited roll attitude retention for the helicopter roll axis. A roll attitude signal (H-60S model) is provided to the SAS amplifier from the No. 1 Embedded Global Positioning System /Inertial Navigation System, also known as EGI, by the roll attitude signal path, which is provided by an internal roll rate gyro and provides sensed roll rate. In the H-60H model, the roll attitude signal is provided to the SAS amplifier from the copilot's Attitude Heading Reference System (AHRS) by the roll attitude signal path. The SAS amplifier receives a roll input signal representing any degree of roll attitude, but limits the signal to represent only up to ±2.1 degrees of roll attitude. The roll attitude signal is summed with a resultant rate + lag rate signal from the internal roll rate gyro. This resultant correction signal is applied to the roll SAS servo valve by the SAS 1 roll valve correction signal path. The servo valve controls the hydraulic pressure applied to the SAS actuator. The SAS actuator provides mechanical movement of the flight controls, producing rotor head movements that oppose the rate gyro and EGI inputs for H-60S models and oppose the rate and displacement gyro inputs for H-60H models. The opposing flight control movements result in the reduction of the sensed roll rate and roll attitude signals to provide rate damping for the helicopter to be restored to a level roll attitude.

The SAS 1 yaw channel provides dynamic stability for the helicopter's yaw axis and turn coordination at airspeeds of 50 knots or greater. At airspeeds of less than 50 knots (for H-60H models) and less than 60 knots (for H-60S models), the No. 1 stabilator amplifier provides a +12 to +15 vdc airspeed switch discrete. The discrete inhibits No. 1 lateral acceleration and roll rate signals in the SAS amplifier. The discrete controls the internal yaw rate gyro in the SAS amplifier as the yaw channel sensor. When sensing a yaw rate, the SAS amplifier processes it to remove long-term yaw rate signals. It then develops a short-term correction signal and applies it to the yaw SAS servo valve. The servo valve controls the actuator, which moves the flight controls to oppose the yaw rate.

At speeds below 50 knots (for H-60H models) and below 60 knots (for H-60S models), the airspeed transducer is applied to the No. 1 stabilator amplifier and sent to the SAS 1

amplifier (discrete signal). This discrete signal allows the yaw SAS amplifier and flight controls to use the internal yaw rate gyro. At speeds above 50 knots (for H-60H models) and above 60 knots (for H-60S models), the SAS amplifier receives a –12 to –15 VDC airspeed switch discrete from the No. 1 stabilator amplifier. This enables filtered No. 1 lateral acceleration and roll rate to sum with the yaw rate signal. Airspeed discrete from No. 1 stabilator amplifier is inhibited for this situation above 50 knots (for H-60H models) and above 60 knots (for H-60S models). Airspeed discrete is not removed from the SAS amplifier.

The AFCS consists of many components. To understand the entire system, you need to know what each component does. The following discussion describes the components that make up the AFCS.

AFCS POWER SWITCHING ASSEMBLY—The AFCS power switching assembly provides power switching for the DAFCScomputer and the SAS and BOOST shutoff valves.

NO. 1 LATERAL ACCELEROMETER—The accelerometer provides lateral acceleration to the SAS amplifier via the No. 1 stabilator amplifier for the turn coordination function of SAS 1.

NO. 1 PITCH RATE GYRO—The gyro provides pitch rate to the SAS amplifier via the No. 1 stabilator amplifier for the pitch dynamic stability function. The pitch rate gyros are also part of the stabilator control system.

SAS ACTUATORS—The SAS actuators, on the pilot-assist servos, convert electrical signals from the analog SAS 1 and digital SAS 2 to mechanical motion to move the flight controls. The actuators are electrohydraulic, operating from pressure supplied by the No. 2 transfer module, applied through the SAS shutoff valve. When the SAS/BOOST HYD switch is pressed, power is removed from the SAS shutoff valve, opening the valve. Opening the valve allows the actuators to move with signals applied from SAS 1, SAS 2, or both. With pressure removed from the actuators, a spring-loaded device locks the actuator piston in center position. Each actuator output piston connects to linkage. When the actuator piston becomes locked, it forms a fixed pivot point on one end of the linkage. This allows the linkage to move with stick, pedal, or trim inputs.

SAS AMPLIFIER—The SAS amplifier contains the No. 1 roll and yaw rate gyro power supplies and processing circuitry for SAS 1. The outputs of the internal roll and yaw rate gyros are used by SAS 1 and the DAFCS computer. The amplifier processes rate and proportional signals. Amplifier outputs operate the SAS actuators on the pilot-assist servo assembly.

NO. 1 STABILATOR AMPLIFIER—The No. 1 stabilator amplifier provides filtered lateral acceleration and pitch rate signals and an airspeed discrete to the SAS amplifier. The stabilator amplifier is part of the stabilator control system.

Stabilator System

The stabilator system optimizes trim attitudes for cruise, climb, and autorotation. Also, it provides pitch stability augmentation to complement the SAS system for additional redundancy. The stabilator system is completely independent of the other two AFCS subsystems except for common airspeed sensors, lateral accelerometers, and pitch rate gyros. The stabilator control system is a completely automatic fly-by-wire control system with a manual backup slew control. The primary purpose of the stabilator control system is to stop undesirable noseup attitudes. The noseup attitude is caused by rotor downwash impinging on the horizontal stabilator during low-speed flight and transition to a hover.

The stabilator panel contains an Automatic Control (AUTO CONTROL) switch, a TEST pushbutton, and a Manual Slew (MAN SLEW) switch. The AUTO CONTROL switch is used to engage the automatic mode or to reset the stabilator if it should fail. The pilot can manually position the stabilator to any position within the stabilator limits by moving the MAN SLEW switch. The TEST pushbutton is used to check the automatic mode fault detector.

Two electric jackscrews, working in series, position the stabilator. Each actuator provides one-half the input to position the stabilator and is controlled by a separate and redundant stabilator amplifier. The stabilator travels from 40 degrees trailing edge down for hover and low-speed flight below 30 knots to 8 degrees trailing edge up for cruise and maneuvering flight. Four inputs are required to position the stabilator—airspeed, collective stick position, lateral acceleration, and pitch rate.

Each stabilator amplifier receives these four inputs, but they receive the inputs from independent sensors. The DAFCS computer monitors each of these sensors for malfunctions, and the stabilator control system monitors and compares the position of the two actuators. Any system malfunction caused by a difference between the two stabilator actuator positions results in the stabilator remaining in the last position. A malfunction also causes an automatic power shutdown to both actuators, an aural tone to the pilot, and a STABILATOR caution light illuminating. The shutdown threshold between the two stabilator actuator positions is 10 degrees for airspeeds less than 50 Knots-Indicated Air Speed (KIAS) and 4 degrees for airspeeds greater than 120 KIAS, with a linear variation between 50 KIAS and 120 KIAS.

The airspeed input aligns the stabilator with the main rotor downwash during slow-speed flight. The collective stick position input decouples aircraft pitch attitude from collective position. Pitch rate and lateral acceleration inputs improve the dynamic response of the aircraft, especially in gusty air conditions. The pitch rate input supplements the dynamic stability provided by the SAS and DAFCS. The lateral accelerometer input decouples the aircraft pitch response from changes in tail rotor lift caused by changes in airflow on the canted tail induced with sideslip.

If a malfunction of the stabilator system occurs, the pilot can manually position the stabilator with the manual slew switch. The manual slew switch bypasses the stabilator amplifier automatic mode, applying power directly to the actuators through relays in the amplifiers. A stabilator position indicator aids the pilot in positioning the stabilator to any position between the stabilator travel limits. However, total travel is restricted if the malfunction is an actuator failure. Stabilator travel is restricted to 35 degrees if an actuator fails in the full-down position and 30 degrees if an actuator fails in the full-up position. The stabilator control rate is limited to ±6 degrees per second.

The following is a description of the components of the stabilator system. To understand the system, you will need to know what these components do.

AIRSPEED TRANSDUCER—The stabilator position program is a function of four sensor inputs. Each function has dual sensors for fail-safe operation. Airspeed for the No. 1 stabilator system is sensed by the airspeed transducer. It connects into the ATO pitot-static system and produces a dc output voltage that is proportional to airspeed.

AIR DATA TRANSDUCER—An air data transducer accomplishes airspeed sensing in the No. 2 stabilator system. The air data transducer connects into the pilot’s pitot-static system. It produces dc output voltages proportional to airspeed, altitude, and altitude rate. Airspeed data is used by the stabilator system and AFCS computer. Altitude and altitude rate are applied to the DAFCS computer only for altitude hold and depart modes of operation.

LATERAL ACCELEROMETERS—There are two lateral accelerometers—No. 1 and No 2. They each produce a dc output signal proportional to helicopter lateral acceleration. Each accelerometer dc signal goes to its related stabilator amplifier, where it is conditioned. The filtered lateral acceleration signal is used to position the stabilator to counteract tail rotor downwash on its upper wing surface. No. 1 and No. 2 filtered lateral acceleration is used by the DAFCS computer for signal quality comparison and software generation. No. 1 filtered lateral acceleration is also used in analog SAS for slip or skid correction above 50 knots.

STABILATOR POSITION INDICATOR—Stabilator position is displayed by an indicator on the center of the crew station instrument panel. This indicator is a synchro-type device driven by a synchro transmitter mounted in the stabilator position transmitter and limit switch assembly in the tail pylon.

STABILATOR CONTROL PANEL—Control functions for the system are provided by the stabilator control panel. The panel consists of an AUTO CONTROL PUSH TO RESET pushbutton switch, a TEST pushbutton, and a MAN SLEW UP/DOWN switch. Engagement of the system is automatic upon application of helicopter ac and dc power, provided all interlocks are in their proper condition.

TEST Pushbutton—A TEST pushbutton, operational below 50 knots, provides a check of the system fault monitors by inserting an airspeed-derived test signal into the No. 1 system. This signal drives only the No. 1 stabilator actuator, which produces a difference between the two actuators. The fault monitor circuit in either the No. 1 or No. 2 amplifier, or both, should disengage the automatic mode of operation when the programmed threshold trips.

MAN SLEW UP/DOWN Switch—If the automatic mode disengages, and cannot be reset due to a malfunction, the MAN SLEW switch is used to manually position the stabilator. Relays in the No. 1 and No. 2 stabilator amplifiers are operated by dc power from the switch when it is placed to UP or DOWN. Using the switch when the automatic mode is engaged will disengage the automatic mode. As a result, the STABILATOR caution light will go on, and a beeping tone will be heard in the Intercommunication System (ICS).

COLLECTIVE STICK POSITION SENSORS—Collective stick position also affects the stabilator position schedule. Stick position is sensed by two collective stick position sensors. No. 1 and No. 2 collective stick position sensors each produce a dc output signal proportional to the collective stick position. Both signals are used by the DAFCS computer for signal level comparison and for software generation of collective-to-yaw pedal coupling.

STABILATOR AMPLIFIER—Processing of airspeed, lateral acceleration, collective stick position, and pitch rate is accomplished within each stabilator amplifier. The amplifiers contain a power supply, processing and feedback circuits, and a fault monitor circuit. Sensor inputs are processed, summed, and applied to a motor driver circuit. The motor driver circuit output is applied, through contacts of relays, to the respective stabilator actuators. Any difference of actuator position is sensed by the fault monitor circuit in either or both amplifiers, causing an automatic mode disengagement.

ACTUATORS—Two actuators position the stabilator. Each actuator contains an electric motor (geared to a jackscrew), limit switches, and a feedback potentiometer. The potentiometer provides actuator position feedback to each amplifier. The actuators extend or retract, as necessary, to position the stabilator.

PITCH RATE GYROS—There are two pitch rate gyros—No. 1 and No. 2. Each rate gyro produces a dc output signal relative to the pitch rate of the aircraft. Each rate gyro signal goes to its respective stabilator amplifier, where it is conditioned. The stabilator system uses the filtered pitch rate signal to enhance the AFCS system's ability to correct short-term pitch disturbances. The DAFCS computer uses No. 1 and No. 2 filtered pitch rate signals for signal quality comparison and software generation. The No. 1 filtered pitch rate signal is also used in analog SAS for short-term pitch correction of the rotor head.

Digital Automatic Flight Control System (DAFCS)

The central component of the DAFCS is the digital computer. The computer commands the Pitch Bias Actuator (PBA), the inner-loop SAS actuators, and the outer-loop trim actuators in all four control channels. The computer also provides self-monitoring, fault isolation, and failure advisory.

The DAFCS uses two types of control—identified as inner loop and outer loop. The inner loop (SAS) uses rate damping to improve helicopter stability. This system is fast in response, is limited in authority, and operates without causing movement of the flight controls. The outer loop (AUTO PILOT) provides long-term inputs by trimming the flight controls to the position required to maintain the selected flight regime. It can drive the flight controls throughout their full range of travel (100-percent authority). The outer-loop drive rate is limited to 10 percent per second. Both inner and outer loops allow for complete pilot override through the normal use of the flight controls.

The DAFCS computer processes incoming information from various sensors *(Figure 8-32)* aboard the aircraft and stores this information in its memory. The Central Processing Unit (CPU) uses the sensor information to compute required correction signals. Inner-loop correction signals go to the SAS actuators, and outer-loop signals operate trim servos and actuators.

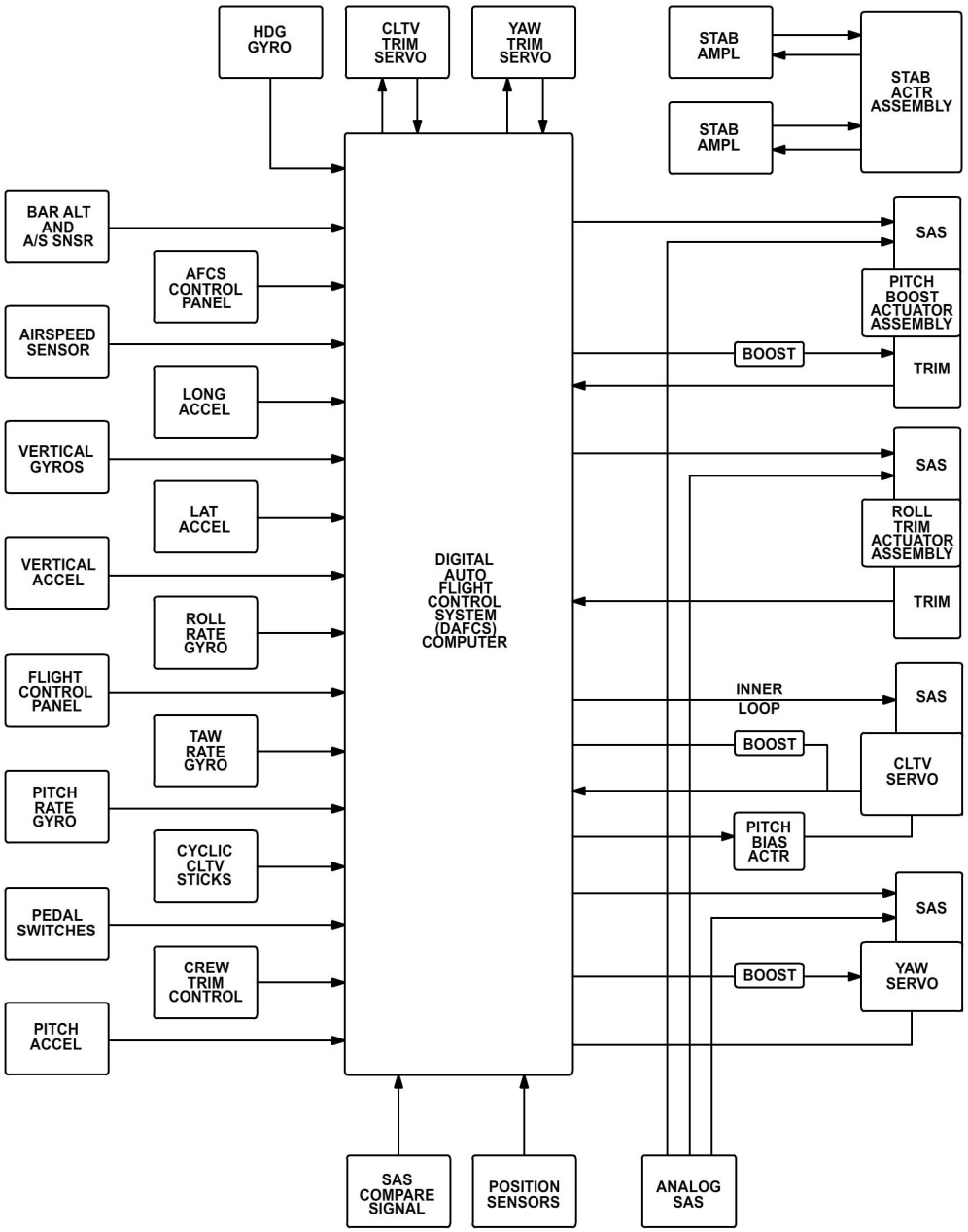


Figure 8-32 — DAFCS input/output block diagram.

TRIM SYSTEM—The parallel trim actuator assemblies provide the flight control force gradients, detent positions and the outer-loop autopilot control functions. The trim actuators command full control authority in all four control channels, but are rate-limited to 10 percent per second. Pressing the trim release switch (cyclic trim release, collective trim release, or pedal release) disengages the respective trim function and allows free control motion. Releasing the trim release switch reengages trim. For yaw trim release above 50 knots, the pilot must press the pedal microswitches and the cyclic trim switch. Below 50 knots, only the pedal microswitches have to be pressed. The pilot can override the trim control forces in all channels.

AUTOPILOT—The autopilot maintains helicopter pitch and roll attitude, airspeed, and heading during cruise flight and provides a coordinated turn feature at airspeeds above 50 knots. To engage the autopilot function, the pilot presses the control panel SAS 1 or

SAS 2 switches, the TRIM switch, and then the AUTO PLT pushbutton. The autopilot may be disengaged by pressing the AUTO PLT pushbutton or pressing the AFCS release button. The computer also provides command signals to the trim actuators to reposition the flight controls using the trim system.

ATTITUDE AND AIRSPEED HOLD—Attitude and airspeed holds are engaged with AUTO PLT. In the pitch channel, at airspeeds of less than 50 knots, attitude changes are commanded by changing the cyclic stick position. The pilot can use the TRIM REL switch or the four-direction (beeper) TRIM switch to change cyclic stick position. This causes the cyclic stick to move and the helicopter attitude to change about 5 degrees per second. When cyclic movement stops, the autopilot stabilizes the helicopter around the new stick position and attitude. At speeds above 50 knots and in bank angles less than 30 degrees, the system becomes airspeed sensitive in pitch. Operating the four-direction TRIM switch causes the cyclic stick to move and the helicopter to change airspeed reference at 6 knots per second. Because of variations in the pitot-static system during gusty conditions, integrated longitudinal acceleration is used for short-term correction. The airspeed sensor is used for long-term updates through a 3-second filter.

The roll channel autopilot holds roll attitude of the helicopter. Attitude information is supplied to the computer from the pilot's and copilot's A/A24G vertical gyros. The command signal is applied to roll SAS 1 and SAS 2 and the roll trim system. When the pilot actuates the four-direction TRIM switch, the helicopter roll attitude will change at about 6 degrees per second. In addition to the attitude hold feature, the system includes an automatic wing-leveling capability. During transitions from hover to airspeeds above 50 knots, this feature automatically retrims the aircraft from a left roll attitude in a hover to a wings-level attitude at 50 knots. After establishing a level attitude, the attitude hold feature maintains that attitude until a new roll attitude is commanded by the pilot.

HEADING HOLD—The yaw channel of the autopilot provides the heading hold feature for hover and forward flight. It is engaged whenever the AUTO PLT PBS is illuminated. Heading hold is an outer-loop function, operating through the yaw trim actuator; therefore, it will work only when the yaw trim is engaged. Releasing all pedal switches at a given heading synchronizes the trim system to the established heading. A potentiometer in the yaw trim actuator applies a trim position feedback signal to the computer. This signal cancels the drive signal at the desired position, stopping the motor. The yaw autopilot also uses a collective stick position sensor to hold reference heading for yaw excursions caused by main rotor torque changes. The collective stick position sensor is controlled by an airspeed signal that reduces its gain as airspeed increases. When the heading hold is engaged, the HDG TRIM (slew) switch on the collective lets the pilot make heading changes without retrimming. Below 50 KIAS, the aircraft slews at 3 degrees per second. Above 50 KIAS, actuation of the switch for less than 1 second provides a 1-degree heading change. Actuation for greater than 1 second provides a 1 degree per second coordinated turn.

The heading hold is reengaged following a turn when the following conditions are maintained for 2 seconds:

- Aircraft roll attitude is within 2 degrees of wings level.
- Yaw rate is less than 2 degrees per second.
- The heading hold is disengaged by the weight-on-wheels switch when the aircraft is on the ground.

ALTITUDE HOLD—Either barometric or radar altitude hold is selectable from the AFCS CONTROL panel. With the altitude hold mode on, the DAFCS computer uses a reference altitude. The reference altitude comes from either the air data transducer or the radar altimeter, depending on whether barometric altitude hold or radar altitude hold is selected. The DAFCS computer uses altitude and rate from the barometric or radar altitude systems (depending on which hold mode is selected) and vertical acceleration to command the collective SAS and trim actuators. The computer also monitors engine torque to prevent dual-engine torque from exceeding 116 percent whenever the collective trim is positioning the collective. Barometric altitude hold is engaged at any altitude and airspeed by depressing the BAR ALT PBS with SAS 2 and autopilot engaged. Depressing the collective trim release button temporarily disengages the mode. Upon release of the trim switch, barometer altitude hold automatically reengages and maintains the altitude at the time of reengagement. Radar altitude hold is engaged at any altitude from 0 to 5,000 feet AGL and at any airspeed by depressing the RDR ALT PBS with SAS 2 and autopilot engaged.

When in the hover coupler mode, altitude hold is referenced to the altitude selected on the AFCS CONTROL panel HVR ALT potentiometer. Depressing the collective trim release temporarily disengages the mode. Upon release of the trim switch, radar altitude hold automatically reengages to the altitude selected on the AFCS CONTROL panel HVR ALT potentiometer. When in the hover coupler mode, transition from one altitude to another is made with the HVR ALT knob on the AFCS CONTROL panel. If the radar altitude mode should fail while engaged, the barometric altitude hold automatically engages. Integrated vertical acceleration provides short-term radar altitude corrections, and rate information from the radar altimeter altitude signal provides long-term updates.

HOVER AUGMENTATION/GUST ALLEVIATION—An additional feature of the SAS, provided only through SAS 2, is hover augmentation/gust alleviation. It further improves aircraft stability at low airspeed using attitude retention and longitudinal and lateral acceleration to eliminate drift.

TURN COORDINATION—Automatic turn coordination is provided at airspeeds greater than 50 knots. Turn coordination lets the pilot fly a coordinated turn with directional control provided by the AFCS. The AFCS uses lateral acceleration and roll rate to determine if the aircraft is out of balanced flight. It also provides the yaw SAS and yaw trim with the inputs necessary to maintain an automatic coordinated turn. Automatic turn coordination is engaged and heading hold disengaged when roll attitude is greater than 1 degree, and any of the following conditions exist:

- Lateral cyclic force is greater than 3 percent stick displacement.
- Cyclic trim release is pressed.
- Roll attitude is beeped beyond 2.5 degrees of bank angle.
- Actuation of the collective-mounted heading slew for greater than 1 second provides a 1 percent per second coordinated trim.

MANEUVERING STABILITY—Pitch control forces are increased to increase pilot effort required for a given pitch rate at bank angles greater than 30 degrees. The higher pitch control forces help alert the pilot to g-loading during maneuvering flight and are provided through the longitudinal trim actuator. A linear longitudinal stick force gradient is provided by trimming 1 percent forward stick for each 1.5 degrees angle of bank between 30 degrees and 75 degrees. At 75 degrees angle of bank, the longitudinal stick

force is equivalent to 30 percent of stick displacement. The maneuvering stability feature is engaged whenever the AUTO PLT PBS is illuminated.

AUTOMATIC APPROACH TO HOVER—The DAFCS provides the capability to perform an automatic approach to a zero longitudinal and any lateral groundspeed selected on the LAT VEL control knob. Also, the DAFCS can perform an automatic approach to any radar altitude selected on the HVR ALT control knob between 40 feet and 200 feet. If the HVR ALT is set below 40 feet, the approach will be made to 40 feet and then continued to the HVR ALT setting when the mode is switched from APPR to HVR. The automatic approach can start at any airspeed and altitude. The automatic approach is an outer-loop-only function, and it commands the aircraft to decelerate or descend until meeting the approach profile conditions. If the approach mode is selected when aircraft conditions are below the approach profile, the DAFCS commands the aircraft to decelerate. The aircraft will decelerate at 1 knot/second while in the radar altitude hold mode until the approach conditions are met. If the approach mode is selected when the aircraft is above the approach profile, the DAFCS commands the aircraft to descend. The descent occurs at 360 feet/minute when the aircraft is more than 50 feet above the approach profile. It occurs at 120 feet/minute when the aircraft is less than 50 feet above the profile. During these conditions, the DAFCS uses the radar altimeter until the approach profile conditions are met. When the approach profile conditions are met, the aircraft simultaneously decelerates at 1 knot/second and descends at 120 feet/minute. This profile is maintained until the aircraft attains 1 knot of Doppler groundspeed and comes to within 1 foot of the selected radar altitude. If the selected altitude is below 40 feet, the aircraft flies to 40 feet and zero longitudinal groundspeed and then descends to the selected attitude. When groundspeed equals 1 knot or less and the aircraft altitude is within 2 feet of the selected altitude, the hover coupler mode automatically engages. The aircraft then accelerates to the selected longitudinal groundspeed.

HOVER COUPLER—The hover coupler provides longitudinal and lateral groundspeed control and stabilization about the selected groundspeed and automatic altitude retention. The longitudinal and lateral groundspeed and the altitude are selectable on the AFCS CONTROL panel. Longitudinal and lateral groundspeed can also be beeped ±10 knots with the cyclic trim switch about the groundspeed selected on the AFCS CONTROL panel. The hover coupler mode can automatically engage at the termination of the automatic approach. Also, the pilot can manually engage it when the aircraft is hovering with less than 5 knots longitudinal groundspeed. To do this, the pilot presses the APPR/HVR button on the AFCS CONTROL panel with SAS 2, TRIM, and AUTO PLT engaged. The hover coupler engages when the longitudinal groundspeed is less than 5 knots if engaged manually. After engagement, the aircraft accelerates to the longitudinal and lateral groundspeeds selected on the AFCS CONTROL panel. Pressing and releasing the cyclic TRIM REL removes cyclic trim switch inputs. This action returns the aircraft to the LONG VEL and LAT VEL settings on the AFCS CONTROL panel. Because of Doppler noise, short-term longitudinal and lateral groundspeed is obtained from integrated longitudinal and lateral inertial acceleration. Long-term correction is obtained from the Doppler sensor using a 7-second filter.

AUTOMATIC DEPART—The automatic depart mode provides the capability to perform an automatic departure from a coupled hover or from an automatic approach. This mode can take the aircraft to a cruise airspeed of 100 KIAS and altitude of 500 feet. If the coupled hover or the automatic approach feature is engaged, the pilot engages the automatic depart mode by depressing the hover depart button on the cyclic grip. Depressing the DEPART PBS a second time disengages the automatic depart mode, but it doesn’t automatically reengage the RAD ALT hold. Depressing the hover depart

button a second time disengages the automatic depart mode and returns aircraft control to the pilot. Upon engagement, the aircraft accelerates at 2 knots/second and climbs at 480 feet/minute. During the departure, the DAFCS computer monitors engine torque to ensure that it does not exceed 116 percent. At 100 KIAS, the airspeed hold automatically engages; at a radar altitude of 500 feet, the radar altitude hold automatically engages. Any alternate cruise airspeed or altitude condition of less than 100 KIAS and 500 feet is available to the pilot. The pilot attains an alternate condition by depressing the cyclic trim release and collective trim release at the desired airspeed and altitude, respectively. If either trim release button is depressed and released, the hold mode (airspeed or altitude) associated with that control axis is engaged. The aircraft continues to follow the depart profile for the other axis until the final cruise condition for that axis is met.

The automatic depart mode is an outer-loop function operating through the pitch, roll, and collective trim actuators. As in the automatic approach mode, above 60 KIAS, roll attitude is maintained, and below 60 KIAS, the DAFCS commands roll to eliminate lateral drift.

CREW HOVER—The crew hover feature lets the crewmember position the helicopter during hoist and rescue operations. The crewmember controls the aircraft from the crew hover-trim panel. The crew hover controller has a control authority of ±5 knots. This authority is laterally and longitudinally about the reference values selected on the AFCS CONTROL panel plus the speeds beeped from the cyclic trim beep switch. The crew hover feature is activated from the AFCS CONTROL panel by depressing the CREW HVR button. It can be activated only if the hover coupler mode is already engaged.

PITCH BIAS ACTUATOR (PBA)—The PBA provides longitudinal cyclic displacement proportional to airspeed. The DAFCS commands the PBA as a function of pitch attitude, pitch rate, and airspeed. The PBA is an electromechanical series actuator with ±15 percent control authority and ±3 percent per second rate limit. The PBA functions automatically upon application of power to the DAFCS computer, and it isn't selectable on the AFCS control panel. The DAFCS computer monitors the PBA position to confirm correct response to the input commands. If the PBA fails, the DAFCS lights the BIAS advisory light and flashes the AFCS DEGRADED light. Also, the DAFCS commands the PBA to a predetermined position, depending on the type of failure. The PBA is driven by the DAFCS computer as a function of airspeed, pitch rate, and pitch attitude. PBA failure modes are as follows:

- Attitude failure—bias actuator centered.
- Pitch rate failure—faded out pitch rate component.
- Airspeed failure—actuator goes to 120-knot position and attitude, and rate continues to function.
- Actuator failure—power removed from actuator.

If the system malfunctions, the BIAS Fail Advisory light on the AFCS CONTROL panel will go on, and, in some cases, remove power from the actuator. If the malfunction that caused the shutdown was of an intermittent nature, the actuator operation can be reset by pressing the appropriate MODE RESET button.

End of Chapter 8

AUTOMATIC FLIGHT CONTROL AND STABILIZATION SYSTEMS

Review Questions

8-1. What are the two main purposes of the AFCS?

A. To reduce flight time and maintenance
B. To provide command and control
C. To ease pilot workload and to provide aircraft stability at all speeds
D. To lessen the time required to start control and movement

8-2. What is an airfoil?

A. Any part of an aircraft designed to produce lift
B. Only the aircraft's leading edge of rounded surfaces
C. Any device mounted on the leading edge and trailing edge
D. Only the Bottom surface of an aircraft

8-3. When the pressure on both sides of the airfoil is nearly equal, what happens to the airfoil?

A. It produces drag
B. It remains constant
C. It increases aircraft speed.
D. It stalls

8-4. On a fixed-wing aircraft, what control surface(s) correct(s) for yaw?

A. Ailerons
B. Rudders
C. Elevators
D. Wings

8-5. As fuel is used, what must the pilot do to lessen lift and prevent a gain in altitude?

A. Reduce angle of attack on the wing
B. Control pitch
C. Adjust ailerons
D. Use the rudder to correct any tendency of the aircraft

8-6. In a helicopter with a constant speed rotor, how does the pilot increase lift?

A. By increasing blade angle of tail rotor
B. By changing tail rotor pitch to compensate for increases or decreases
C. By changing tail rotor speed
D. By increasing the airfoil's angle of attack (blade pitch)

8-7. When does the action called coning take place?

A. When the pilot increases tail rotor speed
B. When the pilot applies collective to the main rotor
C. When there is a decrease in main rotor torque
D. When there are changes to tail rotor pitch

8-8. What two types of altitude signals can the AFCS use to maintain a constant altitude?

A. Sensor and amplifier
B. Data link and aileron
C. Radar and barometric altimeter
D. Fire control system and weapons control

8-9. Why is the AFCS synchronized with the flight controls before engaging the AFCS?

A. To prevent sudden and violent maneuvers upon engagement
B. To maintain the aircraft at a constant altitude
C. To use data-link systems to fly the aircraft during approaches and landings
D. To program a pilot-desired maneuver that is within the capability of the system

8-10. What unit is considered the heart of the AFCS?

A. The control panel
B. The air navigation computer
C. The altitude reference
D. The command coupler

8-11. What AFCS component provides signal outputs representing yaw, pitch, and roll rates?

A. Roll computer amplifier
B. Pitch computer amplifier
C. Heading computer
D. Three-axis rate gyro

8-12. What type of heading signal does the AFCS receive from the compass/INS system?

A. Gear train
B. Tension
C. Reference
D. Clutched

8-13. What are the two modes of operation for electrohydraulic servo actuators?

A. Manual and hydraulics
B. Manual and electrical signals
C. Electrical and pneumatic
D. Synchro and hydro

8-14. What unit(s) of the AFCS send(s) a signal that acts as a followup to flight control movement?

A. Synchro device on the boost package
B. Load sensor
C. Surface position transmitter
D. Boost package

8-15. Name the three major systems that make up the AFCS for helicopters.

A. Longitudinal stick gradient augmentation, blade-fold assist, and stabilator control
B. Stability augmentation system, stabilator system, and digital automatic flight control
C. Stabilator control, automatic approach to hover, and heading hold
D. Maneuvering stability, radar altitude hold, and heading hold

8-16. When only SAS 1 is engaged, what is the percentage of flight control authority?

A. 5
B. 10
C. 12
D. 15

8-17. What is the primary purpose of the stabilator system?

A. To remove long-term yaw rate signals
B. To limit roll stability
C. To stop undesirable noseup attitudes
D. To control the internal yaw rate gyro

8-18. When is the stabilator system TEST pushbutton operational?

A. When airspeed is above 50 knots
B. When airspeed is below 50 knots
C. When airspeed is 60 knots
D. When airspeed is between 60 and 70 knots

8-19. What is the purpose of the DAFCS trim actuators?

A. To provide actuator position feedback
B. To improve helicopter stability
C. To correct short-term pitch disturbances
D. To provide self-monitoring, fault isolation

8-20. What is the rate limit, in percent per second, of the DAFCS trim actuators?

A. 5
B. 10
C. 15
D. 20

8-21. What is the effective altitude range in feet for the DAFCS radar altitude hold mode?

A. 0 to 5,000
B. 5,000 to 6,000
C. 10,000 to 15,000
D. 20,000 to 25,000

8-22. When the helicopter is less than 50 feet above the approach profile, what is the rate of degrees of descent, in feet per minute?

A. 100
B. 120
C. 360
D. 400

RATE TRAINING MANUAL – USER UPDATE

CNATT makes every effort to keep their manuals up-to-date and free of technical errors. We appreciate your help in this process. If you have an idea for improving this manual, or if you find an error, a typographical mistake, or an inaccuracy in CNATT manuals, please write or email us, using this form or a photocopy. Be sure to include the exact chapter number, topic, detailed description, and correction, if applicable. Your input will be brought to the attention of the Technical Review Committee. Thank you for your assistance.

Write: CNATT AV Rate Training Manager
230 Chevalier Field Avenue
Pensacola, FL 32508
COMM: (850) 452-9700 utilize voice directory for AE/AT Rate Training Manager.
DSN: 922-9700 utilize voice directory for AE/AT Rate Training Manager.

E-mail: Refer to NKO AE rate training web page for curent contact information.

Rate____ Course Name_____

Revision Date_____ Chapter Number____ Page Number(s)_____

Description

_____

_____

_____

(Optional) Correction

_____

_____

_____

(Optional) Your Name and Address

_____

_____

_____