traffic management system (ATMS). Data is transferred with no need for human acknowledgement. Microwave and satellite transmissions are used to link the network.

For traffic separation and control, ADS-B has several advantages over conventional ground-based radar. The first is the entire airspace can be covered with a much lower expense. The aging ATC radar system that is in place is expensive to maintain and replace. Additionally, ADS-B provides more accurate information since the vector state is generated from the aircraft with the help of GPS satellites. Weather is a greatly reduced factor with ADS-B. Ultra-high frequency GPS transmissions are not affected. Increased positioning accuracy allows for higher density traffic flow and landing approaches, an obvious requirement to operate more aircraft in and out of the same number of facilities. The higher degree of control available also enables routing for fewer weather delays and optimal fuel burn rates. Collision avoidance is expanded to include runway incursion from other aircraft and support vehicles on the surface of an airport.

ADS-B IN offers features not available in TCAS. Equipped aircraft are able to receive abundant data to enhance situational awareness. Traffic information services-broadcast (TIS-B) supply traffic information from non-ADS-B aircraft and ADS-B aircraft on a different frequency. Ground radar

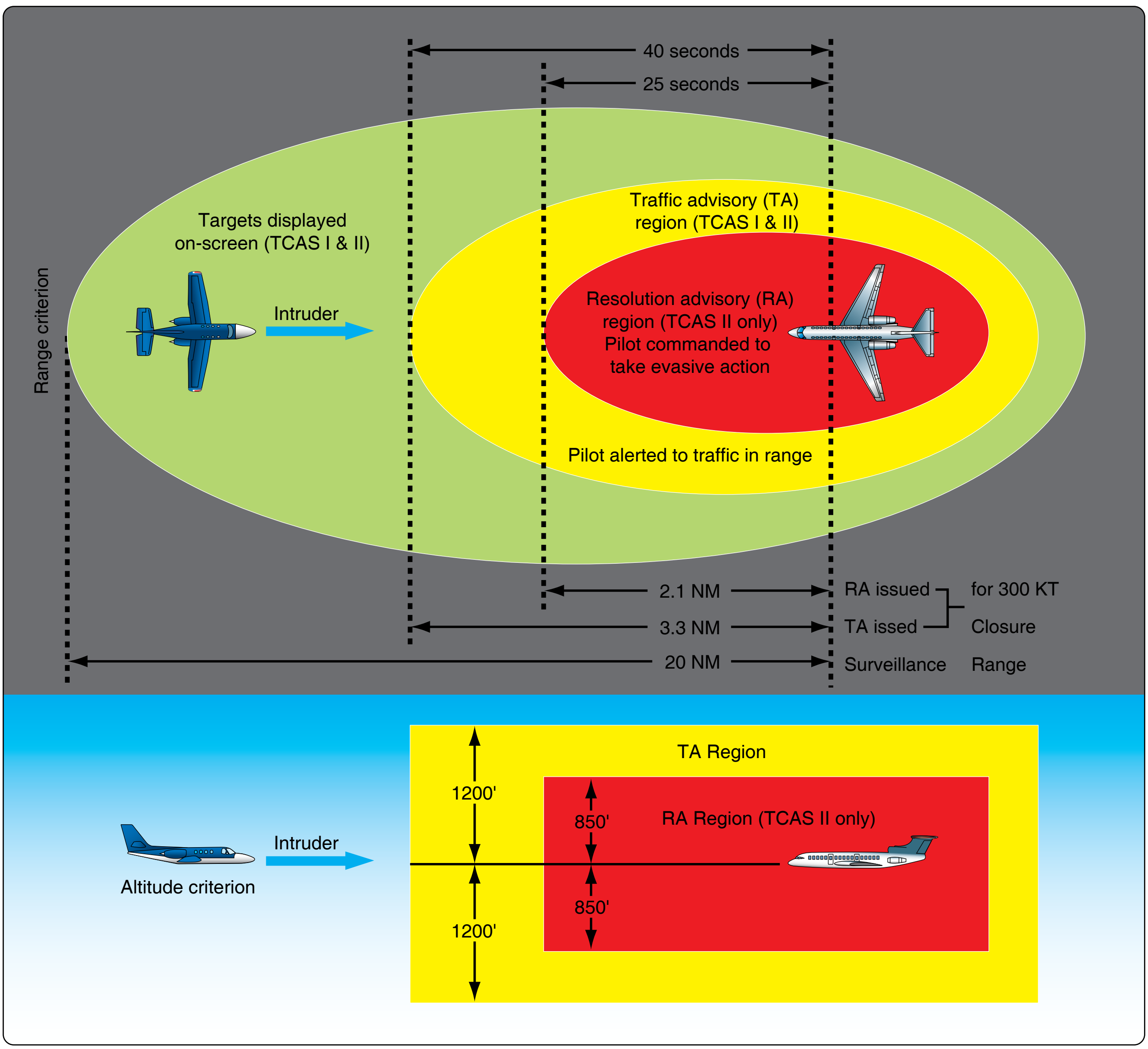

Figure 11-131. *Traffic collision and avoidance system (TCAS) uses an aircraft's transponder to interrogate and receive replies from other aircraft in close proximity. The TCAS computer alerts the pilot as to the presence of an intruder aircraft and displays the aircraft on a screen in the flight deck. Additionally, TCAS II equipped aircraft receive evasive maneuver commands from the computer that calculates trajectories of the aircraft to predict potential collisions or near misses before they become unavoidable.*

Figure 11-132. *TCAS information displayed on an electronic vertical speed indicator.*

Figure 11-133. *TCAS information displayed on a multifunction display. An open diamond indicates a target; a solid diamond represents a target that is within 6 nautical miles of 1,200 feet vertically. A yellow circle represents a target that generates a TA (25-48 seconds before contact). A red square indicates a target that generates an RA in TCAS II (contact within 35 seconds). A (+) indicates the target aircraft is above and a (-) indicates it is below. The arrows show if the target is climbing or descending.*

monitoring of surface targets, and any traffic data in the linked network of ground stations is sent via ADS-B IN to the flight deck. This provides a more complete picture than air-to-air only collision avoidance. Flight information services-broadcast (FIS-B) is also received by ADS-B IN. Weather text and graphics, ATIS information, and NOTAMs are able to be received in aircraft that have 987 UAT capability. *[Figure 11-138]*

Figure 11-134. *This control panel from a Boeing 767 controls the transponder for ATC use and TCAS.*

ADS-B test units are available for trained maintenance personnel to verify proper operation of ADS-B equipment. This is critical since close tolerance of air traffic separation depends on accurate data from each aircraft and throughout all components of the ADS-B system. *[Figure 11-139]*

Radio Altimeter

A radio altimeter, or radar altimeter, is used to measure the distance from the aircraft to the terrain directly beneath it. It is used primarily during instrument approach and low level or night flight below 2,500 feet. The radio altimeter supplies the primary altitude information for landing decision height. It incorporates an adjustable altitude bug that creates a visual or aural warning to the pilot when the aircraft reaches that altitude. Typically, the pilot will abort a landing if the decision height is reached and the runway is not visible.

Using a transceiver and a directional antenna, a radio altimeter broadcasts a carrier wave at 4.3 GHz from the aircraft directly toward the ground. The wave is frequency

Figure 11-135. *Low power requirements allow remote ADS-B stations with only solar or propane support. This is not possible with ground radar due to high power demands which inhibit remote area radar coverage for air traffic purposes.*

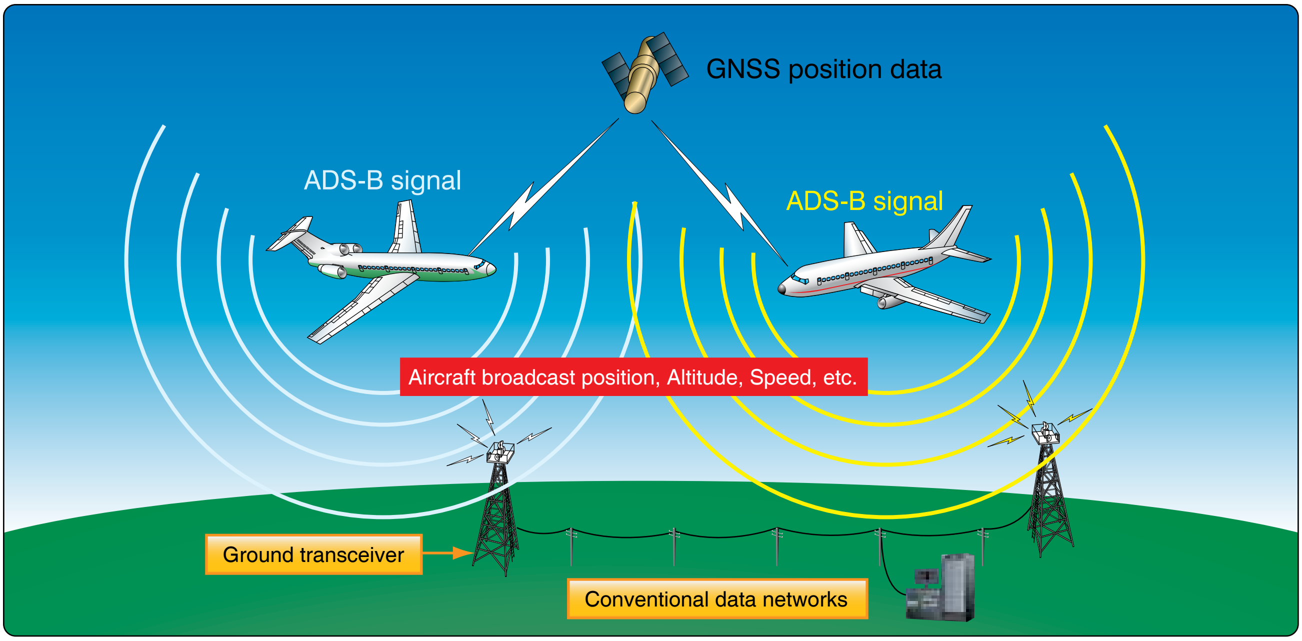

Figure 11-136. *ADS-B OUT uses satellites to identify the position aircraft. This position is then broadcast to other aircraft and to ground stations along with other flight status information.*

modulated at 50 MHz and travels at a known speed. It strikes surface features and bounces back toward the aircraft where a second antenna receives the return signal. The transceiver processes the signal by measuring the elapsed time the signal traveled and the frequency modulation that occurred. The display indicates height above the terrain also known as above ground level (AGL). *[Figure 11-140]*

A radar altimeter is more accurate and responsive than an air pressure altimeter for AGL information at low altitudes. The transceiver is usually located remotely from the indicator. Multifunctional and glass flight deck displays typically integrate decision height awareness from the radar altimeter as a digital number displayed on the screen with a bug, light, or color change used to indicate when that altitude is reached.

Large aircraft may incorporate radio altimeter information into a ground proximity warning system (GPWS) which aurally alerts the crew of potentially dangerous proximity to the terrain below the aircraft. A decision height (DH) window displays the radar altitude on the EADI in *Figure 11-141*.

Weather Radar

There are three common types of weather aids used in an aircraft flight deck that are often referred to as weather radar:

1. Actual on-board radar for detecting and displaying weather activity;
2. Lightning detectors; and
3. Satellite or other source weather radar information that is uploaded to the aircraft from an outside source.

Figure 11-137. *A flight deck display of ADS-B generated targets (left) and an ADS-B airborne receiver with antenna (right).*

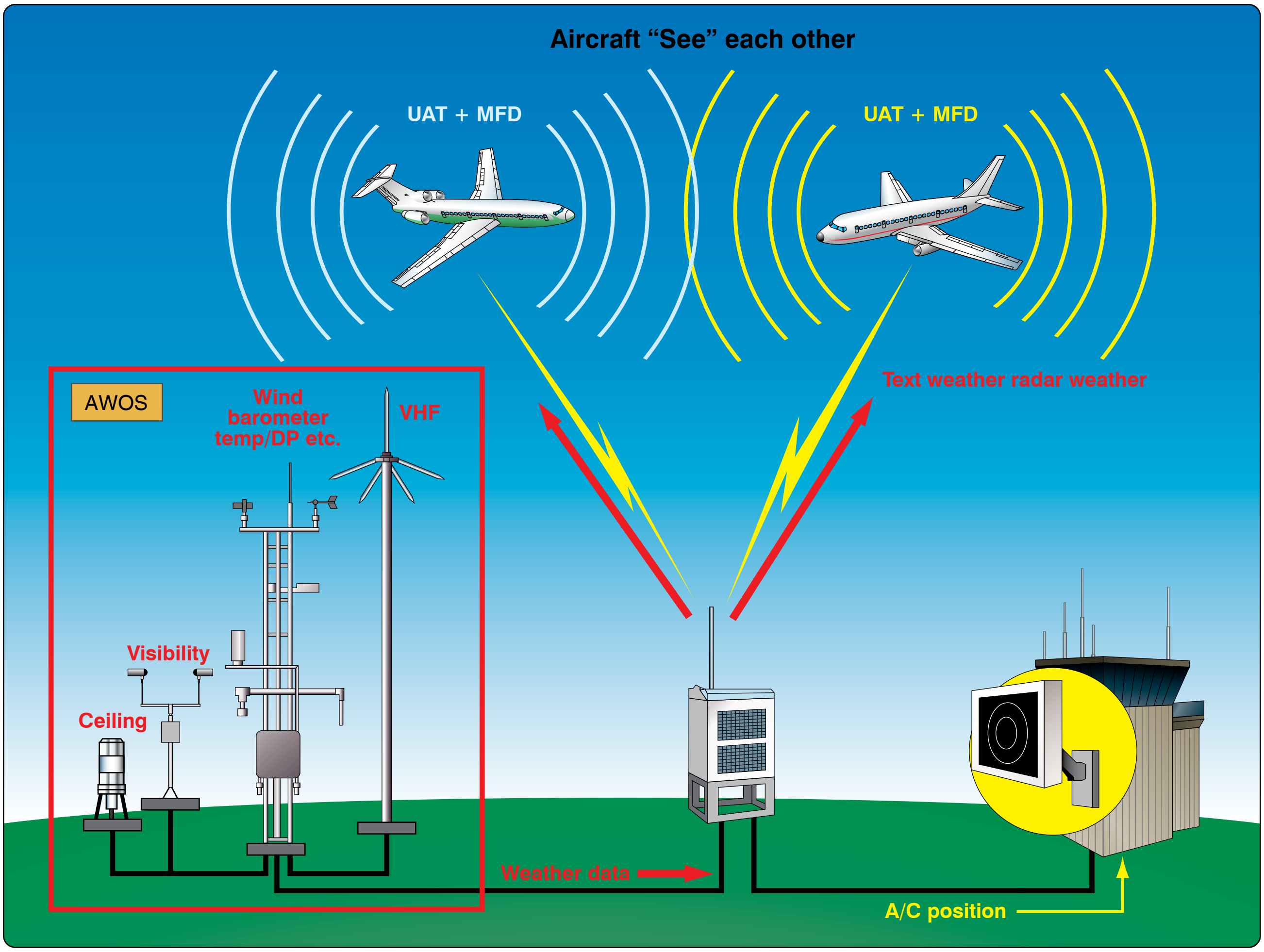

Figure 11-138. *ADS-B IN enables weather and traffic information to be sent into the flight deck. In addition to AWOS weather, NWS can also be transmitted.*

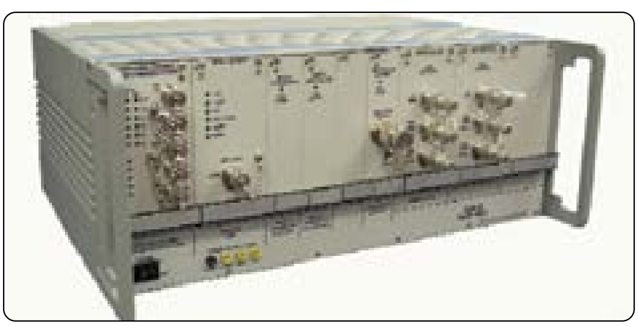

Figure 11-139. *An ADS-B test unit.*

On-board weather radar systems can be found in aircraft of all sizes. They function similar to ATC primary radar except the radio waves bounce off of precipitation instead of aircraft. Dense precipitation creates a stronger return than light precipitation. The on-board weather radar receiver is set up to depict heavy returns as red, medium returns as yellow and light returns as green on a display in the flight deck. Clouds do not create a return. Magenta is reserved to depict intense or extreme precipitation or turbulence. Some aircraft have a dedicated weather radar screen. Most modern

Figure 11-140. *A digital display radio altimeter (top), and the two antennas and transceiver for a radio/radar altimeter (bottom).*

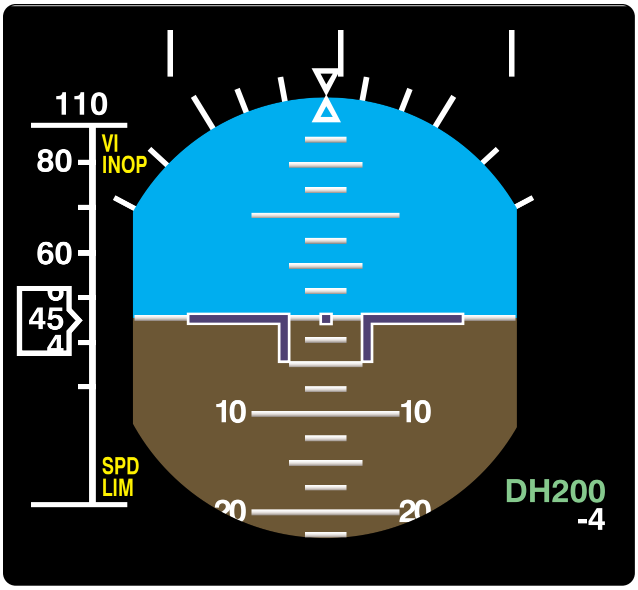

Figure 11-141. *The decision height, DH200, in the lower right corner of this EADI display uses the radar altimeter as the source of altitude information.*

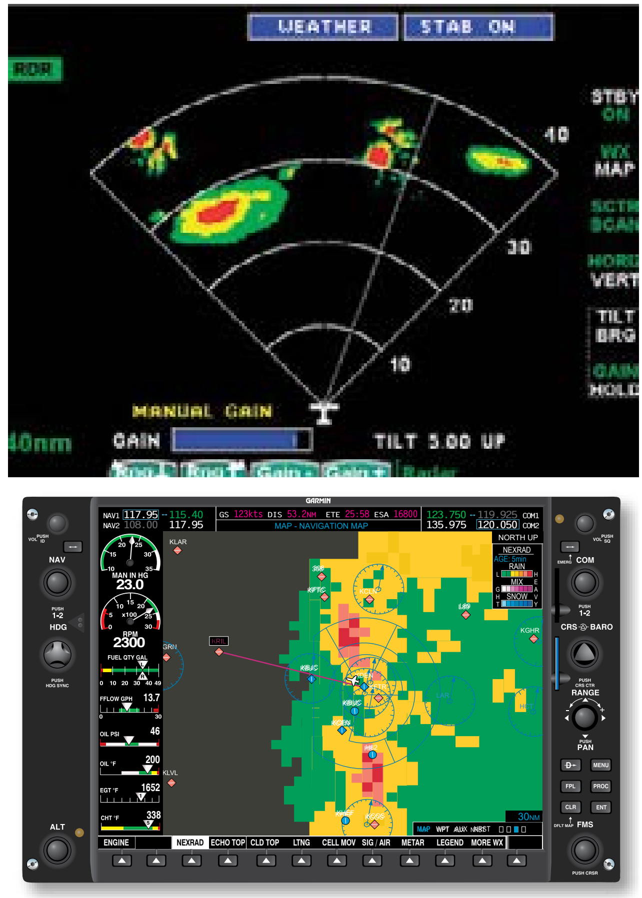

Figure 11-142. *A dedicated weather radar display (top) and a multifunctional navigation display with weather radar overlay (bottom).*

aircraft integrate weather radar display into the navigation display(s). *Figure 11-142* illustrates weather radar displays found on aircraft.

Radio waves used in weather radar systems are in the SHF range such as 5.44 GHz or 9.375 GHz. They are transmitted forward of the aircraft from a directional antenna usually located behind a non-metallic nose cone. Pulses of approximately 1 micro-second in length are transmitted. A duplexer in the radar transceiver switches the antenna to receive for about 2,500 micro seconds after a pulse is transmitted to receive and process any returns. This cycle repeats and the receiver circuitry builds a two dimensional image of precipitation for display. Gain adjustments control the range of the radar. A control panel facilitates this and other adjustments. *[Figure 11-143]*

Severe turbulence, windshear, and hail are of major concern to the pilot. While hail provides a return on weather radar, windshear and turbulence must be interpreted from the movement of any precipitation that is detected. An alert is annunciated if this condition occurs on a weather radar system so equipped. Dry air turbulence is not detectable. Ground clutter must also be attenuated when the radar sweep includes any terrain features. The control panel facilitates this.

Special precautions must be followed by the technician during maintenance and operation of weather radar systems. The radome covering the antenna must only be painted with approved paint to allow the radio signals to pass unobstructed. Many radomes also contain grounding strips to conduct lightning strikes and static away from the dome.

When operating the radar, it is important to follow all manufacturer instructions. Physical harm is possible from the high energy radiation emitted, especially to the eyes and testes. Do not look into the antenna of a transmitting radar. Operation of the radar should not occur in hangars unless special radio wave absorption material is used. Additionally, operation of radar should not take place while the radar is pointed toward a building or when refueling takes place. Radar units should be maintained and operated only by qualified personnel.

Lightning detection is a second reliable means for identifying potentially dangerous weather. Lightning gives off its own electromagnetic signal. The azimuth of a lightning strike can be calculated by a receiver using a loop type antenna such as that used in ADF. *[Figure 11-144]* Some lightning detectors make use of the ADF antenna. The range of the lightning strike is closely associated with its intensity. Intense strikes are plotted as being close to the aircraft.

Stormscope is a proprietary name often associated with lightning detectors. There are others that work in a similar

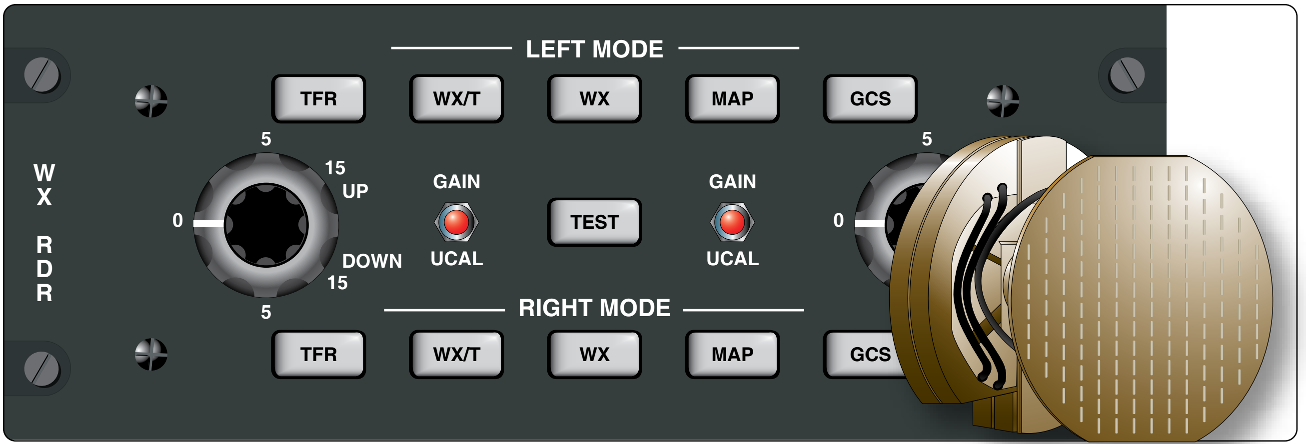

Figure 11-143. *A typical on-board weather radar system for a high performance aircraft uses a nose-mounted antenna that gimbals. It is usually controlled by the inertial reference system (IRS) to automatically adjust for attitude changes during maneuvers so that the radar remains aimed at the desired weather target. The pilot may also adjust the angle and sweep manually as well as the gain. A dual mode control panel allows separate control and display on the left or right HSI or navigational display.*

manner. A dedicated display plots the location of each strike within a 200 mile range with a small mark on the screen. As time progresses, the marks may change color to indicate their age. Nonetheless, a number of lightning strikes in a small area indicates a storm cell, and the pilot can navigate around it. Lightning strikes can also be plotted on a multifunctional navigation display. *[Figure 11-145]*

A third type of weather radar is becoming more common in all classes of aircraft. Through the use of orbiting satellite systems and/or ground up-links, such as described with ADS-B IN, weather information can be sent to an aircraft in flight virtually anywhere in the world. This includes text data as well as real-time radar information for overlay on an aircraft's navigational display(s). Weather radar data produced remotely and sent to the aircraft is refined through consolidation of various radar views from different angles and satellite imagery. This produces more accurate depictions of actual weather conditions. Terrain databases are integrated to eliminate ground clutter. Supplemental data includes the entire range of intelligence available from the National Weather Service (NWS) and the National Oceanographic and Atmospheric Administration (NOAA). *Figure 11-146* illustrates a plain language weather summary received in an aircraft along with a list of other weather information available through satellite or ground link weather information services.

Figure 11-144. *A receiver and antenna from a lightning detector system.*

As mentioned, to receive an ADS-B weather signal, a 1090 ES or 970 UAT transceiver with associated antenna needs to be installed on board the aircraft. Satellite weather services are received by an antenna matched to the frequency of the service. Receivers are typically located remotely and interfaced with existing navigational and multifunction displays. Handheld GPS units also may have satellite weather capability. *[Figure 11-147]*

Emergency Locator Transmitter (ELT)

An emergency locator transmitter (ELT) is an independent battery powered transmitter activated by the excessive G-forces experienced during a crash. It transmits a digital signal every 50 seconds on a frequency of 406.025 MHz at 5 watts for at least 24 hours. The signal is received anywhere in the world by satellites in the Cospas-Sarsat satellite system. Two types of satellites, low earth orbiting satellites (LEOSATs) and geostationary satellites (GEOSATs), are used with different, complimentary capability. The signal is partially processed and stored in the satellites and then relayed to ground stations known as local user terminals (LUTs). Further deciphering of a signal takes place at the LUTs, and appropriate search and rescue operations are notified through mission control centers (MCCs) set up for this purpose.

Note: Maritime vessel emergency locating beacons (EPIRBs) and personal locator beacons (PLBs) use the exact same system. The United States portion of the Cospas-Sarsat system is

Figure 11-145. *A dedicated stormscope lightning detector display (left), and an electronic navigational display with lightning strikes overlaid in the form of green "plus" signs (right).*

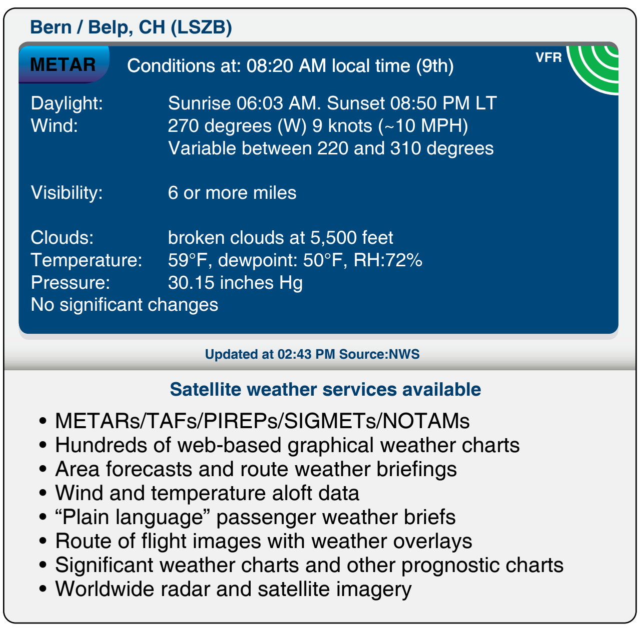

Figure 11-146. *A plain language METAR weather report received in the flight deck from a satellite weather service for aircraft followed by a list of various weather data that can be radioed to the flight deck from a satellite weather service.*

maintained and operated by NOAA. *Figure 11-148* illustrates the basic components in the Cospas-Sarsat system.

ELTs are required to be installed in aircraft according to FAR 91.207. This encompasses most general aviation aircraft not operating under parts 135 or 121. ELTs must be inspected within 12 months of previous inspection for proper installation, battery corrosion, operation of the controls and crash sensor, and the presence of a sufficient signal at the antenna. Built-in test equipment facilitates testing without transmission of an emergency signal. The remainder of the inspection is visual. Technicians are cautioned to not activate the ELT and transmit an emergency distress signal. Inspection must be recorded in maintenance records including the new expiration date of the battery. This must also be recorded on the outside of the ELT.

ELTs are typically installed as far aft in the fuselage of an aircraft as is practicable just forward of the empennage. The built-in G-force sensor is aligned with the longitudinal axis of the aircraft. Helicopter ELTs may be located elsewhere on the airframe. They are equipped with multidirectional activation devices. Follow ELT and airframe manufacturer's instructions for proper installation, inspection, and maintenance of all ELTs. *Figure 11-149* illustrates ELTs mounted locations.

Use of Doppler technology enables the origin of the 406 MHz ELT signal to be calculated within 2 to 5 kilometers. Second generation 406 MHz ELT digital signals are loaded with GPS location coordinates from a receiver inside the ELT unit or integrated from an outside unit. This reduces the location accuracy of the crash site to within 100 meters. The digital signal is also loaded with unique registration information. It identifies the aircraft, the owner, and contact information, etc. When a signal is received, this is used to immediately research the validity of the alert to ensure it is a true emergency transmission so that rescue resources are not deployed needlessly.

Figure 11-147. *A satellite weather receiver and antenna enable display of real-time textual and graphic weather information beyond that of airborne weather radar. A handheld GPS can also be equipped with these capabilities. A built-in multifunctional display with satellite weather overlays and navigation information can be found on many aircraft.*

ELTs with automatic G-force activation mounted in aircraft are easily removable. They often contain a portable antenna so that crash victims may leave the site and carry the operating ELT with them. A flight deck mounted panel is required to alert the pilot if the ELT is activated. It also allows the ELT to be armed, tested, and manually activated if needed. *[Figure 11-150]*

Modern ELTs may also transmit a signal on 121.5 MHz. This is an analog transmission that can be used for homing. Prior to 2009, 121.5 MHz was a worldwide emergency frequency monitored by the Cospas-Sarsat satellites. However, it has been replaced by the 406 MHz standard. Transmissions on 121.5 MHz are no longer received and relayed via satellite.

The use of a 406 MHz ELT has not been mandated by the FAA. An older 121.5 MHz ELT satisfies the requirements of FAR Part 91.207 in all except new aircraft. Thousands of aircraft registered in the United States remain equipped with ELTs that transmit a .75 watt analog 121.5 MHz emergency signal when activated. The 121.5 MHz frequency is still an emergency frequency and is not monitored by over-flying aircraft and control towers.

Technicians are required to perform an inspection/test of 121.5 MHz ELTs within 12 months of the previous one and inspect for the same integrity as required for the 406 MHz ELTs mentioned above. However, older ELTs often lack the built-in test circuitry of modern ELTs certified to TSO C-126. Therefore, a true operational test may include activating the signal. This can be done by removing the antenna and installing a dummy load. Any activation of an ELT signal is required to only be done between the top of each hour and 5 minutes after the hour. The duration of activation must be no longer than three audible sweeps. Contact of the local control tower or flight service station before testing is recommended.

It must be noted that older 121.5 MHz analog signal ELTs often also transmit an emergency signal on a frequency of 243.0 MHz. This has long been the military emergency frequency. Its use is being phased out in favor of digital ELT signals and satellite monitoring. Testing the functionality of a 121.5 MHz transmitter should be accomplished per manufacturer's instructions. Improvements in coverage, location accuracy, identification of false alerts, and shortened response times are so significant with 406 MHz ELTs, they are currently the service standard worldwide.

Testing Considerations for 406 MHz ELTs

Care should be taken to prevent accidentally triggering a SAR (search and rescue) response. Accidental activation of an ELT will generate an emergency signal that cannot be distinguished from that of an actual emergency and could lead to expensive and frustrating searches. Moreover, the unwarranted ELT signal could tie up the emergency frequencies such that a genuine emergency signal would not be picked up. In addition, if an ELT signal is transmitted on or near an airport, it may render some radio communications channels unusable.

Regardless of where the ELT is, or the duration of activation, a 406 MHz beacon broadcast will be detected by at least one Geostationary Local User Terminal (GEOLUT) and possibly every Low Earth Orbit Local User Terminal (LEOLUT) in the Cospas-Sarsat System. Alert messages will be routed to every Mission Control Center (MCC) in the Cospas-Sarsat System for coordination around the world and a response will be made (unless prior coordination is made with Cospas-Sarsat and local authorities).

Direct connect testing is preferred to prevent inadvertent activation of the SAR response system. Over-air testing should always be avoided if possible. Use of an antenna boot

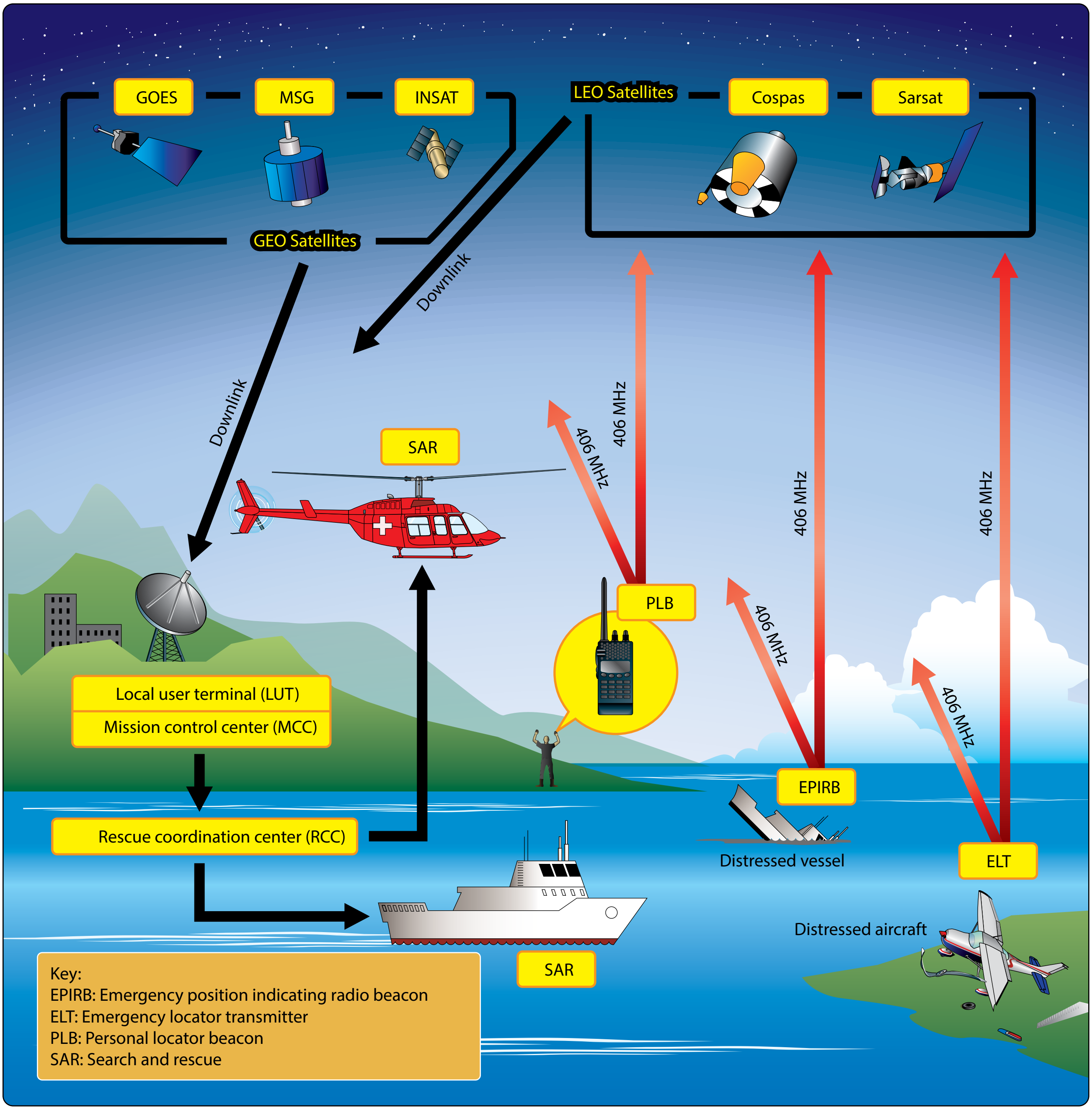

Figure 11-148. *The basic operating components of the satellite-based Cospas-Sarsat rescue system of which aircraft ELTs are a part.*

or a direct connection from test equipment to the antenna port is preferred.

Testing an ELT system in a metal hangar will not guarantee the radiated signal will not be detected by the Cospas-Sarsat System. Technicians testing ELT devices in a hangar should treat the test as if they were testing outside.

When testing an ELT, a 50-ohm dummy load or antenna boot should be used to prevent the signal from being radiated into space. The signal must be attenuated to less than -51 dBW (a power flux density of -37.4 dB (W/m^2) or a field intensity of -11.6 dB (V/m).

If over-air testing must be accomplished, technicians should carefully follow Cospas-Sarsat instructions and use the built-in test message on the ELT device. The ELT test message is different from messages transmitted during an emergency, but is still detectable by the Cospas-Sarsat System. Cospas-Sarsat should be contacted prior to performing over-air testing. Cospas-Sarsat can be contacted at www.cospas-sarsat.int/en/. If over-air testing must be accomplished, the local air traffic control (ATC) facility should be contacted in advance.

Follow test set instructions or place the test set a minimum

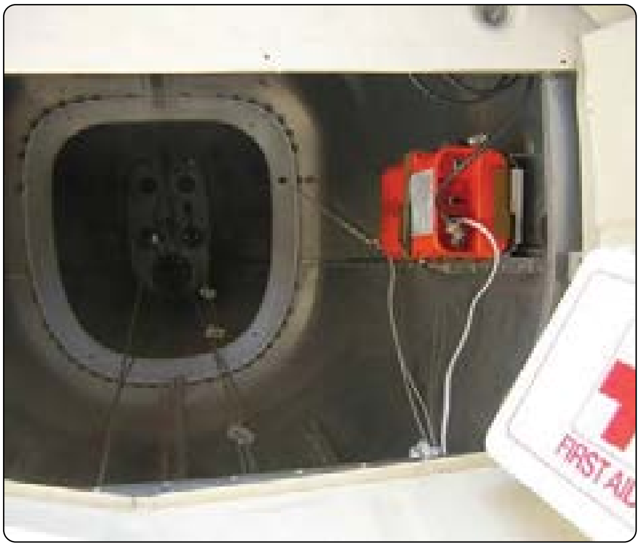

Figure 11-149. *An emergency locator transmitter (ELT) mounting location is generally far aft in a fixed-wing aircraft fuselage in line with the longitudinal axis. Helicopter mounting location and orientation varies.*

Figure 11-150. *An ELT and its components including a flight deck-mounted panel, the ELT, a permanent mount antenna, and a portable antenna.*

of 12 meters, (39.4 feet) from the ELT antenna. Test in each mode and frequency the ELT unit transmits.

406 MHz Testing

Verify the device is outputting a signal of not less than 17 dBm (50 mW) and not greater than 26 dBm (400 mW).

Verify the device is transmitting on the correct frequency. This can be done by running the ELT self-test and detecting the signal with an ELT test set. Receiving and decoding a test message is an indication the unit is transmitting on a correct frequency.

Using appropriate test equipment and shielding, note the ELT code transmitted and verify that the ELT code is registered with Cospas-Sarsat. The testing technician or aircraft owner should verify the information on file with Cospas-Sarsat is accurate and up to date.

Determine that the ELT aural indicator can be heard in the flight deck with the aircraft engine(s) off, and that the visual indicator can be seen from the crew's normal sitting position. If possible, this should be performed in a way that will prevent a SAR response (e.g., with a dummy load installed).

Perform an operational check of the g switch. This should be performed in a way that will prevent a SAR response (e.g., with a dummy load installed). Replace if the g switch fails to activate.

Ensure all cables except the 406 MHz transmitter output are reconnected. Ensure the 406 MHz transmitter is connected to a test set if possible. Activate the ELT (use the remote switch if installed), and determine if the system is radiating a strong 406 MHz signal. Ensure the system is reset if necessary.

If equipped with a water-activated circuit, connect the ELT to a test set if possible. Activate the ELT by shorting the water-sensing leads and determine if the system is radiating a strong 406 MHz signal. Ensure the system is reset if necessary.

Long Range Aid to Navigation System (LORAN)

Long range aid to navigation system (LORAN) is a type of RNAV that is no longer available in the United States. It was developed during World War II, and the most recent edition, LORAN-C, has been very useful and accurate to aviators as well as maritime sailors. LORAN uses radio wave pulses from a series of towers and an on-board receiver/computer to positively locate an aircraft amid the tower network. There are twelve LORAN transmitter tower "chains" constructed across North America. Each chain has a master transmitter tower and a handful of secondary towers. All broadcasts from the transmitters are at the same frequency, 100 KHz. Therefore, a LORAN receiver does not need to be tuned. Being in the low frequency range, the LORAN transmissions travel long distances and provide good coverage from a small number of stations.

Precisely-timed, synchronized pulse signals are transmitted from the towers in a chain. The LORAN receiver measures the time to receive the pulses from the master tower and two other towers in the chain. It calculates the aircraft's position based on the intersection of parabolic curves representing elapsed signal times from each of these known points.

The accuracy and proliferation of GPS navigation has caused the U.S. Government to cease support for the LORAN navigation system citing redundancy and expense of operating the towers as reasons. Panel-mounted LORAN navigation units will likely be removed and replaced by GPS units in aircraft that have not already done so. *[Figure 11-151]*

Global Positioning System (GPS)

Global positioning system (GPS) navigation is the fastest growing type of navigation in aviation. It is accomplished through the use of NAVSTAR satellites set and maintained in orbit around the earth by the U.S. Government. Continuous coded transmissions from the satellites facilitate locating the position of an aircraft equipped with a GPS receiver with extreme accuracy. GPS can be utilized on its own for en route navigation, or it can be integrated into other navigation systems, such as VOR/RNAV, inertial reference, or flight management systems.

There are three segments of GPS: the space segment, the control segment, and the user segment. Aircraft technicians are only involved with user segment equipment such as GPS receivers, displays, and antennas.

Twenty-four satellites (21 active, 3 spares) in six separate planes of orbit 12,625 miles above the planet comprise what is known as the space segment of the GPS system. The satellites are positioned such that in any place on earth at any one time, at least four will be a minimum of 15° above the horizon. Typically, between five and eight satellites are in view. *[Figure 11-152]*
Two signals loaded with digitally coded information are transmitted from each satellite. The L1 channel transmission on a 1575.42 MHz carrier frequency is used in civilian aviation. Satellite identification, position, and time are conveyed to the aircraft GPS receiver on this digitally modulated signal along with status and other information. An L2 channel 1227.60 MHz transmission is used by the military.

Figure 11-151. *Panel-mounted LORAN units are now obsolete as LORAN signals are no longer generated from the tower network.*

The amount of time it takes for signals to reach the aircraft GPS receiver from transmitting satellites is combined with each satellite's exact location to calculate the position of an aircraft. The control segment of the GPS monitors each satellite to ensure its location and time are precise. This control is accomplished with five ground-based receiving stations, a master control station, and three transmitting antennas. The receiving stations forward status information received from the satellites to the master control station. Calculations are made, and corrective instructions are sent to the satellites via the transmitters.

The user segment of the GPS is comprised of the thousands of receivers installed in aircraft as well as every other receiver that uses the GPS transmissions. Specifically, for the aircraft technician, the user section consists of a control panel/display, the GPS receiver circuitry, and an antenna. The control, display and receiver are usually located in a single unit which also may include VOR/ILS circuitry and a VHF communications transceiver. GPS intelligence is integrated into the multifunctional displays of glass flight deck aircraft. *[Figure 11-153]*

The GPS receiver measures the time it takes for a signal to arrive from three transmitting satellites. Since radio waves travel at 186,000 miles per second, the distance to each satellite can be calculated. The intersection of these ranges provides a two dimensional position of the aircraft. It is expressed in latitude/longitude coordinates. By incorporating

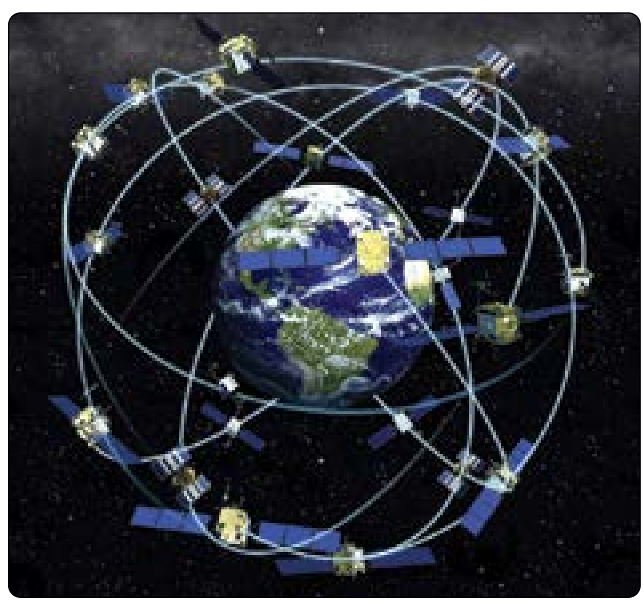

Figure 11-152. *The space segment of GPS consists of 24 NAVSTAR satellites in six different orbits around the earth.*

Figure 11-153. *A GPS unit integrated with NAV/COM circuitry.*

the distance to a fourth satellite, the altitude above the surface of the earth can be calculated as well. This results in a three dimensional fix. Additional satellite inputs refine the accuracy of the position.

Having deciphered the position of the aircraft, the GPS unit processes many useful navigational outputs such as speed, direction, bearing to a waypoint, distance traveled, time of arrival, and more. These can be selected to display for use. Waypoints can be entered and stored in the unit's memory. Terrain features, airport data, VOR/RNAV and approach information, communication frequencies, and more can also be loaded into a GPS unit. Most modern units come with moving map display capability.

A main benefit of GPS use is immunity from service disruption due to weather. Errors are introduced while the carrier waves travel through the ionosphere; however, these are corrected and kept to a minimum. GPS is also relatively inexpensive. GPS receivers for IFR navigation in aircraft must be built to TSO-129A. This raises the price above that of handheld units used for hiking or in an automobile. But the overall cost of GPS is low due to its small infrastructure. Most of the inherent accuracy is built into the space and control segments permitting reliable positioning with inexpensive user equipment.

The accuracy of current GPS is within 20 meters horizontally and a bit more vertically. This is sufficient for en route navigation with greater accuracy than required. However, departures and approaches require more stringent accuracy. Integration of the wide area augmentation system (WAAS) improves GPS accuracy to within 7.6 meters and is discussed below. The future of GPS calls for additional accuracy by adding two new transmissions from each satellite. An L2C channel is for general use in non-safety critical application. An aviation dedicated L5 channel provides the accuracy required for category I, II, and III landings. It enables the NextGen NAS plan along with ADS-B.

Wide Area Augmentation System (WAAS)

To increase the accuracy of GPS for aircraft navigation, the wide area augmentation system (WAAS) was developed. It consists of approximately 25 precisely surveyed ground stations that receive GPS signals and ultimately transmit correction information to the aircraft. An overview of WAAS components and its operation is shown in *Figure 11-154*.

WAAS ground stations receive GPS signals and forward position errors to two master ground stations. Time and location information is analyzed, and correction instructions are sent to communication satellites in geostationary orbit over the NAS. The satellites broadcast GPS-like signals that WAAS enabled GPS receivers use to correct position information received from GPS satellites.

A WAAS-enabled GPS receiver is required to use the wide area augmentation system. If equipped, an aircraft qualifies to perform precision approaches into thousands of airports without any ground-based approach equipment. Separation minimums are also able to be reduced between aircraft that are WAAS equipped. The WAAS system is known to reduce position errors to 1–3 meters laterally and vertically.

Inertial Navigation System (INS)/Inertial Reference System (IRS)

An inertial navigation system (INS) is used on some large aircraft for long range navigation. This may also be

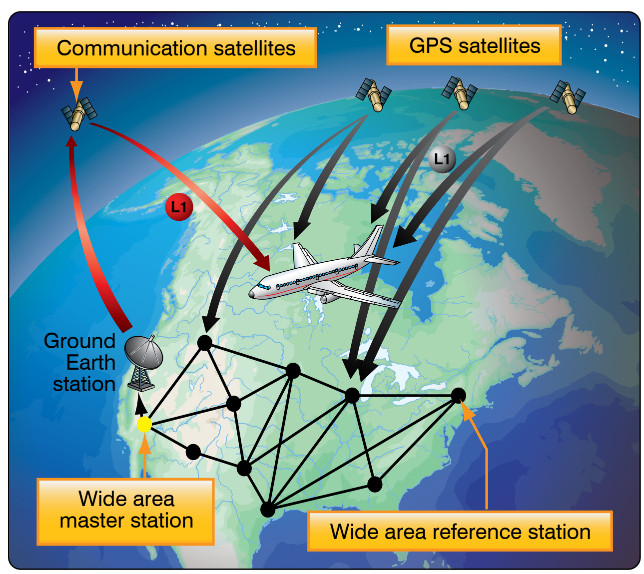

Figure 11-154. *The wide area augmentation system (WAAS) is used to refine GPS positions to a greater degree of accuracy. A WAAS enabled GPS receiver is required for its use as corrective information is sent from geostationary satellites directly to an aircraft's GPS receiver for use.*

identified as an inertial reference system (IRS), although the IRS designation is generally reserved for more modern systems. An INS/IRS is a self-contained system that does not require input radio signals from a ground navigation facility or transmitter. The system derives attitude, velocity, and direction information from measurement of the aircraft's accelerations given a known starting point. The location of the aircraft is continuously updated through calculations based on the forces experienced by INS accelerometers. A minimum of two accelerometers is used, one referenced to north, and the other referenced to east. In older units, they are mounted on a gyro-stabilized platform. This averts the introduction of errors that may result from acceleration due to gravity.

An INS uses complex calculation made by an INS computer to convert applied forces into location information. An interface control head is used to enter starting location position data while the aircraft is stationary on the ground. This is called initializing. *[Figure 11-155]* From then on, all motion of the aircraft is sensed by the built-in accelerometers and run through the computer. Feedback and correction loops are used to correct for accumulated error as flight time progresses. The amount an INS is off in one hour of flight time is a reference point for determining performance. Accumulated error of less than one mile after one hour of flight is possible. Continuous accurate adjustment to the gyro-stabilized platform to keep it parallel to the Earth's surface is a key requirement to reduce accumulated error. A latitude/longitude coordinate system is used when giving the location output.

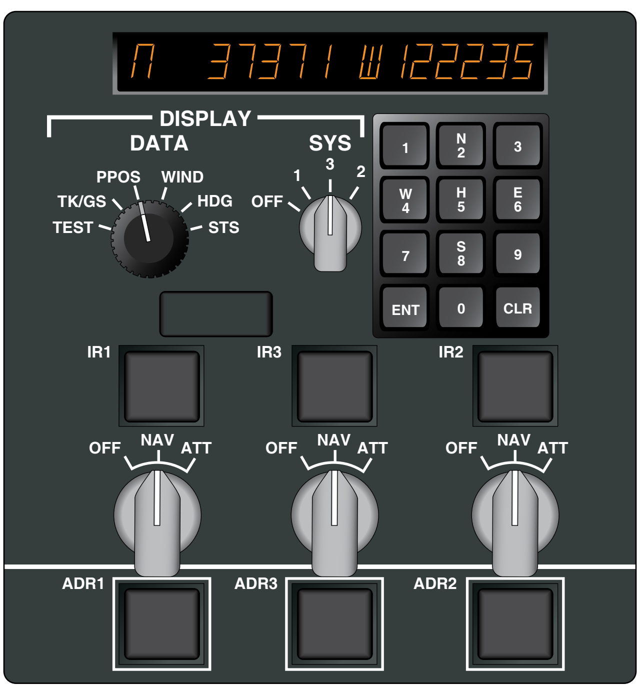

Figure 11-155. *An interface panel for three air data and inertial reference systems on an Airbus. The keyboard is used to initialize the system. Latitude and longitude position is displayed at the top.*

INS is integrated into an airliner's flight management system and automatic flight control system. Waypoints can be entered for a predetermined flightpath and the INS will guide the aircraft to each waypoint in succession. Integration with other NAV aids is also possible to ensure continuous correction and improved accuracy but is not required.

Modern INS systems are known as IRS. They are completely solid-state units with no moving parts. Three-ring, laser gyros replace the mechanical gyros in the older INS platform systems. This eliminates precession and other mechanical gyro shortcomings. The use of three solid-state accelerometers, one for each plane of movement, also increases accuracy. The accelerometer and gyro output are input to the computer for continuous calculation of the aircraft's position.

The most modern IRS integration is the satellite GPS. The GPS is extremely accurate in itself. When combined with IRS, it creates one of the most accurate navigation systems available. The GPS is used to initialize the IRS so the pilot no longer needs to do so. GPS also feeds data into the IRS computer to be used for error correction. Occasional service interruptions and altitude inaccuracies of the GPS system pose no problem for IRS/GPS. The IRS functions continuously and is completely self-contained within the IRS unit. Should the GPS falter, the IRS portion of the system continues without it. The latest electronic technology has reduced the size and weight of INS/IRS avionics units significantly. *Figure 11-156* shows a modern micro-IRS unit that measures approximately six inches on each side.

Aircraft Communication Addressing & Reporting System (ACARS)

ACARS is a two-way communication link between an airliner in flight and the airline's main ground facilities. Data is collected in the aircraft by digital sensors and is transmitted to the ground facilities. Replies from the ground may be printed out so the appropriate flight crewmember can have a hard copy of the response.

Installation of Communication & Navigation Equipment

Approval of New Avionics Equipment Installations

Most of the avionics equipment discussed in this chapter is only repairable by the manufacturer or FAA-certified repair stations that are licensed to perform specific work. The airframe technician; however, must competently remove, install, inspect, maintain, and troubleshoot these ever increasingly complicated electronic devices and systems. It is imperative to follow all equipment and airframe manufacturers' instruction

Figure 11-156. *A modern micro-IRS with built-in GPS.*

when dealing with an aircraft's avionics.

The revolution to GPS navigation and the pace of modern electronic development results in many aircraft owner operators upgrading flight decks with new avionics. The aircraft technician must only perform airworthy installations. The avionics equipment to be installed must be a TSO'd device that is approved for installation in the aircraft in question. The addition of a new piece of avionics equipment and/or its antenna is a minor alteration if previously approved by the airframe manufacturer. A certificated airframe technician is qualified to perform the installation and return the aircraft to service. The addition of new avionics not on the aircraft's approved equipment list is considered a major alteration and requires an FAA Form 337 to be completed. A technician with an inspection authorization is required to complete the approval for return to service following a major alteration and to sign the corresponding approval for return to service block on Form 337.

Most new avionics installations are approved and performed under an STC. The equipment manufacturer supplies a list of aircraft on which the equipment has been approved for installation. The STC includes thorough installation and maintenance instructions which the technician must follow. Regardless, if not on the aircraft's original equipment list, the STC installation is considered a major alteration and an FAA Form 337 must be filed. The STC is referenced as the required approved data.

Occasionally, an owner/operator or technician wishes to install an electronic device in an aircraft that has no STC for the model aircraft in question. A field approval and a Form 337 must be filed on which it must be shown that the installation will be performed in accordance with approved data.

Considerations

There are many factors which the technician must consider prior to altering an aircraft by the addition of avionics equipment. These factors include the space available, the size and weight of the equipment, and previously accomplished alterations. The power consumption of the added equipment must be considered to calculate and determine the maximum continuous electrical load on the aircraft's electrical system. Each installation should also be planned to allow easy access for inspection, maintenance, and exchange of units.

The installation of avionics equipment is partially mechanical, involving sheet metal work to mount units, racks, antennas, and controls. Routing of the interconnecting wires, cables, antenna leads, etc. is also an important part of the installation process. When selecting a location for the equipment, use the area(s) designated by the airframe manufacturer or the STC. If such information is not available, select a location for installation that will carry the loads imposed by the weight of the equipment, and which is capable of withstanding the additional inertia forces.

If an avionics device is to be mounted in the instrument panel and no provisions have been made for such an installation, ensure that the panel is not a primary structure prior to making any cutouts. To minimize the load on a stationary instrument panel, a support bracket may be installed between the rear of the electronics case or rack and a nearby structural member of the aircraft. *[Figure 11-157]*

Avionics radio equipment must be securely mounted to the aircraft. All mounting bolts must be secured by locking devices to prevent loosening from vibration. Adequate clearance between all units and adjacent structure must be provided to prevent mechanical damage to electric wiring or to the avionic equipment from vibration, chafing, or landing shock.

Do not locate avionics equipment and wiring near units containing combustible fluids. When separation is impractical, install baffles or shrouds to prevent contact of the combustible fluids with any electronic equipment in the event of plumbing failure.

Cooling & Moisture

The performance and service life of most avionics equipment is seriously limited by excessive ambient temperatures. High performance aircraft with avionics equipment racks typically route air-conditioned air over the avionics to keep them cool. It is also common for non-air conditioned aircraft to use a blower or scooped ram air to cool avionics installations. When adding a unit to an aircraft, the installation should

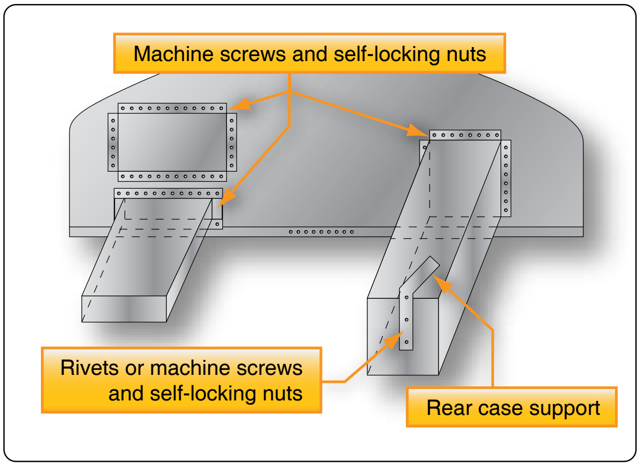

Figure 11-157. *An avionics installation in a stationary instrument panel may include a support for the avionics case.*

be planned so that it can dissipate heat readily. In some installations, it may be necessary to produce airflow over the new equipment either with a blower or through the use of routed ram air. Be sure that proper baffling is used to prevent water from reaching any electronics when ducting outside air. The presence of water in avionics equipment areas promotes rapid deterioration of the exposed components and could lead to failure.

Vibration Isolation

Vibration is a continued motion by an oscillating force. The amplitude and frequency of vibration of the aircraft structure will vary considerably with the type of aircraft. Avionics equipment is sensitive to mechanical shock and vibration and is normally shock mounted to provide some protection against in-flight vibration and landing shock.

Special shock mounted racks are often used to isolate avionics equipment from vibrating structure. *[Figure 11-158]* Such mounts should provide adequate isolation over the entire range of expected vibration frequencies. When installing shock mounts, assure that the equipment weight does not exceed the weight-carrying capabilities of the mounts. Radio equipment installed on shock mounts must have sufficient clearance from surrounding equipment and structure to allow for normal swaying of the equipment.

Radios installed in instrument panels do not ordinarily require vibration protection since the panel itself is usually shock mounted. However, make certain that the added weight of any added equipment can be safely carried by the existing mounts. In some cases, it may be necessary to install larger capacity mounts or to increase the number of mounting points. Periodic inspection of the shock mounts is required, and defective mounts should be replaced with the proper type. The following factors to observe during the inspection are:

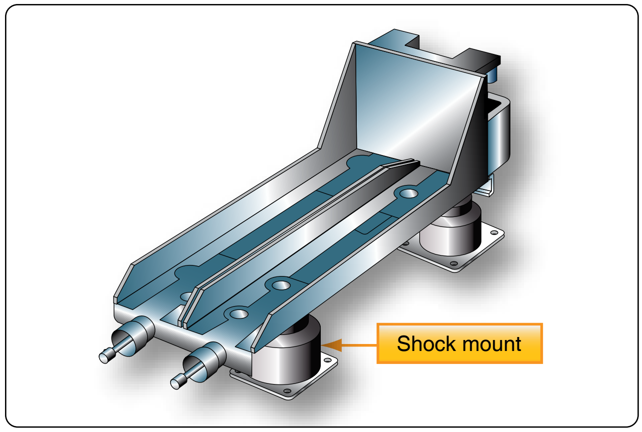

Figure 11-158. *A shock mounted equipment rack is often used to install avionics.*

1. Deterioration of the shock-absorbing material;
2. Stiffness and resiliency of the material; and
3. Overall rigidity of the mount.

If the mount is too stiff, it may not provide adequate protection against the shock of landing. If the shock mount is not stiff enough, it may allow prolonged vibration following an initial shock.

Shock-absorbing materials commonly used in shock mounts are usually electrical insulators. For this reason, each electronic unit mounted with shock mounts must be electrically bonded to a structural member of the aircraft to provide a current path to ground. This is accomplished by secure attachment of a tinned copper wire braid from the component, across the mount, to the aircraft structure as shown in *Figure 11-159*. Occasional bonding is accomplished with solid aluminum or copper material where a short flexible strap is not possible.

Reducing Radio Interference

Suppression of unwanted electromagnetic fields and electrostatic interference is essential on all aircraft. In communication radios, this is noticeable as audible noise. In other components, the effects may not be audible but pose a threat to proper operation. Large discharges of static electricity can permanently damage the sensitive solid-state microelectronics found in nearly all modern avionics.

Shielding

Many components of an aircraft are possible sources of electrical interference which can deteriorate the performance and reliability of avionics components. Rotating electrical devices, switching devices, ignition systems, propeller control systems, AC power lines, and voltage regulators all produce potential damaging fields. Shielding wires to

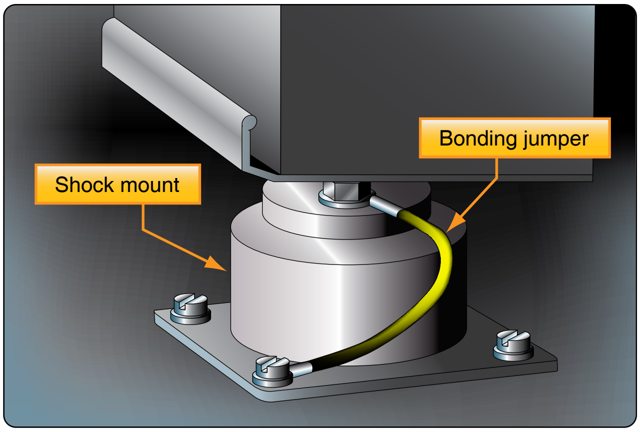

Figure 11-159. *A bonding jumper is used to ground an equipment rack and avionics chassis around the non-conductive shock mount material.*

electric components and ignition systems dissipates radio frequency noise energy. Instead of radiating into space, the braided conductive shielding guides unwanted current flows to ground. To prevent the build-up of electrical potential, all electrical components should also be bonded to the aircraft structure (ground).

Isolation

Isolation is another practical method of radio frequency suppression to prevent interference. This involves separating the source of the noise from the input circuits of the affected equipment. In some cases, noise in a receiver may be entirely eliminated simply by moving the antenna lead-in wire just a few inches away from a noise source. On other occasions, when shielding and isolation are not effective, a filter may need to be installed in the input circuit of an affected component.

Bonding

The aircraft surface can become highly charged with static electricity while in flight. Measures are required to eliminate the build-up and radiation of unwanted electrical charges. One of the most important measures taken to eliminate unwanted electrical charges which may damage or interfere with avionics equipment is bonding. Charges flowing in paths of variable resistance due to such causes as intermittent contact from vibration or the movement of a control surface produce electrical disturbances (noise) in avionics. Bonding provides the necessary electric connection between metallic parts of an aircraft to prevent variable resistance in the airframe. It provides a low-impedance ground return which minimizes interference from static electricity charges.

All metal parts of the aircraft should be bonded to prevent the development of electrical potential build-up. Bonding also provides the low resistance return path for single-wire electrical systems. Bonding jumpers and clamps are examples of bonding connectors. Jumpers should be as short as possible. Be sure finishes are removed in the contact area of a bonding device so that metal-to-metal contact exists. Resistance should not exceed .003 ohm. When a jumper is used only to reduce radio frequency noise and is not for current carrying purposes, a resistance of 0.01 ohm is satisfactory.

Static Discharge Wicks

Static dischargers, or wicks, are installed on aircraft to reduce radio receiver interference. This interference is caused by corona discharge emitted from the aircraft as a result of precipitation static. Corona occurs in short pulses which produce noise at the radio frequency spectrum. Static dischargers are normally mounted on the trailing edges of the control surfaces, wing tips and the vertical stabilizer. They discharge precipitation static at points a critical distance away from avionics antennas where there is little or no coupling of the static to cause interference or noise.

Flexible and semi-flexible dischargers are attached to the aircraft structure by metal screws, rivets, or epoxy. The connections should be checked periodically for security. A resistance measurement from the mount to the airframe should not exceed 0.1 ohm. Inspect the condition of all static dischargers in accordance with manufacturer's instructions. *Figure 11-160* illustrates examples of static dischargers.

Installation of Aircraft Antenna Systems

Knowledge of antenna installation and maintenance is especially important as these tasks are performed by the aircraft technician. Antennas take many forms and sizes dependent upon the frequency of the transmitter and receiver to which they are connected. Airborne antennas must be mechanically secure. The air loads on an antenna are significant and must be considered. Antennas must be electrically matched to the receiver and transmitter that they serve. They must also be mounted in interference free locations and in areas where signals can be optimally transmitted and received. Antennas must also have the same polarization as the ground station.

The following procedures describe the installation of a typical rigid antenna. They are presented as an example only. Always follow the manufacturer's instructions when installing any antenna. An incorrect antenna installation could cause equipment failure.

1. Place a template similar to that shown in *Figure 11-161* on the fore-and-aft centerline at the desired location. Drill the mounting holes and correct diameter hole for the transmission line cable in the fuselage skin.
2. Install a reinforcing doubler of sufficient thickness to reinforce the aircraft skin. The length and width of

Figure 11-160. *Static dischargers or wicks dissipate built up static energy in flight at points a safe distance from avionics antennas to prevent radio frequency interference.*

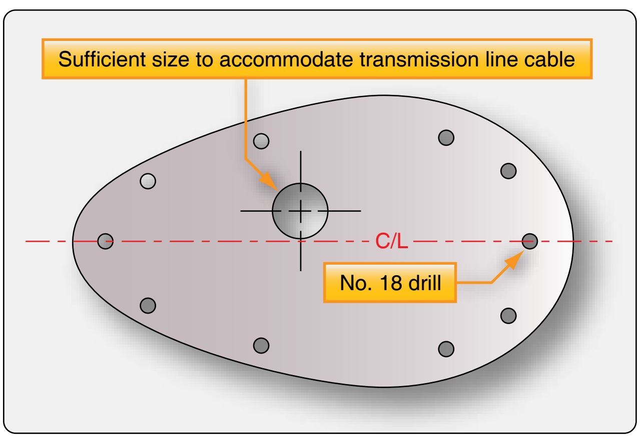

Figure 11-161. *A typical antenna mounting template.*

the reinforcing plate should approximate the example shown in *Figure 11-162*.

3. Install the antenna on the fuselage, making sure that the mounting bolts are tightened firmly against the reinforcing doubler, and the mast is drawn tight against the gasket. If a gasket is not used, seal between the mast and the fuselage with a suitable sealer, such as zinc chromate paste or equivalent.

The mounting bases of antennas vary in shape and sizes; however, the aforementioned installation procedure is typical of mast-type antenna installations.

Transmission Lines

A transmitting or receiving antenna is connected directly to its associated transmitter or receiver by a transmission line. This is a shielded wire also known as coax. Transmission lines may vary from only a few feet to many feet in length. They must transfer energy with minimal loss. Transponders, DME and other pulse type transceivers require transmission lines that are precise in length. The critical length of transmission lines provides minimal attenuation of the transmitted or received signal. Refer to the equipment manufacturer's installation manual for the type and allowable length of transmission lines.

To provide the proper impedance matching for the most efficient power transfer, a balun may be used in some antenna installations. It is formed in the transmission line connection to the antenna. A balun in a dipole antenna installation is illustrated in *Figure 11-163*.

Coax connectors are usually used with coax cable to ensure a secure connection. Many transmission lines are part of the equipment installation kit with connectors previously installed. The aircraft technician is also able to install these

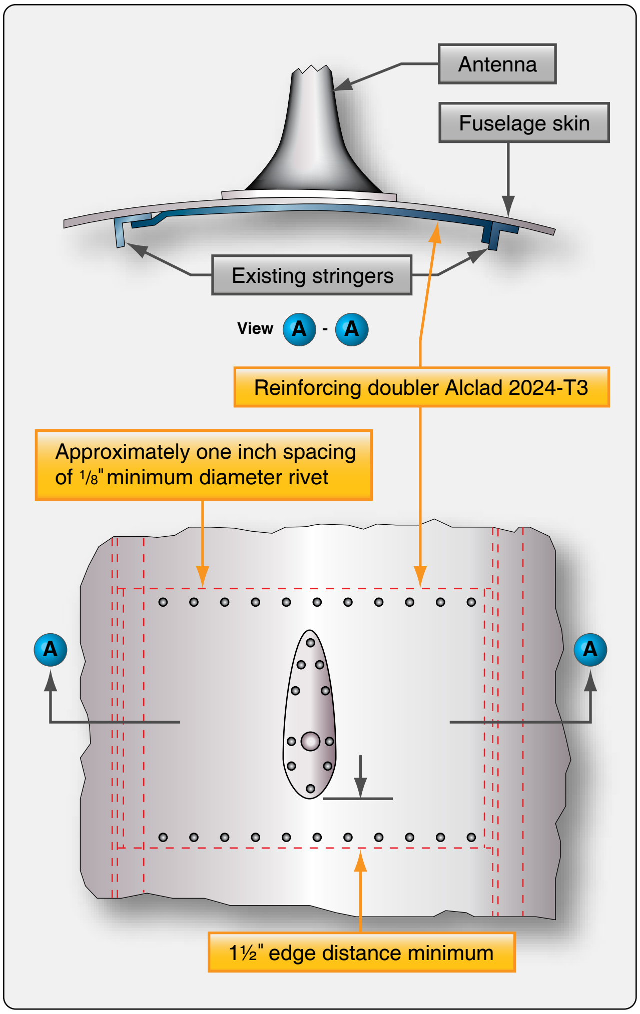

Figure 11-162. *A typical antenna installation on a skin panel including a doubler.*

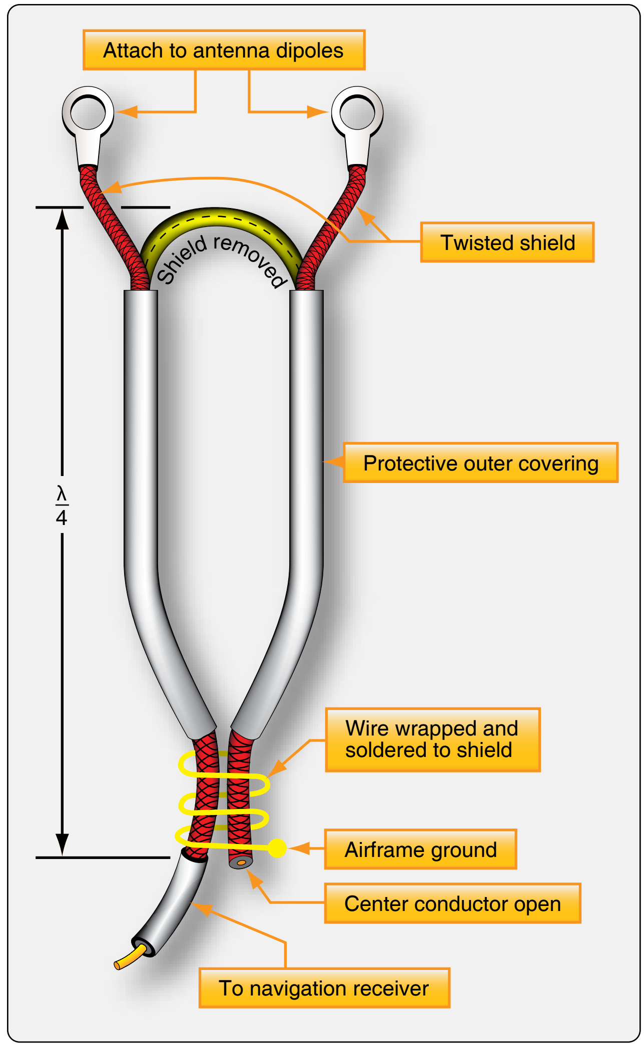

Figure 11-163. *A balun in a dipole antenna installation provides the proper impedance for efficient power transfer.*

connectors on coax. *Figure 11-164* illustrates the basic steps used when installing a coax cable connector.

When installing coaxial cable, secure the cables firmly along their entire length at intervals of approximately 2 feet. To assure optimum operation, coaxial cables should not be routed or tied to other wire bundles. When bending coaxial cable, be sure that the bend is at least 10 times the size of the cable diameter. In all cases, follow the equipment manufacturer's instructions.

Maintenance Procedures

Detailed instructions, procedures, and specifications for the servicing of avionics equipment are contained in the manufacturer's operating manuals. Additional instructions for removal and installation of the units are contained in the maintenance manual for the aircraft in which the equipment is installed. Although an installation may appear to be a simple procedure, many avionics troubles are attributed to careless oversights during equipment replacement. Loose cable connections, switched cable terminations, improper bonding, worn shock mounts, improper safety wiring, and failure to perform an operational check after installation may result in poor performance or inoperative avionics.

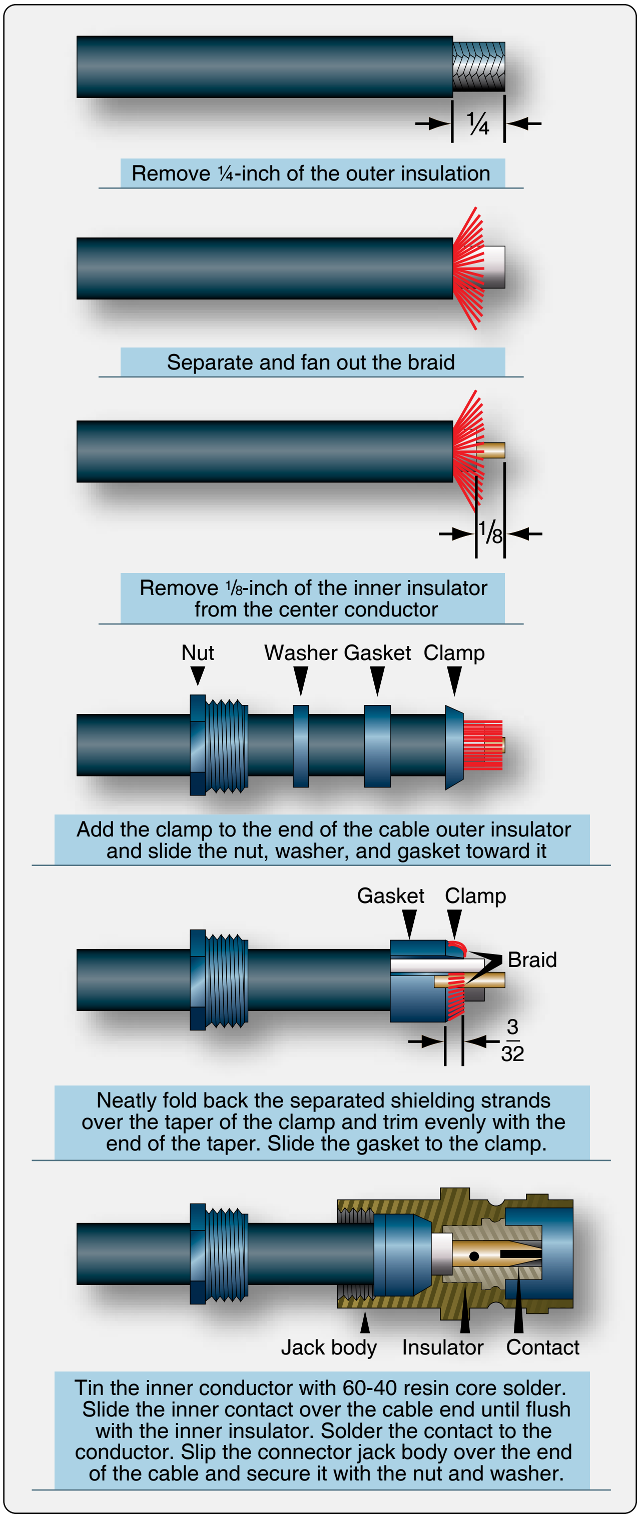

Figure 11-164. *Steps in attaching a connector to coax cable used as antenna transmission lines.*

Chapter 12

Hydraulic & Pneumatic Power Systems

Aircraft Hydraulic Systems

The word "hydraulics" is based on the Greek word for water and originally meant the study of the physical behavior of water at rest and in motion. Today, the meaning has been expanded to include the physical behavior of all liquids, including hydraulic fluid. Hydraulic systems are not new to aviation. Early aircraft had hydraulic brake systems. As aircraft became more sophisticated, newer systems with hydraulic power were developed.

Hydraulic systems in aircraft provide a means for the operation of aircraft components. The operation of landing gear, flaps, flight control surfaces, and brakes is largely accomplished with hydraulic power systems. Hydraulic system complexity varies from small aircraft that require fluid only for manual operation of the wheel brakes to large transport aircraft where the systems are large and complex. To achieve the necessary redundancy and reliability, the system may consist of several subsystems. Each subsystem has a power generating device (pump), reservoir, accumulator, heat exchanger, filtering system, etc. System operating pressure may vary from a couple hundred pounds per square inch (psi) in small aircraft and rotorcraft to 5,000 psi in large transports. Hydraulic systems have many advantages as power sources for operating various aircraft units; they combine the advantages of light weight, ease of installation, simplification of inspection, and minimum maintenance requirements. Hydraulic operations are also almost 100 percent efficient, with only negligible loss due to fluid friction.

Hydraulic Fluid

Hydraulic system liquids are used primarily to transmit and distribute forces to various units to be actuated. Liquids are able to do this because they are almost incompressible. Pascal's Law states that pressure applied to any part of a confined liquid is transmitted with undiminished intensity to every other part. Thus, if a number of passages exist in a system, pressure can be distributed through all of them by means of the liquid.

Manufacturers of hydraulic devices usually specify the type of liquid best suited for use with their equipment in view of the working conditions, the service required, temperatures expected inside and outside the systems, pressures the liquid must withstand, the possibilities of corrosion, and other conditions that must be considered. If incompressibility and fluidity were the only qualities required, any liquid that is not too thick could be used in a hydraulic system. But a satisfactory liquid for a particular installation must possess a number of other properties. Some of the properties and characteristics that must be considered when selecting a satisfactory liquid for a particular system are discussed in the following paragraphs.

Viscosity

One of the most important properties of any hydraulic fluid is its viscosity. Viscosity is internal resistance to flow. A liquid such as gasoline that has a low viscosity flows easily, while a liquid such as tar that has a high viscosity flows slowly. Viscosity increases as temperature decreases. A satisfactory liquid for a given hydraulic system must have enough body to give a good seal at pumps, valves, and pistons, but it must not be so thick that it offers resistance to flow, leading to power loss and higher operating temperatures. These factors add to the load and to excessive wear of parts. A fluid that is too thin also leads to rapid wear of moving parts or of parts that have heavy loads. The instruments used to measure the viscosity of a liquid are known as viscometers or viscosimeters. Several types of viscometers are in use today. The Saybolt viscometer measures the time required, in seconds, for 60 milliliters of the tested fluid at 100 °F to pass through a standard orifice. The time measured is used to express the fluid's viscosity, in Saybolt universal seconds or Saybolt FUROL seconds. *[Figure 12-1]*

Chemical Stability

Chemical stability is another property that is exceedingly important in selecting a hydraulic liquid. It is the liquid's ability to resist oxidation and deterioration for long periods. All liquids tend to undergo unfavorable chemical changes under severe operating conditions. This is the case, for example, when a system operates for a considerable period of time at high temperatures. Excessive temperatures have a great effect on the life of a liquid. It should be noted that the temperature of the liquid in the reservoir of an operating hydraulic system does not always represent a true state of operating conditions. Localized hot spots occur on bearings,

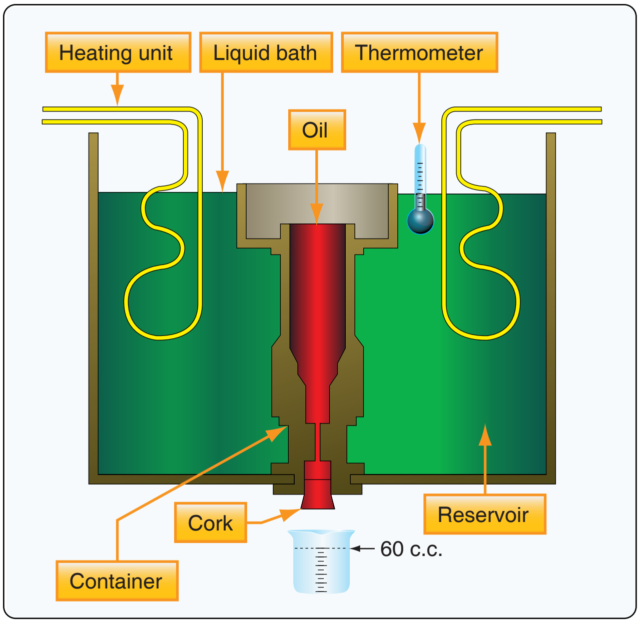

Figure 12-1. *Saybolt viscosimeter.*

gear teeth, or at the point where liquid under pressure is forced through a small orifice. Continuous passage of a liquid through these points may produce local temperatures high enough to carbonize or sludge the liquid, yet the liquid in the reservoir may not indicate an excessively high temperature.

Liquids with a high viscosity have a greater resistance to heat than light or low-viscosity liquids that have been derived from the same source. The average hydraulic liquid has a low viscosity. Fortunately, there is a wide choice of liquids available for use within the viscosity range required of hydraulic liquids.

Liquids may break down if exposed to air, water, salt, or other impurities, especially if they are in constant motion or subject to heat. Some metals, such as zinc, lead, brass, and copper, have an undesirable chemical reaction on certain liquids. These chemical processes result in the formation of sludge, gums, and carbon or other deposits that clog openings, cause valves and pistons to stick or leak, and give poor lubrication to moving parts. As soon as small amounts of sludge or other deposits are formed, the rate of formation generally increases more rapidly. As they are formed, certain changes in the physical and chemical properties of the liquid take place. The liquid usually becomes darker in color, higher in viscosity, and acids are formed.

Flash Point

Flash point is the temperature at which a liquid gives off vapor in sufficient quantity to ignite momentarily or flash when a flame is applied. A high flash point is desirable for hydraulic liquids because it indicates good resistance to combustion and a low degree of evaporation at normal temperatures.

Fire Point

Fire point is the temperature at which a substance gives off vapor in sufficient quantity to ignite and continue to burn when exposed to a spark or flame. Like flash point, a high fire point is required of desirable hydraulic liquids.

Types of Hydraulic Fluids

To assure proper system operation and to avoid damage to nonmetallic components of the hydraulic system, the correct fluid must be used. When adding fluid to a system, use the type specified in the aircraft manufacturer's maintenance manual or on the instruction plate affixed to the reservoir or unit being serviced.

The three principal categories of hydraulic fluids are:

1. Minerals.
2. Polyalphaolefins.
3. Phosphate esters.

When servicing a hydraulic system, the technician must be certain to use the correct category of replacement fluid. Hydraulic fluids are not necessarily compatible. For example, contamination of the fire-resistant fluid MIL-H-83282 with MIL-H-5606 may render the MIL-H-83282 non-fire-resistant.

Mineral-Based Fluids

Mineral oil-based hydraulic fluid (MIL-H-5606) is the oldest, dating back to the 1940s. It is used in many systems, especially where the fire hazard is comparatively low. MIL-H-6083 is simply a rust-inhibited version of MIL-H-5606. They are completely interchangeable. Suppliers generally ship hydraulic components with MIL-H-6083. Mineral-based hydraulic fluid (MIL–H-5606) is processed from petroleum. It has an odor similar to penetrating oil and is dyed red. Some synthetic hydraulic fluids are dyed purple and even green, depending on the identity of the fluid. Synthetic rubber seals are used with petroleum-based fluids.

Polyalphaolefin-Based Fluids

MIL-H-83282 is a fire-resistant hydrogenated polyalphaolefin-based fluid developed in the 1960s to overcome the flammability characteristics of MIL-H-5606. MIL-H-83282 is significantly more flame resistant than MIL-H-5606, but a disadvantage is the high viscosity at low temperature. It is generally limited to –40 °F. However, it can be used in the same system and with the same seals, gaskets, and hoses as MIL-H-5606. MIL-H-46170 is the rust-inhibited version of MIL-H-83282. Small aircraft predominantly use MIL-H-5606, but some have switched to MIL-H-83282 if they can accommodate the high viscosity at low temperature.

Phosphate Ester-Based Fluid

These fluids are used in most commercial transport category aircraft and are extremely fire-resistant. However, they are not fireproof and under certain conditions, they burn. In addition, these fluids are very susceptible to contamination from water in the atmosphere. The earliest generation of these fluids was developed after World War II as a result of the growing number of aircraft hydraulic brake fires that drew the collective concern of the commercial aviation industry. Progressive development of these fluids occurred as a result of performance requirements of newer aircraft designs. The airframe manufacturers dubbed these new generations of hydraulic fluid, such as Skydrol® and Hyjet®, as types based on their performance.

Today, types IV and V fluids are used. Two distinct classes of type IV fluids exist based on their density: class I fluids are low density and class II fluids are standard density. The class I fluids provide weight savings advantages versus class II. In addition to the type IV fluids that are currently in use, type V fluids are being developed in response to industry demands for a more thermally stable fluid at higher operating temperatures. Type V fluids will be more resistant to hydrolytic and oxidative degradation at high temperature than the type IV fluids.

Intermixing of Fluids

Due to the difference in composition, petroleum-based and phosphate ester-based fluids will not mix; neither are the seals for any one fluid usable with or tolerant of any of the other fluids. Should an aircraft hydraulic system be serviced with the wrong type fluid, immediately drain and flush the system and maintain the seals according to the manufacturer's specifications.

Compatibility with Aircraft Materials

Aircraft hydraulic systems designed around phosphate ester-based fluids should be virtually trouble-free if properly serviced. Phosphate ester-based fluids do not appreciably affect common aircraft metals—aluminum, silver, zinc, magnesium, cadmium, iron, stainless steel, bronze, chromium, and others—as long as the fluids are kept free of contamination. Thermoplastic resins, including vinyl compositions, nitrocellulose lacquers, oil-based paints, linoleum, and asphalt may be softened chemically due to phosphate ester-based fluids. However, this chemical action usually requires longer than just momentary exposure, and spills that are wiped up with soap and water do not harm most of these materials. Paints that are resistant to phosphate ester-based fluids include epoxies and polyurethanes. Today, polyurethanes are the standard of the aircraft industry because of their ability to keep a bright, shiny finish for long periods of time and for the ease with which they can be removed.

Hydraulic systems require the use of special accessories that are compatible with the hydraulic fluid. Appropriate seals, gaskets, and hoses must be specifically designated for the type of fluid in use. Care must be taken to ensure that the components installed in the system are compatible with the fluid. When gaskets, seals, and hoses are replaced, positive identification should be made to ensure that they are made of the appropriate material. Phosphate ester-based type V fluid is compatible with natural fibers and with a number of synthetics, including nylon and polyester, which are used extensively in most aircraft. Petroleum oil hydraulic system seals of neoprene or Buna-N are not compatible with phosphate ester-based fluids and must be replaced with seals of butyl rubber or ethylene-propylene elastomers.

Hydraulic Fluid Contamination

Experience has shown that trouble in a hydraulic system is inevitable whenever the liquid is allowed to become contaminated. The nature of the trouble, whether a simple malfunction or the complete destruction of a component, depends to some extent on the type of contaminant. Two general contaminants are:

- Abrasives, including such particles as core sand, weld spatter, machining chips, and rust.
- Nonabrasives, including those resulting from oil oxidation and soft particles worn or shredded from seals and other organic components.

Contamination Check

Whenever it is suspected that a hydraulic system has become contaminated or the system has been operated at temperatures in excess of the specified maximum, a check of the system should be made. The filters in most hydraulic systems are designed to remove most foreign particles that are visible to the naked eye. Hydraulic liquid that appears clean to the naked eye may be contaminated to the point that it is unfit for use. Thus, visual inspection of the hydraulic liquid does not determine the total amount of contamination in the system. Large particles of impurities in the hydraulic system are indications that one or more components are being subjected to excessive wear. Isolating the defective component requires a systematic process of elimination. Fluid returned to the reservoir may contain impurities from any part of the system. To determine which component is defective, liquid samples should be taken from the reservoir and various other locations in the system. Samples should be taken in accordance with the applicable manufacturer's instructions for a particular hydraulic system. Some hydraulic systems are equipped with permanently installed bleed valves for taking liquid samples, whereas on other systems, lines must be disconnected to provide a place to take a sample.

Hydraulic Sampling Schedule

- Routine sampling—each system should be sampled at least once a year, or every 3,000 flight hours, or whenever the airframe manufacturer suggests.
- Unscheduled maintenance—when malfunctions may have a fluid related cause, samples should be taken.
- Suspicion of contamination—if contamination is suspected, fluids should be drained and replaced, with samples taken before and after the maintenance procedure.

Sampling Procedure

- Pressurize and operate hydraulic system for 10 to 15 minutes. During this period, operate various flight controls to activate valves and thoroughly mix hydraulic fluid.
- Shut down and depressurize the system.
- Before taking samples, always be sure to wear the proper personal protective equipment that should include, at the minimum, safety glasses and gloves.
- Wipe off sampling port or tube with a lint-free cloth. Do not use shop towels or paper products that could produce lint. Generally speaking, the human eye can see particles down to about 40 microns in size. Since we are concerned with particles down to 5 microns in size, it is easy to contaminate a sample without ever knowing it.
- Place a waste container under the reservoir drain valve and open valve so that a steady, but not forceful, stream is running.
- Allow approximately 1 pint (250 ml) of fluid to drain. This purges any settled particles from the sampling port.
- Insert a precleaned sample bottle under the fluid stream and fill, leaving an air space at the top. Withdraw the bottle and cap immediately.
- Close drain valve.
- Fill out sample identification label supplied in sample kit, making sure to include customer name, aircraft type, aircraft tail number, hydraulic system sampled, and date sampled. Indicate on the sample label under remarks if this is a routine sample or if it is being taken due to a suspected problem.
- Service system reservoirs to replace the fluid that was removed.
- Submit samples for analysis to laboratory.

Contamination Control

Filters provide adequate control of the contamination problem during all normal hydraulic system operations. Control of the size and amount of contamination entering the system from any other source is the responsibility of the people who service and maintain the equipment. Therefore, precautions should be taken to minimize contamination during maintenance, repair, and service operations. If the system becomes contaminated, the filter element should be removed and cleaned or replaced. As an aid in controlling contamination, the following maintenance and servicing procedures should be followed at all times:

- Maintain all tools and the work area (workbenches and test equipment) in a clean, dirt-free condition.
- A suitable container should always be provided to receive the hydraulic liquid that is spilled during component removal or disassembly procedures.
- Before disconnecting hydraulic lines or fittings, clean the affected area with dry-cleaning solvent.
- All hydraulic lines and fittings should be capped or plugged immediately after disconnecting.
- Before assembly of any hydraulic components, wash all parts in an approved dry-cleaning solvent, i.e., Stoddard solvent.
- After cleaning the parts in the dry-cleaning solution, dry the parts thoroughly and lubricate them with the recommended preservative or hydraulic liquid before assembly. Use only clean, lint-free cloths to wipe or dry the component parts.
- All seals and gaskets should be replaced during the reassembly procedure. Use only those seals and gaskets recommended by the manufacturer.
- All parts should be connected with care to avoid stripping metal slivers from threaded areas. All fittings and lines should be installed and torqued in accordance with applicable technical instructions.
- All hydraulic servicing equipment should be kept clean and in good operating condition.

Contamination, both particulate and chemical, is detrimental to the performance and life of components in the aircraft hydraulic system. Contamination enters the system through normal wear of components, by ingestion through external seals during servicing, or maintenance, when the system is opened to replace/repair components, etc. To control the particulate contamination in the system, filters are installed in the pressure line, in the return line, and in the pump case drain line of each system. The filter rating is given in microns as an indication of the smallest particle size that is filtered out. The replacement interval of these filters is established by the manufacturer and is included in the maintenance manual. In the absence of specific replacement instructions, a recommended service life of the filter elements is:

- Pressure filters—3,000 hours.
- Return Filters—1,500 hours.
- Case drain filters—600 hours.

Hydraulic System Flushing

When inspection of hydraulic filters or hydraulic fluid evaluation indicates that the fluid is contaminated, flushing the system may be necessary. This must be done according to the manufacturer's instructions; however, a typical procedure for flushing is as follows:

1. Connect a ground hydraulic test stand to the inlet and outlet test ports of the system. Verify that the ground unit fluid is clean and contains the same fluid as the aircraft.
2. Change the system filters.
3. Pump clean, filtered fluid through the system, and operate all subsystems until no obvious signs of contamination are found during inspection of the filters. Dispose of contaminated fluid and filter. Note: A visual inspection of hydraulic filters is not always effective.
4. Disconnect the test stand and cap the ports.
5. Ensure that the reservoir is filled to the full line or proper service level.

It is very important to check if the fluid in the hydraulic test stand, or mule, is clean before the flushing operation starts. A contaminated hydraulic test stand can quickly contaminate other aircraft if used for ground maintenance operations.

Health & Handling

Some phosphate ester-based fluids are blended with performance additives. Phosphate esters are good solvents and dissolve away some of the fatty materials of the skin. Repeated or prolonged exposure may cause drying of the skin, which if unattended, could result in complications, such as dermatitis or even secondary infection from bacteria. Phosphate ester-based fluids could cause itching of the skin but have not been known to cause allergic-type skin rashes. Always use the proper gloves and eye protection when handling any type of hydraulic fluid. When phosphate ester-based mist or vapor exposure is possible, a respirator capable of removing organic vapors and mists must be worn. Ingestion of any hydraulic fluid should be avoided. Although small amounts do not appear to be highly hazardous, any significant amount should be tested in accordance with manufacturer's direction, followed with hospital supervised stomach treatment.

Basic Hydraulic Systems

Regardless of its function and design, every hydraulic system has a minimum number of basic components in addition to a means through which the fluid is transmitted. A basic system consists of a pump, reservoir, directional valve, check valve, pressure relieve valve, selector valve, actuator, and filter. *[Figure 12-2]*

Open Center Hydraulic Systems

An open center system is one having fluid flow, but no pressure in the system when the actuating mechanisms are idle. The pump circulates the fluid from the reservoir, through the selector valves, and back to the reservoir. *[Figure 12-3]* The open center system may employ any number of subsystems, with a selector valve for each subsystem. Unlike the closed center system, the selector valves of the open center system are always connected in series with each other. In this arrangement, the system pressure line goes through each selector valve. Fluid is always allowed free passage through each selector valve and back to the reservoir until one of the selector valves is positioned to operate a mechanism.

When one of the selector valves is positioned to operate an actuating device, fluid is directed from the pump through one of the working lines to the actuator. *[Figure 12-3B]* With the selector valve in this position, the flow of fluid through the valve to the reservoir is blocked. The pressure builds up in the system to overcome the resistance and moves the piston of the actuating cylinder; fluid from the opposite end of the

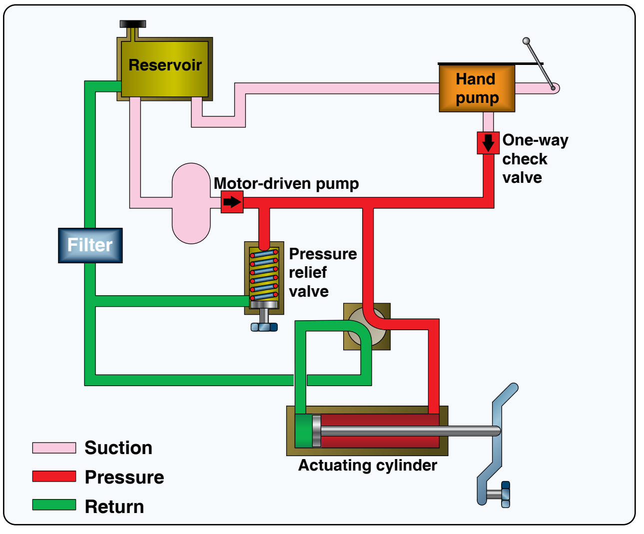

Figure 12-2. *Basic hydraulic system.*

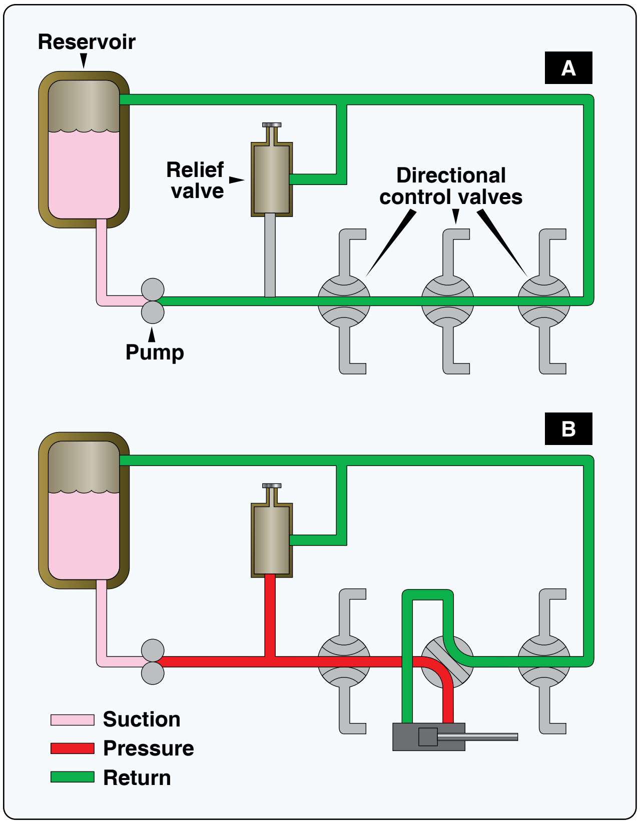

Figure 12-3. *Open center hydraulic system.*

actuator returns to the selector valve and flows back to the reservoir. Operation of the system following actuation of the component depends on the type of selector valve being used.

Several types of selector valves are used in conjunction with the open center system. One type is both manually engaged and manually disengaged. First, the valve is manually moved to an operating position. Then, the actuating mechanism reaches the end of its operating cycle, and the pump output continues until the system relief valve relieves the pressure. The relief valve unseats and allows the fluid to flow back to the reservoir. The system pressure remains at the relief valve set pressure until the selector valve is manually returned to the neutral position. This action reopens the open center flow and allows the system pressure to drop to line resistance pressure.

The manually engaged and pressure disengaged type of selector valve is similar to the valve previously discussed. When the actuating mechanism reaches the end of its cycle, the pressure continues to rise to a predetermined pressure. The valve automatically returns to the neutral position and to open center flow.

Closed-Center Hydraulic Systems

In the closed-center system, the fluid is under pressure whenever the power pump is operating. The three actuators are arranged in parallel and actuating units B and C are operating at the same time, while actuating unit A is not operating. This system differs from the open-center system in that the selector or directional control valves are arranged in parallel and not in series. The means of controlling pump pressure varies in the closed-center system. If a constant delivery pump is used, the system pressure is regulated by a pressure regulator. A relief valve acts as a backup safety device in case the regulator fails.

If a variable displacement pump is used, system pressure is controlled by the pump's integral pressure mechanism compensator. The compensator automatically varies the volume output. When pressure approaches normal system pressure, the compensator begins to reduce the flow output of the pump. The pump is fully compensated (near zero flow) when normal system pressure is attained. When the pump is in this fully compensated condition, its internal bypass mechanism provides fluid circulation through the pump for cooling and lubrication. A relief valve is installed in the system as a safety backup. *[Figure 12-4]* An advantage of the open-center system over the closed-center system is that the continuous pressurization of the system is eliminated. Since the pressure is built up gradually after the selector valve is

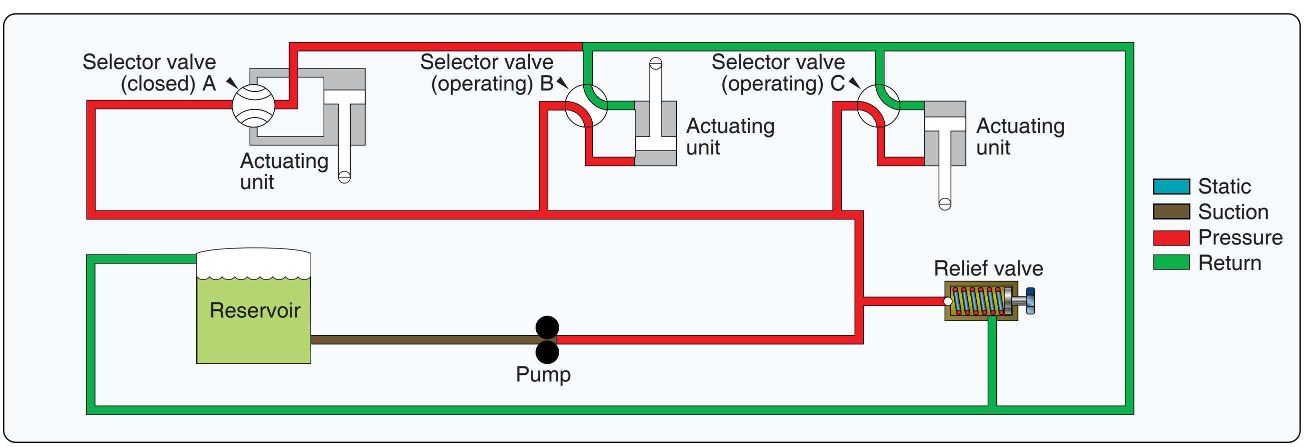

Figure 12-4. *A basic closed-center hydraulic system with a variable displacement pump.*

moved to an operating position, there is very little shock from pressure surges. This action provides a smoother operation of the actuating mechanisms. The operation is slower than the closed-center system, in which the pressure is available the moment the selector valve is positioned. Since most aircraft applications require instantaneous operation, closed-center systems are the most widely used.

Hydraulic Power Systems

Evolution of Hydraulic Systems

Smaller aircraft have relatively low flight control surface loads, and the pilot can operate the flight controls by hand.

Hydraulic systems were utilized for brake systems on early aircraft. When aircraft started to fly faster and got larger in size, the pilot was not able to move the control surfaces by hand anymore, and hydraulic power boost systems were introduced. Power boost systems assist the pilot in overcoming high control forces, but the pilot still actuates the flight controls by cable or push rod.

Many modern aircraft use a power supply system and fly-by-wire flight control. The pilot input is electronically sent to the flight control servos. Cables or push rods are not used. Small power packs are the latest evolution of the hydraulic system. They reduce weight by eliminating hydraulic lines and large quantities of hydraulic fluid. Some manufacturers are reducing hydraulic systems in their aircraft in favor of electrically controlled systems. The Boeing 787 is the first aircraft designed with more electrical systems than hydraulic systems.

Hydraulic Power Pack System

A hydraulic power pack is a small unit that consists of an electric pump, filters, reservoir, valves, and pressure relief valve. *[Figure 12-5]* The advantage of the power pack is that there is no need for a centralized hydraulic power supply system and long stretches of hydraulic lines, which reduces weight. Power packs could be driven by either an engine gearbox or electric motor. Integration of essential valves, filters, sensors, and transducers reduces system weight, virtually eliminates any opportunity for external leakage, and simplifies troubleshooting. Some power pack systems have an integrated actuator. These systems are used to control the stabilizer trim, landing gear, or flight control surfaces directly, thus eliminating the need for a centralized hydraulic system.

Hydraulic System Components

Figure 12-6 is a typical example of a hydraulic system in a large commercial aircraft. The following sections discuss the components of such system in more detail.

Figure 12-5. *Hydraulic power pack.*

Reservoirs

The reservoir is a tank in which an adequate supply of fluid for the system is stored. Fluid flows from the reservoir to the pump, where it is forced through the system and eventually returned to the reservoir. The reservoir not only supplies the operating needs of the system, but it also replenishes fluid lost through leakage. Furthermore, the reservoir serves as an overflow basin for excess fluid forced out of the system by thermal expansion (the increase of fluid volume caused by temperature changes), the accumulators, and by piston and rod displacement.

The reservoir also furnishes a place for the fluid to purge itself of air bubbles that may enter the system. Foreign matter picked up in the system may also be separated from the fluid in the reservoir or as it flows through line filters. Reservoirs are either pressurized or nonpressurized.

Baffles and/or fins are incorporated in most reservoirs to keep the fluid within the reservoir from having random movement, such as vortexing (swirling) and surging. These conditions can cause fluid to foam and air to enter the pump along with the fluid. Many reservoirs incorporate strainers in the filler neck to prevent the entry of foreign matter during servicing. These strainers are made of fine mesh screening and are usually referred to as finger strainers because of their shape. Finger strainers should never be removed or punctured as a means of speeding up the pouring of fluid into the reservoir. Reservoirs could have an internal trap to make sure fluid goes to the pumps during negative-G conditions.

Most aircraft have emergency hydraulic systems that take over if main systems fail. In many such systems, the pumps of both systems obtain fluid from a single reservoir. Under such circumstances, a supply of fluid for the emergency pump is ensured by drawing the hydraulic fluid from the bottom of the reservoir. The main system draws its fluid through a standpipe

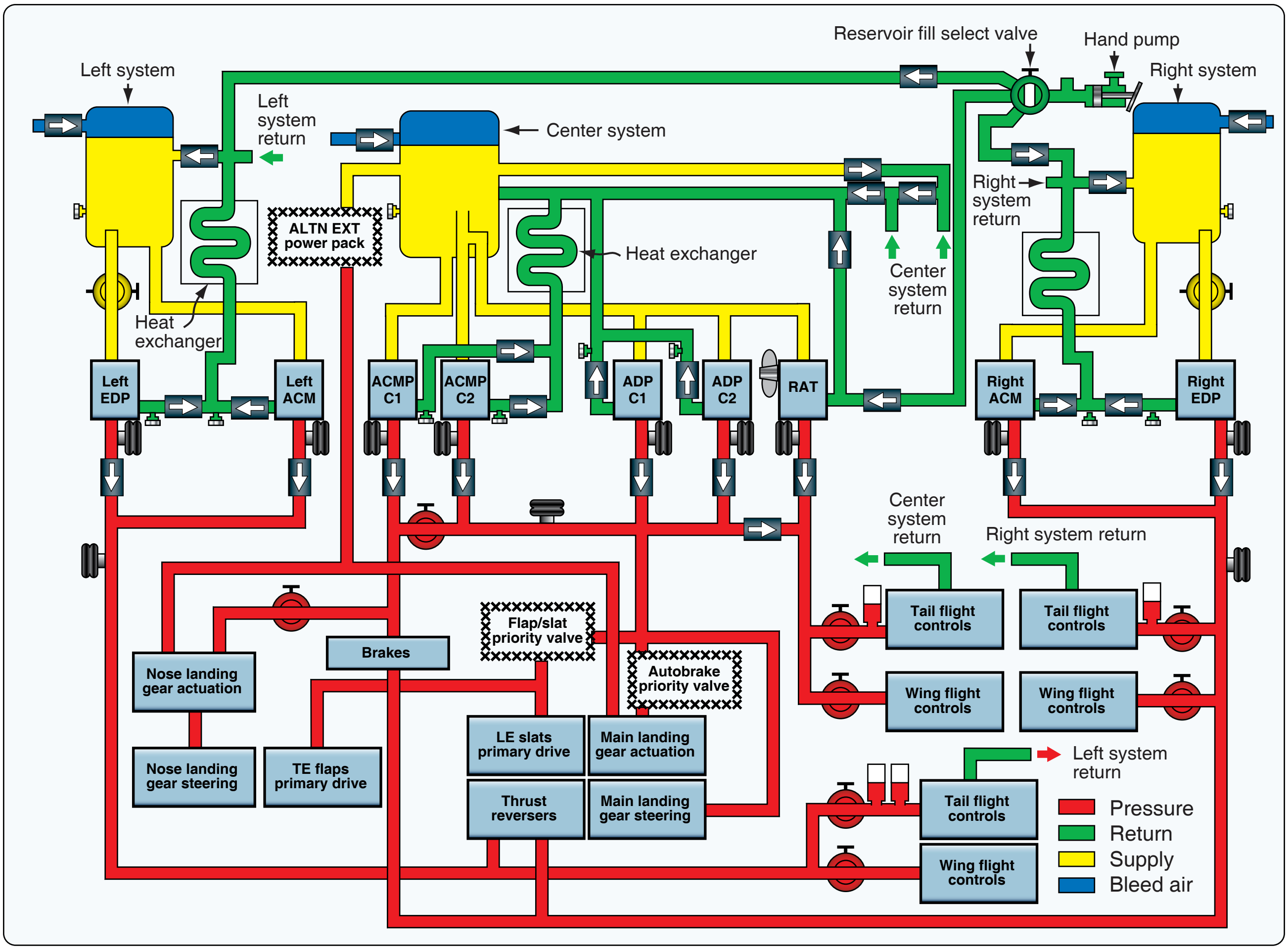

Figure 12-6. *Large commercial aircraft hydraulic system.*

located at a higher level. With this arrangement, should the main system's fluid supply become depleted, adequate fluid is left for operation of the emergency system. *Figure 12-7* illustrates that the engine-driven pump (EDP) is not able to draw fluid any more if the reservoir gets depleted below the standpipe. The alternating current motor-driven pump (ACMP) still has a supply of fluid for emergency operations.

Nonpressurized Reservoirs

Nonpressurized reservoirs are used in aircraft that are not designed for violent maneuvers, do not fly at high altitudes, or in which the reservoir is located in the pressurized area of the aircraft. High altitude in this situation means an altitude where atmospheric pressure is inadequate to maintain sufficient flow of fluid to the hydraulic pumps. Most nonpressurized reservoirs are constructed in a cylindrical shape. The outer housing is manufactured from a strong corrosion-resistant metal. Filter elements are normally installed within the reservoir to clean returning system hydraulic fluid.

In some of the older aircraft, a filter bypass valve is incorporated to allow fluid to bypass the filter in the event the filter becomes clogged. Reservoirs can be serviced by pouring fluid directly into the reservoir through a filler strainer (finger strainer) assembly incorporated within the filler well to strain out impurities as the fluid enters the reservoir. Generally, nonpressurized reservoirs use a visual gauge to indicate the fluid quantity. Gauges incorporated on or in the reservoir may be a direct reading glass tube-type or a float-type rod that is visible through a transparent dome. In some cases, the fluid quantity may also be read in the flight deck through the use of quantity transmitters. A typical nonpressurized reservoir is shown in *Figure 12-8*. This reservoir consists of a welded body and cover assembly clamped together. Gaskets are incorporated to seal against leakage between assemblies.

Nonpressurized reservoirs are slightly pressurized due to thermal expansion of fluid and the return of fluid to the reservoir from the main system. This pressure ensures that there is a positive flow of fluids to the inlet ports of the hydraulic pumps. Most reservoirs of this type are vented directly to the atmosphere or cabin with only a check valve and filter to control the outside air source. The reservoir system includes a pressure and vacuum relief valve. The purpose of

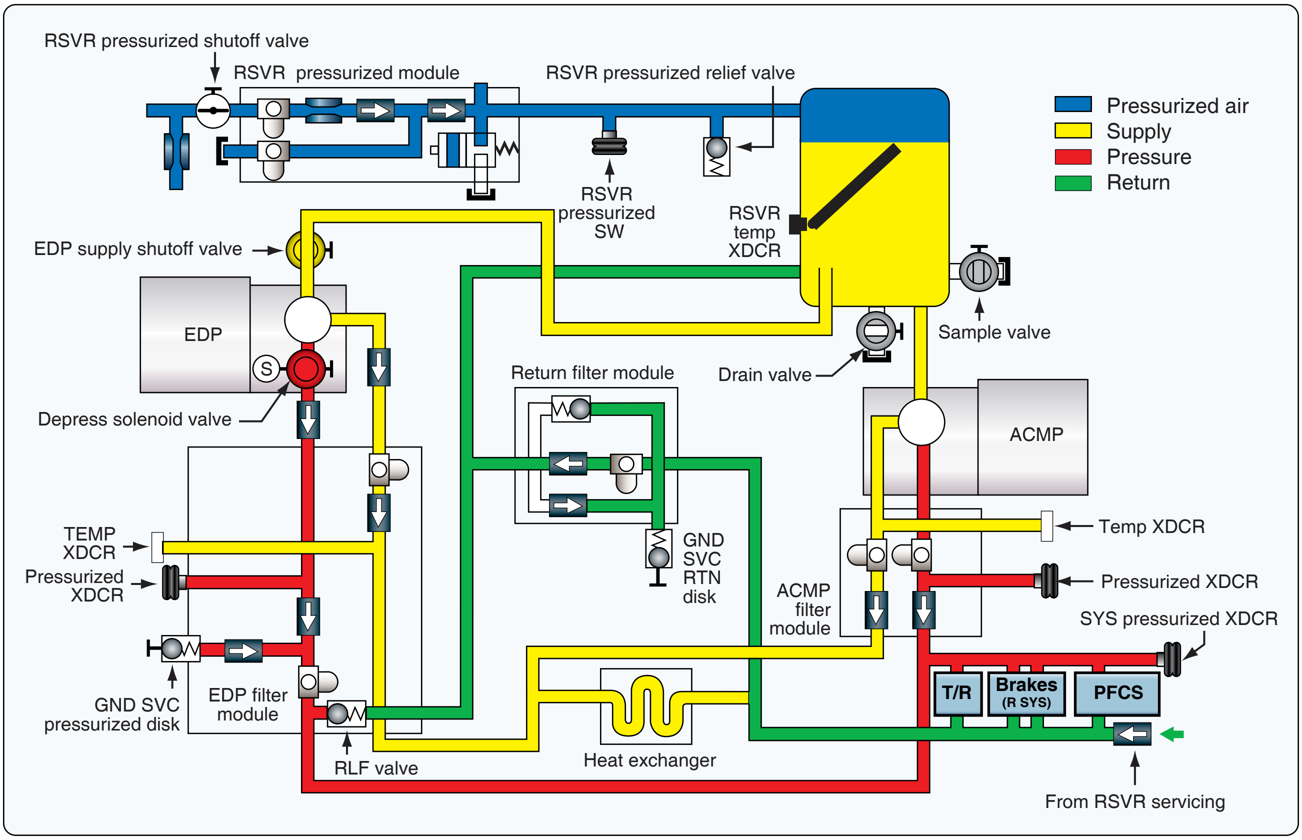

Figure 12-7. *Hydraulic reservoir standpipe for emergency operations.*

the valve is to maintain a differential pressure range between the reservoir and cabin. A manual air bleed valve is installed on top of the reservoir to vent the reservoir. The valve is connected to the reservoir vent line to allow depressurization of the reservoir. The valve is actuated prior to servicing the reservoir to prevent fluid from being blown out of the filler as the cap is being removed. The manual bleed valve also needs to be actuated if hydraulic components need to be replaced.

Pressurized Reservoirs

Reservoirs on aircraft designed for high-altitude flight are usually pressurized. Pressurizing assures a positive flow of fluid to the pump at high altitudes when low atmospheric pressures are encountered. On some aircraft, the reservoir is pressurized by bleed air taken from the compressor section of the engine. On others, the reservoir may be pressurized by hydraulic system pressure.

Air-Pressurized Reservoirs

Air-pressurized reservoirs are used in many commercial transport-type aircraft. *[Figures 12-9* and *12-10]* Pressurization of the reservoir is required because the reservoirs are often located in wheel wells or other non-pressurized areas of the aircraft and at high altitude there is not enough atmospheric pressure to move the fluid to the pump inlet. Engine bleed air is used to pressurize the reservoir. The reservoirs are typically cylindrical in shape. The following components are installed on a typical reservoir:

- Reservoir pressure relief valve—prevents over pressurization of the reservoir. Valve opens at a preset value.
- Sight glasses (low and overfull)—provides visual indication for flight crews and maintenance personnel that the reservoir needs to be serviced.
- Reservoir sample valve—used to draw a sample of hydraulic fluid for testing.
- Reservoir drain valve—used to drain the fluids out of the reservoir for maintenance operation.
- Reservoir temperature transducer—provides hydraulic fluid temperature information for the flight deck. *[Figure 12-11]*
- Reservoir quantity transmitter—transmits fluid quantity to the flight deck so that the flight crew can monitor fluid quantity during flight. *[Figure 12-11]*

A reservoir pressurization module is installed close to the reservoir. *[Figure 12-12]* The reservoir pressurization module supplies airplane bleed air to the reservoirs. The module

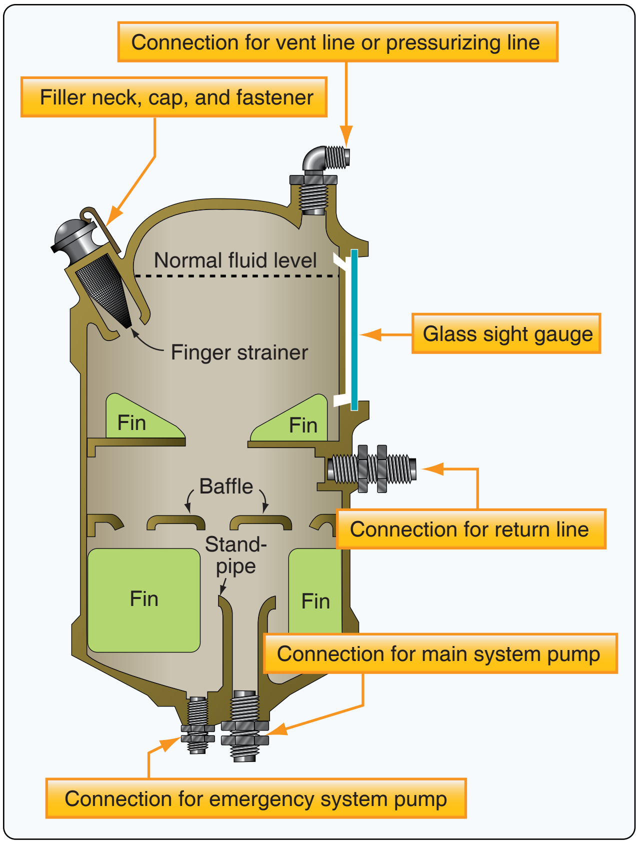

Figure 12-8. *Nonpressurized reservoir.*

Figure 12-9. *Air-pressurized reservoir.*

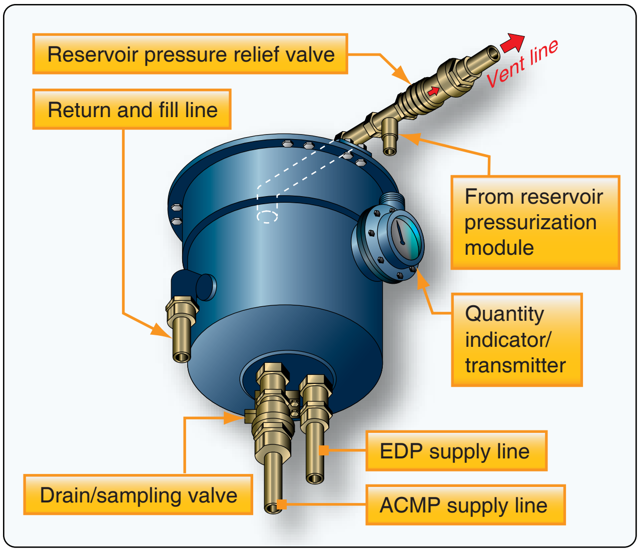

Figure 12-10. *Components of an air-pressurized reservoir.*

Figure 12-11. *Temperature and quantity sensors.*

consists of the following parts:

- Filters (2).
- Check valves (2).
- Test port.
- Manual bleed valve.
- Gauge port.

A manual bleeder valve is incorporated into the module. During hydraulic system maintenance, it is necessary to relieve reservoir air pressure to assist in the installation and removal of components, lines, etc. This type of valve is small in size and has a push button installed in the outer case. When the bleeder valve push button is pushed, pressurized air from the reservoir flows through the valve to an overboard vent until the air pressure is depleted or the button is released. When the button is released, the internal spring causes the

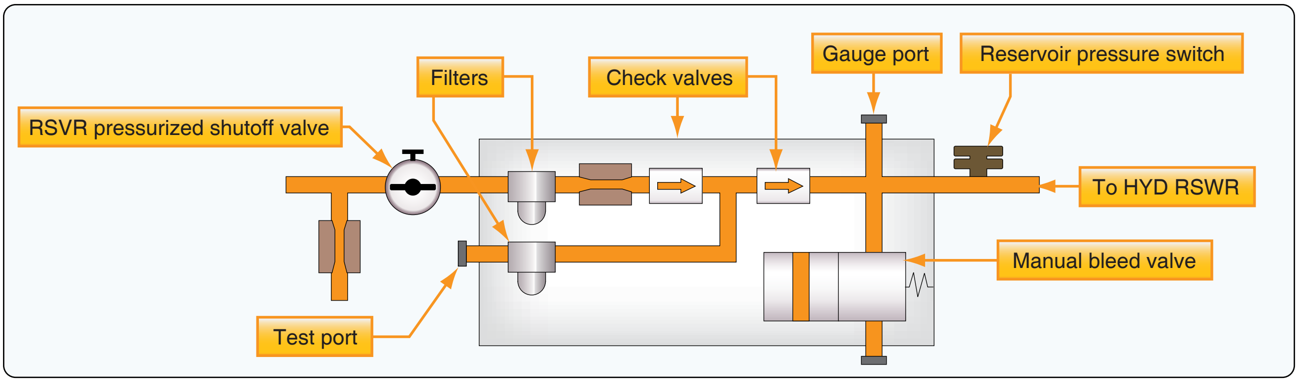

Figure 12-12. *Reservoir pressurization module.*

poppet to return to its seat. Some hydraulic fluid can escape from the manual bleed valve when the button is depressed.

Caution: Put a rag around the air bleed valve on the reservoir pressurization module to catch hydraulic fluid spray. Hydraulic fluid spray can cause injuries to persons.

Fluid-Pressurized Reservoirs

Some aircraft hydraulic system reservoirs are pressurized by hydraulic system pressure. Regulated hydraulic pump output pressure is applied to a movable piston inside the cylindrical reservoir. This small piston is attached to and moves a larger piston against the reservoir fluid. The reduced force of the small piston when applied by the larger piston is adequate to provide head pressure for high altitude operation. The small piston protrudes out of the body of the reservoir. The amount exposed is used as a reservoir fluid quantity indicator. *Figure 12-13* illustrates the concept behind the fluid-pressurized hydraulic reservoir.

The reservoir has five ports: pump suction, return, pressurizing, overboard drain, and bleed port. Fluid is supplied to the pump through the pump suction port. Fluid returns to the reservoir from the system through the return port. Pressure from the pump enters the pressurizing cylinder in the top of the reservoir through the pressurizing port. The overboard drain port drains the reservoir, when necessary, while performing maintenance. The bleed port is used as an aid in servicing the reservoir. When servicing a system equipped with this type of reservoir, place a container under the bleed drain port. The fluid should then be pumped into the reservoir until air-free fluid flows through the bleed drain port.

The reservoir fluid level is indicated by the markings on the part of the pressurizing cylinder that moves through the reservoir dust cover assembly. There are three fluid level markings indicated on the cover: full at zero system pressure (FULL ZERO PRESS), full when system is pressurized (FULL SYS PRESS), and REFILL. When the system is unpressurized and the pointer on the reservoir lies between the two full marks, a marginal reservoir fluid level is indicated. When the system is pressurized, and the pointer lies between REFILL and FULL SYS PRESS, a marginal reservoir fluid level is also indicated.

Reservoir Servicing

Nonpressurized reservoirs can be serviced by pouring fluid directly into the reservoir through a filler strainer (finger strainer) assembly incorporated within the filler well to

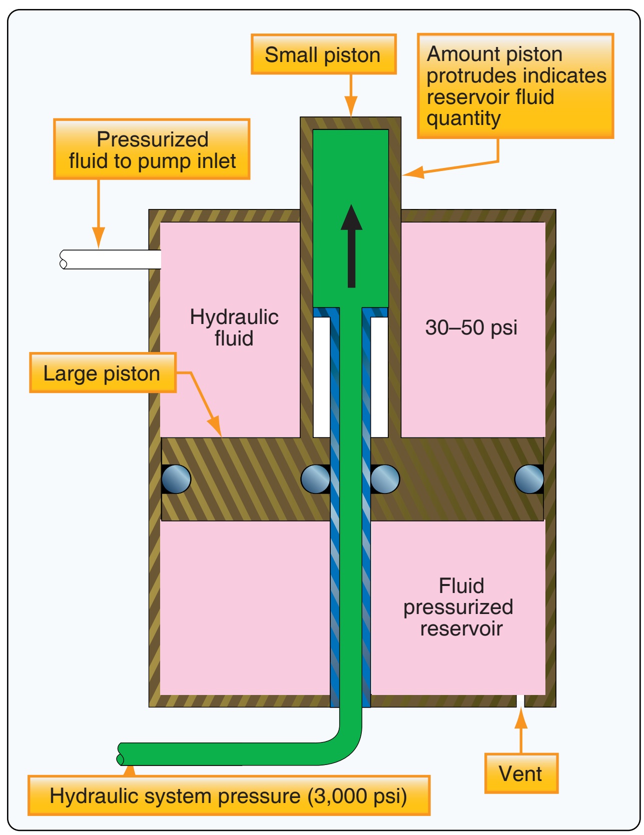

Figure 12-13. *Operating principle behind a fluid-pressurized hydraulic reservoir.*

strain out impurities as the fluid enters the reservoir. Many reservoirs also have a quick disconnect service port at the bottom of the reservoir. A hydraulic filler unit can be connected to the service port to add fluid to the reservoir. This method reduces the chances of contamination of the reservoir. Aircraft that use pressurized reservoirs often have a central filling station in the ground service bay to service all reservoirs from a single point. *[Figure 12-14]*

A built-in hand pump is available to draw fluid from a container through a suction line and pump it into the reservoirs. Additionally, a pressure fill port is available for attachment of a hydraulic mule or serving cart, which uses an external pump to push fluid into the aircraft hydraulic system. A check valve keeps the hand pump output from exiting the pressure fill port. A single filter is located downstream of both the pressure fill port and the hand pump to prevent the introduction of contaminants during fluid servicing.

It is very important to follow the maintenance instructions when servicing the reservoir. To get the correct results when the hydraulic fluid quantities are checked, or the reservoirs are to be filled, the airplane should be in the correct configuration. Failure to do so could result in overservicing of the reservoir. This configuration could be different for each aircraft. The following service instructions are an example of a large transport-type aircraft.

Before servicing always make sure that the:

- Spoilers are retracted,
- Landing gear is down,
- Landing gear doors are closed,
- Thrust reversers are retracted, and
- Parking brake accumulator pressure reads at least 2,500 psi.

Filters

A filter is a screening or straining device used to clean the hydraulic fluid, preventing foreign particles and contaminating substances from remaining in the system. *[Figure 12-15]* If such objectionable material were not removed, the entire hydraulic system of the aircraft could fail through the breakdown or malfunctioning of a single unit of the system.

The hydraulic fluid holds in suspension tiny particles of metal that are deposited during the normal wear of selector valves, pumps, and other system components. Such minute particles of metal may damage the units and parts through which they pass if they are not removed by a filter. Since tolerances within the hydraulic system components are quite small, it is apparent that the reliability and efficiency of the entire system depends upon adequate filtering.

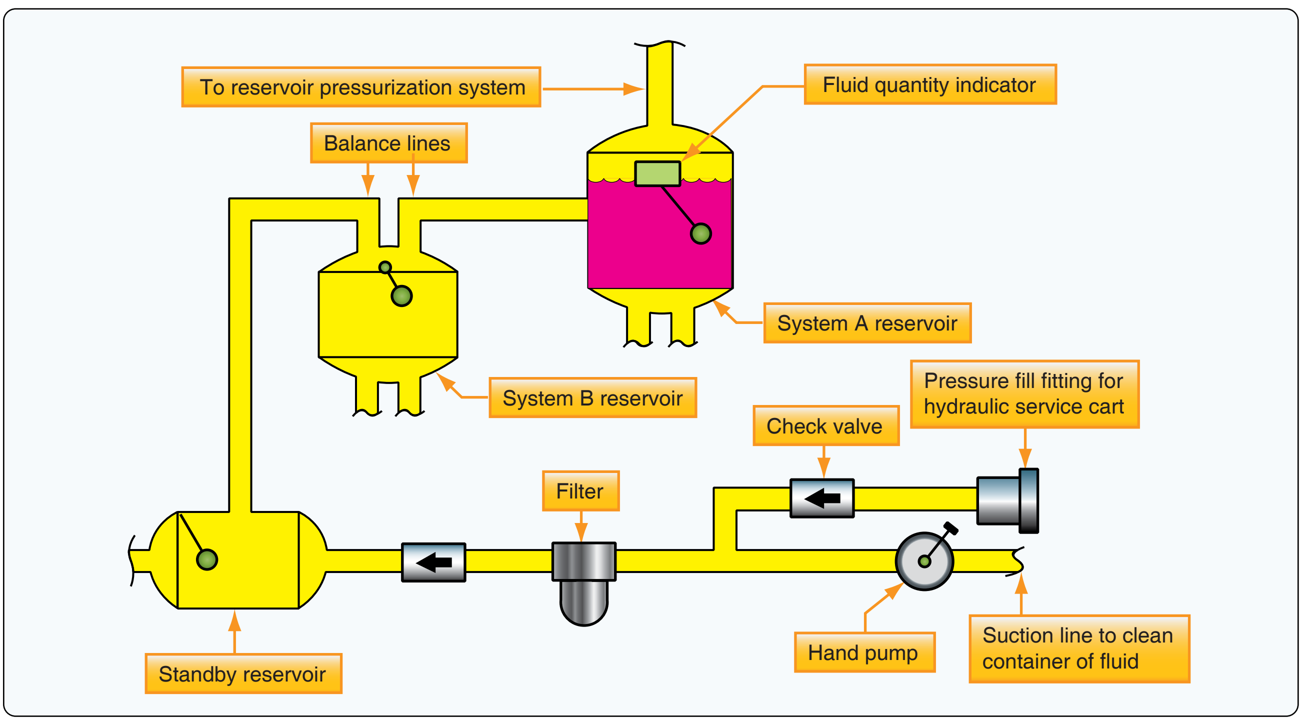

Figure 12-14. *The hydraulic ground serive station on a Boeing 737 provides for hydraulic fluid servicing with a hand pump or via an external pressure fluid source. All three reservoirs are serviced from the same location.*

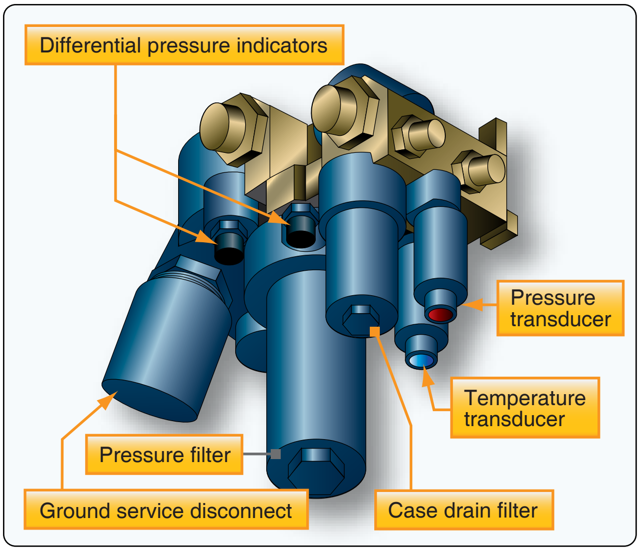

Figure 12-15. *Filter module components.*

Filters may be located within the reservoir, in the pressure line, in the return line, or in any other location the designer of the system decides that they are needed to safeguard the hydraulic system against impurities. Modern design often uses a filter module that contains several filters and other components. *[Figure 12-16]* There are many models and styles of filters. Their position in the aircraft and design requirements determine their shape and size. Most filters used in modern aircraft are of the inline type. The inline filter assembly is comprised of three basic units: head assembly, bowl, and element. The head assembly is secured to the aircraft structure and connecting lines. Within the head, there is a bypass valve that routes the hydraulic fluid directly from the inlet to the outlet port if the filter element becomes clogged with foreign matter. The bowl is the housing that holds the element to the filter head and is removed when element removal is required.

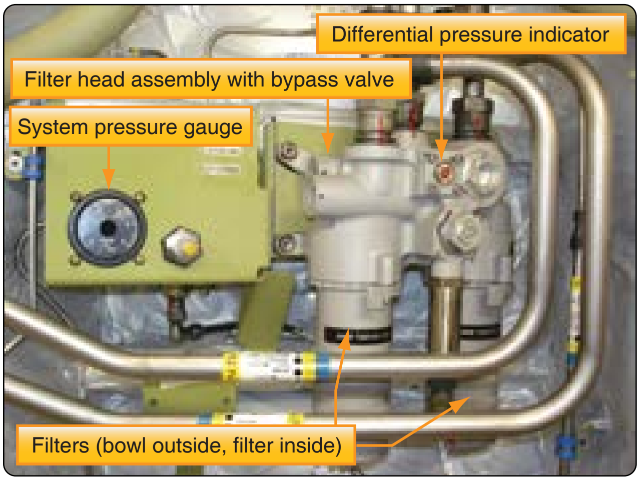

Figure 12-16. *A transport category filter module with two filters.*

The element may be a micron, porous metal, or magnetic type. The micron element is made of a specially treated paper and is normally thrown away when removed. The porous metal and magnetic filter elements are designed to be cleaned by various methods and replaced in the system.

Micron-Type Filters

A typical micron-type filter assembly utilizes an element made of specially treated paper that is formed in vertical convolutions (wrinkles). An internal spring holds the elements in shape. The micron element is designed to prevent the passage of solids greater than 10 microns (0.000394 inch) in size. *[Figure 12-17]* In the event that the filter element becomes clogged, the spring-loaded relief valve in the filter head bypasses the fluid after a differential pressure of 50 psi has been built up. Hydraulic fluid enters the filter through the inlet port in the filter body and flows around the element inside the bowl. Filtering takes place as the fluid passes through the element into the hollow core, leaving the foreign material on the outside of the element.

Maintenance of Filters

Maintenance of filters is relatively easy. It mainly involves cleaning the filter and element or cleaning the filter and replacing the element. Filters using the micron-type element should have the element replaced periodically according to applicable instructions. Since reservoir filters are of the micron type, they must also be periodically changed or cleaned. For filters using other than the micron-type element, cleaning the filter and element is usually all that is necessary. However, the element should be inspected very closely to ensure that it is completely undamaged. The methods and materials used in cleaning all filters are too numerous to be included in this text. Consult the manufacturer's instructions for this information.

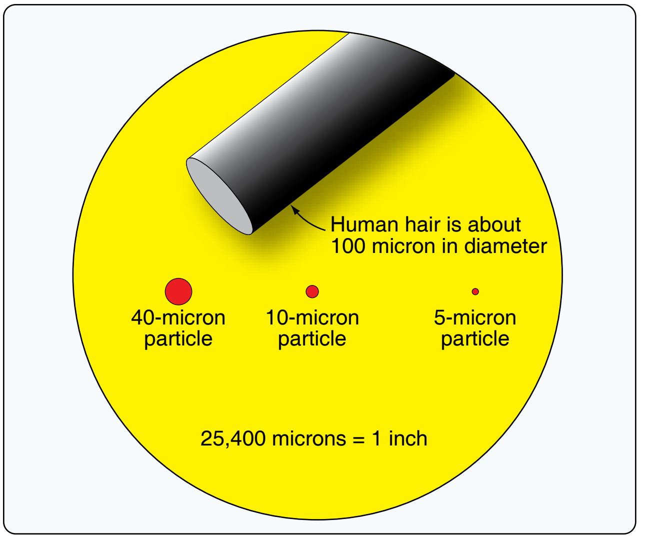

Figure 12-17. *Size comparison in microns.*

When replacing filter elements, be sure that there is no pressure on the filter bowl. Protective clothing and a face shield must be used to prevent fluid from contacting the eye. Replace the element with one that has the proper rating. After the filter element has been replaced, the system must be pressure tested to ensure that the sealing element in the filter assembly is intact.

In the event of a major component failure, such as a pump, consideration must be given to replacing the system filter elements, as well as the failed component.

Filter Bypass Valve

Filter modules are often equipped with a bypass relief valve. The bypass relief valve opens if the filter clogs, permitting continued hydraulic flow and operation of aircraft systems. Dirty oil is preferred over no flow at all. *Figure 12-18* shows the principle of operation of a filter bypass valve. The ball valve opens when the filter becomes clogged and the pressure over the filter increases.

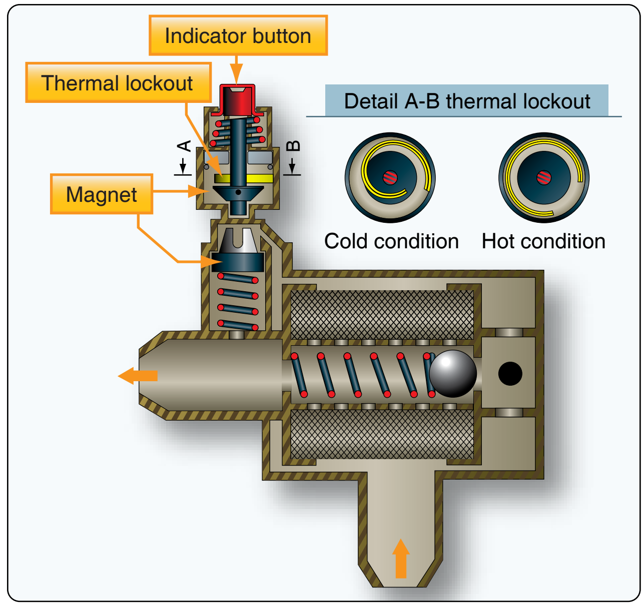

Figure 12-18. *Filter bypass valve.*

Filter Differential Pressure Indicators

The extent to which a filter element is loaded can be determined by measuring the drop in hydraulic pressure across the element under rated flow conditions. This drop, or differential pressure, provides a convenient means of monitoring the condition of installed filter elements and is the operating principle used in the differential pressure or loaded-filter indicators found on many filter assemblies.

Differential pressure indicating devices have many configurations, including electrical switches, continuous-reading visual indicators (gauges), and visual indicators with memory. Visual indicators with memory usually take the form of magnetic or mechanically latched buttons or pins that extend when the differential pressure exceeds that allowed for a serviceable element. *[Figure 12-18, top]* When this increased pressure reaches a specific value, inlet pressure forces the spring-loaded magnetic piston downward, breaking the magnetic attachment between the indicator button and the magnetic piston. This allows the red indicator to pop out, signifying that the element must be cleaned. The button or pin, once extended, remains in that position until manually reset and provides a permanent (until reset) warning of a loaded element. This feature is particularly useful where it is impossible for an operator to continuously monitor the visual indicator, such as in a remote location on the aircraft.

Some button indicators have a thermal lockout device incorporated in their design that prevents operation of the indicator below a certain temperature. The lockout prevents the higher differential pressure generated at cold temperatures by high fluid viscosity from causing a false indication of a loaded filter element.

Differential pressure indicators are a component part of the filter assembly in which they are installed and are normally tested and overhauled as part of the complete assembly. With some model filter assemblies, however, it is possible to replace the indicator itself without removal of the filter assembly if it is suspected of being inoperative or out of calibration. It is important that the external surfaces of button-type indicators be kept free of dirt or paint to ensure free movement of the button. Indications of excessive differential pressure, regardless of the type of indicator employed, should never be disregarded. All such indications must be verified and action taken, as required, to replace the loaded filter element. Failure to replace a loaded element can result in system starvation, filter element collapse, or the loss of filtration where bypass assemblies are used. Verification of loaded filter indications is particularly important with button-type indicators as they may have been falsely triggered by mechanical shock, vibration, or cold start of the system. Verification is usually obtained by manually resetting the indicator and operating the system to create a maximum flow demand ensuring that the fluid is at near normal operating temperatures.

Pumps

All aircraft hydraulic systems have one or more power-driven pumps and may have a hand pump as an additional unit when the engine-driven pump is inoperative. Power-driven pumps are the primary source of energy and may be either engine driven, electric motor driven, or air driven. As a general rule, electrical motor pumps are installed for use in emergencies or during ground operations. Some aircraft can deploy a ram air turbine (RAT) to generate hydraulic power.

Hand Pumps

The hydraulic hand pump is used in some older aircraft for the operation of hydraulic subsystems and in a few newer aircraft systems as a backup unit. Hand pumps are generally installed for testing purposes, as well as for use in emergencies. Hand pumps are also installed to service the reservoirs from a single refilling station. The single refilling station reduces the chances for the introduction of fluid contamination.

Several types of hand pumps are used: single action, double action, and rotary. A single action hand pump draws fluid into the pump on one stroke and pumps that fluid out on the next stroke. It is rarely used in aircraft due to this inefficiency.

Double-action hand pumps produce fluid flow and pressure on each stroke of the handle. *[Figure 12-19]* The double-action hand pump consists essentially of a housing that has a cylinder bore and two ports, a piston, two spring-loaded check valves, and an operating handle. An O-ring on the piston seals against leakage between the two chambers of the piston cylinder bore. An O-ring in a groove in the end of the pump housing seals against leakage between the piston rod and housing.

When the piston is moved to the right, the pressure in the chamber left of the piston is lowered. The inlet port ball check valve opens, and hydraulic fluid is drawn into the chamber. At the same time, the rightward movement of the piston forces the piston ball check valve against its seat. Fluid in the chamber to the right of the piston is forced out of the outlet port into the hydraulic system. When the piston is moved to the left, the inlet port ball check valve seats. Pressure in the chamber left of the piston rises, forcing the piston ball check valve off of its seat. Fluid flows from the left chamber through the piston to the right chamber. The volume in the chamber right of the piston is smaller than that of the left chamber due to the displacement created by the piston rod. As the fluid from the left chamber flows into the smaller right chamber, the excess volume of fluid is forced out of the outlet port to the hydraulic system.

A rotary hand pump may also be employed. It produces continuous output while the handle is in motion. *Figure 12-20* shows a rotary hand pump in a hydraulic system.

Power-Driven Pumps

Many of the power driven hydraulic pumps of current aircraft are of variable delivery, compensator-controlled type. Constant delivery pumps are also in use. Principles of operation are the same for both types of pumps. Modern aircraft use a combination of engine-driven power pumps, electrical-driven power pumps, air-driven power pumps, power transfer units (PTU), and pumps driven by a RAT. For example, large aircraft, such as the Airbus A380, have

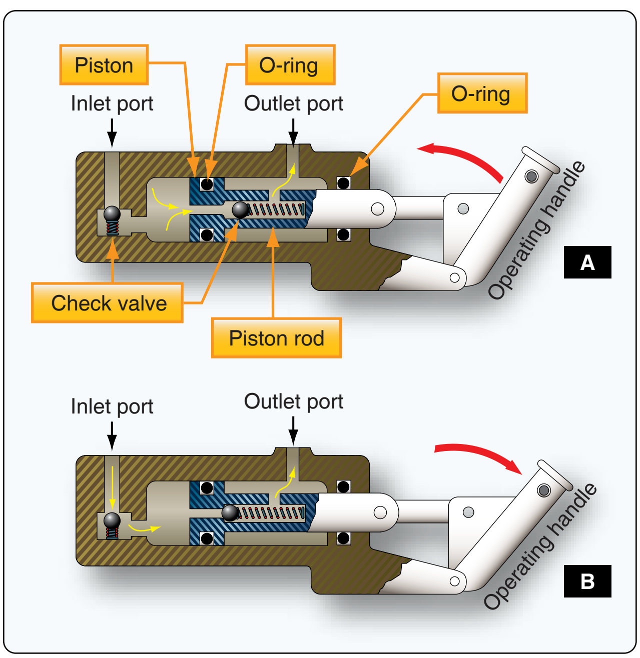

Figure 12-19. *Double action hand pump.*

Figure 12-20. *Rotary hand pump.*

two hydraulic systems, eight engine-driven pumps, and three electrical driven pumps. The Boeing 777 has three hydraulic systems with two engine driven pumps, four electrical driven pumps, two air driven pumps, and a hydraulic pump motor driven by the RAT. *[Figure 12-21* and *12-22]*

Figure 12-21. *Engine-driven pump.*

Figure 12-22. *Electrically-driven pump.*

Classification of Pumps

All pumps may be classified as either positive-displacement (constant displacement) or nonpositive-displacement (variable displacement). Most pumps used in hydraulic systems are positive displacement. Engine driven pumps may be either constant displacement or variable displacement. A nonpositive-displacement pump produces a continuous flow. However, because it does not provide a positive internal seal against slippage, its output varies considerably as pressure varies. Centrifugal and impeller pumps are examples of nonpositive-displacement pumps. If the output port of a nonpositive-displacement pump was blocked off, the pressure would rise, and output would decrease to zero. Although the pumping element would continue moving, flow would stop because of slippage inside the pump. In a positive-displacement pump, slippage is negligible compared to the pump's volumetric output flow. If the output port were plugged, pressure would increase instantaneously to the point that the pump pressure relief valve opens.

Constant-Displacement Pumps

A constant-displacement pump, regardless of pump rotations per minute, forces a fixed or unvarying quantity of fluid through the outlet port during each revolution of the pump. Constant-displacement pumps are sometimes called constant-volume or constant-delivery pumps. They deliver a fixed quantity of fluid per revolution, regardless of the pressure demands. Since the constant-delivery pump provides a fixed quantity of fluid during each revolution of the pump, the quantity of fluid delivered per minute depends upon pump rotations per minute. When a constant-displacement pump is used in a hydraulic system in which the pressure must be kept at a constant value, a pressure regulator is required.

Gear-Type Power Pump

A gear-type power pump is a constant-displacement pump. It consists of two meshed gears that revolve in a housing. *[Figure 12-23]* The driving gear is driven by the aircraft engine or some other power unit. The driven gear meshes with, and is driven by, the driving gear. Clearance between the teeth as they mesh and between the teeth and the housing is very small. Excessive clearance will result in lower output pressure. The inlet port of the pump is connected to the reservoir, and the outlet port is connected to the pressure line.

When the driving gear turns, as shown in *Figure 12-23,* it turns the driven gear. Fluid is captured by the teeth as they pass the inlet, and it travels around the housing and exits at the outlet.

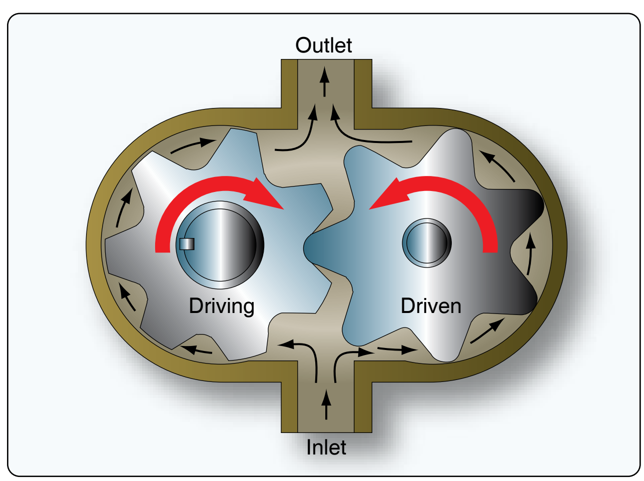

Figure 12-23. *Gear-type power pump.*

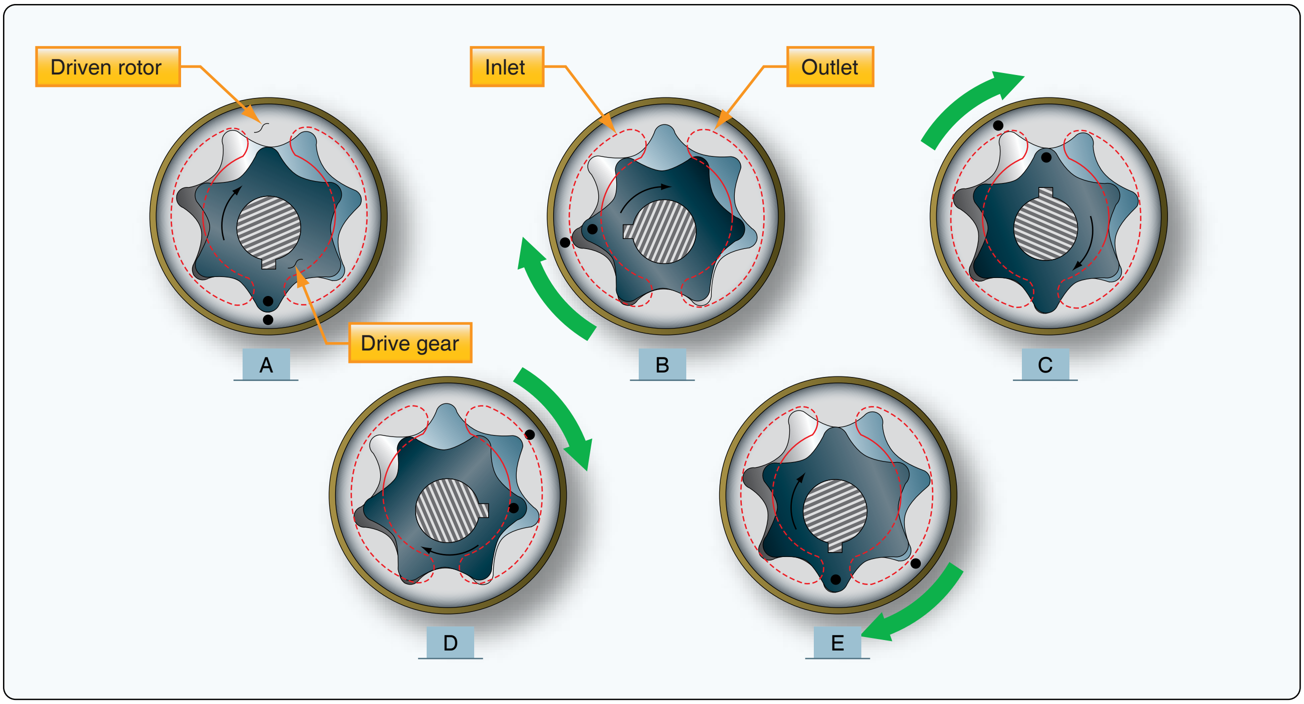

Figure 12-24. *Gerotor pump.*

Gerotor Pump

A gerotor-type power pump consists essentially of a housing containing an eccentric-shaped stationary liner, an internal gear rotor having seven wide teeth of short height, a spur driving gear having six narrow teeth, and a pump cover that contains two crescent-shaped openings. *[Figure 12-24]* One opening extends into an inlet port and the other extends into an outlet port. During the operation of the pump, the gears turn clockwise together. As the pockets between the gears on the left side of the pump move from a lowermost position toward a topmost position, the pockets increase in size, resulting in the production of a partial vacuum within these pockets. Since the pockets enlarge while over the inlet port crescent, fluid is drawn into them. As these same pockets (now full of fluid) rotate over to the right side of the pump, moving from the topmost position toward the lowermost position, they decrease in size. This results in the fluid being expelled from the pockets through the outlet port crescent.

Piston Pump

Piston pumps can be constant-displacement or variable-displacement pumps. The common features of design and operation that are applicable to all piston-type hydraulic pumps are described in the following paragraphs. Piston-type power-driven pumps have flanged mounting bases for the purpose of mounting the pumps on the accessory drive cases of aircraft engines. A pump drive shaft, which turns the mechanism, extends through the pump housing slightly beyond the mounting base. Torque from the driving unit is transmitted to the pump drive shaft by a drive coupling. The drive coupling is a short shaft with a set of male splines on both ends. The splines on one end engage with female splines in a driving gear; the splines on the other end engage with female splines in the pump drive shaft. Pump drive couplings are designed to serve as safety devices. The shear section of the drive coupling, located midway between the two sets of splines, is smaller in diameter than the splines. If the pump becomes unusually hard to turn or becomes jammed, this section shears, preventing damage to the pump or driving unit. *[Figure 12-25]* The basic pumping mechanism of piston-type pumps consists of a multiple-bore cylinder block, a piston for each bore, and a valve plate with inlet and outlet slots. The purpose of the valve plate slots is to let fluid into and out of the bores as the pump operates. The cylinder bores lie parallel to and symmetrically around the pump axis. All aircraft axial-piston pumps have an odd number of pistons. *[Figure 12-26]*

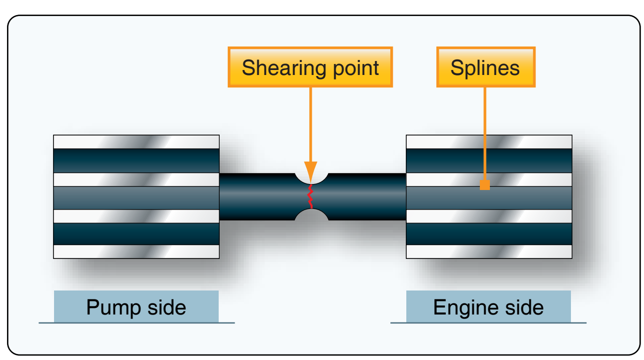

Figure 12-25. *Hydraulic pump shear shaft.*

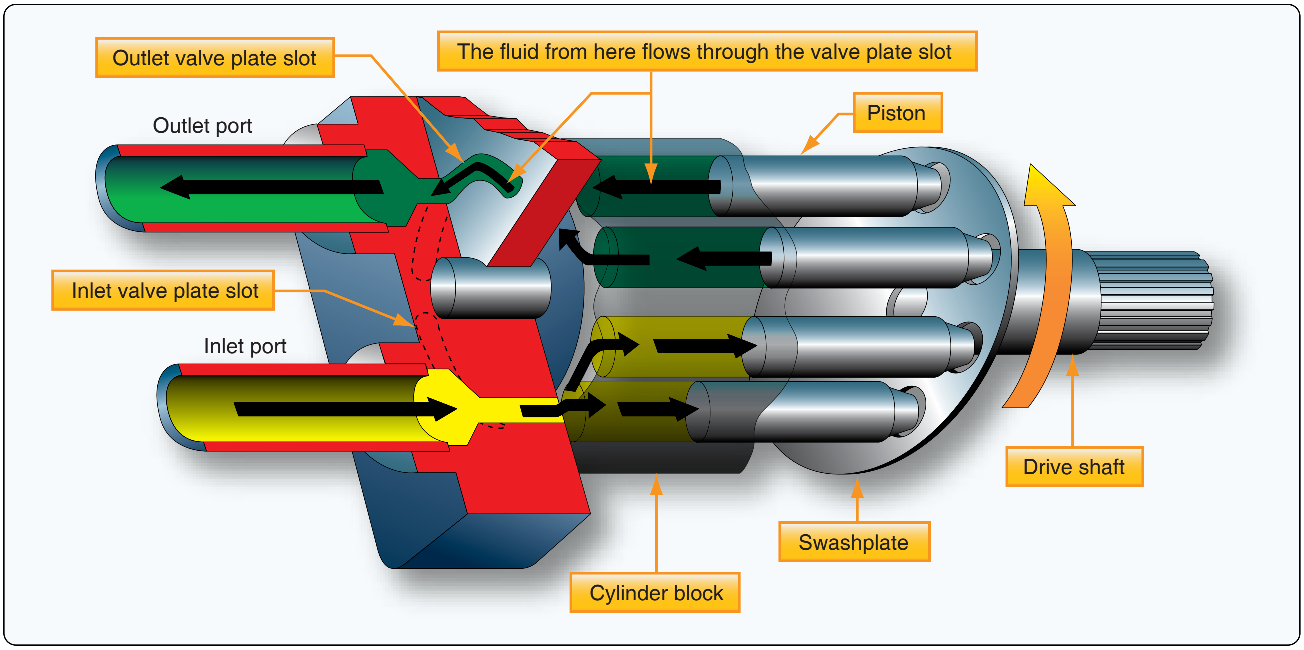

Figure 12-26. *Axial inline piston pump.*

Bent Axis Piston Pump

A typical constant-displacement axial-type pump is shown in *Figure 12-27.* The angular housing of the pump causes a corresponding angle to exist between the cylinder block and the drive shaft plate to which the pistons are attached. It is this angular configuration of the pump that causes the pistons to stroke as the pump shaft is turned. When the pump operates, all parts within the pump (except the outer races of the bearings that support the drive shaft, the cylinder bearing pin on which the cylinder block turns, and the oil seal) turn together as a rotating group. At one point of rotation of the rotating group, a minimum distance exists between the top of the cylinder block and the upper face of the drive shaft plate. Because of the angled housing at a point of rotation 180° away, the distance between the top of the cylinder block and the upper face of the drive shaft plate is at a maximum. At any given moment of operation, three of the pistons are moving away from the top face of the cylinder block, producing a partial vacuum in the bores in which these pistons operate. This occurs over the inlet port, so fluid is drawn into these bores at this time. On the opposite side of the cylinder block, three different pistons are moving toward the top face of the block. This occurs while the rotating group is passing over the outlet port causing fluid to be expelled from the pump by these pistons. The continuous and rapid action of the pistons is overlapping in nature and results in a practically nonpulsating pump output.

Inline Piston Pump

The simplest type of axial piston pump is the swash plate design in which a cylinder block is turned by the drive shaft. Pistons fitted to bores in the cylinder block are connected through piston shoes and a retracting ring so that the shoes bear against an angled swash plate. As the block turns, the piston shoes follow the swash plate, causing the pistons to reciprocate. The ports are arranged in the valve plate so that the pistons pass the inlet as they are pulled out, and pass the outlet as they are forced back in. In these pumps, displacement is determined by the size and number of pistons, as well as their stroke length, which varies with the swash plate angle. This constant-displacement pump is illustrated in *Figure 12-26*.

Vane Pump

The vane-type power pump is also a constant-displacement pump. It consists of a housing containing four vanes (blades), a hollow steel rotor with slots for the vanes, and a coupling to turn the rotor. *[Figure 12-28]* The rotor is positioned off center within the sleeve. The vanes, which are mounted in the slots in the rotor, together with the rotor, divide the bore of the sleeve into four sections. As the rotor turns, each section passes one point where its volume is at a minimum and another point where its volume is at a maximum. The volume gradually increases from minimum to maximum during the first half of a revolution and gradually decreases from maximum to minimum during the second half of the revolution. As the volume of a given section increases, that section is connected to the pump inlet port through a slot in the sleeve. Since a partial vacuum is produced by the increase in volume of the section, fluid is drawn into the section through the pump inlet port and the slot in the sleeve. As the rotor turns through the second half of the revolution and the

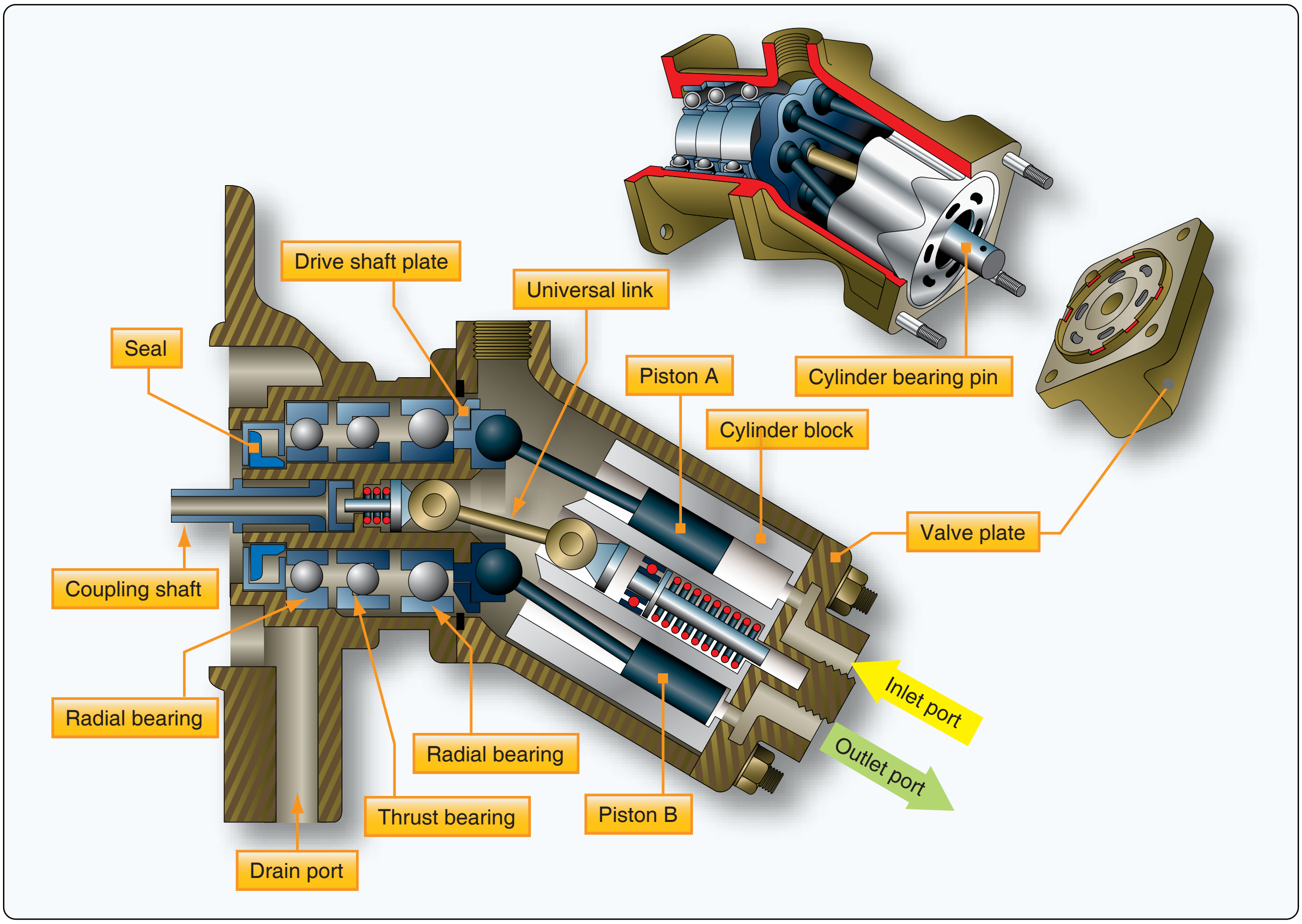

Figure 12-27. *Bent axis piston pump.*

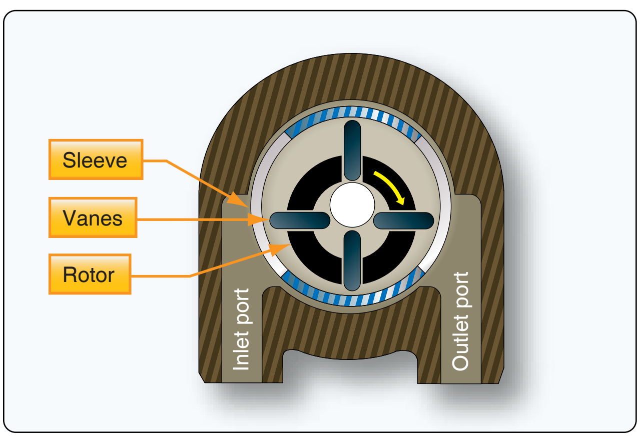

Figure 12-28. *Vane-type power pump.*

volume of the given section is decreasing, fluid is displaced out of the section, through the slot in the sleeve aligned with the outlet port, and out of the pump.

Variable-Displacement Pump

A variable-displacement pump has a fluid output that is varied to meet the pressure demands of the system. The pump output is changed automatically by a pump compensator within the pump. The following paragraph discusses a two-stage Vickers variable displacement pump. The first stage of the pump consists of a centrifugal pump that boosts the pressure before the fluid enters the piston pump. *[Figure 12-29]*

Basic Pumping Operation

The aircraft's engine rotates the pump drive shaft, cylinder block, and pistons via a gearbox. Pumping action is generated by piston shoes that are restrained and slide on the shoe bearing plate in the yoke assembly. Because the yoke is at an angle to the drive shaft, the rotary motion of the shaft is converted to piston reciprocating motion.

As the piston begins to withdraw from the cylinder block, system inlet pressure forces fluid through a porting arrangement in the valve plate into the cylinder bore. The piston shoes are restrained in the yoke by a piston shoe retaining plate and a shoe plate during the intake stroke. As the drive shaft continues to turn the cylinder block, the piston shoe continues following the yoke bearing surface. This begins to return the piston into its bore (i.e., toward the valve block).

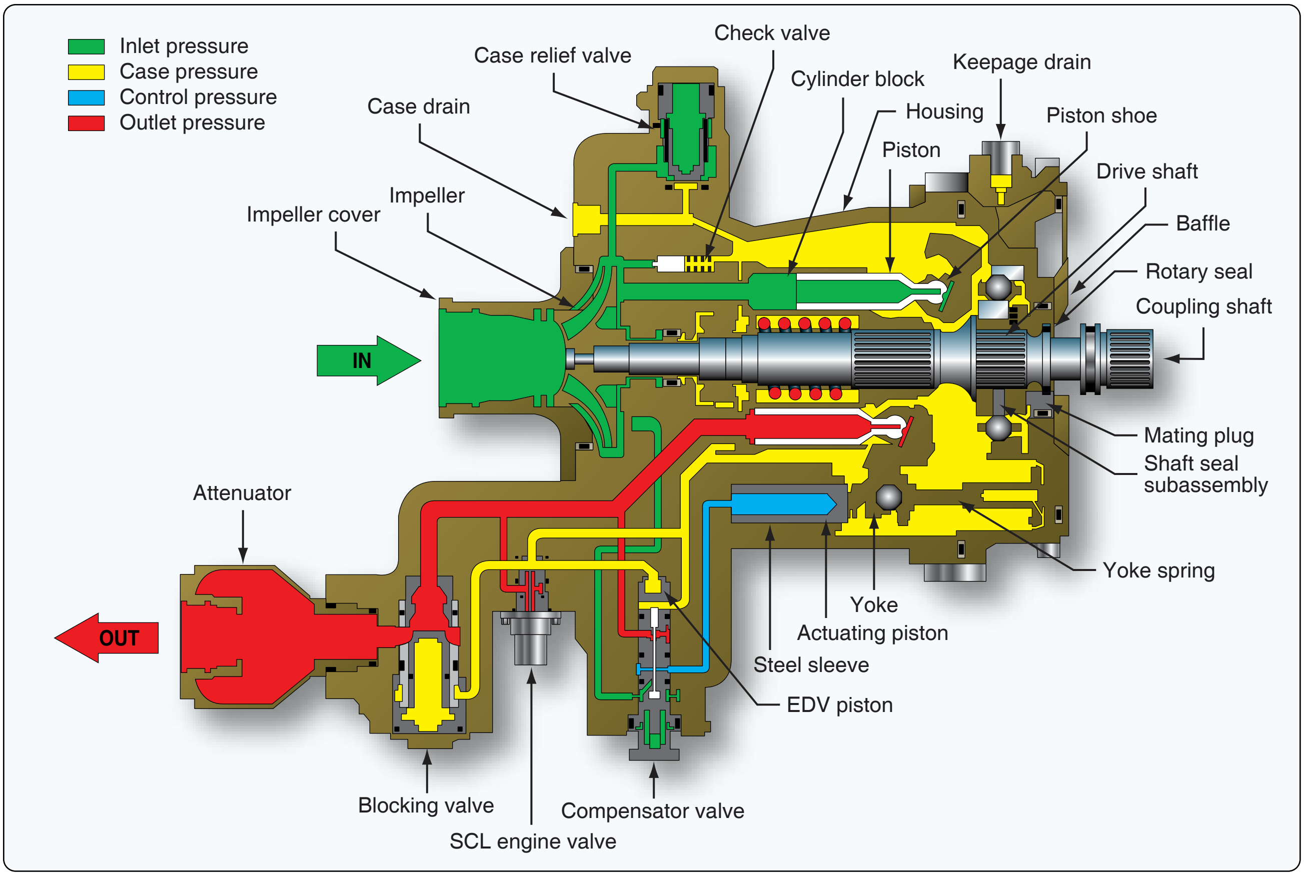

Figure 12-29. *Variable displacement pump.*

The fluid contained in the bore is precompressed, then expelled through the outlet port. Discharge pressure holds the piston shoe against the yoke bearing surface during the discharge stroke and also provides the shoe pressure balance and fluid film through an orifice in the piston and shoe subassembly.

With each revolution of the drive shaft and cylinder block, each piston goes through the pumping cycle described above, completing one intake and one discharge stroke. High-pressure fluid is ported out through the valve plate, past the blocking valve, to the pump outlet. The blocking valve is designed to remain open during normal pump operation. Internal leakage keeps the pump housing filled with fluid for lubrication of rotating parts and cooling. The leakage is returned to the system through a case drain port. The case valve relief valve protects the pump against excessive case pressure, relieving it to the pump inlet.

Normal Pumping Mode

The pressure compensator is a spool valve that is held in the closed position by an adjustable spring load. *[Figure 12-30]* When pump outlet pressure (system pressure) exceeds the pressure setting (2,850 psi for full flow), the spool moves to admit fluid from the pump outlet against the yoke actuator piston. In *Figure 12-30,* the pressure compensator is shown at cracking pressure; the pump outlet pressure is just high enough to move the spool to begin admitting fluid to the actuator piston.

The yoke is supported inside the pump housing on two bearings. At pump outlet pressures below 2,850 psi, the yoke is held at its maximum angle relative to the drive shaft centerline by the force of the yoke return spring. Decreasing system flow demand causes outlet pressure to become high enough to crack the compensator valve open and admit fluid to the actuator piston.

This control pressure overcomes the yoke return spring force and strokes the pump yoke to a reduced angle. The reduced angle of the yoke results in a shorter stroke for the pistons and reduced displacement. *[Figure 12-31]*

The lower displacement results in a corresponding reduction in pump flow. The pump delivers only that flow required to maintain the desired pressure in the system. When there is no demand for flow from the system, the yoke angle decreases to nearly zero degrees stroke angle. In this mode, the unit

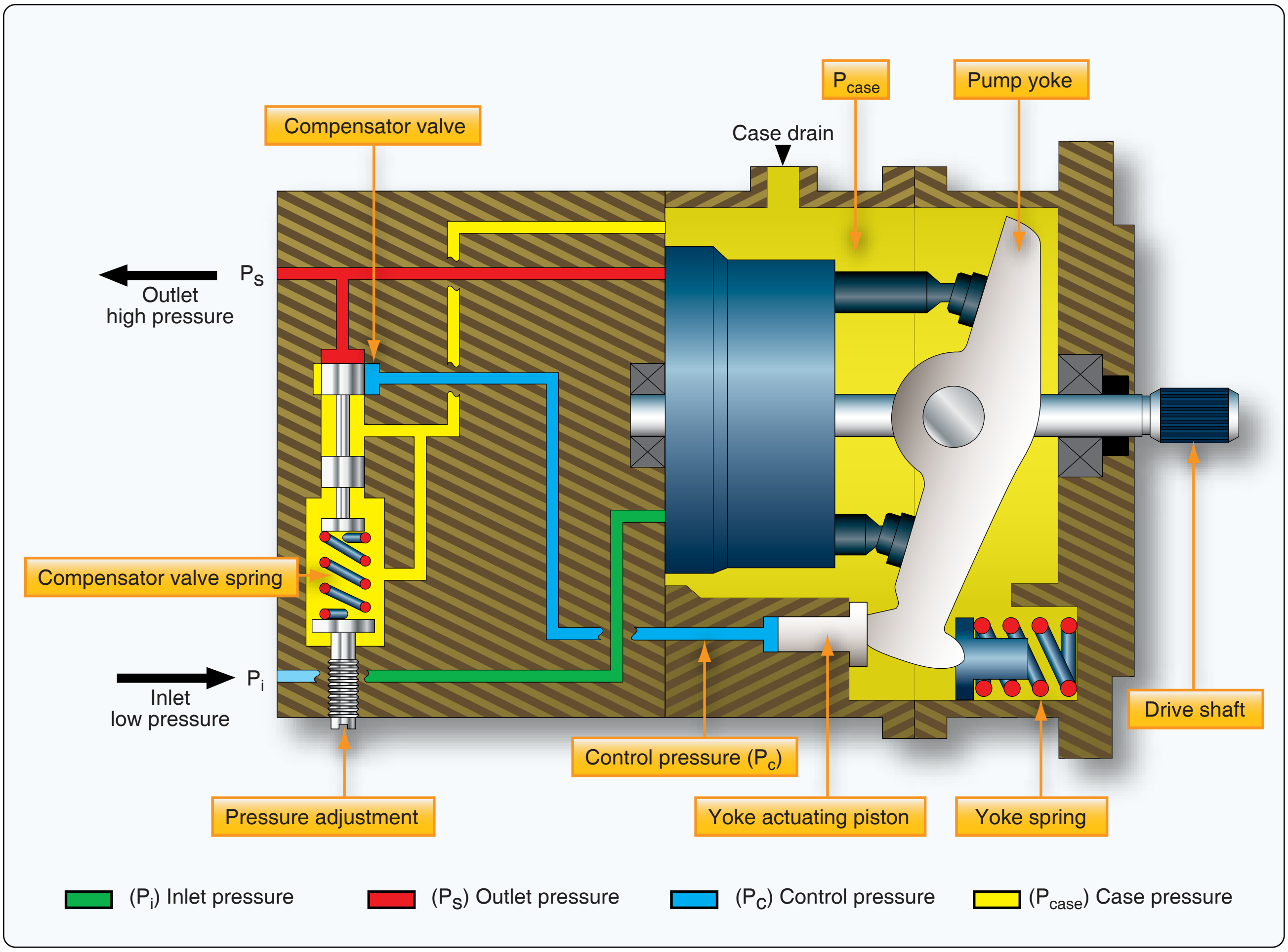

Figure 12-30. *Normal pumping mode.*

pumps only its own internal leakage. Thus, at pump outlet pressures above 2,850 psi, pump displacement decreases as outlet pressure rises. At system pressures below this level, no fluid is admitted through the pressure compensator valve to the actuator piston and the pump remains at full displacement, delivering full flow. Pressure is then determined by the system demand. The unit maintains zero flow at system pressure of 3,025 psi.

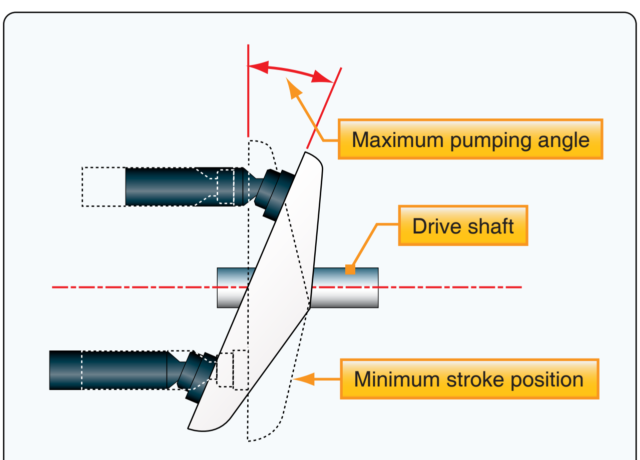

Figure 12-31. *Yoke angle.*

Depressurized Mode

When the solenoid valve is energized, the electrical depressurization valve (EDV) solenoid valve moves up against the spring force and the outlet fluid is ported to the EDV control piston on the top of the compensator (depressurizing piston). *[Figure 12-32]* The high-pressure fluid pushes the compensator spool beyond its normal metering position. This removes the compensator valve from the circuit and connects the actuator piston directly to the pump outlet. Outlet fluid is also ported to the blocking valve spring chamber, which equalizes pressure on both sides of its plunger. The blocking valve closes due to the force of the blocking valve spring and isolates the pump from the external hydraulic system. The pump strokes itself to zero delivery at an outlet pressure that is equal to the pressure required on the actuator piston to reduce the yoke angle to nearly zero, approximately 1,100 psi. This depressurization and blocking feature can be used to reduce the load on the engine during startup and, in a multiple pump system, to isolate one pump at a time and check for proper system pressure output.

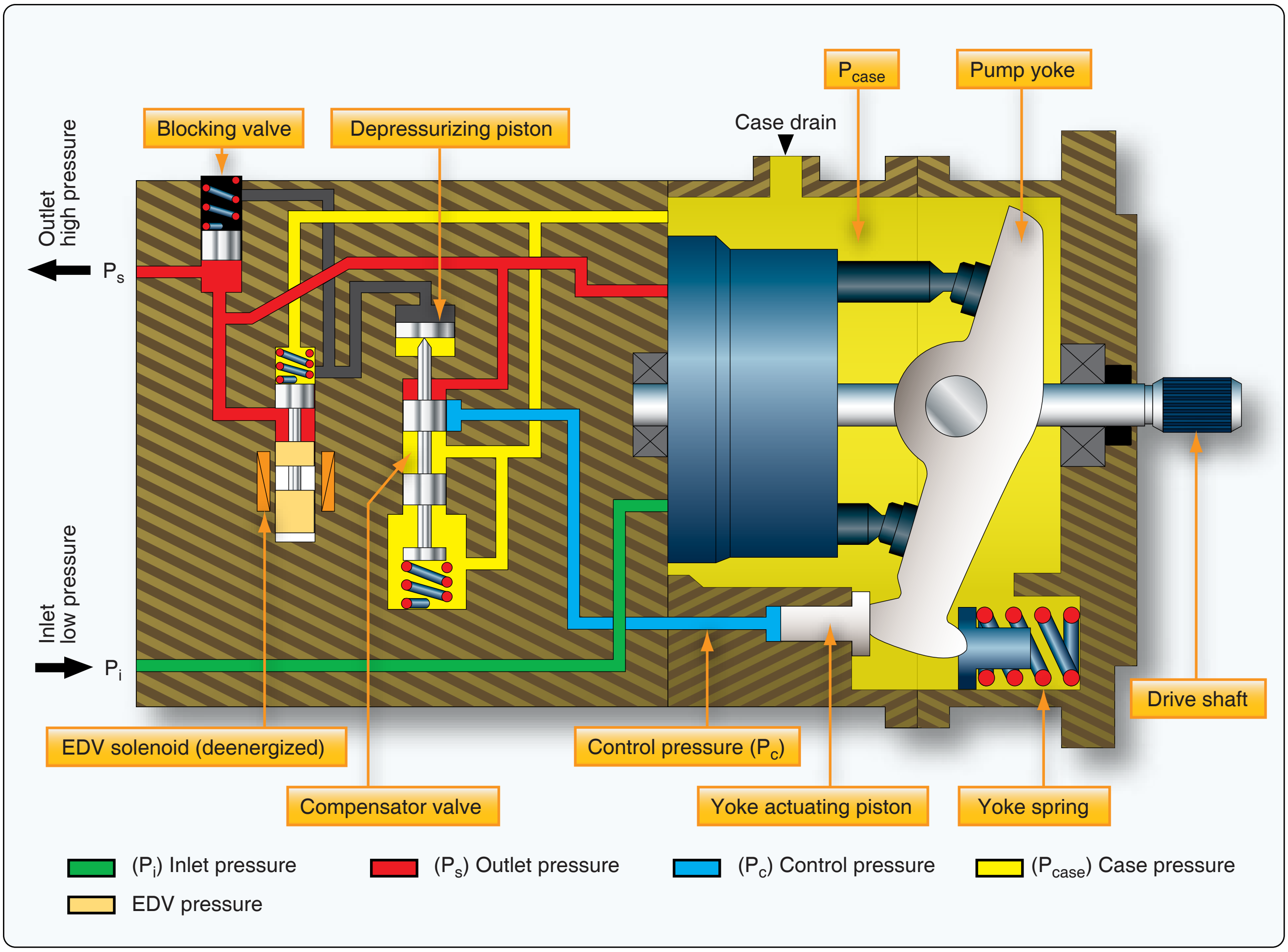

Figure 12-32. *Depressurized mode.*

Valves

Flow Control Valves

Flow control valves control the speed and/or direction of fluid flow in the hydraulic system. They provide for the operation of various components when desired and the speed at which the component operates. Examples of flow control valves include: selector valves, check valves, sequence valves, priority valves, shuttle valves, quick disconnect valves, and hydraulic fuses.

Selector Valves

A selector valve is used to control the direction of movement of a hydraulic actuating cylinder or similar device. It provides for the simultaneous flow of hydraulic fluid both into and out of the unit. Hydraulic system pressure can be routed with the selector valve to operate the unit in either direction and a corresponding return path for the fluid to the reservoir is provided. There are two main types of selector valves: open-center and closed-center. An open center valve allows a continuous flow of system hydraulic fluid through the valve even when the selector is not in a position to actuate a unit. A closed-center selector valve blocks the flow of fluid through the valve when it is in the NEUTRAL or OFF position. *[Figure 12-33A]*

Selector valves may be poppet-type, spool-type, piston-type, rotary-type, or plug-type. *[Figure 12-34]* Regardless, each selector valve has a unique number of ports. The number of ports is determined by the particular requirements of the system in which the valve is used. Closed-centered selector valves with four ports are most common in aircraft hydraulic systems. These are known as four-way valves. *Figure 12-33* illustrates how this valve connects to the pressure and return lines of the hydraulic system, as well as to the two ports on a common actuator. Most selector valves are mechanically controlled by a lever or electrically controlled by solenoid or servo. *[Figure 12-35]*

The four ports on a four-way selector valve always have the same function. One port receives pressurized fluid from the system hydraulic pump. A second port always returns fluid to the reservoir. The third and fourth ports are used to connect the selector valve to the actuating unit. There are two ports

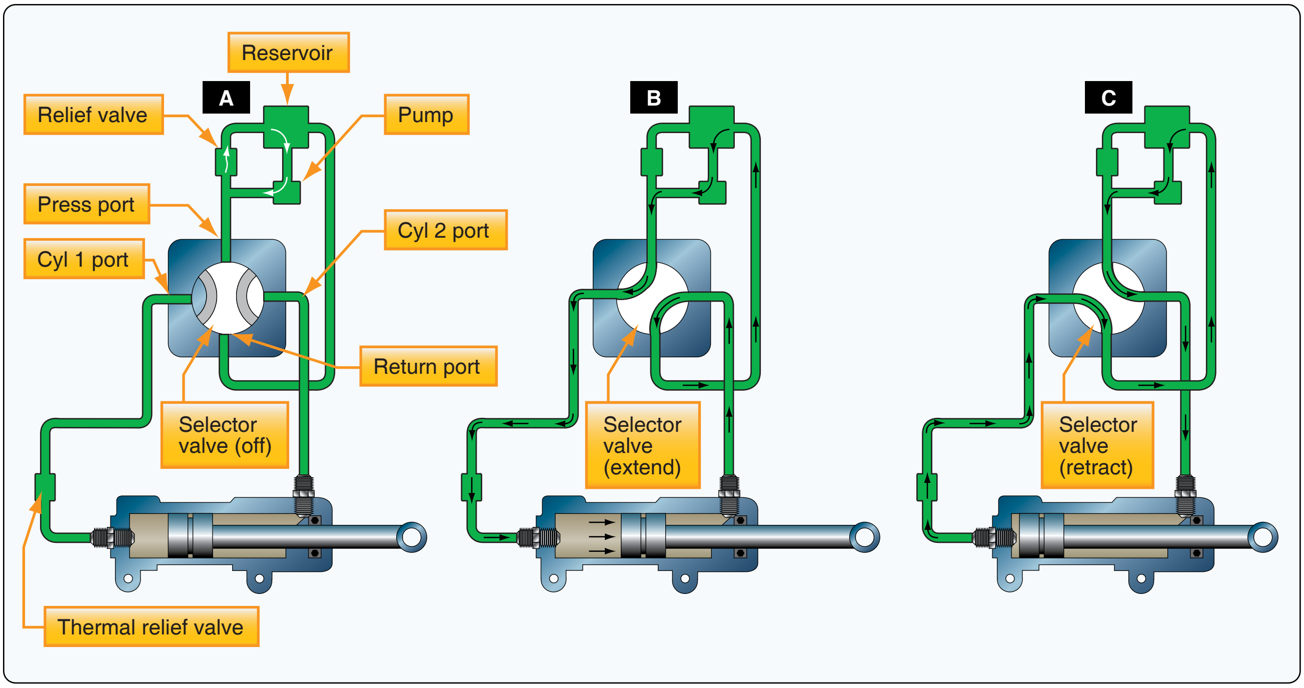

Figure 12-33. *Operation of a closed-center four-way selector valve, which controls an actuator.*

on the actuating unit. When the selector valve is positioned to connect pressure to one port on the actuator, the other actuator port is simultaneously connected to the reservoir return line through selector valve. *[Figure 12-33B]* Thus, the unit operates in a certain direction. When the selector valve is positioned to connect pressure to the other port on the actuating unit, the original port is simultaneously connected to the return line through the selector valve and the unit operates in the opposite direction. *[Figure 12-33C]*

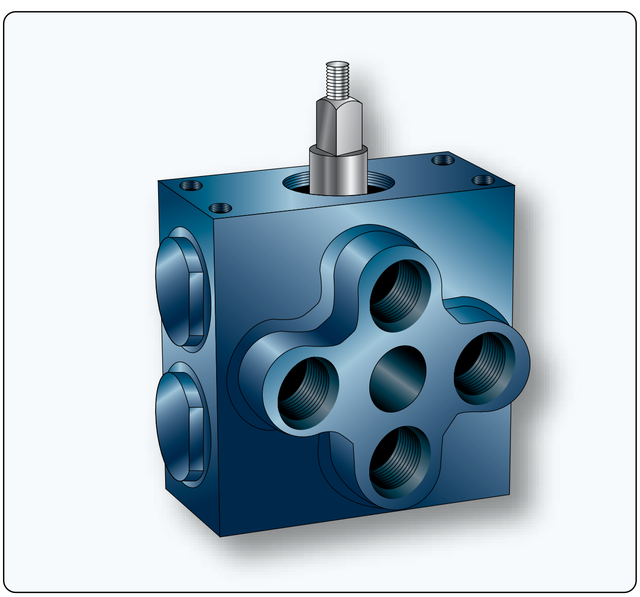

Figure 12-34. *A poppet-type four-way selector valve.*

Figure 12-36 illustrates the internal flow paths of a solenoid operated selector valve. The closed center valve is shown in the NEUTRAL or OFF position. Neither solenoid is energized. The pressure port routes fluid to the center lobe on the spool, which blocks the flow. Fluid pressure flows through the pilot valves and applies equal pressure on both ends of the spool. The actuator lines are connected around the spool to the return line.

When selected via a switch in the flight deck, the right solenoid is energized. The right pilot valve plug shifts left, which blocks pressurized fluid from reaching the right end of the main spool. The spool slides to the right due to greater

Figure 12-35. *Four-way servo control valve.*

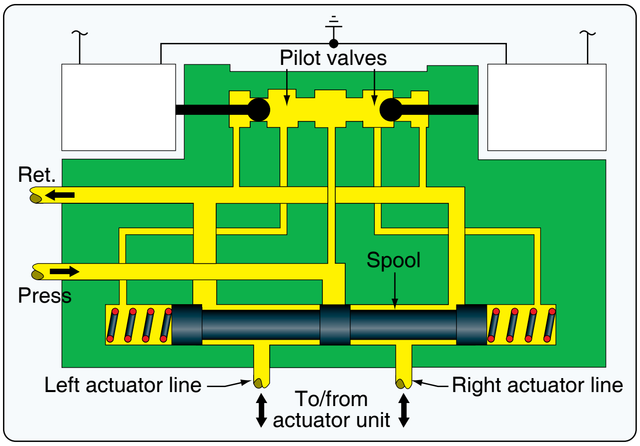

Figure 12-36. *Servo control valve solenoids not energized.*

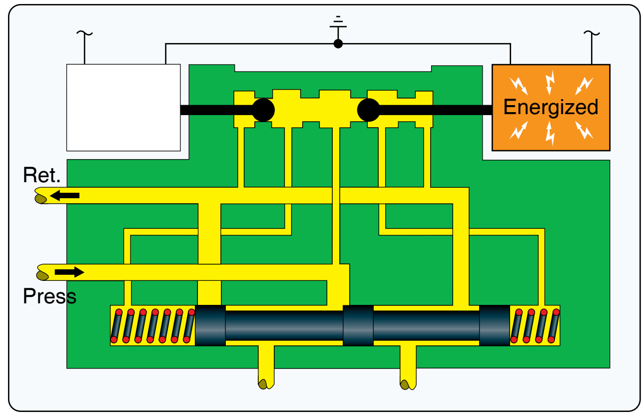

Figure 12-37. *Servo control valve right solenoid energized.*

pressure applied on the left end of the spool. The center lobe of the spool no longer blocks system pressurized fluid, which flows to the actuator through the left actuator line. At the same time, return flow is blocked from the main spool left chamber so the actuator (not shown) moves in the selected direction. Return fluid from the moving actuator flows through the right actuator line past the spool and into the return line. *[Figure 12-37]*

Typically, the actuator or moving device contacts a limit switch when the desired motion is complete. The switch causes the right solenoid to de-energize and the right pilot valve reopens. Pressurized fluid can once again flow through the pilot valve and into the main spool right end chamber. There, the spring and fluid pressure shift the spool back to the left into the NEUTRAL or OFF position shown in *Figure 12-36*.

To make the actuator move in the opposite direction, the flight deck switch is moved in the opposite direction. All motion inside the selector valve is the same as described above but in the opposite direction. The left solenoid is energized. Pressure is applied to the actuator through the right port and return fluid from the left actuator line is connected to the return port through the motion of the spool to the left.

Check Valve

Another common flow control valve in aircraft hydraulic systems is the check valve. A check valve allows fluid to flow unimpeded in one direction but prevents or restricts fluid flow in the opposite direction. A check valve may be an independent component situated inline somewhere in the hydraulic system or it may be built-in to a component. When part of a component, the check valve is said to be an integral check valve.

A typical check valve consists of a spring-loaded ball and seat inside a housing. The spring compresses to allow fluid flow in the designed direction. When flow stops, the spring pushes the ball against the seat which prevents fluid from flowing in the opposite direction through the valve. An arrow on the outside of the housing indicated the direction in which fluid flow is permitted. *[Figure 12-38]* A check valve may also be constructed with spring loaded flapper or coned shape piston instead of a ball.

Orifice-Type Check Valve

Some check valves allow full fluid flow in one direction and restricted flow in the opposite direction. These are known as orifice-type check valves, or damping valves. The valve contains the same spring, ball, and seat combination as a normal check valve, but the seat area has a calibrated orifice machined into it. Thus, fluid flow is unrestricted in the designed direction while the ball is pushed off of its seat. The downstream actuator operates at full speed. When fluid back flows into the valve, the spring forces the ball against the seat which limits fluid flow to the amount that can pass through the orifice. The reduced flow in this opposite direction slows the motion, or dampens, the actuator associated with the check valve. *[Figure 12-38]*

An orifice check valve may be included in a hydraulic landing gear actuator system. When the gear is raised, the check valve allows full fluid flow to lift the heavy gear at maximum speed. When lowering the gear, the orifice in the check valve prevents the gear from violently dropping by restricting fluid flow out of the actuating cylinder.

Sequence Valves

Sequence valves control the sequence of operation between two branches in a circuit; they enable one unit to automatically set another unit into motion. An example of the use of a sequence valve is in an aircraft landing gear actuating system. In a landing gear actuating system, the landing gear doors must open before the landing gear starts to extend. Conversely,

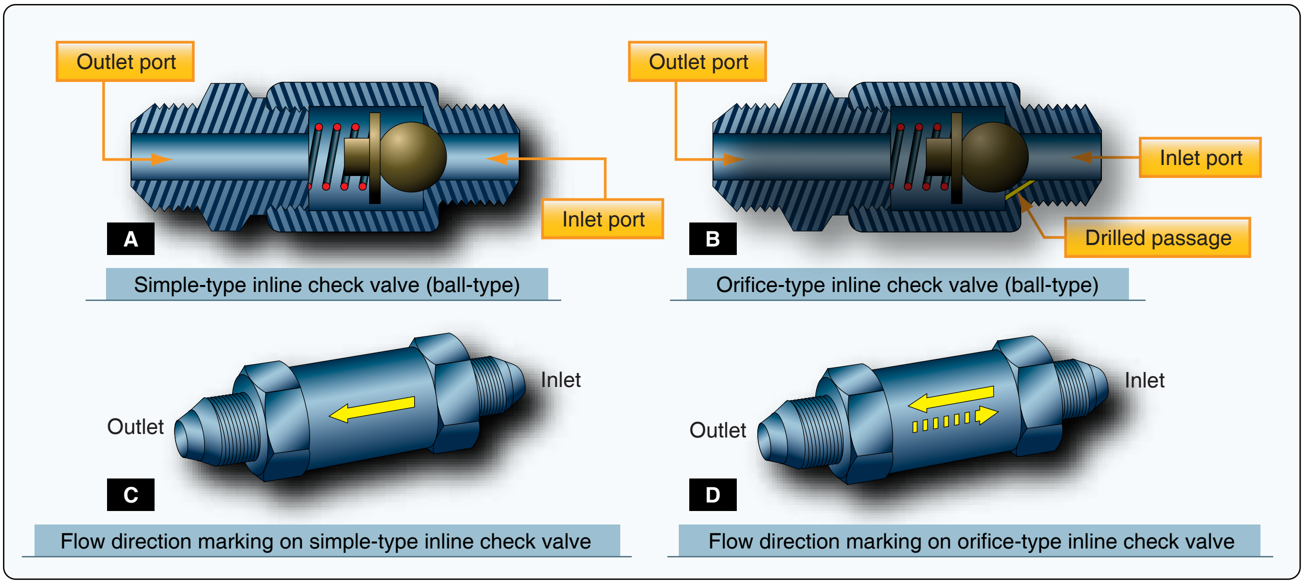

Figure 12-38. *An inline check valve and orifice type inline check valve.*

the landing gear must be completely retracted before the doors close. A sequence valve installed in each landing gear actuating line performs this function. A sequence valve is somewhat similar to a relief valve except that, after the set pressure has been reached, the sequence valve diverts the fluid to a second actuator or motor to do work in another part of the system. There are various types of sequence valves. Some are controlled by pressure, some are controlled mechanically, and some are controlled by electric switches.

Pressure-Controlled Sequence Valve

The operation of a typical pressure-controlled sequence valve is illustrated in *Figure 12-36.* The opening pressure is obtained by adjusting the tension of the spring that normally holds the piston in the closed position. (Note that the top part of the piston has a larger diameter than the lower part.) Fluid enters the valve through the inlet port, flows around the lower part of the piston and exits the outlet port, where it flows to the primary (first) unit to be operated. *[Figure 12-39A]* This fluid pressure also acts against the lower surface of the piston.

When the primary actuating unit completes its operation, pressure in the line to the actuating unit increases sufficiently to overcome the force of the spring, and the piston rises. The valve is then in the open position. *[Figure 12-39B]* The fluid entering the valve takes the path of least resistance and flows to the secondary unit. A drain passage is provided to allow any fluid leaking past the piston to flow from the top of the valve. In hydraulic systems, this drain line is usually connected to the main return line.

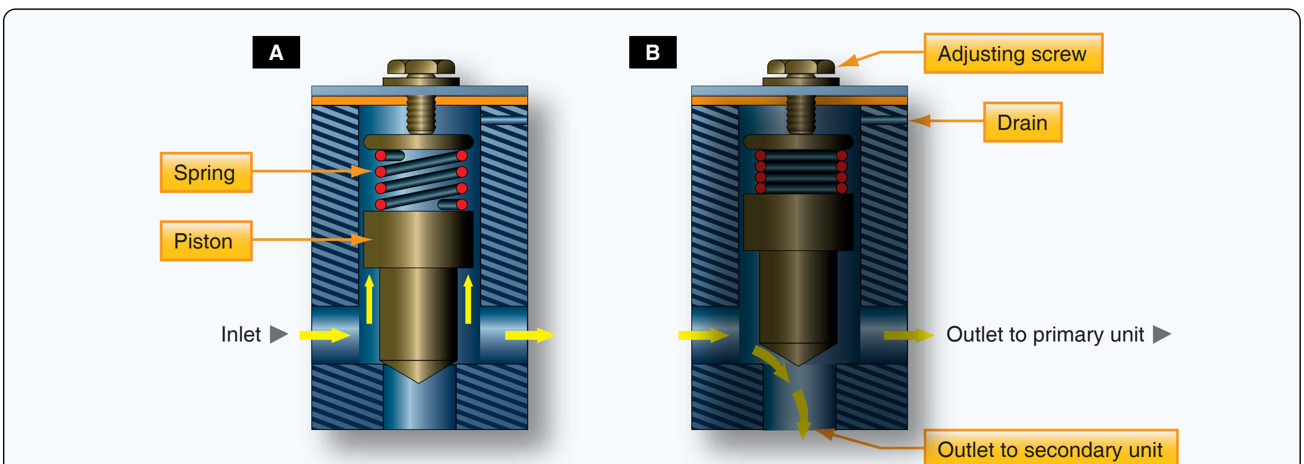

Figure 12-39. *A pressure-controlled sequence valve.*

Mechanically-Operated Sequence Valve

The mechanically-operated sequence valve is operated by a plunger that extends through the body of the valve. *[Figure 12-40]* The valve is mounted so that the plunger is operated by the primary unit. A check valve, either a ball or a poppet, is installed between the fluid ports in the body. It can be unseated by either the plunger or fluid pressure. Port A and the actuator of the primary unit are connected by a common line. Port B is connected by a line to the actuator of the secondary unit. When fluid under pressure flows to the primary unit, it also flows into the sequence valve through port A to the seated check valve in the sequence valve. In order to operate the secondary unit, the fluid must flow through the sequence valve. The valve is located so that the primary unit moves the plunger as it completes its operation. The plunger unseats the check valve and allows the fluid to flow through the valve, out port B, and to the secondary unit.

Priority Valves

A priority valve gives priority to the critical hydraulic subsystems over noncritical systems when system pressure is low. For instance, if the pressure of the priority valve is set for 2,200 psi, all systems receive pressure when the pressure is above 2,200 psi. If the pressure drops below 2,200 psi, the priority valve closes, and no fluid pressure flows to the noncritical systems. *[Figure 12-41]* Some hydraulic designs use pressure switches and electrical shutoff valves to assure that the critical systems have priority over noncritical systems when system pressure is low.

Quick Disconnect Valves

Quick disconnect valves are installed in hydraulic lines to prevent loss of fluid when units are removed. Such valves are installed in the pressure and suction lines of the system immediately upstream and downstream of the power pump. In addition to pump removal, a power pump can be disconnected

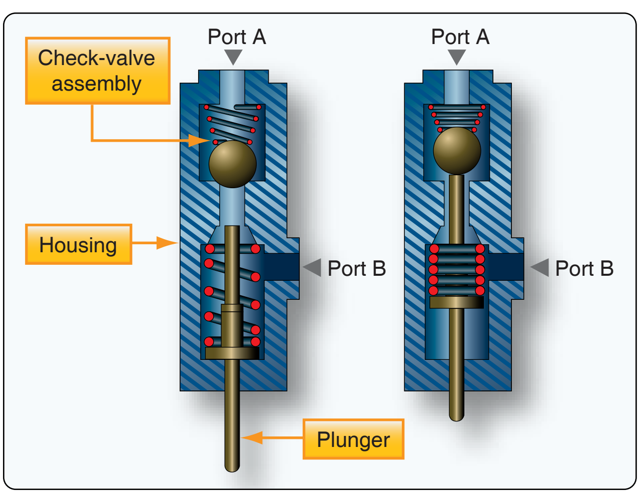

Figure 12-40. *Mechanically operated sequence valve.*

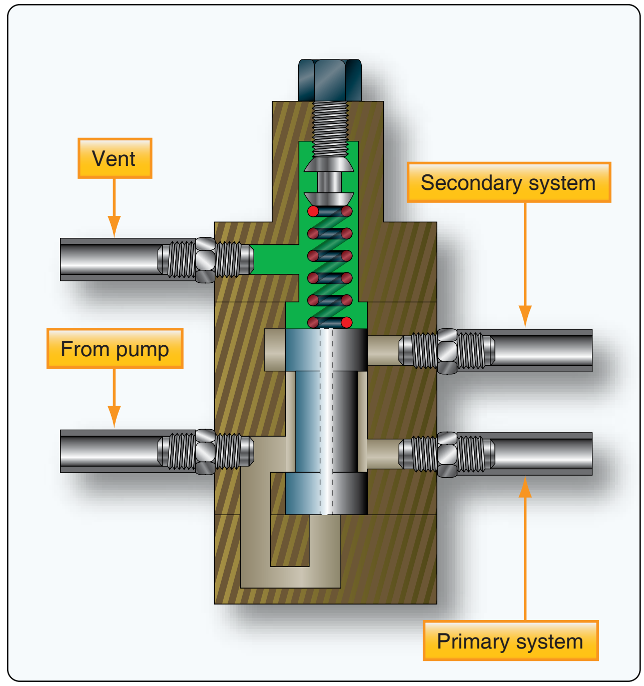

Figure 12-41. *Priority valve.*

from the system and a hydraulic test stand connected in its place. These valve units consist of two interconnecting sections coupled together by a nut when installed in the system. Each valve section has a piston and poppet assembly. These are spring loaded to the closed position when the unit is disconnected. *[Figure 12-42]*

Hydraulic Fuses

A hydraulic fuse is a safety device. Fuses may be installed at strategic locations throughout a hydraulic system. They detect a sudden increase in flow, such as a burst downstream,

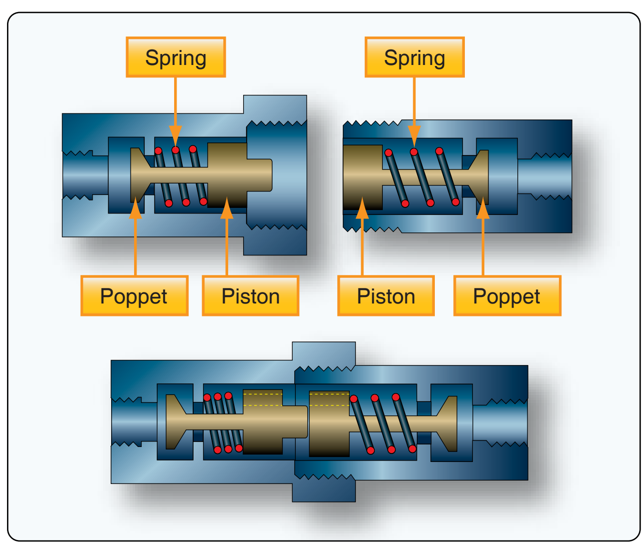

Figure 12-42. *A hydraulic quick-disconnect valve.*

and shut off the fluid flow. By closing, a fuse preserves hydraulic fluid for the rest of the system. Hydraulic fuses are fitted to the brake system, leading edge flap and slat extend and retract lines, nose landing gear up and down lines, and the thrust reverser pressure and return lines. One type of fuse, referred to as the automatic resetting type, is designed to allow a certain volume of fluid per minute to pass through it. If the volume passing through the fuse becomes excessive, the fuse closes and shuts off the flow. When the pressure is removed from the pressure supply side of the fuse, it automatically resets itself to the open position. Fuses are usually cylindrical in shape, with an inlet and outlet port at opposite ends. *[Figure 12-43]*

Pressure Control Valves

The safe and efficient operation of fluid power systems, system components, and related equipment requires a means of controlling pressure. There are many types of automatic pressure control valves. Some of them are an escape for pressure that exceeds a set pressure; some only reduce the pressure to a lower pressure system or subsystem; and some keep the pressure in a system within a required range.

Relief Valves

Hydraulic pressure must be regulated in order to use it to perform the desired tasks. A pressure relief valve is used to limit the amount of pressure being exerted on a confined liquid. This is necessary to prevent failure of components or rupture of hydraulic lines under excessive pressures. The pressure relief valve is, in effect, a system safety valve.

The design of pressure relief valves incorporates adjustable spring-loaded valves. They are installed in such a manner as to discharge fluid from the pressure line into a reservoir return line when the pressure exceeds the predetermined maximum for which the valve is adjusted. Various makes and designs of pressure relief valves are in use, but, in general, they all employ a spring-loaded valving device operated by hydraulic pressure and spring tension. *[Figure 12-44]* Pressure relief valves are adjusted by increasing or decreasing the tension on the spring to determine the pressure required to open the valve. They may be classified by type of construction or uses in the system. The most common types of valve are:

1. Ball type—in pressure relief valves with a ball-type valving device, the ball rests on a contoured seat. Pressure acting on the bottom of the ball pushes it off its seat, allowing the fluid to bypass.
2. Sleeve type—in pressure relief valves with a sleeve-type valving device, the ball remains stationary and a sleeve-type seat is moved up by the fluid pressure. This allows the fluid to bypass between the ball and the sliding sleeve-type seat.
3. Poppet type—in pressure relief valves with a poppet-type valving device, a cone-shaped poppet may have any of several design configurations; however, it is basically a cone and seat machined at matched angles to prevent leakage. As the pressure rises to its predetermined setting, the poppet is lifted off its seat, as in the ball-type device. This allows the fluid to pass through the opening created and out the return port.

Pressure relief valves cannot be used as pressure regulators in large hydraulic systems that depend on engine-driven pumps for the primary source of pressure because the pump is constantly under load and the energy expended in holding the pressure relief valve off its seat is changed into heat. This

Figure 12-43. *Hydraulic fuse.*

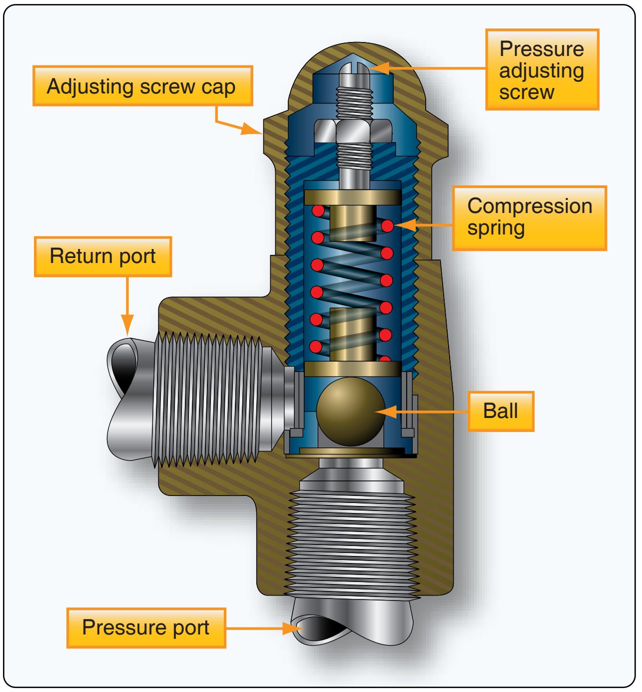

Figure 12-44. *Pressure relief valve.*

heat is transferred to the fluid and, in turn, to the packing rings, causing them to deteriorate rapidly. Pressure relief valves, however, may be used as pressure regulators in small, low-pressure systems or when the pump is electrically driven and is used intermittently.

Pressure relief valves may be used as:

1. System relief valve—the most common use of the pressure relief valve is as a safety device against the possible failure of a pump compensator or other pressure regulating device. All hydraulic systems that have hydraulic pumps incorporate pressure relief valves as safety devices.
2. Thermal relief valve—the pressure relief valve is used to relieve excessive pressures that may exist due to thermal expansion of the fluid. They are used where a check valve or selector valve prevents pressure from being relieved through the main system relief valve. Thermal relief valves are usually smaller than system relief valves. As pressurized fluid in the line in which it is installed builds to an excessive amount, the valve poppet is forced off its seat. This allows excessive pressurized fluid to flow through the relief valve to the reservoir return line. When system pressure decreases to a predetermined pressure, spring tension overcomes system pressure and forces the valve poppet to the closed position.

Pressure Regulators

The term pressure regulator is applied to a device used in hydraulic systems that are pressurized by constant-delivery-type pumps. One purpose of the pressure regulator is to manage the output of the pump to maintain system operating pressure within a predetermined range. The other purpose is to permit the pump to turn without resistance (termed unloading the pump) at times when pressure in the system is within normal operating range. The pressure regulator is located in the system so that pump output can get into the system pressure circuit only by passing through the regulator. The combination of a constant-delivery-type pump and the

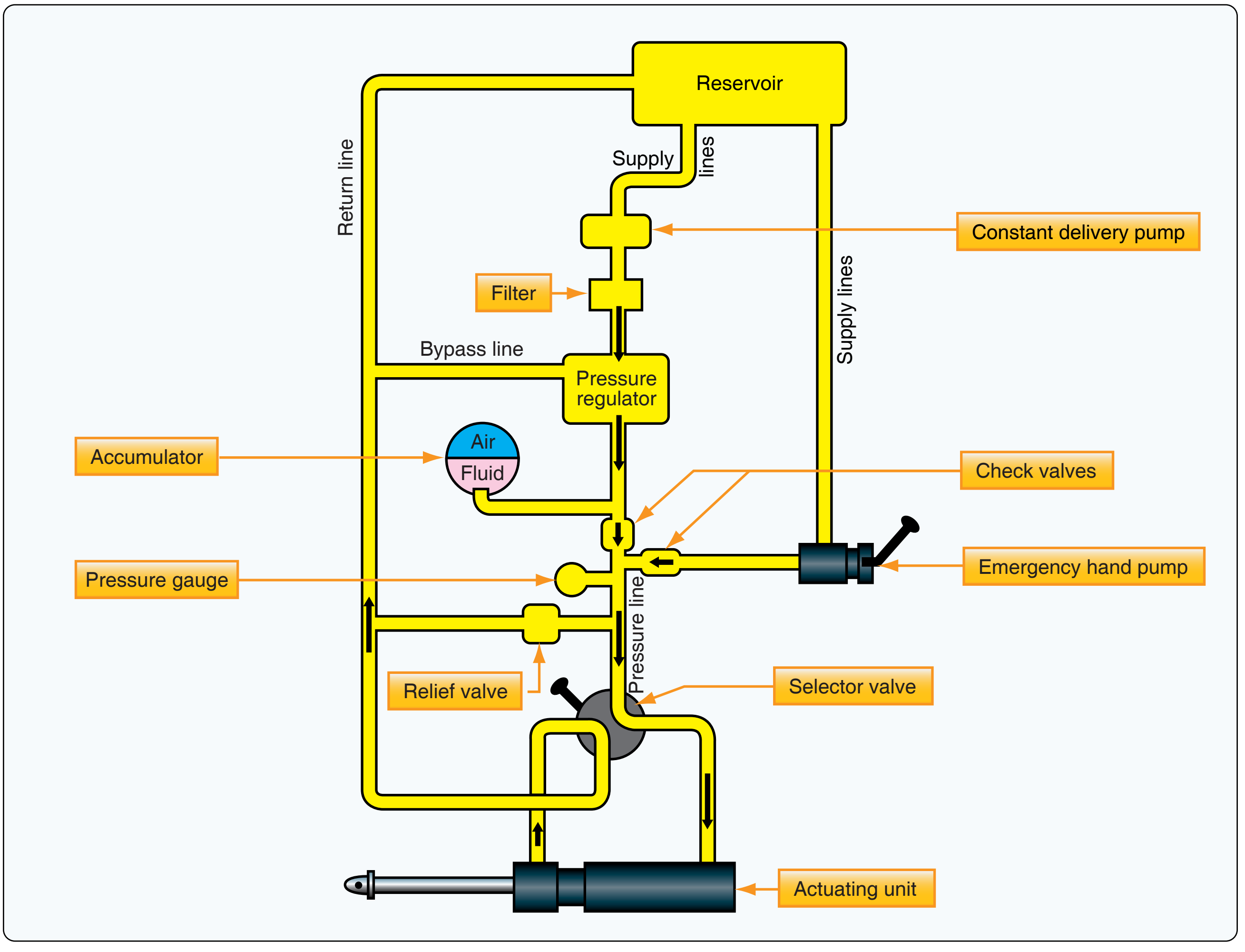

Figure 12-45. *The location of a pressure regulator in a basic hydraulic system. The regulator unloads the constant delivery pump by bypassing fluid to the return line when the predetermined system pressure is reached.*

pressure regulator is virtually the equivalent of a compensator-controlled, variable-delivery-type pump. *[Figure 12-45]*

Pressure Reducers

Pressure reducing valves are used in hydraulic systems where it is necessary to lower the normal system operating pressure by a specified amount. Pressure reducing valves provide a steady pressure into a system that operates at a lower pressure than the supply system. A reducing valve can normally be set for any desired downstream pressure within the design limits of the valve. Once the valve is set, the reduced pressure is maintained regardless of changes in supply pressure (as long as the supply pressure is at least as high as the reduced pressure desired) and regardless of the system load, if the load does not exceed the designed capacity of the reducer. *[Figure 12-46]*

Shuttle Valves

In certain fluid power systems, the supply of fluid to a subsystem must be from more than one source to meet system requirements. In some systems, an emergency system is provided as a source of pressure in the event of normal system failure. The emergency system usually actuates only essential components. The main purpose of the shuttle valve is to isolate the normal system from an alternate or emergency system. It is small and simple; yet, it is a very important component. *[Figure 12-47]* The housing contains three ports—normal system inlet, alternate or emergency system inlet, and outlet. A shuttle valve used to operate more than one actuating unit may contain additional unit outlet ports.

Enclosed in the housing is a sliding part called the shuttle. Its purpose is to seal off one of the inlet ports. There is a shuttle seat at each inlet port. When a shuttle valve is in the normal operation position, fluid has a free flow from the normal system inlet port, through the valve, and out through the outlet port to the actuating unit. The shuttle is seated against the alternate system inlet port and held there by normal system pressure and by the shuttle valve spring. The shuttle remains in this position until the alternate system is activated. This action directs fluid under pressure from the alternate system to the shuttle valve and forces the shuttle from the alternate system inlet port to the normal system inlet port. Fluid from the alternate system then has a free flow to the outlet port but is prevented from entering the normal system by the shuttle, which seals off the normal system port.

The shuttle may be one of four types:

1. Sliding plunge.
2. Spring-loaded piston.
3. Spring-loaded ball.
4. Spring-loaded poppet.

In shuttle valves that are designed with a spring, the shuttle is normally held against the alternate system inlet port by the spring.

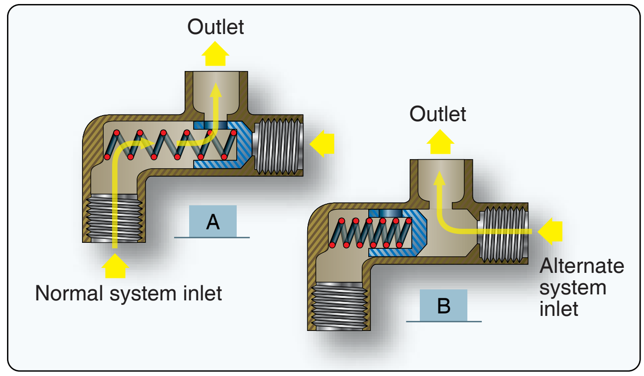

Figure 12-47. *A spring-loaded piston-type shuttle valve in normal configuration (A) and with alternate/emergency supply (B).*

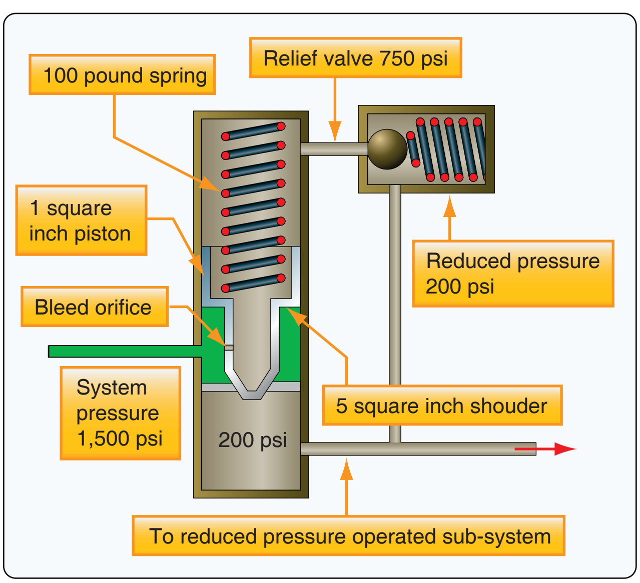

Figure 12-46. *Operating mechanism of a pressure reducing valve.*

Shutoff Valves

Shutoff valves are used to shut off the flow of fluid to a particular system or component. In general, these types of valves are electrically powered. Shutoff valves are also used to create a priority in a hydraulic system and are controlled by pressure switches. *[Figure 12-48]*

Accumulators

The accumulator is a steel sphere divided into two chambers by a synthetic rubber diaphragm. The upper chamber contains fluid at system pressure, while the lower chamber is charged with nitrogen or air. Cylindrical types are also used in high-pressure hydraulic systems. Many aircraft have several accumulators in the hydraulic system. There may be a main system accumulator and an emergency system accumulator.

Figure 12-48. *Shutoff valves.*

There may also be auxiliary accumulators located in various sub-systems.

The function of an accumulator is to:

- Dampen pressure surges in the hydraulic system caused by actuation of a unit and the effort of the pump to maintain pressure at a preset level.
- Aid or supplement the power pump when several units are operating at once by supplying extra power from its accumulated, or stored, power.
- Store power for the limited operation of a hydraulic unit when the pump is not operating.
- Supply fluid under pressure to compensate for small internal or external (not desired) leaks that would cause the system to cycle continuously by action of the pressure switches continually kicking in.

Types of Accumulators

There are two general types of accumulators used in aircraft hydraulic systems: spherical and cylindrical.

Spherical

The spherical-type accumulator is constructed in two halves that are fastened and threaded, or welded, together. Two threaded openings exist. The top port accepts fittings to connect to the pressurized hydraulic system to the accumulator. The bottom port is fitted with a gas servicing valve, such as a Schrader valve. A synthetic rubber diaphragm, or bladder, is installed in the sphere to create two chambers. Pressurized hydraulic fluid occupies the upper chamber and nitrogen or air charges the lower chamber. A screen at the fluid pressure port keeps the diaphragm, or bladder, from extruding through the port when the lower chamber is charged, and hydraulic fluid pressure is zero. A rigid button or disc may also be attached to the diaphragm, or bladder, for this purpose. *[Figure 12-49]* The bladder is installed through a large opening in the bottom

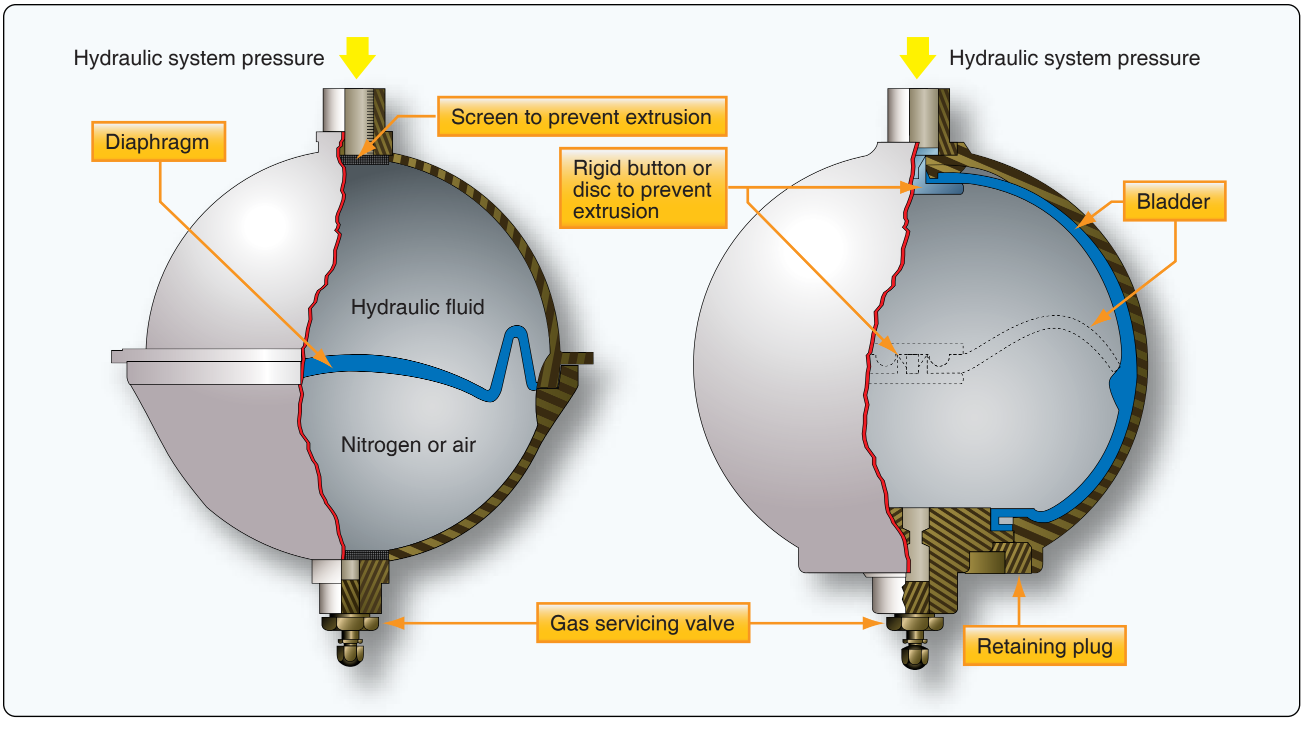

Figure 12-49. *A spherical accumulator with diaphragm (left) and bladder (right). The dotted lines in the right drawing depict the bladder when the accumulator is charged with both hydraulic system fluid and nitrogen preload.*

of the sphere and is secured with a threaded retainer plug. The gas servicing valve mounts into the retainer plug.

Cylindrical

Cylindrical accumulators consist of a cylinder and piston assembly. End caps are attached to both ends of the cylinder. The internal piston separates the fluid and air/nitrogen chambers. The end caps and piston are sealed with gaskets and packings to prevent external leakage around the end caps and internal leakage between the chambers. In one end cap, a hydraulic fitting is used to attach the fluid chamber to the hydraulic system. In the other end cap, a filler valve is installed to perform the same function as the filler valve installed in the spherical accumulator. *[Figure 12-50]*

Operation

In operation, the compressed-air chamber is charged to a predetermined pressure that is somewhat lower than the system operating pressure. This initial charge is referred to as the accumulator preload. As an example of accumulator operation, let us assume that the cylindrical accumulator is designed for a preload of 1,300 psi in a 3,000-psi system. When the initial charge of 1,300 psi is introduced into the unit, hydraulic system pressure is zero. As air pressure is applied through a gas servicing valve, it moves the piston toward the opposite end until it bottoms. If the air behind the piston has a pressure of 1,300 psi, the hydraulic system pump has to create a pressure within the system greater than 1,300 psi before the hydraulic fluid can actuate the piston. At 1,301 psi the piston starts to move within the cylinder, compressing the air as it moves. At 2,000 psi, it has backed up several inches. At 3,000 psi, the piston has backed up to its normal operating position, compressing the air until it occupies a space less than one-half the length of the cylinder. When actuation of hydraulic units lowers the system pressure, the compressed air expands against the piston, forcing fluid from the accumulator. This supplies an instantaneous supply of fluid to the hydraulic system component. The charged accumulator may also supply fluid pressure to actuate a component(s) briefly in case of pump failure.

Figure 12-50. *Cylindrical accumulator.*

Maintenance of Accumulators

Maintenance consists of inspections, minor repairs, replacement of component parts, and testing. There is an element of danger in maintaining accumulators. Therefore, proper precautions must be strictly observed to prevent injury and damage.

Before disassembling any accumulator, ensure that all preload air (or nitrogen) pressure has been discharged. Failure to release the preload could result in serious injury to the technician. Before making this check, be certain you know the type of high-pressure air valve used. When you know that all air pressure has been removed, you can take the unit apart. Be sure to follow manufacturer's instructions for the specific unit you have.

Heat Exchangers

Transport-type aircraft use heat exchangers in their hydraulic power supply system to cool the hydraulic fluid from the hydraulic pumps. This extends the service life of the fluid and the hydraulic pumps. They are located in the fuel tanks of the aircraft. The heat exchangers use aluminum finned

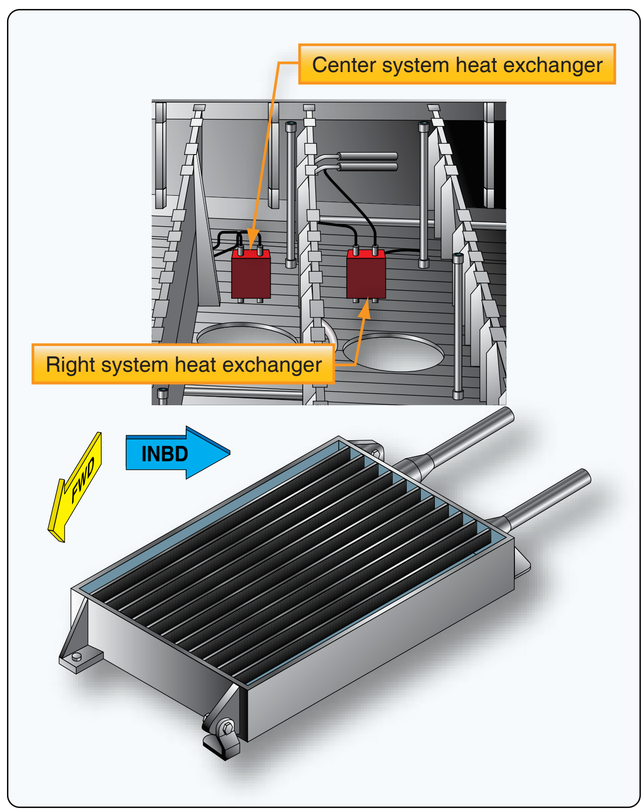

Figure 12-51. *Hydraulic heat exchanger.*

tubes to transfer heat from the fluid to the fuel. The fuel in the tanks that contain the heat exchangers must be maintained at a specific level to ensure adequate cooling of the fluid. *[Figure 12-51]*

Actuators

An actuating cylinder transforms energy in the form of fluid pressure into mechanical force, or action, to perform work. It is used to impart powered linear motion to some movable object or mechanism. A typical actuating cylinder consists of a cylinder housing, one or more pistons and piston rods, and some seals. The cylinder housing contains a polished bore in which the piston operates, and one or more ports through which fluid enters and leaves the bore. The piston and rod form an assembly. The piston moves forward and backward within the cylinder bore, and an attached piston rod moves into and out of the cylinder housing through an opening in one end of the cylinder housing.

Seals are used to prevent leakage between the piston and the cylinder bore and between the piston rod and the end of the cylinder. Both the cylinder housing and the piston rod have provisions for mounting and for attachment to an object or mechanism that is to be moved by the actuating cylinder.

Actuating cylinders are of two major types: single action and double action. The single-action (single port) actuating cylinder is capable of producing powered movement in one direction only. The double-action (two ports) actuating cylinder is capable of producing powered movement in two directions.

Linear Actuators

A single-action actuating cylinder is illustrated in *Figure 12-52A.* Fluid under pressure enters the port at the left and pushes against the face of the piston, forcing the piston to the right. As the piston moves, air is forced out of the spring chamber through the vent hole, compressing the spring. When pressure on the fluid is released to the point it exerts less force than is present in the compressed spring, the spring pushes the piston toward the left. As the piston moves to the left, fluid is forced out of the fluid port. At the same time, the moving piston pulls air into the spring chamber through the vent hole. A three-way control valve is normally used for controlling the operation of a single-action actuating cylinder.

A double-action (two ports) actuating cylinder is illustrated in *Figure 12-52B.* The operation of a double-action actuating cylinder is usually controlled by a four-way selector valve. *Figure 12-53* shows an actuating cylinder interconnected with a selector valve. Operation of the selector valve and actuating cylinder is discussed below.

When the selector valve is placed in the ON or EXTEND position, fluid is admitted under pressure to the left-hand chamber of the actuating cylinder. *[Figure 12-53]* This results in the piston being forced toward the right. As the piston moves toward the right, it pushes return fluid out of the right-hand chamber and through the selector valve to the reservoir. When the selector valve is placed in its RETRACT position, as illustrated in *Figure 12-50,* fluid pressure enters

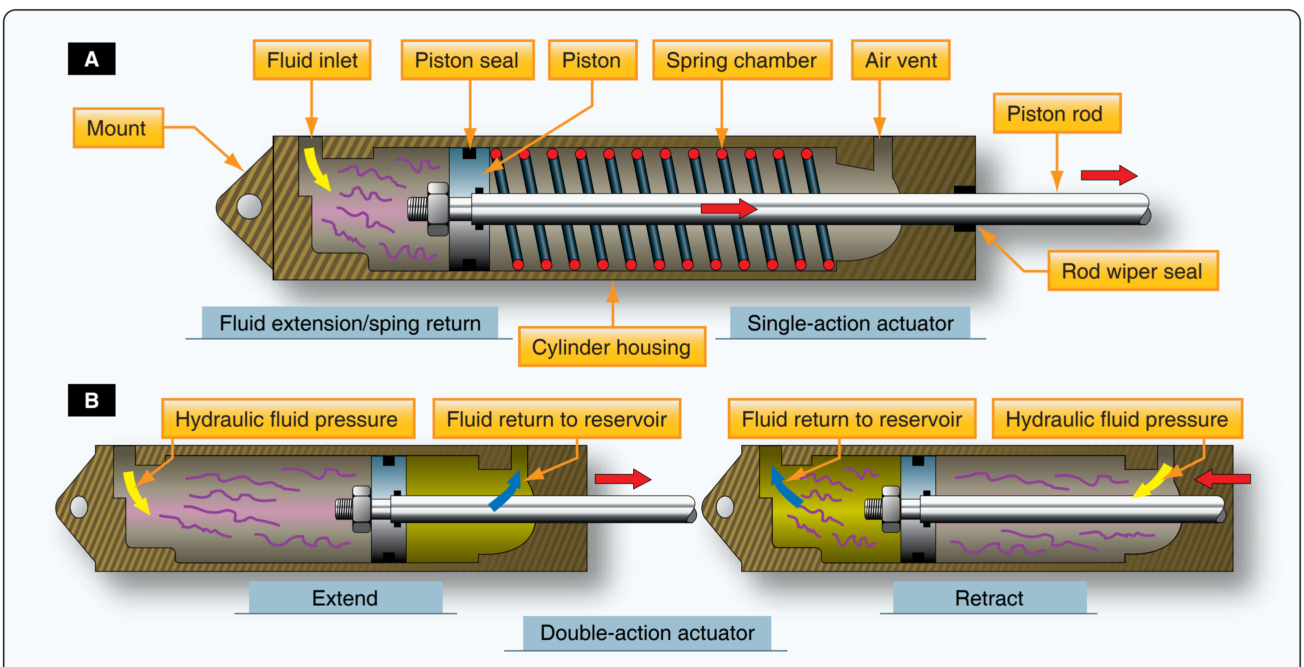

Figure 12-52. *Linear actuator.*

the right chamber, forcing the piston toward the left. As the piston moves toward the left, it pushes return fluid out of the left chamber and through the selector valve to the reservoir.

Besides having the ability to move a load into position, a double-acting cylinder also has the ability to hold a load in position. This capability exists because when the selector valve used to control operation of the actuating cylinder is placed in the off position, fluid is trapped in the chambers on both sides of the actuating cylinder piston. Internal locking actuators also are used in some applications.

Rotary Actuators

Rotary actuators can mount right at the part without taking up the long stroke lengths required of cylinders. Rotary actuators are not limited to the 90° pivot arc typical of cylinders; they can achieve arc lengths of 180°, 360°, or even 720° or more, depending on the configuration. An often-used type of rotary actuator is the rack and pinion actuator used for many nose wheel steering mechanisms. In a rack-and-pinion actuator, a long piston with one side machined into a rack engages a pinion to turn the output shaft. *[Figure 12-54]* One side of the piston receive fluid pressure while the other side is connected to the return. When the piston moves, it rotates the pinion.

Hydraulic Motor

Piston-type motors are the most commonly used in hydraulic systems. *[Figure 12-55]* They are basically the same as hydraulic pumps except they are used to convert hydraulic energy into mechanical (rotary) energy. Hydraulic motors are either of the axial inline or bent-axis type. The most commonly used hydraulic motor is the fixed-displacement bent-axis type. These types of motors are used for the activation of trailing edge flaps, leading edge slats, and stabilizer trim. Some equipment uses a variable-displacement piston motor where very wide speed ranges are desired. Although some piston-type motors are controlled by directional control valves, they are often used in combination with variable-displacement pumps. This pump-motor combination is used to provide a transfer of power between a driving element and a driven element. Some applications for which hydraulic transmissions may be used are speed reducers, variable speed drives, constant speed or constant torque drives, and torque converters.

Some advantages of hydraulic transmission of power over mechanical transmission of power are as follows:

- Quick, easy speed adjustment over a wide range while the power source is operating at a constant (most efficient) speed.
- Rapid, smooth acceleration or deceleration.
- Control over maximum torque and power.
- Cushioning effect to reduce shock loads.
- Smoother reversal of motion.

Ram Air Turbine (RAT)

The RAT is installed in the aircraft to provide electrical and hydraulic power if the primary sources of aircraft power are

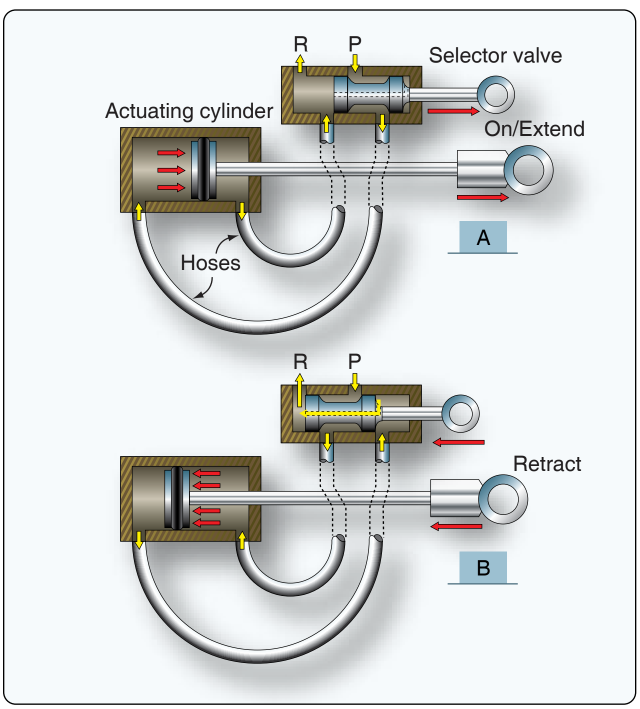

Figure 12-53. *Linear actuator operation.*

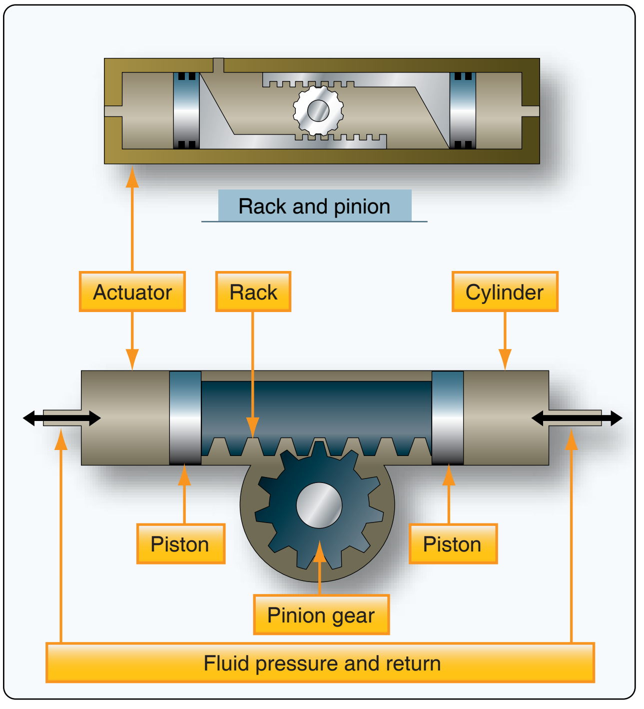

Figure 12-54. *Rack and pinion gear.*

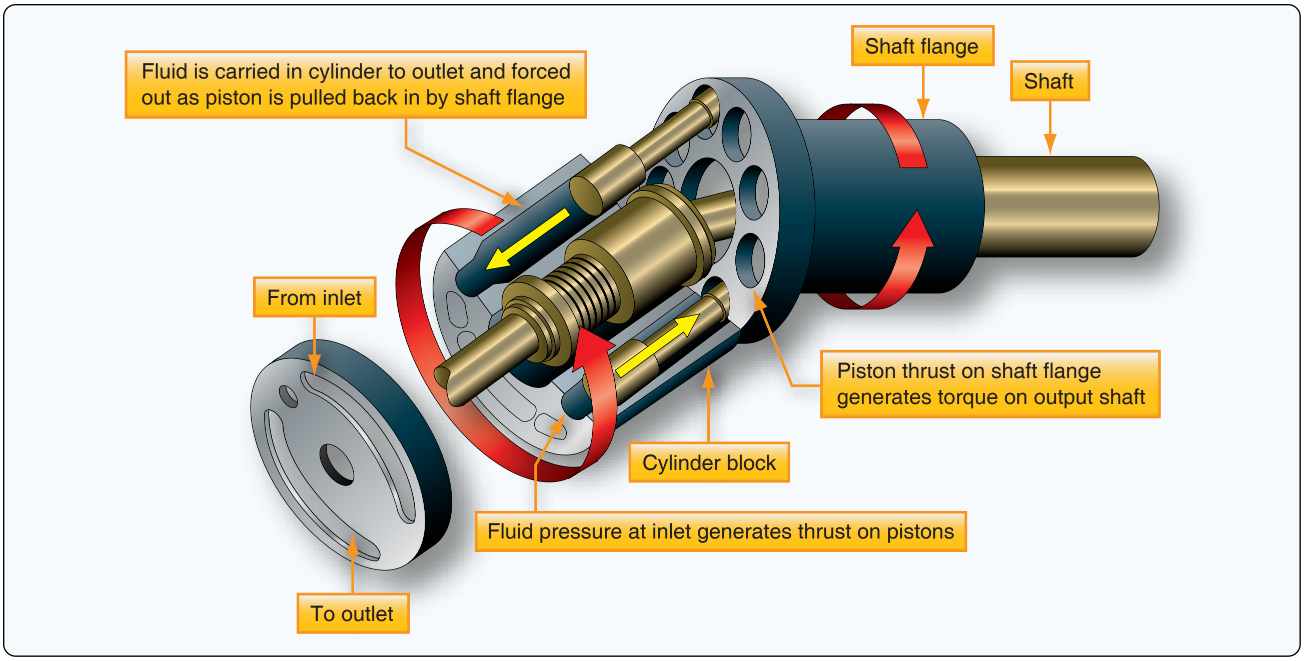

Figure 12-55. *Bent axis piston motor.*

lost. Ram air is used to turn the blades of a turbine that, in turn, operates a hydraulic pump and generator. The turbine and pump assembly is generally installed on the inner surface of a door installed in the fuselage. The door is hinged, allowing the assembly to be extended into the slipstream by pulling a manual release in the flight deck. In some aircraft, the RAT automatically deploys when the main hydraulic pressure system fails, and/or electrical system malfunction occurs. *[Figure 12-56]*

Power Transfer Unit (PTU)

The PTU is able to transfer power but not fluid. It transfers power between two hydraulic systems. Different types of PTUs are in use; some can only transfer power in one direction while others can transfer power both ways. Some PTUs have a fixed displacement, while others use a variable displacement hydraulic pump. The two units, hydraulic pump and hydraulic motor, are connected via a single drive shaft so that power can be transferred between the two systems. Depending on the direction of power transfer, each unit in turn works either as a motor or a pump. *[Figure 12-57]*

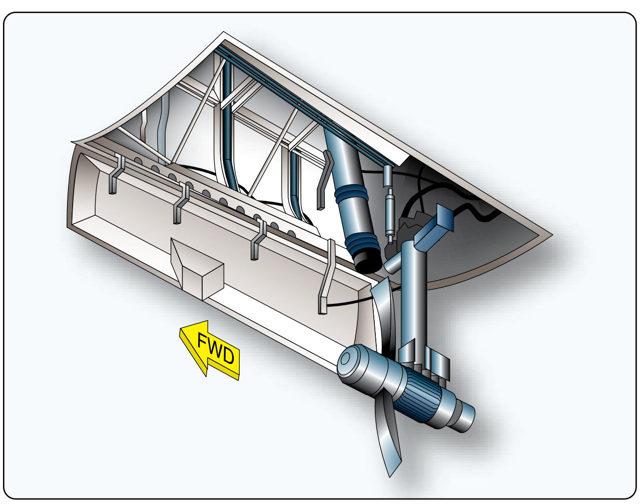

Figure 12-56. *Ram air turbine.*

Hydraulic Motor-Driven Generator (HMDG)

The HMDG is a servo-controlled variable displacement motor integrated with an AC generator. The HMDG is designed to maintain a desired output frequency of 400 Hz. In case of an electrical failure, the HMDG could provide an alternative source of electrical power.

Seals

Seals are used to prevent fluid from passing a certain point, and to keep air and dirt out of the system in which they are used. The increased use of hydraulics and pneumatics in aircraft systems has created a need for packings and gaskets of varying characteristics and design to meet the many variations of operating speeds and temperatures to which they are subjected. No one style or type of seal is satisfactory for all installations. Some of the reasons for this are:

- Pressure at which the system operates.
- The type fluid used in the system.
- The metal finish and the clearance between adjacent parts.
- The type motion (rotary or reciprocating), if any.

Seals are divided into three main classes: packings, gaskets,

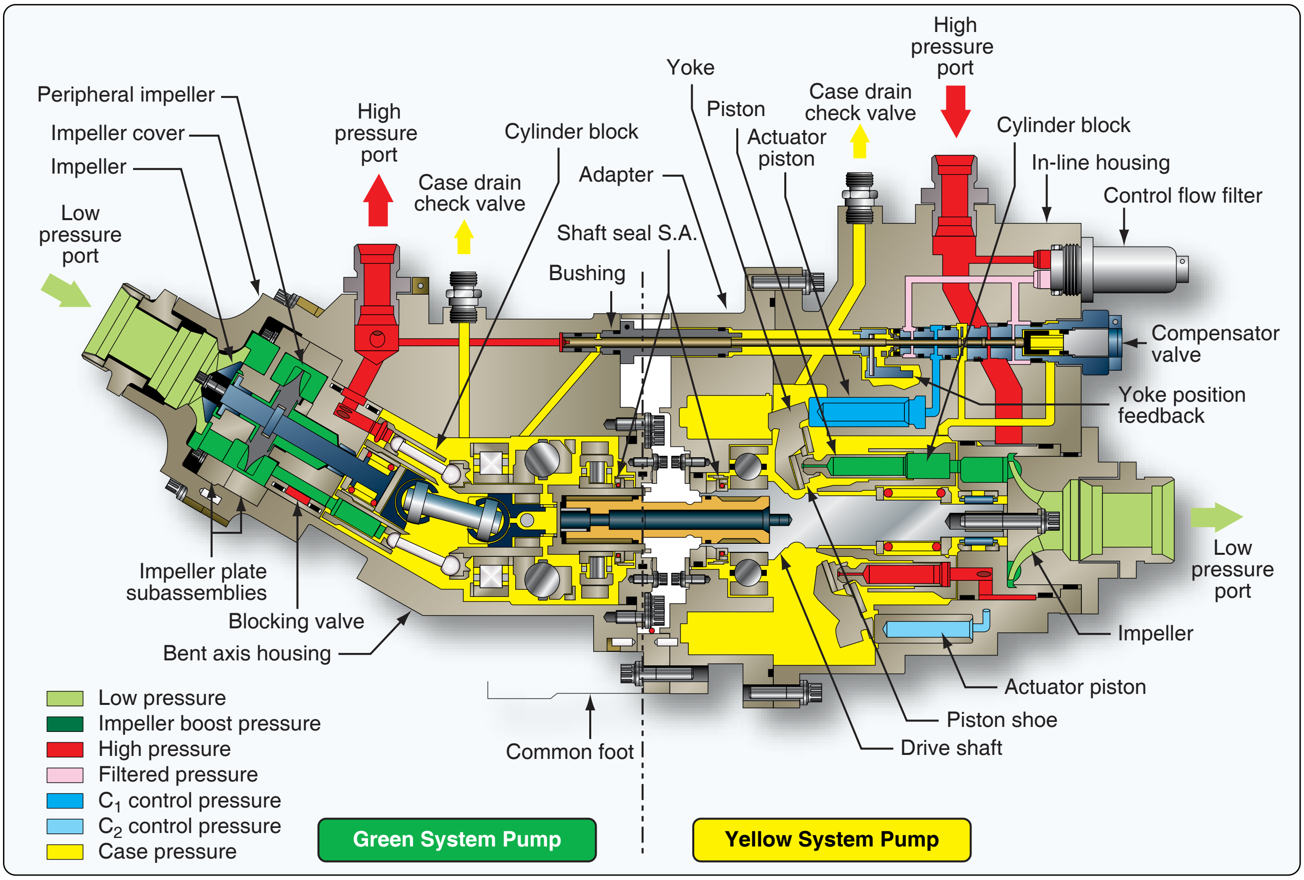

Figure 12-57. *Power transfer unit.*

and wipers. A seal may consist of more than one component, such as an O-ring and a backup ring, or possibly an O-ring and two backup rings. Hydraulic seals used internally on a sliding or moving assembly are normally called packings. *[Figure 12-58]* Hydraulic seals used between nonmoving fittings and bosses are normally called gaskets.

V-Ring Packings

V-ring packings (AN6225) are one-way seals and are always installed with the open end of the V facing the pressure. V-ring packings must have a male and female adapter to hold them in the proper position after installation. It is also necessary to torque the seal retainer to the value specified by the manufacturer of the component being serviced, or the seal may not give satisfactory service.

U-Ring

U-ring packings (AN6226) and U-cup packings are used in brake assemblies and brake master cylinders. The U-ring and U-cup seals pressure in only one direction; therefore, the lip of the packings must face toward the pressure. U-ring packings are primarily low-pressure packings to be used with pressures of less than 1,000 psi.

O-Rings

Most packings and gaskets used in aircraft are manufactured in the form of O-rings. An O-ring is circular in shape, and its cross-section is small in relation to its diameter.

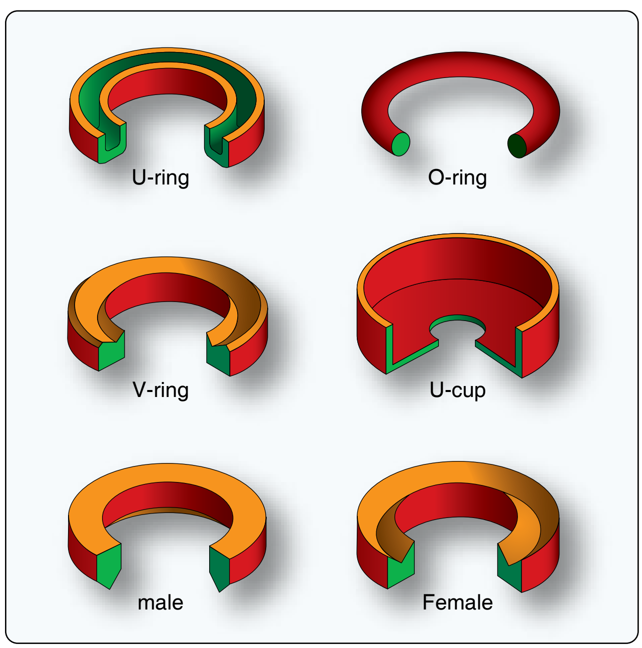

Figure 12-58. *Packings.*

The cross-section is truly round and has been molded and trimmed to extremely close tolerances. The O-ring packing seals effectively in both directions. This sealing is done by distortion of its elastic compound.

Advances in aircraft design have made new O-ring composition necessary to meet changing conditions. Hydraulic O-rings were originally established under Air Force-Navy (AN) specification numbers 6227, 6230, and 6290 for use in fluid at operating temperatures ranging from –65 °F to +160 °F. When new designs raised operating temperatures to a possible +275 °F, more compounds were developed and perfected.

Recently, newer compounds were developed under Military Standard (MS) specifications that offered improved low-temperature performance without sacrificing high-temperature performance. These superior materials were adopted in the MS28775 O-ring, which is replacing AN6227 and AN6230 O-rings, and the MS28778 O-ring, which is replacing the AN6290 O-ring. These O-rings are now standard for systems where the operating temperatures may vary from –65 °F to +275 °F.

O-Ring Color Coding

Manufacturers provide color coding on some O-rings, but this is not a reliable or complete means of identification. The color coding system does not identify sizes, but only system fluid or vapor compatibility and, in some cases, the manufacturer. Color codes on O-rings that are compatible with MIL-H-5606 fluid always contains blue but may also contain red or other colors. Packings and gaskets suitable for use with phosphate ester-based fluids are always coded with a green stripe, but may also have a blue, grey, red, green, or yellow dot as a part of the color code. Color codes on O-rings that are compatible with hydrocarbon fluid always contain red, but never contain blue. A colored stripe around the circumference indicates that the O-ring is a boss gasket seal. The color of the stripe indicates fluid compatibility: red for fuel, blue for hydraulic fluid. The coding on some rings is not permanent. On others, it may be omitted due to manufacturing difficulties or interference with operation. Furthermore, the color coding system provides no means to establish the age of the O-ring or its temperature limitations. Because of the difficulties with color coding, O-rings are available in individual hermetically sealed envelopes labeled with all pertinent data. When selecting an O-ring for installation, the basic part number on the sealed envelope provides the most reliable compound identification.

Backup Rings

Backup rings (MS28782) made of Teflon™ do not deteriorate with age, are unaffected by any system fluid or vapor, and can tolerate temperature extremes in excess of those encountered in high pressure hydraulic systems. Their dash numbers indicate not only their size but also relate directly to the dash number of the O-ring for which they are dimensionally suited. They are procurable under a number of basic part numbers, but they are interchangeable; any Teflon™ backup ring may be used to replace any other Teflon™ backup ring if it is of proper overall dimension to support the applicable O-ring. Backup rings are not color coded or otherwise marked and must be identified from package labels. The inspection of backup rings should include a check to ensure that surfaces are free from irregularities, that the edges are clean cut and sharp, and that scarf cuts are parallel. When checking Teflon™ spiral backup rings, make sure that the coils do not separate more than ¼ inch when unrestrained. Be certain that backup rings are installed downstream of the O-ring. *[Figure 12-59]*

Gaskets

Gaskets are used as static (stationary) seals between two flat surfaces. Some of the more common gasket materials are asbestos, copper, cork, and rubber. Asbestos sheeting is used wherever a heat resistant gasket is needed. It is used extensively for exhaust system gaskets. Most asbestos exhaust gaskets have a thin sheet of copper edging to prolong their life.

A solid copper washer is used for spark plug gaskets where it is essential to have a noncompressible, yet semisoft gasket. Cork gaskets can be used as an oil seal between the engine crankcase and accessories, and where a gasket is required that is capable of occupying an uneven or varying space caused by a rough surface or expansion and contraction. Rubber sheeting can be used where there is a need for a compressible gasket. It should not be used in any place where it may come in contact with gasoline or oil because the rubber deteriorates very rapidly when exposed to these substances. Gaskets are used in fluid systems around the end caps of actuating cylinders, valves, and other units. The gasket generally used for this purpose is in the shape of an O-ring, similar to O-ring packings.

Seal Materials

Most seals are made from synthetic materials that are compatible with the hydraulic fluid used. Seals used for MIL-H-5606 hydraulic fluid are not compatible with phosphate ester-based fluids and servicing the hydraulic system with the wrong fluid could result in leaks and system malfunctions. Seals for systems that use MIl-H-5606 are made of neoprene or Buna-N. Seals for phosphate ester-based fluids are made from butyl rubber or ethylene-propylene elastomers.