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AEROSPACE RECOMMENDED PRACTICE

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AEROSPACE DESIGN AND INSTALLATION OF COMMERCIAL TRANSPORT HELICOPTER HYDRAULIC SYSTEMS

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1. SCOPE:

This SAE Aerospace Recommended Practice (ARP) establishes the factors which should be considered in the design and installation of a hydraulic system fitted to a commercial transport rotorcraft.

1.1 Purpose:

The purpose of this document is to provide in one document information and guidelines to the designers of commercial transport rotorcraft hydraulic systems and components including:

a. Reliability and Maintainability requirements;

b. Federal Aviation regulations (FAR)/Joint Airworthiness requirements (JAR) that are applicable to hydraulic systems;

c. Design and installation practices.

1.2 Field of Application:

This document applies to the hydraulic systems installed into commercial transport rotorcraft which are designed to comply with FAR and/or JAR 29 regulations.

2. REFERENCES:

2.1 Applicable Documents:

The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this specification and references cited herein, the text of this specification takes precedence. Nothing in this specification, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

The majority of the documents referenced in this section are aerospace hydraulic system standards. They include advisory, guidance and certification documentation that can be used for designing and evaluating all rotorcraft hydraulic systems. However, these documents may be supplemented, or overridden by, specific aircraft and/or airworthiness requirements, particularly when the documents such as Military specifications, are oriented towards military aircraft. While military and commercial hydraulic systems may use different fluid types (current commercial helicopters use hydrocarbon based fluids, (red-oil)) the intent of the military specifications is to provide important and reliant requirements and guidance for commercial applications.

2.1.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001

AIR310	Fittings, Catalog of Flared, Flareless, Pipe Threaded, Port and Other Type Tube Standard Connectors
ARP490	Electro-Hydraulic Flow Control Servovalves
AS568	Aerospace Size Standard for O-Rings
ARP584	Coiled Tubing
AS595	Civil Type Aircraft Variable Delivery Hydraulic Pump
AS604	Hose Assembly, Tetrafluoroethylene, 400 °F, 3000 psi Hydraulic, Heavy Braid
AS620	High Temperature Hose Assembly, Convoluted, Tetrafluoroethylene-, for Aircraft
AIR737	Aerospace Hydraulic and Pneumatic Specifications and Standards
ARP819	Fluid System Characteristics Affecting Hydraulic Pump Operation
AIR887	Liquid Filter Ratings, Parameters and Tests
ARP994	Design of Tubing Installations for Aerospace Fluid Power Systems, Recommended Practice for
AS1055	Fire Testing of Flexible Hoses, Tube Assemblies, Coils, Fittings and Similar Components
AS1227	High Temperature, Low Pressure Hose Assembly, Convoluted-Fluoroethylene for Aerospace
AS1241	Fire Resistant Phosphate Ester Hydraulic Fluid for Aircraft
ARP1280	Application Guide for Hydraulic Power Transfer Units
ARP1281	Actuators: Aircraft Flight Controls, Power Operated, Hydraulic, General Specification for
AS1290	Graphic Symbols for Aircraft Hydraulic and Pneumatic Systems
AS1300	Boss, Ring Locked Fluid Connection Type, Standard Dimension for
AS1339	Hose Assembly, Tetrafluoroethylene, 400 °F, 3000 Psi, Hydraulic Light Weight
AIR1379	Prestressing (Autofrettaging) of Hydraulic Tubing Lines
ARP1383	Impulse Testing of Hydraulic Actuators, Valves, Pressure Containers and Similar Fluid System Safety Components
ARP1658	Visual Inspection Guide for Installed Hose Assemblies
AS1709	Coupling Assembly, Self-Sealing, Quick Disconnect
AS1896	Coupling Assembly, Self-Sealing, One Side Only, Hydraulic
ARP1897	Clamp Selection and Installation Guide
AIR1922	System Integration Factors that Affect Hydraulic Pump Life
AS3121	Plug Expansion - Aluminum, 2024-T4, Long, Standard and 0.010 Oversize Diameters
AS3131	Plug, Expansion - CRES 303, Short, Standard and 0.010 Oversize Diameters
AIR4057	Secondary Filters for Fluid System Reliability
AS4059	Aerospace Cleanliness Specification for Hydraulic Fluids
AIR4092	Investigation Into PTFE 'Melt' Phenomenon for High Pressure Hoses
ARP4146	Coiled Tubing, Titanium Alloy, Hydraulic Applications
AIR4150	Inspection of Inservice Airborne Accumulators
ARP4268	Aerospace Hydraulic System Sampling Points
ARP4378	Accumulators, Hydraulic, Cylindrical, Aircraft, Maintenance Free, Factory Precharged

2.1.1 (Continued):

ARP4379 Accumulator, Hydraulic, Cylindrical, Aircraft
AS4395 Fitting End, Flared Tube Connection, Design Standard
ARP4553 Self-Displacing Hydraulic Accumulators
AS4716 Aerospace Standard, Gland Design, O-Rings and Other Elastomeric Seals

AMS 4944 Titanium Alloy Tubing, Seamless, Hydraulic, 3.0A1-2.5V, Cold Worked and Stress Relieved
AMS 5561 Steel Tubing, Welded and Drawn, Corrosion Resistant Steel, 9.0Mn-20Cr-6.5 Ni-0.28N, High Pressure Hydraulics

2.1.2 US Government Publications: Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094

MIL-H-5440 Hydraulic Systems, Aircraft, Design and Installation, Requirements for
MIL-A-5498 Accumulators, Aircraft, Hydropneumatic Pressure
MIL-A-5503 Actuators: Aeronautical, Hydraulic Actuating, General Requirements for
MIL-J-5513 Joints, Hydraulic Swivel
MIL-G-5514 Gland Design, Packings, Hydraulic, General Requirements for
MIL-R-5520 Reservoirs, Aircraft, Non-Separated Type
MIL-H-5606 Hydraulic Fluid, Petroleum Base; Aircraft, Missile and Ordnance
MIL-P-5994 Pump, Hydraulic, Electric Motor Driven, Variable Delivery, General Specification for
MIL-T-7081 Tube, Aluminum Alloy, Seamless, Round, Drawn, 6061, Aircraft Hydraulic Quality
MIL-P-7858 Pump, Hydraulic, Power Driven, Fixed Displacement
MIL-M-7997 Motors, Aircraft Hydraulic, Constant Displacement, General Specification for
MIL-H-8775 Hydraulic System Components, Aircraft and Missile, General Specification for
MIL-R-8791 Retainer, Packing, Hydraulic and Pneumatic Tetrafluoroethylene Resin
MIL-V-8813 Valves: Aircraft, Hydraulic Pressure Relief, Type II Systems
MIL-F-8815 Filter and Filter Elements, Fluid Pressure, Hydraulic Line, 15 Micron Absolute and 5 Micron Absolute, Type II Systems, General Specification for
MIL-R-8931 Reservoirs: Aircraft and Missiles, Hydraulic Separated Type
MIL-S-9395 Switch Pressure (Absolute Gauge and Differential), Specification for
MIL-F-18280 Fittings, Flareless Tube, Fluid Connection
MIL-V-19068 Valves, Shuttle, Hydraulic, Aircraft, Type II Systems
MIL-P-19692 Pump, Hydraulic, Variable Delivery, General Specification for
MIL-C-25427 Coupling Assembly, Hydraulic, Self-Sealing, Quick Disconnect
MIL-H-25579 Hose Assembly, Tetrafluoroethylene, High Temperature, Medium Pressure, General Requirements for
MIL-V-27162 Valves, Servo Control, Electro-Hydraulic, General Specification for
MIL-H-27267 Hose Tetrafluoroethylene, High Temperature, Medium Pressure
MIL-F-27272 Fitting, Tetrafluoroethylene Hose, High Temperature, Medium Pressure, General Requirements for
MIL-R-83248 Rubber, Fluorocarbon Elastomer, High Temperature Fluid and Compression Set Resistant, O-Rings Class 1, 75 Hardness

2.1.2 (Continued):

MIL-H-83282 Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Aircraft
MIL-F-83296 Fittings, Tetrafluoroethylene Hose, High Temperature, High Pressure (3000 psi), Hydraulic and Pneumatic
MIL-H-83298 Hose, Tetrafluoroethylene, High Temperature, High Pressure (3000 psi), Hydraulic and Pneumatic
MIL-P-83461 Packing, Preformed, Petroleum Hydraulic Fluid Resistant, Improved Performance At 275 °F
MIL-R-83485 Rubber, Fluorocarbon Elastomer, Improved Performance, at Low Temperatures (-40 to +400 °F)(-40 to +204 °C)
MIL-H-87257 Hydraulic Fluid, Fire Resistant; Low Temperature Synthetic Hydrocarbon Base, Aircraft and Missile

MIL-STD-1247 Markings, Functions and Hazard Designations of Hose, Pipe and Tube Lines for Aircraft, Missile And Space Systems
MS24391 Plug,-Bleeder, Tube, Precision Type
MS33566 Fittings, Installation of Flareless Tube, Straight-Threaded Connectors
MS33611 Tube Bend Radii
MS33649 Bosses, Fluid Connection - Internal Straight Thread

2.1.3 Government Airworthiness Documents: Available from FAA, 800 Independence Avenue, SW, Washington, DC 20591.

FAR Part 29 Airworthiness Standards: Transport Category Rotorcraft
TSO-C75 Hydraulic Hose Assemblies

2.1.4 National Aerospace Standards: Available from Aerospace Industries Association, 1250 Eye Street NW, Washington, DC 20005.

NAS1601 Packing, Preformed, O-Ring, Phosphate Ester Resistant (-65° to 160 °F)
NAS1602 Packing, Preformed, Straight Thread Tube Fitting Boss (-65° to 160 °F)
NAS1613 Packing, Preformed, O-ring, Phosphate Ester Resistant (-65° to 160 °F)
NAS1638 Cleanliness of Parts Used in Hydraulic Systems

2.1.5 ANSI Publications: Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ISO 12 Pipelines, Identification Schemes
ISO 8278 Aerospace, Hydraulic, Pressure Compensated, Variable Delivery Pumps, General Requirements
ISO 9206 Aerospace, Constant Displacement Hydraulic Motors, General Specifications

2.1.6 Joint Aviation Authorities Committee Documents:

JAR-29 Joint Aviation Requirements, Large Rotorcraft

3. OVERALL HYDRAULIC SYSTEM REQUIREMENTS:

3.1 General Requirements:

3.1.1 Design: If the rotorcraft is to be flyable, it must be controllable. Therefore, the system must be designed such that the rotor controls remain functional following many types of system and/or component failures. Rotor controls in this case means the main rotor controls for the fore and aft rotor on tandem rotor designs, or the main and anti-torque device controls on single (main) rotor aircraft.

The rotary wing aircraft flight differs from fixed wing flight; in a fixed wing aircraft, lift is provided by a "fixed set" of wings, with the forward thrust (propulsion) being supplied by an engine, driving a propeller or providing thrust directly as in pure jet or turbo fan. In the case of the rotary wing aircraft, lift is provided by rotating the wings. Hence no forward speed is required in order to generate sufficient lift to become airborne. Horizontal motion is attained by pointing the rotor head thrust vector into the desired direction, forward, left, right or even backwards. Thrust changes are accomplished by varying the angle of attack of each wing (rotor blade). Equal changes on all blades varies the magnitude of the thrust, hence the available lift or power. Changing the angle of attack on each blade individually as a function of the azimuth angle, (blade position relative to the aircraft centerline), changes the thrust vector orientation relative to the aircraft cg, thus providing locomotion in the horizontal plane. The rotor torque is compensated by the use of anti-torque devices on single rotor machines. The most common device is a rotor mounted at the tail to provide thrust in the horizontal plane. Ducted fans, fenestrons and vectored thrust devices are alternatives used on smaller aircraft where the tail rotor may present a hazard to ground personal and passengers. Tandem rotor machines have rotors rotating in opposite directions thus canceling the rotor torques.

The complex aerodynamic forces, to which the rotor blades are subjected to during flight, coupled with any unbalances inherent in the rotating system, give rise to the infamous helicopter vibrations. These vibrations, magnitude and frequency, must be taken into account when designing the hydraulic system(s), components and installations.

3.1.2 System Pressure: Working pressures common in commercial transport helicopters in operation today are 1000 psi (6896 kPa) or less for smaller craft, 1500 psi (10,344 kPa) to 2000 psi (13,792 kPa) for medium size craft, and 3000 psi (20,690 kPa) for larger aircraft, but higher pressures are anticipated to be used in the next generation of transport helicopters. This will impact the availability of suitable ground support equipment, but the use of higher pressure levels will result in reduced installation envelopes and can lead to a reduction in system weight, but to a lesser extent than which can be realized in fixed wing systems due to the relatively compact supply system arrangement. Plumbing in a rotary wing aircraft is usually a smaller percentage of the overall hydraulic system weight than for a fixed wing aircraft. A cost/benefit trade is advisable early in the design development.

3.1.3 Hydraulic Fluid: MIL-H-5606, MIL-H-83282, and MIL-H-87257 are referred to as hydrocarbon based fluids in this document. Fluid conforming to MIL-H-5606 had been the most commonly used hydraulic fluid to date, but fluid conforming to MIL-H-83282 is now being introduced into the commercial operator fleet and should be considered over MIL-H-5606. Where the use of MIL-H-83282 causes restrictions in the aircraft operation due to the low temperature limitations of MIL-H-83282, MIL-H-87257 can be substituted. Phosphate Ester fluids, used in the fixed wing commercial arena, are generally not used in commercial helicopters. The majority of commercial transport helicopters have been derived from military aircraft, and the limited market has never warranted the changeover to phosphate-ester fluids. Many commercial helicopter operations started using military surplus aircraft, and later on derivatives of military models. The maintenance facilities evolved to service these aircraft. Also, due to the smaller aircraft size, compact systems, the total volume of fluid contained in a helicopter system is but a fraction of the volume contained in the systems of large transport aircraft. System volumes of less than 1 gallon (3.8 l) are common. Larger aircraft may have somewhat larger fluid capacities, with reservoir sizes between 1 and 2 gallons (4 to 8 l). If the design specification requires the use of phosphate-ester fluids, fluid conforming to AS1241 Type IV Grade A should be used. It must be noted that phosphate-ester based and hydrocarbon based hydraulic fluids are not compatible, nor can the components designed for operation in one type of fluid be used in a system with the other fluid.

3.1.4 System Temperatures: Each hydraulic system should be designed for operating in ambient temperatures which are dictated by the individual aircraft model operating requirements and be nondegraded at:

a. The minimum temperature that the aircraft will likely to be subjected to during an overnight cold soak. A warm-up period may be required before the system is operational for flight.

b. The maximum temperature which could occur during prolonged ground operation or temperature soak-back, for example on engine or main gear box mounted components. Engine temperatures of 320 °F (160 °C) and transmission housing temperatures of 220 °F (105 °C) are common with higher temperatures possible on future rotorcraft. Therefore provisions should be made to protect the hydraulic system from these temperature extremes.

The system should be designed so that for normal operation the hydraulic fluid temperatures in the power generation systems are between -20 to 220 °F (-29 to 105 °C) for hydrocarbon based fluids and -20 to 175 °F (-29 to +79 °C) for phosphate ester fluids. Operation of the system at the upper limits of the hydraulic fluids, +275 °F(135 °C) for hydrocarbon based fluids and 225 °F (+107 °C) for phosphate ester fluids should be limited to short periods or a reduction in system reliability may result.

Operation of all hydraulic services should still be possible at -65 °F (-54 °C), but performance degradation is expected.

3.1.4 (Continued):

It should be noted that:

The lower limit for cold soak ambient and operating temperatures for aircraft using MIL-H-83282 hydraulic fluid should be limited to -40 °F (-40 °C), or as established by test. This is due to the high kinematic viscosity of this fluid at low temperatures.

3.1.5 Seals: AS4716 or MIL-G-5514 (AS4716 is preferred) should be used as a guide for the installation of seals in glands, except for specialized proprietary seals.

3.1.5.1 Gland Design: Seal gland dimensions should conform to AS4716 or MIL-G-5514 (AS 4716 is preferred) except for specialized proprietary packings.

3.1.5.2 Packings: O-ring seals and elastomers installed in systems using MIL-H-83282, MIL-H-87257 or MIL-H-5606 hydraulic fluid should conform to MIL-P-83461. In components subjected to high temperatures, elastomer materials conforming to MIL-R-83248 or MIL-R-83485 should be used. Systems using phosphate ester type fluids must use O-rings manufactured from NAS-1613 materials and molded to meet the dimensions of NAS-1601 and NAS-1602. O-ring dimensions shall conform to AS568, MA2010 or ISO 3601 as applicable.

3.1.5.3 Backup Rings: Backup rings must be installed on all O-ring installations where operating pressures are above 1500 psi (10,344 kPa) and should conform to MIL-R-8791. More extrusion resistant compounds should be used for backup rings used in systems operating at pressures of 4000 psi (27,584 kPa) or in locations where continuous operation at the high temperature limits is anticipated.

3.1.6 Hydraulic System Schematic Diagram: Whenever a system schematic diagram of a hydraulic system is prepared, the symbols and presentation principles should conform to AS1290/ISO 5859. This provides the benefit of having a consistent set of symbols/drawings layouts which can be understood by a variety of disciplines and organizations including the aircraft hydraulic system engineers, aircraft customer, support engineers, component suppliers and airline engineering groups.

3.2 Applicable Airworthiness Requirements:

Modern day Commercial Transport Helicopters are designed to meet the airworthiness requirements as defined in the Federal Air Worthiness Regulation (FAR), Part 29 (for US aircraft) or to the Joint Airworthiness Requirements (JAR) Part 29 (for non-US certified aircraft).

3.2 (Continued):

The sections in these regulations which are applicable to the design of commercial transport rotorcraft hydraulic systems are:

29.141 General, Power On/Power Off
29.143 Controllability and Maneuverability
29.307 Proof of Structure
29.601 Design and Construction, General
* 29.602 Critical Parts
29.603 Materials
29.610 Lightning Protection
29.611 Inspection Provisions
29.671 Control Systems, General
29.672 Stability Augmentation and Automatic and Power Operated Systems
29.673 Primary Flight Controls
29.729 Retracting Mechanisms
29.863 Flammable Fluid Protection
29.921 Rotor Brake
29.1181 Designated Fire Zones
29.1183 Flammable Fluid - Carrying Components
29.1185 Flammable Fluids
29.1189 Shutoff Means
29.1309 Equipment and Installation
29.1322 Warning, Caution and Advisory Lights
25.1435 Design of Hydraulic Systems

* JAR requirement only.

The impact of these regulations on the design of commercial transport rotorcraft hydraulic systems will be referred to throughout this document.

3.3 Design Concepts and Overall Layout Requirements:

The general concept and layout of the hydraulic system design and the type of components used within the system have to comply with the FAR/JAR requirements of 29.307, 29.671, 29.672, 29.695, 29.729, and 29.1309. These requirements are concerned with the effects of single and multiple failures of systems, power sources, subsystems or components within the system and their subsequent effect upon the operation of the rotorcraft. Consideration has to be given to the ability of the flight crew to maintain control of the rotorcraft at any point in the flight following a single failure. The regulations state that if power boosted or power operated control systems are used, an alternate system must be available that allows the continued safe flight and landing in the event of a single failure in the power portion of the system or failure of all engines. In this respect Part 29 regulations differ from those defined in Part 25 which requires safe operation following a "two system" failure. The requirement for rotorcraft are less stringent in this area due to the shorter mission duration, which lowers the probability of a dual system failure occurring during the flight.

3.3 (Continued):

For rotorcraft designed for greater range, it is prudent to provide a two-fail-operate system configuration as required in FAR Part 25. In addition, the effect of the failures and subsequent degree of difficulty in safely operating the rotorcraft has to be related to the probability of these failure(s) occurring. Furthermore, the helicopter is designed to operate on unprepared landing sites. As such they may be required to operate under severe dust and sand conditions.

Off-shore operation exposes the systems and components to a salt atmosphere possibly leading to corrosion unless addressed properly during the design stage.

Therefore, the design of the overall hydraulic system has to relate to the type of potential failures within the system and their effect on the aircraft. This in turn is related to the type and number of services supplied by the hydraulic system.

Regardless of the number of hydraulic systems installed, if the aircraft contains power boosted or power operated controls, means must be provided to allow full control movement of all primary flight control prior to flight, or a means must be provided that will allow the pilot to determine that full control authority is available prior to rotor engagement.

3.3.1 Rotorcraft Utilizing a Single Main Hydraulic System: If the aircraft's flight control system is capable of manual reversion/operation, only a single hydraulic supply system may be required. If however, the aircraft is equipped with a retractable landing gear, then FAR/JAR 29.729(c) requires that alternate methods for deploying the gear must be available if the gear cannot be deployed via free fall. Examples of the alternate means include a simple auxiliary hydraulic system or a stored gas system. Power boosted braking systems on rotorcraft usually are not required to be provided with a backup system due to the low landing speeds.

3.3.2 Rotorcraft Utilizing Two Independent Hydraulic Systems: Two independent hydraulic systems are required if the aircraft cannot be controlled without hydraulic power. Thus, if one of the two system fails, there shall be no, or negligible, effect on the aircraft handling and the aircraft can safely complete its mission and land. If the aircraft is equipped with a retractable landing gear, and the gear is powered by one of the two systems which supply the primary flight controls, the following must be provided:

a. An alternate means to deploy the landing gear
b. A priority valve which assures priority of the primary control system over any utility functions.

3.3.3 Rotorcraft Utilizing More Than Two Hydraulic Systems: If the aircraft's hydraulic system supplies all the primary and secondary flight controls and the aircraft cannot be controlled without hydraulic power, and where certain mission requirements increase the probability of a dual power failure, three hydraulic systems should be considered. Even though this is not mandated by the regulations, it nevertheless represents prudent design practice. The requirement to provide a redundant power source for the landing gear on aircraft so equipped applies.

3.3.4 Loss of Electrical Generated Power: Hydraulic components and subsystems are increasingly dependent upon electrical power to function properly. The electrical power generating and distribution system should have equal or better redundancy than the hydraulic system. The overall system comprising the electrical power supply, distribution and the flight control system and it's components (control valves, pump mode selectors and directional valves, etc.) should be configured such that following a complete failure of the main electrical system, the rotorcraft can continue safe flight and land safely under these conditions.

In addition, the relationship between the electrical supplies to the hydraulic components and the function of the hydraulic components must be carefully reviewed. This is especially true of electronic logic systems which due to their high impedance inputs can be subject to spurious inputs. This must be reviewed in the context that a potentially catastrophic event might possibly occur due to a combination of single failures of:

a. The electrical and hydraulic systems;
b. Components within the two systems;
c. A failure of one of the systems and a component in the other system;

3.3.5 Hydraulic System Backup Sources: Independent of the number of separate supply systems installed within the overall aircraft system, consideration has to be given to the level of redundancy of the power sources within the system. Usually each independent system contains a main hydraulic power source, for example a gearbox driven hydraulic pump, a switching valve or PTU (Power Transfer Unit) and a backup power source. Thus, if the main power source fails, the backup source will provide for continued safe operation.

If the aircraft has all Primary and Secondary flight controls powered by the hydraulic system, then it has to comply with 29.695(a). This states that the aircraft has to be controllable when all engines fail. In order to comply with this requirement, at least one of the main system pumps and the backup pump, or all pumps, must be driven off the main transmission. Each pump should be driven off a separate drive train to prevent loss of all hydraulic pumps due to a single transmission shaft or gear failure. The backup source may be electric motor driven. Ram air turbine (RAT) systems are not used on rotorcraft. The aircraft speeds are low compared with fixed wing aircraft which would require a rather large turbine diameter and would be too heavy. Also finding a location on the aircraft to mount the RAT, where the airstream is relatively undisturbed, may be difficult or impossible.

Another means to provide backup power has been the use of an accumulator. This approach has extremely limited capability, as it provides power only for a very short time and thus is useful only as a means to control the aircraft for an emergency landing.

3.3.6 Hydraulic System Protection Devices: Consideration should be given to the use of protection devices to provide some capability of operating key hydraulic subsystems following loss of the primary system, or to protect against loss of the primary supply system due to a failure (leak) in a subsystem or component.

Examples of these type of devices which can be used are:

3.3.6.1 Check Valve: This is the simplest of all protection devices and can be used to isolate subsystems from the main hydraulic system. This then allows the subsystem to be supplied by a secondary source:

a. An accumulator which can supply power for a finite time or number of cycles.
b. A backup pump having its own fluid supply separate from the main system.

Check valves can also be installed in the return ports/lines of the various components and services to prevent loss of fluid from the reservoir due to return system failure. If it is possible for the check valve to be dormantly failed open, a functional test to determine the correct operation of the valve should be conducted at an interval specified by the reliability analysis.

3.3.6.2 Pressure Maintaining Valve (PMV): This type of valve can be used to isolate a subsystem from the main system whenever the pressure upstream of the valve falls below a specified value. If the subsystem has an accumulator, the use of a PMV enables the accumulator to supplement the flow from the main system pump. However, following the loss of the main system, the valve would close and conserve the accumulator stored energy for the subsystem.

3.3.6.3 Priority Valve: This type of device is used to isolate nonessential functions from essential services in systems where the capacity limitation of the hydraulic power supply is inadequate to supply all functions simultaneously. This type of device does not protect against fluid loss but responds to pressure drops which occur in a system when the pump capacity is exceeded. This will assure that flight essential services have priority over nonessential ones by limiting, or momentarily interrupting, power flow to the nonessential functions.

3.3.6.4 Hydraulic Fuses: This type of device measures fluid flow (Velocity or rate Fuse) or fluid quantity (fluid quantity fuse) and interrupts the flow of fluid whenever the preset value of flow rate or fluid quantity is exceeded. Rate fuses are usually installed in the aircraft to isolate a failed subsystem where the failure results in excessive flow as occurs following a line failure. A quantity fuse is installed in subsystems which always use a predictable amount of fluid during a normal operational cycle, such as lowering or raising the landing gear. The fuse closes whenever the fluid volume displaced exceeds the amount predicted for normal operation. Both types of fuses have threshold limits which must be considered.

3.3.6.5 Electrically Operated Shutoff Valve: This type of valve can be used to shut off all, or part, of a system in accordance with the overall system design logic arrangement. It can be used to isolate certain portions, or branches, of a system by electrically linking the valve to a reservoir quantity measurement arrangement; by using signals generated by the computer of a failure detection system, which uses pressure and/or fluid flow/quantity information, to generate logical decision based upon various system algorithms.

3.3.6.6 Hydraulic Circuit Breaker (Flow Comparison Device): This type of device compares the flow rate to and from a set of services. If there is a difference between the two rates, which exceeds the normal rate by a predetermined value, a shutoff valve will be actuated to isolate the faulty branch from the remainder of the hydraulic system. The circuit breaker and the shutoff valve are usually combined into one component.

3.4 Segregation Requirements:

The location of components and the routing of lines has to consider the effects of a noncontained engine burst (as required by FAR/JAR 29.901(c)), and that of an engine, tail rotor or connecting drive shaft, or shaft coupling, failure. This is usually accomplished by routing the lines of each independent system with sufficient physical separation between each other such that neither a noncontained engine or a shaft failure can damage the lines or components of all systems.

It is mandatory for safe operation of the aircraft that hydraulic power is maintained at those services required to maintain safe flight, which for a rotary wing aircraft is the rotor control system. To meet this requirement, it may be necessary to locate systems on different sides of the transmission, which includes having the pump drive pads on opposite sides of the main gear box housing. It is also prudent to arrange the internal pump gearing to have each drive pad be driven by a different transmission section (Load path) well upstream of the final combining stage. Supply lines should be routed on opposite sides of the fuselage.

On some occasions it may be necessary to route the plumbing from all hydraulic systems in a single area. In a helicopter with a tail rotor drive, this usually is the tail pylon area. Under these conditions it may be possible to damage all hydraulic systems which would prevent the aircraft from being controlled. For these reasons, consideration must be given to provide means to isolate this section of the system such that the primary control hydraulic system remains operational. The use of localized hydraulic systems should be considered on aircraft where isolation or protection means are inadequate to assure continued operation of the primary control system following a failure in the critical area, such as a tail drive shaft or shaft coupling failure.

Although landing speeds of a rotary wing aircraft are much slower than those required by fixed wing aircraft, the landing sites are often less than ideal and damage to the lines and hoses of the brake and gear retraction circuit can occur as a result of landing in rough unprepared landing sites or due to the rotor down wash especially again in unprepared landing areas. The design and installation of the system must take this into consideration as required by FAR/JAR 29.729. The use of aluminum alloy tubing should be avoided in these areas.

Bird strike is less of a threat for the hydraulic system in a helicopter than for fixed wing aircraft, primarily due to the lower airspeed, and because systems are normally located in more protected areas, often within the shadow of the rotor disc. Where this is not the case, the system routing, component locations and system logic should be changed to prevent loss of all essential services from a single bird strike.

3.5 Maintainability Requirements:

3.5.1 General: A commercial rotorcraft has to be affordable and be able to operate economically. Therefore, the hydraulic system has to be easy to maintain and be highly reliable.

The components and tubing within the aircraft should be located such that there is access and adequate space for inspections, repair or replacement of them. The installation of tubing and components should be such that it should never be necessary to remove a fully serviceable part in order to gain access to a defective part. The tubing joints in adjacent tubing runs should be located and configured to eliminate the possibility of cross connecting the lines when performing maintenance.

There should be easy access to those parts and components which require regular servicing and inspections; for example, hydraulic reservoirs, bleed and system drain ports, accumulator charging valves, fluid sampling points and filters.

The system should be designed as simple and foolproof as possible to maintain. All functions and servicing instructions should be clearly written and simple to comprehend. All equipment used to troubleshoot or service the system should be straight forward and easy to operate.

On aircraft, where design or airworthiness requirements dictate complex systems, this may be difficult to achieve. In this case diagnostic systems should be considered.

3.5.2 Provision of Labels: Labels should be provided at strategic locations which will give relevant information to maintenance personnel for proper servicing of the aircraft without the need to refer to maintenance manuals for routine tasks. Typical labels which should be fitted include:

a. Hydraulic fluid used
b. Instructions for servicing of reservoirs
c. Accumulator charging instructions
d. Identification of important components, including system reservoirs
e. Procedures for depressurizing charged circuits or components
f. Identification of ground cart connections and specific ground cart operating instructions and limitations
g. Fluid sampling instructions

3.5.3 Minimizing the Requirement for Regular Servicing: The system should be designed to require a minimum of periodic checks, servicing or inspection requirements. Components should utilize the "on-condition" monitoring instead of being removed for overhaul at regular intervals. The components should be designed to the maximum practical life and tested to verify the adequacy of the design. Where the component life is less than the airframe design life, the mean time between failures of critical components requires them to be removed and replaced at a fixed period so as to comply with the certification rules for safety and reliability.

3.5.4 Ease of Performing Routine Servicing: The system shall be so designed such that routine servicing of the system is easily and safely accomplished. This requires that:

If accumulators are fitted which require periodic servicing with gas, there should be a standard charging valve and a permanently mounted pressure gage. A gage with an integral charging valve is the preferred installation. The gage shall be large enough to allow for easy determination of the pressure. In the immediate vicinity of the gage/charge valve, there should be clear, concise, easy-to-read servicing instructions, which should include a gas charge pressure-ambient temperature chart. These services should also be provided for any hydraulic reservoir which is pressurized by dry air or nitrogen.

The taking of fluid samples shall be as easy as possible. The valves shall be located in the system so that samples from such a valve accurately reflect the condition of the system fluid. Fluid sampling valves should be installed in each independent system and located in readily accessible areas and allow use of standard sampling containers. ARP4268/ISO 11217 provides guidance for placement and location of the sampling valves. The sampling procedures should state that the fluid samples shall be taken with the system fully pressurized and operational.

3.5.5 Minimum Use of External Equipment: The system should be designed to function on the ground with a minimum of external equipment and use if possible on-board equipment. This will allow checkout and servicing of the hydraulic system in remote locations in which the helicopter is more likely to operate then fixed wing aircraft. An on-board auxiliary power unit (APU) driving an accessory gear box or a pump or electric generator is preferred for ground checkout over the use of a main engine. Main engines have been used to drive an accessory section of the main gear box for ground checkout, but this arrangement requires that the engine be declutched from the main rotor drive system during ground check-out operation. This requires installing a clutch in addition to the engine disengage clutch, which usually is just an over-running, free-wheel, device. The former needs to be a clutch which can be controlled to engage and disengage the engine and accessory gear box from the main rotor drive system. This adds complexity and weight to the gear train assembly and increases the maintenance burden.

3.5.6 Ground Servicing: A central ground service attachment station should be provided for each independent hydraulic system, which contains connections for the attachments of ground test and service equipment for system checkout, flushing, reservoir filling and bleeding. Self-sealing couplings should be provided for each independent system for pressure, return and reservoir fill. Placards should be attached at the service connections stating:

a. Maximum system working pressure
b. Minimum system flow rate
c. Ground cart connection and system identification
d. System hydraulic fluid

The accumulator gas charging provisions should also be located here. Access to reservoir and system filters should be provided to allow for easy inspection of reservoir fluid levels and filter differential pressure indicators.

3.5.7 Ease of Checking Operation of Components: The system should be designed to allow easy check-out and diagnosis of system and component operation. Information relating to pump flow, pump case flow and system temperature and pressures can be provided by built-in flow, pressure and temperature sensors. An additional diagnostic aids to be considered are the incorporation of valve position indication on directional or turn on/off valves and electrical switches at the filter differential pressure indicators. This information can then be processed either by on-board or ground based diagnostic equipment and used give the status of the system operational capability, and to identify faulty components or systems when applicable.

3.5.8 Ease of Flushing/Draining/Bleeding and Filling of Hydraulic Fluid: The system should be designed such that it is easy to flush or drain hydraulic fluid from the system in the event that the fluid exceeds the chemical or particulate contamination limits specified by the airframe manufacturer. NAS 1638 or AS4059/ISO11218 can be used to specify fluid particulate contamination levels. A class 8 or better system cleanliness level has been the common practice. Solvent and water contamination, acid number, kinematic viscosity and specific gravity limits are specified by the airframe manufacturer.

3.5.9 Minimum Use of Special Tools: The hydraulic system shall be designed such that special tools will not be required for installation, removal and servicing of components and systems.

3.5.10 Pressure Release Valves: Where accumulators are installed in systems, means must be provided to depressurize the system without having to operate the system. All pressure release valves shall be of the normally closed type to prevent valves being left in the open position.

Pressurized reservoirs shall be fitted with pressure release valves to allow depressurization of the system for component replacement. This device is commonly integrated into the reservoir bleed/relief valve. In spring pressurized reservoirs provisions shall be made to allow for ease of draining of the hydraulic fluid from the reservoir without fluid spillage.

3.5.11 Use of Common Parts: In order to reduce the cost of ownership, the design should use as many common parts as possible. Included in this are:

a. Common filter and /or filter elements used in more than one application.

b. Common motor actuators or solenoids used on all valves in the hydraulic system.

c. Hydraulic pumps which can be used in more than one system. One common pump is preferred.

d. Identical reservoirs which can be installed in each of the systems.

(Every effort should be made to have as many common components as possible, unique designs should only be used as a last resort.)

3.6 Reliability Requirements:

To optimize the utilization of commercial rotorcraft, the hydraulic system must be highly reliable meeting or exceeding the reliability guaranties as agreed to between the manufacturer, user and airworthiness agencies. In order to achieve these guarantees, it is essential to have a sound overall system design. This can be achieved by regular reviews of the system design by the design, reliability and product support specialist engineers. Previous aircraft designs should be reviewed to determine where failures and problems have occurred, to assure that they will be eliminated in the new system. The use of "Lessons Learned" from other aircraft should be encouraged and incorporated where applicable.

The components used within the system should be thoroughly scrutinized. The specifications for each component should be clearly written to accurately reflect the operation of the component within the system as well as its performance requirements. The duty cycle quoted and the qualification test requirements for the component should accurately reflect the conditions to which it will be subjected in service. If possible, components used on other aircraft should be used provided they have been found to be reliable in service, and their use in the new system is similar to the previous installation.

No single failure shall cause loss of more than one hydraulic system; therefore, care should be taken to avoid points within the hydraulic system where two or more different hydraulic systems come together in one housing. This is a common failure mode. A cracked housing could result in loss of all these systems. As a requirement all primary systems shall never be within close proximity of each other, regardless of the precautions taken. Where tandem actuators are used, rip-stop design should be used to separate the two systems. Maximum possible separation should be maintained between the pressure and return connection.

4. GENERAL HYDRAULIC SYSTEM AIRWORTHINESS REQUIREMENTS:

It should be noted that the equivalent FAR and JAR requirements are not always the same. Where there are differences between the requirements, they are discussed in the following sections.

The detail design of each commercial transport helicopter hydraulic system has to be such that compliance can be demonstrated with the requirements of 29.307, 29.601, 29.602*, 29.603, 29.605, 29.1301, 29.1315, 29.1322. These requirements are general ones that have an impact on the hydraulic system.

* JAR only

4.1 FAR/JAR 29.307 - Proof of Structure:

This requirement demands compliance with the strength and deformation requirement of a subpart or element must be shown for each critical loading condition for the environment to which the structure will be exposed during operation. Structural analysis may be used only if the structure conforms to those for which experience has shown this method to be reliable. In other cases, substantiating load tests must be made.

4.1.1 FAR/JAR 29.307 (1) - Dynamic and endurance tests of rotors, rotor drives and rotor controls: Compliance to this requirement is usually performed on a test-rig and a ground-test-vehicle. Element testing should be done on the test rig using the load and usage spectrum developed for the rotorcraft. System testing of the hydraulic system including all supply and distribution system is usually performed on the ground test aircraft, which is a full-up aircraft tied to the ground while exercising the rotor, rotor drive and control (including the hydraulic systems) in accordance with a typical flight profile.

4.1.2 FAR/JAR 29.307 (6) - Any additional tests required for new or unusual design features: Under this requirement nonrotor control elements are tested. Compliance with this requirement is done by limit and ultimate load and endurance testing of each element or subsystem in accordance with the manufacturers, regulatory agency approved test plan. Items tested under this category are landing gear retract systems, rescue hoist and cargo winch and hoist systems.

4.2 FAR/JAR 29.601 - General:

This requirement calls for the overall hydraulic system, subsystems or components not to have design features that experience has shown to be hazardous or unreliable. Hence, during the design phase, there should be emphasis placed on reviewing previous aircraft systems to identify those areas which have been problem areas, and to ensure that they are not repeated on the new design. If however, it is considered that there are some features which are questionable, then these should be proven by rigorous testing prior to incorporating them on the aircraft.

4.3 JAR 29.602 - Critical Parts:

This requirement states that all part of the hydraulic system which are defined as critical parts, the failure of which could be hazardous to the safe operation of the rotorcraft, must be subject to a critical parts plan. The critical parts plan is a plan which controls the manufacture, servicing and overhaul of the part via a defined and controlled plan.

4.4 FAR/JAR 29.603 - Materials:

This requirement states that the suitability and durability of materials, the failure of which could effect safety, must:

a. Be established on the basis of experience or test

b. Conform to approved specifications that insure that the material have the strength and other properties assumed in the design data

In order to comply with this requirement, the materials used in the hydraulic systems shall conform to the applicable aerospace specifications referenced herein.

4.5 FAR/JAR 29.671(c) - Control System Check-out Prior to Flight:

This regulation requires that a means must be provided to allow full control movement prior to flight. Since hydraulic pumps are transmission driven, hydraulic power must be made available prior to rotor engagement. Unlike fixed wing aircraft, rotary wing aircraft cannot perform control system check-outs on the ground with the rotor turning. On aircraft with battery start, a small electric motor driven pump (EMP) has been used. Helicopters with auxiliary power units (APU) can be used to supply power via a direct mounted pump, an APU driven accessory section of the gear box or an APU mounted generator driving an EMP. Also main engine driven clutched accessory gear boxes have been used to supply ground power.

4.6 FAR/JAR 29.1301 - Function and Installation:

This requirement is concerned with the equipment that is installed in the aircraft. When it is applied to the hydraulic system, it has the following requirements for each piece of system equipment:

4.6.1 Qualification of Each Component: Each component shall be of a kind and design that has been shown to be appropriate to its intended function. Compliance with this requirement is usually demonstrated by ensuring that every installed part of the hydraulic system has been qualified in accordance with the aircraft manufacturer's specification.

4.6.2 Identification of Each Component: Each component shall have a part number and serial number and, where appropriate, function and/or operating limitations. Examples of appropriate limitations can include:

a. The hydraulic fluid used.
b. System working pressure.
c. Maximum operating temperature.
d. Direction of rotation of a pump or motor.

4.6.3 Installation Limitations: Each component shall be installed according to the limitations specified for that equipment. This means that it is the responsibility of both the aircraft manufacturer and the equipment suppliers to ensure the parts are not subjected to conditions that exceed those to which the part has been qualified, for example:

a. Working pressure
b. Fluid and/or ambient temperature
c. Pressure impulse limitations
d. Vibration environment

4.6.4 Demonstration of Satisfactory Operation: Each component shall have been shown to operate in a satisfactory manner. This is usually demonstrated during the aircraft development and certification testing program. This is in addition to the routine function tests conducted on the aircraft for production and maintenance purposes.

4.7 FAR/JAR 29.1309 - Equipment, Systems and Installations:

The requirements contained in this section are frequently used when the requirements and objectives are formulated for the hydraulic system architecture and installation in the aircraft. The implications of the requirement in terms of system redundancy and segregation requirements are discussed in 3.3.

In addition, there are other requirements which are presented below:

4.7.1 Correct Operation of the Hydraulic System: The hydraulic system must be designed so that it will be able to function correctly under any foreseeable operating condition. As part of the assessment for the hydraulic system, the following should be considered:

a. Critical environmental conditions including vibration, and acceleration loads;
b. The effect of system pressure on the hydraulic system, the equipment and the system installation

This may be demonstrated by:

a. Qualification testing of components
b. Aircraft and laboratory (Iron Bird) testing of the hydraulic system
c. Design analysis
d. Reference to comparable service experience on other aircraft.

4.7.2 Hydraulic System Indicators and Warnings: The hydraulic system must incorporate means of providing warnings to the flight crew of failures within the system:

a. Alert the crew of potential unsafe system operating conditions;
b. Enable the crew or vehicle management system electronics to take appropriate corrective actions.

In addition, the operation of the hydraulic system, its controls, associated monitoring and warnings, has to be designed to minimize crew errors which could create additional hazards. In order to comply with this requirement, hydraulic systems usually provide the following indications and warnings:

a. The supply pressure in each independent hydraulic system
b. Low pressure warnings that notify the flight crew of the loss of a hydraulic system or the failure of a hydraulic pump to generate output
c. High hydraulic fluid temperature by an overheat warning light and/or a temperature gauge
d. The quantity of hydraulic fluid in each independent hydraulic system reservoir
e. Low reservoir fluid quantity warning to notify the flight crew of the loss of hydraulic fluid due to a failed tube, seal, etc.
f. Valve position indications to inform the flight crew of the ineffective operation of important selector valves such as those for pump and/or system isolation and landing gear retract/deployment.

4.7.2 (Continued):

The crew drills (check lists) shall utilize the information provided by the hydraulic system indicators and warnings. Therefore, the system operating procedures have to be written so that the flight crew are able to correctly diagnose the fault and take the necessary action to isolate hydraulic pumps, operate backup pumps, shut down hydraulic systems, etc., as applicable. In addition, it should be possible for the flight crew to diagnose a faulty transducer or warning switch by referring to other indications that are provided. This can be achieved, for example, by comparing the pressure indicated on a gage to determine if there is a genuine low system pressure condition or if the pressure switch is defective.

It should be noted that much of the operation and control of the hydraulic system, when faults have occurred, should be handled by the vehicle management system electronics, if this is fitted to the aircraft.

4.8 FAR/JAR 25.1322 - Warning, Caution and Advisory Lights:

This requirement details the colors that are required for warning, cautionary and advisory lights that are installed in the cockpit.

If the lights are used for warning purposes to indicate a hazard which may require immediate corrective action, then they must be Red in color. An example of the application of a Red warning is for engine fire indications.

If the lights are used for cautionary purposes to indicate the possible need for future corrective action, then they should be Amber in color. Examples of the applications of Amber warnings for the hydraulic system are low supply pressure, low reservoir fluid quantity warnings.

If the lights are used in an advisory manner to indicate safe operation, then they should be Green in color. An example of the application of a Green warning is the landing gear down and locked indications.

When the systems are operating correctly, there should be no warning or caution lights illuminated.

5. SPECIFIC HYDRAULIC SYSTEMS AIRWORTHINESS REQUIREMENTS:

Each commercial transport rotorcraft hydraulic system has to comply with the requirements of FAR29.1435 and/or JAR29.1435 regulations. This section of the FAR/JAR Part 29 regulations contains the specific requirements for the design of hydraulic systems. The JAR requirements are indicated where they are different from, or where there is no equivalent FAR requirement.

5.1 Part (a) - Design:

This part provides a series of requirements which are concerned with the design of the system and each individual part of the system from tubes and fittings to complex hydraulic parts (all defined as elements).

5.1.1 FAR/JAR 29.1435 (a)(1): This requirement is concerned with the strength of the elements. It requires each element of the hydraulic system to be designed to withstand the design operating pressure loads in combination with limit structural loads which may be imposed. The design operating pressure is the maximum normal operating pressure, excluding transient pressure. No permanent or temporary deformation of the element is permitted under these conditions that would prevent it from performing its intended function.

5.1.2 FAR/JAR 29.1435 (a)(2): This requirement is concerned with the strength of each element. It requires that each element must withstand, without rupture, the design operating pressure loads multiplied by a factor of 1.5 in combination with limit (maximum operating) structural loads that can reasonably occur simultaneously. The design pressure is the maximum normal operating pressure, excluding transient pressures. It should be noted that it is acceptable to nominate an artificially elevated pressure to account for high surge pressures (see 6.1.1).

Compliance with the requirements (a)(1) and (a)(2) for each element is usually demonstrated during the qualification testing.

Some aircraft manufacturers choose to use MIL-H-5440, Table 1 requirements for the strength requirements of the elements. The MIL-H-5440 strength requirements are equivalent to, or exceed, the requirements of FAR 29.1435(a)(1) and (a)(2).

5.1.3 FAR/JAR 29.1435 (a)(3): This requirement is concerned with the flight deck indication of system pressure for each independent hydraulic system if:

a. The system is required to perform a function that is essential for continued safe flight and landing

b. In the event of a system malfunction, requires corrective action by the crew to ensure continued safe flight and landing. Indication of system pressure is normally provided by a pressure transducer that sends electrical signals to a dedicated gauge or is presented on a cathode ray tube (CRT) or flat panel displays and a pressure switch that gives a warning of low system pressure.

The FAR/JAR Part 29 regulations differ here from Part 25 in that the FAR/JAR 29 does not require providing reservoir quantity cockpit indication. But it would be prudent for the designer to include a reservoir quantity indicating system into the system. When so fitted, indication of system fluid quantity is usually provided by a transducer located in the system reservoir which sends electrical signals to a dedicated fluid quantity indicator or CRT or flat panel displays, and a low quantity warning provided by a switch that operates when the fluid in the reservoir falls below a predetermined level.

5.1.4 FAR/JAR 29.1435 (a)(4): This requirement dictates that there must be means to ensure that no pressure in any part of the system will exceed a safe limit above the maximum operating pressure and to prevent excessive pressures resulting from any volumetric change in portions of the system likely to remain closed long enough for such a change to occur. The possibility of transient (surge) pressures during operation must be considered. The requirements are usually satisfied by:

a. Installation of system relief valves which will limit the maximum system pressure in case of a pump pressure regulation system.

b. The installation of thermal relief valves in closed systems;

c. Limit transient surge pressures by using controlled rate opening valves, limit actuator rates especially in aiding load situations and reduce pump ripple pressures by installing suitable ripple dampers. (Pumps with integral ripple dampers are preferred).

5.1.5 FAR/JAR 29.1435 (a)(5): This requirement is concerned with the installation of the hydraulic system in the aircraft. This requires that each element is installed and supported to prevent excessive vibration, abrasion, corrosion, mechanical damage and to withstand inertia loads. This means that the component and tubing supports and brackets, etc., must be carefully designed to ensure that these requirements are met. Of particular importance therefore is the Design Handbook for the Company/aircraft which must provide clear guidelines and procedures for the installation of hydraulic elements. In addition, each installation in the aircraft should be carefully scrutinized by the installation designer and the airworthiness authorities prior to the first flight.

5.1.6 FAR/JAR 29.1435 (a)(6): This requirement calls for the means of providing flexibility to be provided to connect points in a hydraulic tube between which relative motion or differential vibration exists.

In order to comply with this requirement, any of the following should be used, as applicable, in the areas where these conditions can occur:

a. Hoses (see 7.6)

b. Coiled tubing in accordance with ARP584 for steel tubing, ARP4146 for titanium tubing. Looped, or straight aluminum tubing, should not be used between two connections where there is designed relative motion. A stress analysis should be performed to determine the correct wall thicknesses for tubes which are coiled.

c. Tubing can be used in torsion where there is little angular motion (up to 5 degrees).

d. Swivel joints should be used only when circumstances do not permit hoses or tubing to be utilized, for example, limited space.

5.1.6 (Continued):

When using coiled or noncoiled tubing to provide flexibility, the tubing should be qualified by conducting a specific test program. This should include the application of angular displacements on the tubing, while applying pressure impulse cycles simultaneously. The number of flexure and pressure cycles shall be predicated on the anticipated usage and applicable factors.

5.2 Part (b) - Tests:

This part stipulates the tests that are required to be conducted on the aircraft hydraulic system and are as follows:

5.2.1 FAR/JAR 29.1435 (b): This requirement states that each element of the system must be tested to a proof pressure of 1.5 times the maximum pressure to which the element will be subjected in normal operation, without failure, or detrimental deformation, of any part of the system. This is a one time test only and it is recommended that these tests are performed on a development aircraft during the aircraft flight development/certification program. Detail elements of the system may be tested and compliance verified in laboratory testing. All elements of the system shall remain usable following proof pressure testing and shall not evidence any sign of permanent deformation.

For endurance requirements see FAR/JAR 29.307

5.3 Part (c) - Fire Protection:

This requirement calls for each hydraulic system that uses flammable hydraulic fluid to meet the applicable requirements of 29.863, 29.113, 29.1185 and 29.1189. The fire safety definitions insist that the hydraulic fluid used in modern day hydraulic systems should be considered to be flammable even though they might be fire resistant. Compliance with these requirements will be by reports that deal with the fire safety aspects of all regions of the aircraft and which highlight particular design measures/procedures that have been incorporated in the aircraft. The following are examples of the various means that have been used:

5.3.1 Prevention of Ignition of Fluid or Vapor: In any area where it is possible that hydraulic fluid or vapor may be liberated, there must be means to prevent ignition of the fluid or vapor. The precautions that should be undertaken in order to achieve this include:

a. Shrouding the installation where applicable

b. The use of fuses to prevent an excessive volume of hydraulic fluid from impinging on hot surfaces, particularly rotor brakes or hot ducting

c. Providing ventilating air to prevent buildup of vapors

NOTE: Fuses should be used only in applications where either the required fluid quantity is known; a quantity fuse, or where the fluid flow is bound as in an accumulator recharge circuit; a velocity fuse.

5.3.2 Precautions for Installations in Fire Zones:

a. Hoses that are located in the fire zone should have a means of protecting them from high temperatures, preferably by using integral firesleeves. They should meet the requirements of TSO C-75 and/or AS1055.

b. Aluminum tubing and fittings shall not be used in a fire zone.

c. Any components located in fire zones shall be fire resistant. Compliance should be demonstrated through suitable testing, for example, in accordance with ISO2685.

d. Shutoff devices should be installed to limit the amount of fluid into the fire zone. Activation of these device should be via the relevant fire emergency handle.

5.3.3 Location of Hydraulic Reservoirs: There should be no hydraulic reservoirs located in a designated fire zone. There must be at least 1/2 in space between any hydraulic reservoir and any firewall or shroud isolating a designated fire zone. In addition, any absorbent materials close to the hydraulic system components must be covered or treated to prevent the absorption of hazardous quantities of hydraulic fluid.

5.3.4 Precautions for Electric Motor Driven Pumps: Electric motors that are used to drive hydraulic pumps must be explosion proof and approved by suitable testing.

6. DESIGN PRACTICES AND GUIDELINES:

This section describes the general design practices that have been adopted for modern day commercial rotorcraft hydraulic systems and provides guidelines for future hydraulic system designs.

6.1 Pressure Limitations:

6.1.1 System Pressure: As noted in Section 3, if the maximum hydraulic system working pressure is 3000 psi (20,690 kPa) and, in order to comply with FAR 29.1435(a)(4), the maximum transient pressure should not exceed 3750 psi (25 862 kPa). However, the components may be designed to a higher nominal pressure to account for surge pressures greater than 125% of system pressure.

Lines, fittings and equipment in the return circuits should normally be designed for one third the nominal system pressure. However, designers may wish to nominate other pressure levels, dependent upon the philosophy adopted for the system design or if it is considered that the return pressure surges may be high. One example of this is the pressures chosen for heat exchangers. These are required to have thin walls for maximum efficiency and hence will not be able to withstand high working pressures. Therefore, it is suggested that these units can be designed for a working pressure that is twice the system reservoir pressure. This is provided that the heat exchanger is located relatively close to the reservoir.

6.1.1 (Continued):

The hydraulic reservoir pressure should be as low as possible in order to ensure that there is as little back pressure as possible to hydraulic fluid returning from the services or pumps to the reservoir. The level of pressure required in the reservoir should be calculated using the guidelines as laid down in AIR1922. This takes into consideration the need to have the pressure high enough to accelerate fluid into the pump to prevent cavitation of the unit.

6.1.2 Back Pressure: The system should be designed such that proper functioning of any unit, such as internal actuator locks, will not be affected by the back pressure or changes in the back pressure of the system. The system, or systems, should also be designed such that malfunctioning of any unit in the system will not render any other subsystem, emergency system, or alternate system inoperative because of back pressure. In addition, consideration should also be given to the effects of hydraulic fluid with a high viscosity at low fluid temperatures and/or high flows, on other units/subsystems due to the potentially high back pressures which can be generated under these circumstances.

6.1.2.1 Back Pressure Affecting Brakes: Back pressure resulting from the operation of any unit while the aircraft is on the ground should create no greater back pressure at the brake control valve return port than 90% of that pressure which will cause contact of braking surfaces. This requirement applies to both wheel and rotor brake systems. In addition for boosted wheel brake systems, the supply pressure to the brake system should not drop below the maximum brake operating pressure during the operation of any other subsystem in the aircraft during the taxi, landing or takeoff.

6.2 Reservoir Pressurization:

On many rotorcraft, the reservoir is located very close to the pump, resulting in a suction line of 2 ft or less (0.5 m). For small aircraft, having low capacity pumps and limited altitude performance requirements, nonpressurized reservoirs have been used successfully. When using nonpressurized reservoirs the following precautions should be taken:

a. Assure the suction line is of sufficient size to assure proper pump inlet pressure under all operating conditions.

b. System return flow is baffled to prevent internal flow currents and foaming.

c. The vent system is equipped with means which will prevent ingress of moisture and contamination.

6.2.1 Spring Pressurized Reservoirs: A method used to pressurize the reservoir is to use a mechanical spring acting on the separator. The design may use a piston separator or diaphragm. The relatively low reservoir pressure requirement due to the close proximity of the reservoir to the pump, the weight penalty associated with the mechanical spring is acceptable and the design is relatively simple and reliable.

6.2.2 Hydraulic Pressurization: A method of pressurizing hydraulic reservoirs that incorporate a piston is to utilize the system hydraulic pressure, acting on a differential piston, to achieve the required tank pressure. The value of tank pressure achieved is directly related to the ratio of the areas of the high and low pressure pistons. This type of reservoir is known as a bootstrap reservoir.

It is recommended that, if possible, the high pressure source be linked to an accumulator which is isolated from the main system by a check/relief valve. This means that if the main hydraulic system is shut down, then the tank remains pressurized until the accumulator hydraulic pressure has fully decayed. Another method to accomplish this has been to incorporate a mechanical spring into the design which will supply a partial pressure, sufficient for start up, but with a weight penalty. This has the following benefits:

a. It minimizes the possibility of pump cavitation during subsequent starting up of the pumps.

b. It ensures that the gland seals in hydraulic actuators are energized by base pressure. This prevents the possibility of external fluid leakage and ingress of air from ambient into the system as the fluid temperature decreases.

6.2.3 Pneumatic Pressurization: Another method, less widely used on commercial transport rotorcraft, is by regulated engine bleed air. If this type of system is used, then the following guidelines are recommended:

6.2.3.1 Pneumatic System Equipment: Each reservoir should have the following equipment:

a. Outward (overboard) relief valve to protect the reservoir in the event of:

(1) A failure of the pneumatic system regulating valve; or

(2) The buildup of pressure which could occur with an overfilled reservoir, and/or fluid returning to the reservoir with the operation of unequal area actuators.

There should be tubing provided to vent any air from the valve directly overboard and thereby prevent any buildup of hydraulic mist occurring as a result of hydraulic fluid vapors being entrained in the air being exhausted from the valve. The setting of the relief valve should be such that the valve does not function in order to maintain a constant tank pressure as the aircraft altitude decreases. However, if the valve does operate every flight, then there should be a secondary means of protection, for example an additional relief valve or a "burster" disc.

b. An inward relief valve to protect the reservoir if there are conditions where the outside pressure could be greater than the reservoir internal pressure, for example, following the loss of the pneumatic pressure.

Both relief valves should have the minimum possible leakage of reservoir air pressure to ambient in order to maintain tank pressure for as long as possible. This is in order to minimize the possibility of pump cavitation during subsequent engine starting and during ground checks.

6.2.3.1 (Continued):

c. Pressure gauges to provide indication of reservoir pressure. These can be used when performing checks on the pneumatic system, or ensuring that the reservoirs are correctly pressurized prior to the operation of the hydraulic system pumps.

d. Low pressure switch to provide a warning to the flight crew that there is a system fault such that the reservoir is not adequately pressurized and may lead to limited pump flow capability and premature failure of the pumps due to cavitation. Care should be taken as to the choice of settings of the switch in order to avoid spurious warnings as it can be possible for the reservoir pressure to decay due to the available bleed pressure being lower than the regulating pressure, particularly during the aircraft descent with the engines at idle settings.

e. A means to pressurize the reservoir from ground rigs.

f. A check valve should be installed in the pneumatic pressurization line close to the reservoir. This is in order to maintain pressure in the reservoir when the engines are shut down and thereby prevent pump cavitation during backup pump checks, engine starting, etc. An additional check valve should also be installed in each pneumatic line so as to prevent hydraulic fluid from entering the cabin air supply ducting or other pneumatic systems in the event of the check valve that is located at the reservoir, failing to close.

6.2.3.2 The pneumatic pressurization system should include: Pressure regulating valves that incorporate the following features:

a. A regulation mechanism to regulate the air pressure within the required tolerance of the nominal setting.

b. A filter to prevent particulates from the pneumatic source from entering the system.

c. A relief valve which prevents over pressurization of the reservoir following a failure of the regulation mechanism of the valve.

d. A restrictor to limit the maximum available flow from the regulating valve in the event of a failure of a pneumatic system pipe downstream of the valve.

e. Means to remove moisture from the pneumatic pressurization system air and so control the water content in the hydraulic fluid. The dew point of the air in the reservoir should be below the lowest ambient temperature that would be encountered in service.

6.2.3.3 Pneumatic Sources: There should be more than one source of pneumatic pressure to each reservoir so that in the event of the loss of that source, the reservoir can still remain pressurized for the remainder of the flight, and hence minimize the possibility of pump cavitation.

6.2.3.3 (Continued):

Care should be taken to ensure that the source(s) of pneumatic pressure is (are) sufficient to provide adequate pressure to the reservoir throughout the aircraft flight envelope. This particularly relates to the engine stage at which the bleed air is tapped.

6.2.4 Gas Charge Pressurization: If the reservoir is a separated type, then one of the methods of pressurizing the reservoir is by a fixed gas (for example, nitrogen) charge. The reservoir is pressurized via a charge valve from a rig. Instructions should be provided that the charge should be conducted at a constant temperature. The following guidelines are recommended:

a. Each reservoir should have its own charge valve, relief valve (to protect the reservoir and system from excess charge pressure) and a pressure gauge.

b. The actual pressure to charge the reservoir should take into account the ambient temperature and the fluid level in the reservoir. This is to ensure that there is still adequate reservoir pressure with the minimum normal operating fluid level.

c. The cracking pressure of the relief valve should be such that it should not operate with the maximum normal operating fluid level in the reservoir which in turn causes the maximum gas charge pressure.

6.3 Fluid Velocity Limitations:

Tubing size and maximum fluid velocity for each system should be determined by considering, but not limited to, the following:

a. The allowable pressure drop at minimum required operating temperatures.

b. The need to limit pressure surges, caused by high fluid velocity and fast response valves, to 125% of working pressure.

c. Back pressure in return lines as it may affect brake operation, and pump outlet pressure if the pump senses drain pressure for regulation purposes.

d. Pump inlet pressure, as affected by long suction lines and a high response rate variable displacement pump. Consideration should be given to both pressure surges and cavitation.

6.3.1 Fluid Flow Effects: The system should be so designed that the malfunction of any unit or subsystem will not occur because of reduced flow, such as created by single pump operation of a multipump operation. The system should also be so designed that increased flow will not adversely affect the proper functioning of any unit or subsystems, such as increased flow rate caused by accumulator operation or units affected by the operation with aiding loads.

6.4 Subsystem Isolation:

Where two or more subsystems are powered by a common pressure source, one of which is essential to flight control operation and the other is not, there should be means to:

a. Ensure that priority of supply is given to the flight control operation subsystem when there are high flow demands on the pressure source.

b. Ensure as much as possible that each power source can be so configured that if a nonessential subsystem is damaged, it can be isolated to assure that the subsystem essential to flight operations can still be employed.

6.5 Hydraulic System Filling:

If possible, there should be an on-board pump which can transfer fluid from a container into each of the systems. In addition, or as the primary means if no filler pump is fitted, connections should be provided which allow filling from a low pressure source. Self-sealing couplings or check valves integral with hydraulic fittings are often used for attachment to ground filling connections. A dust cover, secured with a chain or safety strap, should be provided for each filling connection to protect the fitting when not in use. The reservoir level indicator should be visible from this location or a remote level indicator should be located at this point. Any fluid that enters the system should be filtered prior to it entering the system, preferably by a nonbypass type filter with a filtration rating that is at least equivalent to the aircraft's system filters. It is not recommended to fill the system by direct pouring of the fluid into the reservoir. This is because of the ease of introducing contaminants into the system by this method.

6.6 Removal of Entrapped Air:

Suitable means, such as bleeder valves, should be provided for removal of entrapped air. Disconnection of lines or loosening of tubing nuts does not constitute suitable means.

Particular areas of the system where bleeding is required are:

a. Brakes

b. Hydraulic reservoirs (if a separated type)

c. Pump suction and/or case drain lines

d. Actuator installations at elevations above reservoirs

e. Actuators controlled by three-way valves where air may be trapped without being able to return to the reservoir. This condition can also occur when four-way valves are used, particularly when the fluid path between the valve and the actuator is long.

6.6 (Continued):

Ideally, however, equipment and system configurations should be designed, as much as practical, to automatically scavenge free air to the reservoir or other collections points, where operation will not be affected, and where release of the air can be conveniently accomplished.

The bleeder valves should be so located that they can be operated without necessitating the removal of other aircraft components. The valves should be installed so as to permit the attachment of a flexible hose so that fluid bled off may be directed into a container.

It may be desired to install an air removal device, in addition to manual bleed valves, particularly at the reservoir, to vent undissolved air from the hydraulic system without operator intervention. The automatic bleed valves should be designed such that in the case of a failure of the valve in the open position, leakage of fluid shall be minimal. In the most adverse case of flight duration, pressure and temperatures, the leakage should not be such as to cause the loss of the hydraulic system. The automatic bleed function can be combined with the manual bleed and reservoir relief valves.

6.6.1 System Air Tolerance: The system should be designed and configured such that the presence of entrapped air in actuators and motors does not cause sustained loss of system pressure or degradation of system performance during all conditions of intended performance. When performing calculations which include bulk modulus, an allowance for the effect of entrained air in the fluid should be made in the value assigned for the bulk modulus. For MIL-H-5606 and MIL-H-83282 values from 110,000 to 160,000 psi have been used. The actual value used should consider the criticality of the particular application being analyzed.

6.7 Subsystem Pressure:

Any subsystems, which use a pressure lower than the full system pressure, should be designed to withstand and operate under the full pressure, or should have an adequate relief valve installed downstream of the pressure reducing valve if the full pressure would be detrimental or dangerous. The relief valve could be incorporated into the same housing as the pressure reducer, provided that the relief valve mechanism is independent of the mechanism of the pressure reducer.

6.8 System Interconnections:

For those aircraft where there are two or more independent hydraulic systems, there should not be any point in the system where they come together, even though they might be separated by shuttle or control valves. This is because, under these circumstances, there is always the possibility of fluid transfer from one system to another. This is unacceptable because it results in major maintenance penalties in the subsequent draining, replenishment or functioning of the systems to transfer the fluid back to the original reservoirs.

6.8 (Continued):

However, it is acknowledged that acceptable design practices and in-service experience has allowed a deviation from this requirement. The majority of the deviations are in designs where back up systems are connected via valves to a primary system. Where two systems are in a single component such as in a dual actuator, the component must be designed to preclude a single failure causing the loss of two systems.

6.9 Component Design:

It is recommended that the components used in the hydraulic system should conform to the guidelines contained in MIL-H-8775 and the applicable component specifications identified in this document and AIR737, with modifications as necessary to suit the particular application.

The components should be designed so that it is not possible to:

a. Install them incorrectly

b. Be able to have the wrong tubes connected to them

c. Tamper with adjustable features during general aircraft servicing

The components should be the lightest weight possible so as to be able to meet the strength, impulse and endurance/operational requirements, and not compromise the reliability of the units.

6.9.1 Standard Components: Components that comply with industry consensus or standard military specifications, or are existing components, should be used in preference to specially designed customized components wherever they are able to conform fully to the aircraft component requirements. When standard items are used (such as O-rings, screws, washers, adapters, nuts), the standard number should be used and not a vendor allocated part number.

6.9.2 Fixed Orifices: Orifices larger than 0.012 in (0.30 mm) but smaller than 0.070 in (1.78 mm) in diameter should be protected by adjacent secondary filters having screen openings one-third to two-thirds of the diameter of the orifice being protected. Orifices smaller than 0.005 in diameter (0.13 mm) should not be used. Multiple-orifice fixed restrictors are recommended as a means of increasing the orifice diameter and allowing the use of coarser strainer elements, thus minimizing the risk of clogging. Orifices and secondary filter elements should be strong enough to absorb system design flow and pressure without rupture or permanent deformation.

6.10 Accumulators:

Accumulators should be installed with the utmost consideration given to the protection of the flight and ground crew, passengers and critical parts of the aircraft in the case of structural failure or loss of the accumulator end cap. The accumulator must not be mounted so that a structural failure will propel failed parts into the cabin, flight deck or areas where components critical for safe flight may be damaged. The accumulators should be designed in accordance with MIL-A-5489, ARP4378, ARP4379, or ARP4553 requirements and the standard drawings listed therein.

6.10 (Continued):

They should be charged with dry aircraft quality nitrogen in order to:

a. Prevent the possibility of any dieseling action and consequent explosion.
b. Minimize the potential of internal corrosion.

For those accumulators which require periodic gas charging, space shall be provided around the gas charging valve to permit the easy connection of the charging rig.

Each accumulator installation should be designed so that the accumulator can be easily inspected for evidence of corrosion. AIR4150 provides a guide for determining the condition of the accumulators.

6.11 General Valve Requirements:

ARP490 contains requirements for electrohydraulic servovalves. Refer to AIR737 for other types of valves which are suitable for use in aircraft hydraulic systems.

6.11.1 Directional Control Valves: The installation of directional control valves should be compatible with the control valve performance such that the system operation will not be affected by back pressure, interflow, or pressure surges which might tend to cause the valves to open or move from their setting or cause them to bypass fluid in other than the intended manner.

6.11.2 Control Valve Actuation: Control valve operation may be direct, such as push-pull rods or cable control, or indirect, such as electrically operated controls. If required, electrically operated valves can be provided with a mechanical override control mechanism. All controls should be designed to prevent over or under travel of the valve control handle by the use of internal or external stops. This is particularly useful if there is a requirement to operate the particular service with no electrical supply available or to isolate the valve for maintenance functions.

6.11.3 Valve Position Indication: Valve position indication is not normally provided for the majority of valves fitted to an aircraft (for example, check valves, priority valves, actuator control valves, etc.). However, when position indication is provided, it is generally for the following reasons:

a. To indicate either correct or incorrect operation of the valve in order to comply with certification requirements

b. To assist system troubleshooting.

Valve position indication can be provided by:

a. Electrical means such as the use of microswitches or position transducers that are independent from those used for valve control;

b. Mechanical means by the use of indicators that are linked to the valve or the valve actuator.

6.11.4 Incorrect Use of Check Valves: Check valves should not be relied upon to maintain pressure in a line while some other function is performed, for example, to hold the landing gear doors out during the retraction/deployment operations. This is due to the concern that a malfunction of the valve can cause the incorrect sequence of operations.

6.11.5 Installation of a Shutoff Valve and Check Valve in the Same Subsystem: If the design requires both a shutoff valve and a check valve in the same subsystem, the shutoff valve must be upstream of the check valve. If the positions are reversed, operation of the shutoff valve can trap fluid between the valves and thermal expansion could damage the shutoff valve. If the check valve is downstream of the shutoff valve, fluid expansion will be relieved through the check valve.

6.12 Filter Requirements:

All vent openings except actuator and valve seal vents or fluid exposed to breathing action should be protected by vent filter/driers. Line filters, when installed in the aircraft system in close proximity to an accumulator, should be installed upstream of the accumulator. When a secondary filter or line filter is provided, either internally or in close proximity to a component, suitable provisions should be made for removal of the screen or filter for cleaning or replacement.

The hydraulic power generation filter assemblies used to filter all circulating fluid in a hydraulic system should incorporate the following characteristics similar to those identified in MIL-F-8815.

a. Incorporate a differential pressure indicator (DPI) or an electronic type to provide a warning that the filter element is nearly or fully clogged. There should be a surge damper incorporated in the DPI mechanism if the DPI is sensitive to sudden flow surges. The DPI should not be resettable without removing the filter bowl. In addition, the DPI mechanism should incorporate a temperature lock-out device that inhibits the operation of the DPI when it senses that there is low hydraulic fluid temperature that could cause a false indication;

b. Provide an automatic shutoff valve to prevent fluid loss from the inlet and outlet of the filter and minimize air ingestion, when the filter bowl is removed to change the filter element.

c. If blockage of the filter element could cause other system failures to occur, the filter assembly should incorporate a bypass valve.

6.12.1 Filter Element Requirements: The rating of the element should be chosen according to the requirements of the system equipment that it is designed to protect, and to maintain the cleanliness of the fluid to the level that is specified by the system designer. Typically, for commercial rotorcraft, the filter elements with a $Beta_{10}$ of 75 or greater should be used. See AIR887 for a discussion of filter ratings.

The element shall be of the disposable type as it has been found that there are little economic benefits in using a cleanable element, and it is possible to introduce into the system harmful solvents used to clean the element.

6.12.2 Filter Locations: All filters in the aircraft should be located such that the filter bowls can be removed easily, and new filter elements installed without the risk of external debris from the aircraft entering the system during the operation of changing elements.

It is recommended that filters should be at least provided in the following locations:

6.12.2.1 Pressure Line Installation: A nonbypass line filter should be installed in the pressure line of each independent system and should be so located that all fluid from the system pump(s) and the ground test equipment pressure connection will be filtered prior to entering any major equipment or components of the system.

6.12.2.2 Return Line Installation: A line filter should be installed in the return line of each independent system. The filter should be a bypass type unless it can be ensured that regular monitoring of the filter DPI will result in the timely replacement of the filter elements.

All fluid entering the return circuit should be circulated through the filter prior to it entering the return line to the pump(s) and reservoir.

6.12.2.3 Pump Case Drain Line Installation: A filter should be fitted in the case drain line for each pump that runs continuously or occasionally during every flight. Although protection of the system can be provided by a single filter, the use of individual case drain filters for each pump in a multipump system, means that it is possible to identify which pump is generating contamination and could therefore could be subject to incipient failure. In addition, a separate case filter will protect the parallel pump from potential excessive back pressure.

A bypass for the case drain filter can be used if desired.

It is not recommended that suction filters be installed between each independent system reservoir and the system pump(s) suction port(s). This is because of the potential problem of pump cavitation with the use of this type of filter, as well as the relatively large size of the filter that is required for the necessary low pressure loss requirements.

6.12.3 Hydraulic Sequencing: Where hydraulic sequencing is critical, and where contamination can prevent proper sequencing, each sequence valve should be protected from contamination in each direction of flow by a suitable screen type filter. This element can be included as a part of the sequence valve assembly.

6.12.4 Integral Filtration in Components: Filtration should be incorporated in those items whose operation should be significantly affected by contamination. Integral or secondary component filters should have a lower efficiency rating than the main system filters to prevent them from being clogged with small size contaminants circulating in the system. AIR4057 provides guidelines for secondary filters.

6.12.4 Examples of where integral filtration should be used include:

a. Mechanically signaled servovalves which use close tolerance spool and sleeve assemblies
b. Electrohydraulic servovalves
c. Solenoid valves which incorporate small bore pilot holes
d. Single direction flow restricting orifices

6.13 Flow Regulators:

Flow regulators may be used in the hydraulic system to limit the rate of fluid flow.

One typical application of a flow regulator is to limit the available hydraulic flow to the motor of a power transfer unit (PTU). These are used to prevent:

a. The unit from over speeding in the event of potential higher than permitted flow demand conditions.

b. To prevent the potential loss of two hydraulic systems in the event of loss of system fluid that the pump of the PTU is supplying. Under this condition, it is possible, without a flow regulator fitted, to lose the motor supply hydraulic system pressure as it provides unrestricted flow to the PTU.

In addition, flow regulators can be used to regulate the rate of linear actuators and/or hydraulic motor driven systems with aiding/opposing loads.

6.14 Snubbers:

Pressure snubbers should be used to protect hydraulic pressure transmitters, hydraulic pressure switches, and hydraulic pressure gages, which are susceptible to the effects of sudden changes in system pressure. The snubbers can be integrated within these components if desired.

6.15 Hydraulic Pumps:

All hydraulic pumps, that are used on commercial aircraft, should be designed for long life. ARP819 or MIL-P-19692 should be referred to for selecting each pump. The pump should be integrated within the aircraft hydraulic system using the guidelines as detailed in AIR1922.

In order to preserve pump components, the pressure at the case drain connection should be kept to the minimum possible under normal operating conditions. Due to environmental constraints, all external leakage from the shaft seal should be routed to a collector tank with a vent.

The pump speed choice should be guided by the recommendations in the nomograph of AS595 or MIL-P-19692.

A check valve should be installed in each pump high pressure line in order to prevent the pump being pressurized by system pressure generated by other sources.

6.15 (Continued):

The pump internal leakage flow that is routed through the pump case drain should be:

a. Sufficiently high as to ensure pump and/or system cooling and to provide for proper pump lubrication; and

b. Sufficiently low to preserve pump efficiency and avoid overheating of the hydraulic system if oil coolers are not installed in the hydraulic system.

Although the foregoing is mainly a function of the pump design, the system configuration should assure that no external factor impedes the pump internal leakage flow and that the maximum case flow allowed by the pump specification is sufficient to provide the necessary lubrication.

6.15.1 Variable Displacement Pumps: Variable displacement pumps should be designed and qualified in accordance with AS595 or MIL-P-19692 requirements.

6.15.2 Fixed Displacement Pumps: Fixed displacement pumps are not being used as the main source of fluid power in any aircraft hydraulic system. If used for any other function, the MIL-P-7858 requirements should be used for guidance in selecting these pumps.

6.15.3 Electric Motor Driven Pumps: Electric motor driven variable displacement pumps can be used for normal, back up, emergency or ground servicing operation of hydraulic systems. MIL-P-5994 requirements should be used for guidance in selecting these pumps.

6.15.4 Power Transfer Units: A power transfer unit (PTU) is a hydraulic pump driven by a hydraulic motor and usually both the motor and pump are fixed displacement units. In some applications, a variable displacement unit ,may be considered appropriate. A PTU can be used for ground servicing, backup or emergency operation of the hydraulic system by transferring power from one system to another without transferring hydraulic fluid. The units can be "uni" or "bi" directional. The principles of construction, installation and operation of a PTU should follow the practices as detailed in ARP1280. The PTU should be designed in accordance with the applicable sections of MIL-M-7997, AS595, ISO 8278 and MIL-P-7858 requirements.

6.15.5 Air Turbine Driven Pumps: Air driven pumps are not usually employed in rotorcraft hydraulic systems, but if used they are mounted to an air turbine housing that contains a pneumatic turbine, shutoff and speed control valving, gearing and a lubrication system. The turbine is driven by the engine compressor bleed air. Air driven pumps can be used as a normal, backup emergency or ground servicing source of hydraulic system power. However, typically, an air driven pump is intermittently activated for additional hydraulic flow capacity during high system demand loads such as landing gear extension/retraction, or as a redundant source following power loss of the normal hydraulic power source. The pump should meet the requirements of 6.15.1 and should also comply with the following regulation:

6.15.5 (Continued):

FAR/JAR 29.246l - Equipment containing high energy rotors.

This is additional to the FAR/JAR regulations that are applicable for the pump as discussed in Sections 4 and 5. In addition, the pump and the air turbine drive unit should be designed for the unique considerations of rapid start-up acceleration, number of starts/duty cycle, noise, bleed air duct and turbine burst, and overspeed.

6.15.6 Manually Operated Pumps: Manually operated pumps that are permanently installed in hydraulic systems can be used for the following applications:

a. To function hydraulic services during ground maintenance and to recharge an accumulator;

b. To fill hydraulic systems having the facility of drawing fluid from fluid suppliers' standard cans and drums.

Where a manually operated pump is utilized in a system, either a hand operated or foot operated pump can be used. In installations where the pump can be operated by personnel in a standing position, it is recommended that a foot pump is used to minimize physical exertion.

No screen or filter should be used in the suction line of the pump. The suction line should be of a suitable diameter and length to ensure priming and obtaining full-rated flow within a few full pump strokes. The pump circuit should be capable of full priming and rated flow at all conditions at which pump operation is essential and intended.

A relief valve should be installed in the pump pressure line so as to limit the maximum pressure that can be generated by the pump.

It is recommended that the effective operating handle length of hand pumps be such that the handle load should not exceed 50 lb when the pump is pressurizing the hydraulic system at the design working pressure. The length of this handle travel at the hand grip should not exceed 18 in (0.46 m).

6.16 Hydraulic Motors:

All constant displacement motors should be in accordance with MIL-M-7997 and ISO 9206 requirements. All motors should be accessible for maintenance and inspection. Proper case drain returns to the respective system reservoir should be provided. External leakage from the shaft seal should be connected to a collector tank with a vent.

6.17 Relief Valves, System and Thermal Relief:

MIL-V-8813 may be used as a design guide on how to specify relief valve characteristics. Relief valves may be incorporated as part of another unit and are designed to be used as a safety device to:

a. Prevent bursting of, or damage to, the system in the event of the normal pressure regulation device in the system malfunctions;

b. To relieve excessive pressure in a blocked line condition, due to either thermal expansion of the fluid or overload forces on actuating units. Therefore, relief valves should not be used as the sole means of limiting pressure in a power circuit but should function only as a safety valve.

It should be noted that dynamic coupling can occur between a pump compensator and a relief valve. This can be avoided by ensuring the minimum relief cracking/reseat pressure is sufficiently above the maximum pump compensation pressure.

6.17.1 System Relief Valves: Provisions should be made to ensure that pressure in any part of the system should not exceed 125% of the normal design pressure of that part of the system.

NOTE: Relief valves do not react rapidly enough to prevent "water hammer" excessive pressure spikes).

Valves should be located in the hydraulic system wherever necessary to accomplish this pressure relief through the bypass from the high pressure to the low pressure side of the system. The system relief valve should have a flow capacity equal to or greater than the largest pump flow capacity.

6.17.2 Thermal Expansion Relief Valve: Relief valves should be installed as necessary to prevent pressure rise exceeding 125% of system working pressure and system damage resulting from the thermal expansion of system fluid and, in the case of an accumulator, the rise in gas charge pressure due to thermal effects. The valve should relieve fluid to the low pressure side of the system. Internal leakage should not be considered as an acceptable method of thermal relief. It is preferable to have the setting of the thermal relief valve slightly higher than the system relief valve. This is to ensure that if there is a loss of pump pressure control, the pump flow goes through the system relief valve rather than the thermal relief valve.

6.18 Reservoirs:

Several types of hydraulic reservoirs, are used by aircraft manufacturers. Each type, for example, air-oil interface, bootstrap, etc. are all reservoir designs that have merit depending on the application.

Hydraulic reservoirs should be designed using the guidelines of MIL-R-5520 or MIL-R-8931, as applicable.