SAE Aerospace
An SAE International Group

AEROSPACE RECOMMENDED PRACTICE

ARP4752 | **REV. A**

Issued 1994-09
Revised 2007-07

Superseding ARP4752

(R) Aerospace - Design and Installation of Commercial Transport Aircraft Hydraulic Systems

RATIONALE

The changes to ARP4752 at Revision A include:

a. Technical changes to reflect the latest hydraulic system technologies and changes to applicable airworthiness regulations.

b. Editorial changes including updating the references and improving the readability of the document.

TABLE OF CONTENTS

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
SAE WEB ADDRESS: http://www.sae.org

1. SCOPE

This SAE Aerospace Recommended Practice (ARP) establishes the requirements for the design and installation of a commercial aircraft hydraulic system, including the applicable airworthiness regulations that affect the hydraulic system.

This ARP also provides information and guidelines on the many factors that arise in the design process to provide cost effectiveness, reliability, maintainability and accepted design and installation practices.

2. REFERENCES

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, testing and evaluating the design of aircraft hydraulic systems. However, these documents may be added to, or overridden by, specific aircraft and/or airworthiness requirements, particularly when the documents are oriented towards military aircraft requirements. While military and commercial aircraft hydraulic systems generally utilize different fluid types, the intent of Military Specifications (MIL-specs) provides important and relevant requirements and guidelines for commercial aircraft applications.

2.1 Applicable Documents

The following publications form a part of this document 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 document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org

AIR310	Fittings, Catalog of Flared, Flareless, Pipe Threaded, Port, Hose, and Other Type Tube Standard Connectors
ARP490	Electrohydraulic Flow - Control Servovalves
ARP584	Coiled Tubing
AS595	Civil Type Aircraft Variable Delivery Pressure Compensated Hydraulic Pump
ARP603	Impulse Testing of Hydraulic Hose Assemblies, Tubing and Fittings
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
AIR787	Filter Element Cleaning Methods
AIR797	Hose Characteristics and Selection Chart
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 System Components
AS1227	High Temperature Low Pressure Hose Assembly, Convoluted - Tetrafluoroethylene for Aerospace
AS1241	Fire Resistant Phosphate Ester Hydraulic Fluid for Aircraft
ARP1280	Application Guide for Power Transfer Units
ARP1281	Actuators: Aircraft Flight Controls, Power Operated, Hydraulic, General Specification for
ARP1288	Placarding of Aircraft Hydraulic Equipment to Identify Fluid Suitability
AS1290	Graphic Symbols for Hydraulic and Pneumatic Systems
AS1300	Boss, Ring Locked Fluid Connection Type, Standard Dimensions for
AS1339	Hose Assembly, Tetrafluoroethylene, 400 °F, 3000 psi Hydraulic, Lightweight
AIR1379	Prestressing (Autofrettaging) of Hydraulic Tubing Lines
ARP1383	Impulse Testing of Hydraulic Actuators, Valves, Pressure Containers and Similar Fluid System Safety Components
AIR1569	Handling and Installation Practice for Aerospace Hose Assemblies
AS1709	Coupling Assembly, Hydraulic Self-Sealing, Quick Disconnect
ARP1870	Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety
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 .010 Oversize Diameters
AS3122	Plug Expansion - Aluminum, 2024-T4, Long
AS3123	Plug Expansion - Aluminum, 2024-T4, Short, Standard and .010 Oversize Diameters
AS3124	Plug Expansion - Aluminum, 2024-T4, Short
AS3125	Plug Expansion - CRES, 416, Long, Standard and .010 Oversize Diameters
AS3126	Plug Expansion - CRES, 416, Long
AS3127	Plug Expansion - CRES, 416, Short, Standard and .010 Oversize Diameters
AS3128	Plug Expansion - CRES, 416, Short
AS3129	Plug Expansion - CRES, 303, Long, Standard and .010 Oversize Diameters

AS3130	Plug Expansion - CRES, 303, Long
AS3131	Plug Expansion - CRES, 303, Short, Standard and .010 Oversize Diameters
AS3132	Plug Expansion - CRES, 303, Short
AIR4057	Secondary Filters for Fluid Systems Reliability
AS4059	Aerospace Cleanliness Classification for Hydraulic Fluids
AIR4092	Investigation of PTFE "Melt" Phenomenon for High Pressure Hoses
AS4098	Hose Assembly, Polytetrafluoroethylene, Heavy Duty, Metallic Reinforced, 400 °F, 5000 psi Hydraulic and Pneumatic
ARP4146	Coiled Tubing - Titanium Alloy, Hydraulic Applications
AIR4150	Inspection of In-service Airborne Accumulators for Corrosion and Damage
ARP4378	Accumulators, Hydraulic, Cylindrical, Aircraft, Maintenance Free, Factory Pre-charged
ARP4379	Accumulators, Hydraulic Cylindrical, Aircraft
ARP4386	Terminology and Definitions for Aerospace Fluid Power, Actuation and Control Technologies
AS4396	Fitting End - Bulkhead Flared Tube Connection, Design Standard
AIR4543	Aerospace Hydraulics and Actuation Lessons Learned
ARP4553	Self Displacing Hydraulic Accumulators
ARP4754	Certification Aspects for Highly Integrated or Complex Aircraft Systems
ARP4761	Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment
AS4941	General Requirements for Commercial Aircraft Hydraulic Components
AIR5005	Commercial Aircraft Hydraulic Systems
AS5169	Fitting, Port Plug and Bleeder
AS5202	Bosses, Fluid Connection - Internal Straight Thread
ARP5376	Fluid Systems and Components. Methods, Locations and Criteria for System Sampling and Measuring the Solid Particle Contamination of Hydraulic Fluids
AS5550	Fitting Assembly, Ring-Locked, Adapter, Flareless to Port, Extra Fine Threads, 5080 psi
AS5586	General Requirements for Hydraulic System Reservoirs
AS5951	Hose Assembly, Polytetrafluoroethylene (PTFE), Para-Aramid Reinforced, 5080 psi (35,000 kPa), 275 °F (135 °C), Aircraft Hydraulic Systems

AS5958	Fittings, Axially Swaged Tube With Flareless Separable, Fluid System 5080 psi (35,000 kPa), Specification for
AS5960	Hose Assembly, Polytetrafluoroethylene (PTFE), Metallic Braid Reinforced, 5080 psi (35,000 kPa), 400 °F (204 °C), Aircraft Hydraulic Systems
AS5994	Pump Units, Hydraulic, Electric Motor Driven, Variable Delivery
AS18280	Fittings, Flareless Tube, Fluid Connection
AS28889	Valve, Air, High Pressure Charging, 5000 psi
AS33611	Tube Bend Radii
AS33656	Fitting End, Standard Dimensions for Flared Tube Connection and Gasket Seal
AMS 4944	Titanium Alloy Tubing, Seamless, Hydraulic, 3.0Al-2.5V, Cold Worked and Stress Relieved
AMS 4945	Titanium Alloy Tubing, Seamless, Hydraulic, 3.0Al-2.5V, Controlled Contractile Strain Ratio, Cold Worked, Stress Relieved
AMS 4946	Titanium Alloy Tubing, Seamless, Hydraulic 3Al-2.5V, Texture Controlled Cold Worked, Stress Relieved
AMS 5561	Steel Tubing, Welded and Drawn, Corrosion Resistant Steel, 9.0Mn-20Cr-6.5Ni-0.28N, High Pressure Hydraulics
AMS-T-7081	Tube, Aluminum Alloy, Seamless, Round, Drawn, 6061, Aircraft Hydraulic Quality
J1927	Cumulative Damage Analysis for Hydraulic Hose Assemblies

2.1.2 Air Transport Association of America Publications

Available from Air Transport Association of America, Inc., 1301 Pennsylvania Avenue, NW, Suite 1100, Washington, DC 20004, Tel: 202-626-4000, www.airlines.org.

MSG-3	Airline/Manufacturer Maintenance Program Planning Document

2.1.3 Department of Defense Publications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, http://assist.daps.dla.mil/quicksearch/.

MIL-STD-810	Environmental Engineering Considerations and Laboratory Tests
MIL-PRF-5503	Cylinders: Aeronautical, Linear Utility, Hydraulic, General Specification for
MIL-J-5513	Joints, Hydraulic Swivel
MIL-PRF-5606	Hydraulic Fluid, Petroleum Base; Aircraft, Missile and Ordnance
MIL-PRF-6164	Valve, Aircraft, Pneumatic, High-Pressure Charging

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-DTL-9395	Detail Specification, Switches, Pressure, (Absolute, Gage, And Differential), General Specification for
MIL-DTL-25579	Detail Specification Hose Assembly, Polytetrafluoroethylene, High Temperature, Medium Pressure, General Specification for
MIL-DTL-27267	Detail Specification Hose, Polytetrafluoroethylene, 450F, Medium Pressure
MIL-DTL-27272	Fitting, Tetrafluoroethylene, Hose, High Temperature, Medium Pressure, General Requirements for
MIL-V-81940	Valve, Sampling and Bleed, Hydraulic, Type II Systems
MIL-PRF-83282	Hydraulic Fluid, Fire Resistant Synthetic Hydrocarbon Base, Aircraft
MIL-DTL-83296	Detail Specification Fittings, Corrosion Resistant Steel, High Temperature, High Pressure (3000 PSI), Hydraulic And Pneumatic
MIL-DTL-83298	Detail Specification Hose, Polytetrafluoroethylene, High Temperature, High Pressure (3000 psi), Hydraulic And Pneumatic
MIL-H-85800	Hose Assemblies Polytetrafluoroethylene, Aramid Fiber Reinforced, 5000 and 8000 psi, General Specification For
MIL-PRF-87257	Hydraulic Fluid, Fire Resistant, Low Temperature, Synthetic Hydrocarbon Base, Aircraft and Missile

2.1.4 FAR Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

FAR Part 25	Code of Federal Regulations, 14 CFR 1.1, part 25 Airworthiness Standards, Transport Category Airplanes
TSO C-140	Aerospace Fuel, Engine Oil, and Hydraulic Fluid Hose Assemblies

2.1.5 ISO Publications

Available from American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

ISO12	Pipelines, Identification Schemes
ISO2685	Environmental Test Conditions for Airborne Equipment - Resistance to Fire in Designated Fire Zones
ISO3323	Aircraft, Hydraulic Components, Marking to Indicate Fluid for Which Component is Approved
ISO5859	Aerospace, Graphic Symbols for Schematic Drawings of Hydraulic and Pneumatic Systems and Components

ISO7137	Aircraft, Environmental Conditions and Test Procedures for Airborne Equipment
ISO8278	Aerospace, Hydraulic, Pressure Compensated, Variable Displacement
ISO9206	Aerospace, Constant Displacement Hydraulic Motors, General Specifications
ISO12333	Aerospace, Constant Displacement Hydraulic Motors - General Specifications for 35,000 kPa Systems
ISO12334	Aerospace, Hydraulic, Pressure Compensated, Variable Displacement Pumps - General Specifications for 35,000 kPa Systems
ISO22072	Electrohydrostatic Actuator (EHA) - Procurement Specifications

2.1.6 EASA Publications

Available from European Aviation Safety Agency, Postfach 10 12 53, D-50452 Koeln, Germany, Tel: +49-221-8999-000, www.easa.eu.int.

CS 25	Joint Aviation Requirements, Large Aeroplanes

2.1.7 Joint Aviation Authorities Committee Documents

Available from Printing & Publications Services Ltd., Grenville House 37, Gratton Road, Cheltenham GL50 2BN, England, Tel: +44(0) 1242 235 151, Fax +44(0) 1242 584 139, Credit Card Hotline +44(0) 1242 263 993.

JAR 25	Joint Airworthiness Requirements, Large Aeroplanes

2.1.8 RTCA Publications

Available from Radio technical Commission for Aeronautics, Inc., 1828 L Street, NW, Suite 805, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

RTCA/DO-160	Environmental Conditions and Test Procedures for Airborne Equipment

2.2 Related Publications

The following publication is provided for information purposes only and is not a required part of this SAE Aerospace Technical Report.

FAA TSO C-53	Fuel and Engine Oil System Hose Assemblies
FAA TSO C-75	Hydraulic Hose Assemblies
AS5440	Hydraulic Systems, Aircraft, Design and Installation Requirements for

2.3 Definitions

Refer to ARP4386 for general hydraulic system terms that are used in this Aerospace Recommended Practice.

OEM: An OEM (Original Equipment Manufacture) is defined as the organization that has the engineering responsibility for the aircraft that includes the hydraulic system. Typically, the OEM is an aircraft manufacturer or a modification center.

DESIGN OPERATING PRESSURE: The design operating pressure (DOP) is defined as the normal maximum steady pressure. Excluded are:

a. Reasonable tolerances and transient pressure effects such as may arise from acceptable pump ripple, or

b. Reactions to system functioning or demands that may affect fatigue

ELECTROHYDROSTATIC ACTUATOR: An electrohydrostatic actuator (EHA) is defined as an integrated electrically powered actuator that includes:

a. One or several actuators

b. A hydraulic reservoir

c. A bi-directional, fixed displacement pump driven by a bi-directional, variable speed electric motor

d. Power electronics to drive the motor in accordance with actuation position demands

ELECTROMECHANICAL ACTUATOR: An electromechanical actuator (EMA) is defined as an integrated electrically powered actuator that includes:

a. A mechanical actuator driven by a bi-directional, variable speed electric motor(s) through a gearbox/clutch mechanism

b. Power electronics to drive the motor in accordance with actuation position demands

AIR TURBINE DRIVEN PUMP: An air turbine driven pump is defined as a pump mounted to an air turbine housing that contains a pneumatic turbine, shutoff and speed control valving, gearing and a lubrication system. The engine compressor bleed air drives the turbine.

POWER TRANSFER UNIT: A Power Transfer Unit (PTU) is defined as a hydraulic pump driven by a hydraulic motor.

NON-SEPARATED RESERVOIR: A non-separated hydraulic reservoir is defined as a reservoir where the fluid surface is in direct contact with a gas (for example, air).

SEPARATED RESERVOIR: A separated hydraulic reservoir is defined as a reservoir where stored fluid is pressurized by means where no fluid surface is in direct contact with a gas.

ENDURANCE TEST: An endurance test is defined as a test that is intended to determine the wear characteristics of an element (component, sub-system or system) in order to determine if the element will operate satisfactory throughout its operational lifetime. The endurance test comprises the realistic simulation of the operation of the element over the life that has been declared for it, using the appropriate test rig.

FATIGUE TEST: A fatigue test is defined as a test that is intended to determine the fatigue strength of a component. The fatigue test comprises the repeated application of loads (pressure impulse test and/or external structural loads), using the appropriate test rig.

CENTRALIZED MAINTENANCE SYSTEM (CMS): A centralized maintenance system is defined as an integrated computer system that is used to facilitate the day-to-day maintenance of the aircraft. It provides information to the ground crew of system faults that have occurred during a flight by detailing all systems messages including those that are either not annunciated to the flight crew at all or inhibited in certain flight phases to manage flight crew workload.

3. OVERALL HYDRAULIC SYSTEM REQUIREMENTS

3.1 General Requirements

3.1.1 Design

Flight critical hydraulic systems and their components must be designed to operate satisfactorily under all conditions that the aircraft may encounter within its flight envelope and structural limitations. This includes forces or conditions caused by acceleration, deceleration, negative gravity, flight attitude, structural deflections, vibration or other environmental conditions, failures and other incidents.

The aircraft must also be controllable following many types of system and/or component failures. In addition, if the aircraft remains flyable following the loss of, or damage to, either side of the horizontal stabilizer, the vertical stabilizer or at the extremities of the wing, then it should still be controllable.

3.1.2 System Integration

If the hydraulic system is part of a highly integrated or complex aircraft, then it should be integrated with other systems and structural elements using the processes and procedures that are provided in ARP4754.

3.1.3 System Pressure

The normal working pressure used in the majority of commercial aircraft hydraulic systems is 3000 psi (20,684 kPa). Higher or lower working pressures can be used but they will suffer from lack of commonality of ground equipment, components, etc. Higher working pressures will generally provide a reduction in system weight and smaller installation envelopes. A cost/benefits trade study is advisable early in the design development.

3.1.4 Hydraulic Fluid

Fire resistant phosphate-ester hydraulic fluid conforming to AS1241 is generally used in commercial aircraft hydraulic systems. However, fluid conforming to MIL-PRF-5606, MIL-PRF-83282, or MIL-PRF-87257 can be used under certain circumstances, (for example, executive and commuter aircraft with small hydraulic systems and military aircraft adapted for commercial use (for example, C-130)) recognizing the different characteristics of the fluid types.

It shall be noted that AS1241 fluids are not miscible or interchangeable with MIL-PRF-5606, MIL-PRF-83282, or MIL-PRF-87257 fluids. The seals used for AS1241 fluids are incompatible with the other fluids, and vice versa.

3.1.4.1 Hydraulic Fluid Properties

The airframe manufacturer shall specify limits for the following contamination and chemical properties in order to advise the aircraft operator when the hydraulic fluid should be replaced:

a. Fluid particulate classification levels in accordance with AS4059

b. Chlorinated solvent

c. Water contamination

d. Acid number

e. Kinematic viscosity

f. Specific gravity limits

Suggestions for the system contamination environment for hydraulic pumps are given in AIR1922.

3.1.5 Temperatures

The hydraulic system shall be designed for operating in ambient temperatures that are dictated by the individual aircraft operating requirements and be non-degraded at:

a. The minimum temperature that the aircraft will likely to be subjected to during an overnight cold soak

b. The maximum temperature that could occur during high temperature soak backs, for example, in the engine pod area and/or brake lines

Each hydraulic system should be designed such that under normal operating conditions, the fluid temperatures in the power generation systems are between -20 to +175 °F (-29 to +79 °C). The hydraulic fluids are capable of operation at higher or lower temperatures but if the system is normally run at temperatures greater than 175 °F (79 °C), a reduction in system reliability may result.

Operation of the hydraulic services shall still be possible at -65 °F (-54 °C) if they are installed in locations that are exposed to that temperature, for example, at the extremities of the wings or empennage.

If the aircraft is continually operating at low ambient ground temperatures (for example, -20 °F (-29 °C) or below), then heating of the hydraulic fluid may be provided to ensure the correct performance of the hydraulic system.

It shall be noted that the lower limit for ground cold soak ambient and operating temperatures for aircraft using MIL-PRF-83282 hydraulic fluid shall be limited to -40 °F (-40 °C), or higher if established by test. This is due to the high viscosity of this fluid at low temperatures. However if heating of the hydraulic fluid is provided, then this temperature limit could be reduced.

3.1.6 Schematic Diagram

The graphic symbols and presentation principles shall conform to AS1290/ISO5859, whenever a schematic diagram of a hydraulic system is prepared. This provides the benefit of having a consistent set of symbols/drawing layouts that can be understood by a variety of disciplines/organizations including:

a. The aircraft hydraulic system engineers.

b. System installation designers.

c. Aircraft customer support engineers.

d. Component suppliers.

e. Airline engineering groups.

3.2 Applicable Airworthiness Requirements

Commercial transport aircraft are designed to meet the airworthiness requirements of the Federal Airworthiness Regulations (FAR), Part 25 (for US certified aircraft) or the Certification Standards for Large Aeroplanes (CS-25)/Joint Airworthiness Requirements (JAR), Part 25 (for European certified aircraft).

The sections in these regulations that are applicable to the design of commercial aircraft hydraulic systems are:

25.301	Loads
25.303	Factor of safety
25.581	Lightning protection
25.601	Design and construction - general
25.603	Materials
25.611	Accessibility provisions
25.671	Control Systems - general
25.672	Stability augmentation and automatic and power operated systems
25.729	Retracting mechanisms
25.863	Flammable fluid protection
25.863	Flammable fluid protection
25.899**	Electrical bonding and protection against static electricity
25.903	Engines
25.943*	Negative accelerations
25.1182	Nacelle areas behind firewalls and engine pod attaching structures containing flammable fluid lines
25.1183	Flammable fluid - carrying components
25.1185	Flammable fluids
25.1189	Shutoff means
25.1301	Function and installation
25.1309	Equipment, systems and installations
25.1310**	Power source capacity and distribution
25.1315**	Negative accelerations
25.1322	Warning, caution and advisory lights

25.1353 Electrical installations and equipment

25.1541 Markings and placards - general

* FAR requirement only

** CS/JAR requirement only. FAR 25.1309 includes requirements of CS/JAR 25.1310.

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

3.3 Design Concept and Overall Layout Requirements

The general concept and layout of the hydraulic system design and the type of components used within the hydraulic system shall comply with the requirements of:

a. FAR/CS/JAR 25.671

b. FAR/CS/JAR 25.672

c. FAR/CS/JAR 25.729

d. FAR/CS/JAR 25.1309

These requirements are concerned with the effects of single and multiple failures of systems, power sources, subsystems or components within the systems and their subsequent effect upon the operation of the aircraft.

It is necessary to identify those components that, if they fail, will significantly lower the airworthiness or safe handling of the aircraft. This is normally achieved during the safety assessments of the system that are conducted in the form of:

1. Functional hazard Analysis (FHA)
2. Common Cause Analysis (CCA)
3. Failure Modes and Effects Analysis (FMEA)
4. Fault Tree Analysis (FTA) or
5. System Safety Assessment (SSA)

ARP4761 provides a guide for conducting fault or failure analyses.

Consideration shall be given to the ability of the flight crew to maintain control of the aircraft at any point in the flight, following two independent failures, and to continue a safe flight and landing. In addition, the allowable effect of a failure, or two failures, on the subsequent degree of difficulty in safely operating the aircraft is related to the probability of these failure(s) occurring.

Therefore, the design of the overall hydraulic system shall 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 that the hydraulic system supplies.

NOTE: AIR5005 provides information on hydraulic systems that are fitted to many commercial aircraft, including the number of independent hydraulic systems, and the number and type of the power sources.

3.3.1 Aircraft Utilizing a Single Main Hydraulic System

If the aircraft's hydraulic system supplies no primary flying controls, then usually only a single main hydraulic system is required. This is because any single failure of the hydraulic system would not prevent the aircraft from safely completing the flight.

However, if the hydraulic system is the sole power source for retracting/deploying the landing gear, then FAR/CS/JAR 25.729(c) requires that an alternative means of deploying them must be available if they cannot be deployed freefall.

If slats and/or flaps are required for safe operation, then an alternative means must be provided to deploy them. Examples of alternative means include:

a. A simple auxiliary hydraulic system

b. A stored gas system

c. A dedicated electro-mechanical actuator (EMA) or an electro-hydrostatic actuator (EHA)

d. If the braking system is operated hydraulically, then hydraulic power stored in dedicated accumulators or a separate fluid source and dedicated pump will be required to enable the aircraft to complete its landing run safely following the loss of the normal system.

3.3.2 Aircraft Utilizing Two Independent Hydraulic Systems

Usually, only two independent hydraulic systems are required if:

a. The aircraft's hydraulic system only supplies a single primary flight control (for example, the rudder) with the remainder of the primary flight controls being non-powered, or

b. The flight controls are hydraulically powered but they can be operated by other means if there is a total loss of hydraulic power. Examples of other means are:

- Mechanical operation
- Powered by EHAs and/or EMAs

Thus, if one of the hydraulic systems fails, there is only a small effect on the aircraft handling qualities and, if both systems fail, the aircraft will be able to safely complete the flight.

The following is required to enable the flight to be safely completed following the loss of one or both systems where applicable:

1. Provide more than one supply of power to the brakes

2. Provide an alternative method of deploying the landing gear if freefall is not utilized

3. Provide a second power source (hydraulic or electric) for flaps and/or slats deployment if they are required for safe aircraft operation

3.3.3 Aircraft Utilizing More Than Two Independent Hydraulic Systems

If the aircraft's hydraulic system supplies all the primary and secondary flight controls and there is no manual reversion available, then usually a minimum of three hydraulic systems will be required. This is in order to comply with the requirements of FAR/CS/JAR 25.671 and 25.1309. However, it is noted that:

a. The use of EHAs or EMAs to supply primary and/or secondary flight controls means that it is possible to use only two hydraulic systems if all the primary and secondary flight controls are powered. This is dependent on having sufficient redundancy within the electrical power generation system such that the probability of failures of electrical and hydraulic systems that could result in the total loss of flight controls is less than 1×10^{-9}/flight hour (see 3.3.4).

b. If there is a large number of services that are powered hydraulically, four independent hydraulic systems may be a design solution in order to:

   1. Reduce the size of the main and backup pumps

   2. Optimize the redundancy of the supplies to the hydraulic services, etc.

c. Protective devices that preserve certain hydraulic subsystem capabilities may be required when considering engine burst, tire burst, mid-air collisions, and other system failures, due to the aircraft configuration and/or systems layout, for example.

The requirements to have more than one power source for the flaps (if needed), landing gear (if they cannot be deployed freefall) and brakes also apply.

3.3.4 Loss of Electrical Generated Power

Many components in a hydraulic system are controlled by electrical power. The electrical power generation and distribution, flight control, hydraulic systems, etc., within the aircraft and these components (electrohydraulic servovalves, pump mode selectors, solenoid valves, etc.) must be configured such that, following a complete failure of the main electrical power generation system(s), the aircraft can continue to make and complete a safe flight and landing.

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 because a potentially catastrophic event might possibly occur due to a combination of single failures of:

a. An electrical and a hydraulic system

b. Components within the two systems

c. A failure of one of the systems and a component in the other system

3.3.5 Directional Control of the Aircraft on the Ground

If the aircraft hydraulic systems supply the services that control the direction of the aircraft on the ground, that is, nosewheel (and/or main gear) steering, differential braking and the rudder, consideration shall be given to supplying the nosewheel steering and normal brakes from different hydraulic systems. Hence, if either system fails during the takeoff run before the rudder has any effectiveness, the flight crew can maintain directional control by either nosewheel steering or differential braking.

3.3.6 Backup Power Sources

As well as the number of independent aircraft systems within the overall aircraft system that would be required, consideration shall be given to the level of redundancy of hydraulic power sources within each hydraulic system.

Usually each independent system contains a main power source, for example, an engine driven hydraulic pump (EDP) or an electric motor driven pump (EMP), and a backup power source such as another EDP, EMP, a power transfer unit (PTU), an air turbine driven pump and/or accumulators. Thus, if the main pump fails, the backup power source will provide continued safe functioning of the system.

If the aircraft has all the primary and secondary flight controls powered by the hydraulic system, then it shall comply with FAR/CS/JAR 25.671(d). This states that the aircraft shall be controllable if all engines fail. In order to meet this requirement, the aircraft can be fitted with a ram air turbine (RAT) when sufficient hydraulic or electrical power is not available from pumps powered by windmilling engines or batteries. The RAT could either power a hydraulic pump or an electrical generator (which would supply an EMP), or both, so that essential flying controls and other services can operate under these conditions.

NOTE: There may be other means of generating emergency hydraulic power, such as an emergency power unit; however, it is generally recognized that a RAT is the preferred solution, if required.

3.3.7 Protection Devices

Consideration shall be given to the use of protection devices to provide some capability of operating key hydraulic subsystems following the loss of one or more main hydraulic systems, or following structural failures (as required in 3.1.1). The following are examples of devices that can be used:

3.3.7.1 Check Valve

This can be used to isolate a subsystem from the main hydraulic system. In the event of the failure of the main system, the subsystem can be supplied by the following dedicated hydraulic power sources:

a. An accumulator for a limited time and/or cycles

b. A pump that has its own fluid supply from a separate source than for the main system pump(s)

The check valve can also be installed in the return lines from the hydraulic services. In the event of a failure in a return line, the check valve will prevent pressurized fluid from the reservoir from being forced out of the line.

If it is possible for the check valve to be dormantly failed open, a function test to determine the correct operation of the valve shall be conducted at an interval specified by the reliability analysis.

3.3.7.2 Pressure Maintaining Valve (PMV)

This valve isolates a subsystem from the main system when the pressure upstream of the valve falls below a nominal value. If the subsystem has an accumulator, the use of the PMV enables the accumulator to supplement the flow from the main system pump. However, following the loss of the main system, the PMV would close and conserve the accumulator supply for the subsystem.

3.3.7.3 Priority Valve

This valve is usually used to isolate the supply of fluid to general services' (utility) subsystems when it is required to conserve the fluid supply to critical services (for example, to primary flight controls). However, the valve can also be used to isolate a subsystem, if there is a loss of fluid and/or pressure in it, from the remainder of the hydraulic system.

3.3.7.4 Fuse

This component typically senses the flow rate and/or fluid volume through it so that if the rated value is exceeded, the fuse will close. Fuses are typically used in the wheel braking system to cater for tire debris striking a brake tube/hose causing the line to fail. Under these circumstances, the fuse would close, thereby conserving the fluid supply to the other wheel brake lines. The fuse can also be used in other applications, for example, to ensure the supply of hydraulic power to flight controls following the failure of a tubeline in a non-essential hydraulic service.

3.3.7.5 Electrically Operated Shutoff Valve

This valve is electrically linked to the respective hydraulic system reservoir contents monitoring system. In the event that the reservoir contents fall below a declared minimum value (due to loss of fluid), the valve or a series of valves will close. The valve(s) can be located in a hydraulic system to provide maximum possible protection of the supplies to critical hydraulic services.

3.3.7.6 Circuit Breaker (Flow Comparison Device)

This component compares the flow rate to and from a set of services. If there is a difference between the flow rates that is greater than would normally occur, a shutoff valve would be operated to isolate the hydraulic circuit to the services from the remainder of the hydraulic system. The circuit breaker can be installed in the same locations as the shutoff valves as discussed in 3.3.7.5.

3.4 Segregation Requirements

The installation of the hydraulic system components and tubelines within the aircraft must be segregated so as to minimize the effect of many different events that could damage the system.

No single failure should cause the loss of more than one hydraulic system. Where it is unavoidable that two hydraulic systems come together in one housing (such as brake units and switching valves), special precautions must be taken such that housing failures causing loss of both systems is remote. The routing of the hydraulic systems should be such that the primary systems are not within a close proximity of each other, regardless of the precautions taken.

Consideration shall be given to the effects of engine debris, flailing tires or tire debris, flailing shafts, and damage to the aircraft structure.

3.4.1 Engine Debris Requirements

The effects of non-contained engine bursts, as required by FAR/CS/JAR 25.903(d)(1) shall be considered in the design of the hydraulic system. This is usually accomplished by ensuring that the tubing of each independent system and their respective components are sufficiently physically separated such that a non-contained engine failure could not damage the lines of all systems.

It must be possible to retain hydraulic power to those services that are considered essential for safe flight and landing, for example, some primary or secondary flying controls, landing gear deployment and brakes. If necessary, in order to meet this requirement, tubing for one system may be required to be installed in the fuel tank areas in the wing with the other systems installed on the wing front and rear spars. In addition, if the hydraulic bays are all located within the engine burst zones then the bays shall be as far apart from each other as practically possible.

It may be necessary to route the plumbing from all the hydraulic systems in a single area to achieve the necessary degree of redundancy. Under these conditions, it could be possible that damage to all of the systems in this area would prevent the aircraft from being controlled. Therefore, consideration shall be given to providing means to isolate this section of each system so that operability of the remainder of the system is maintained or that the system redundancy is not reduced.

3.4.2 Protection Against Flailing Tires and Tire Debris

Consideration must be given to the effect of flailing tires or tire debris on tubing installed in the wheel well, as required by FAR/CS/JAR 25.729(f). It is required that the design of the tubing installation on landing gears, in landing gear and/or hydraulic bays, etc., is such that only a limited amount of damage is possible, for example, the loss of not more than one system when a redundant system remains functional.

The choice of tubing material in this area shall consider the risk of exposure of the tubing to the tire failure. The design and installation of components and the tubing in each wheel well area must also take into account the possibility of a tire burst when the landing gear is retracted or deployed. If necessary, some components and tubing may be required to be protected from a tire burst that would otherwise cause a failure of more than one hydraulic system.

3.4.3 Protection Against Flailing Shafts

Flailing shafts, such as those resulting from a broken flap drive system; have the potential to damage hydraulic equipment and tubing. To reduce the effects of the flailing shafts, the movement of failed shafts should be restricted and the hydraulic systems should be located to minimize damage, particularly to multiple hydraulic systems.

3.4.4 Minimizing the Effect of Structural Damage

The layout of hydraulic systems on either side of the horizontal stabilizer, the vertical stabilizer and at the extremities of the wing shall be reviewed. This is to ensure that, following an incident (like a midair collision), which causes the loss of one of these structures such that the aircraft remains flyable, there are sufficient hydraulically powered primary (and secondary, as required) flying controls that are able to function.

The hydraulic system layout must also take into consideration the effect of other situations, including rapid depressurization and engine pods coming off the airframe or wing. In addition, in the event of a hard landing such that the floor collapses or there is other substantial structural damage, the hydraulic supply to the braking system must be protected so that it is possible to bring the aircraft to a safe stop.

Consideration shall also be given to a birdstrike penetrating the aircraft structure. It should not be possible to lose more than one independent hydraulic system under these circumstances.

3.5 Maintainability Requirements

3.5.1 General

The hydraulic system should be designed to be as simple and foolproof as possible to maintain. All servicing and functioning instructions should be clearly written and simple to comprehend.

All the equipment that is used to check or service the system should be easy to operate.

The components and tubing within the aircraft should be located such that there is access and adequate space for inspection, repair and replacement of them.

The tubing and/or hose end fittings in adjacent runs should be located and/or have different sizes in order to minimize the possibility of cross-connecting the lines when performing maintenance.

3.5.2 Provision of Labels

There should be labels provided in the aircraft that will give relevant information to assist maintenance personnel as they conduct routine servicing of the hydraulic system, and as they conduct replacement of hydraulic system components.

Typical labels include:

a. Hydraulic fluid used (see 5.2.5)

b. Instructions for filling/draining the reservoirs

c. Hydraulic reservoir pneumatic charging instructions (when applicable)

d. Accumulator gas charging instructions (see 3.5.3)

e. Identification of important components, including the system reservoir(s)

f. Operating procedures for pressure (dump) valves, or manual overrides on selector valves

NOTE: Tubing and fitting identification is covered in 8.6.5.

3.5.3 Servicing Requirements

The system should be designed to require minimum periodic checks and servicing requirements. The need for hydraulic system checks shall be derived using the principles laid down in the MSG-3 document and from the findings of the System Safety Assessment. The OEM, airworthiness authorities and the aircraft operators shall agree on these checks.

Components should utilize on-condition monitoring rather than being removed for overhaul at regular intervals. The only components that should require a fixed interval removal period are those that are critical to the safe operation of the aircraft and are required to be overhauled, pending more flight hours, to increase the confidence factor in their usage.

The system should be designed such that routine servicing of the system is easily and safely accomplished. There should be easy access to those parts of the system which require regular servicing, for example, hydraulic reservoirs, reservoir depressurization valves, system bleed and drain points, accumulators, charging valves, fluid sampling valves and filters.

If accumulators are fitted that are required to be gas charged by ground servicing equipment, there should be a standard charging valve fitted (such as specified in MIL-PRF-6164) and a permanent pressure gage attached to the gas side of the accumulators. There should be clear, easy-to-read instructions with a charge pressure-ambient temperature chart in the immediate vicinity of the charge valve/pressure gage. These facilities should also be provided for the hydraulic reservoir if it is pressurized by dry air or nitrogen.

Fluid sampling valves should be installed in each independent system, be located in a readily accessible area and allow for the convenient use of sampling containers. ARP5376 gives guidance regarding sampling valve locations.

There should be a central ground servicing station provided in an easily accessible location to facilitate servicing of the hydraulic systems. Provisions for checking reservoir levels, replenishing hydraulic fluid, and servicing the filters and accumulators shall be available to the maintenance crew. However, caution must be taken if the accumulators have different charge pressures. Some aircraft may use the central servicing station for system checkout and flushing.

If the central servicing station encompasses all the hydraulic systems, then suitable design features shall be incorporated to prevent losing all hydraulic systems because of damage to this area.

Further servicing requirements are provided in 7.3 for reservoirs, 7.6.2 for filters, and 8.3 for accumulators.

3.5.4 Use of External Equipment

The system should be designed to function on the ground with the minimum of external equipment and use, if possible, main or backup system pumps. This facilitates the checking of the systems, taking of fluid samples and system bleeding at remote airfields where minimum facilities are available.

3.5.4.1 Provision for Hydraulic Power Ground Carts

Each hydraulic system shall have self-sealing couplings installed to permit the attachment of a hydraulic power ground cart to operate the system during initial installation or following component replacement, major overhaul, and for the flushing of contaminated systems.

The supply fluid from the hydraulic power carts shall pass through the aircraft pressure filter. Fluid returning to the hydraulic cart shall pass through a return filter of equal or better filtration capacity than the aircraft system filter.

In order to ensure that general-purpose hydraulic ground carts are compatible with the aircraft hydraulic system, the aircraft manufacturer shall furnish the following details to the aircraft operators:

a. Maximum system working pressure

b. Minimum required flow rate

c. Ground cart connections - the connections must be foolproof to ensure that it is only possible to connect the ground cart to the applicable HP, LP and case drain (if required) connections on the aircraft

d. System hydraulic fluid

e. Filtration requirements

3.5.5 Internal Leakage Checks

The system should be designed such that it is possible to check each independent hydraulic system for excessive internal leakage and to be able to diagnose the defective component. This can be achieved by isolating subsystems by using built-in valves and monitoring the accumulator decay rates or the current draw on electric motor pumps.

Monitoring and diagnosis of unacceptable hydraulic system internal leakage of components can also be provided as discussed in AIR1922 for pump monitoring. Pump case drain flow and temperature, pump discharge flow, and servo-actuator quiescent internal leakage flow can be provided by built-in flow and temperature sensors that are linked to a computer based monitoring system. This will eliminate the need for built-in isolation valves.

3.5.6 Filling and Bleeding

The system should be designed such that it is easy to fill the hydraulic system, and require the minimum of specialist ground equipment.

The hydraulic system and equipment should be designed, as far as practical, to automatically scavenge free air to the reservoir or to other collection points where operation will not be affected and where the release of the air can be conveniently accomplished.

3.5.7 Draining and Flushing

The system should be designed to facilitate draining.

Means shall also be provided to enable the system to be flushed during aircraft build or whenever it is confirmed that the fluid exceeds the chemical or contamination limits that are specified by the airframe manufacturer.

Where a flushing procedure is developed using a kit of by-pass lines, it should be developed in conjunction with 8.7.1 to facilitate connections and avoid strain on installed tubing.

3.5.8 Use of Special Tools

The hydraulic systems should be designed such that special tools will not be required for the installation or removal of components.

3.5.9 Pressure Release (Dump) Valves

Where accumulators are installed in subsystems that are isolated from the main system by check valves, pressure release valves shall be fitted to depressurize the accumulator without having to operate the subsystem. The pressure release valves shall return to the normal closed position when released to prevent them from being left open in the wrong position.

When hydraulic reservoirs are pressurized, pressure release valves shall be provided in an easily accessible location. This is to allow the reservoir(s) to be depressurized such that any hydraulic component replacement may be accomplished without excessive fluid spillage.

3.5.10 Common Parts

In order to reduce cost of ownership, there should be as many common parts as possible within the system. Included in this are:

a. Filter elements that can be used in more than one filter assembly

b. Electric motor actuators that are common for all motorized valves that are used in the hydraulic system

c. Hydraulic pumps that could be used in more than one system

d. Valves that could be used in more than one system

e. Tubing, reconnectable fittings, hoses, etc. that could be used in more than one hydraulic system

f. Every effort should be made to eliminate the need to have unique designs for opposite side installations

3.5.11 Centralized Maintenance System

The hydraulic system design shall contribute to the definition of the CMS by providing:

a. The hydraulic system related messages,

b. Suggesting their priority of the messages

c. Suggesting the output format of the messages

This is to ensure that:

- All irregularities of the hydraulic system are captured
- The likelihood of bogus messages is low
- Sufficient information is given to ground maintenance personnel to enable them to troubleshoot the hydraulic system
- The information is provided in an understandable format

If a hydraulic control and interface computer is utilized, it shall be designed to:

1. Comply with avionics equipment requirements
2. Have the required reliability
3. Properly interface with the avionic system of the aircraft, the data bus, data format and protocol

3.6 Reliability Requirements

All commercial aircraft are required to have a high reliability to enable the aircraft to accomplish many flights and many hours utilization per day without incurring delays or cancellations. Therefore, the hydraulic system shall be designed to meet reliability guarantees as agreed between the aircraft manufacturer and the operators. The hydraulic system must:

a. Comply with airworthiness requirements,
b. Comply with detail level requirements and to
c. Consider the effect of manufacturing processes and component selections

These reliability guarantees can be achieved by:

1. Regular reviews of the system by the system designers, reliability engineers and product support specialist engineers, and
2. Following the processes and methods detailed in ARP4754 and ARP4761

Previous aircraft system designs should be analyzed to determine where problems had occurred and to make certain that, if possible, they can be designed out on the new system. Also, the use of "lessons learned" from other aircraft designs should be incorporated. AIR4543 provides data on lessons learned from a wide variety of problems.

The components within the system should be subjected to the same scrutiny as that given for the system design. The specification for each component should be clearly written to reflect the operation of it within the system as well as its performance requirements. The duty cycle quoted for each component and its qualification testing should accurately reflect the conditions that it will be subjected in service. If possible, components utilized on other aircraft hydraulic systems should be used provided that they have been found to be reliable in service and it has been determined that their application in the new system is similar to previous installations.

4. GENERAL HYDRAULIC SYSTEM AIRWORTHINESS REQUIREMENTS

The detail design of each commercial transport aircraft hydraulic system shall be such that compliance can be demonstrated with the requirements of:

a. FAR/CS/JAR 25.581

b. FAR/CS/JAR 25.601

c. FAR/CS/JAR 25.603

d. FAR 25.943

e. FAR/CS/JAR 25.1301

f. FAR/CS/JAR 25.1309

g. CS 25.1315/JAR 25X1315

h. FAR/CS/JAR 25.1322

These are general requirements that have an impact on the hydraulic system.

4.1 FAR/CS/JAR 25.581 - Lightning Protection

This requirement calls for the bonding and grounding of the components to the aircraft structure in order to protect the aircraft against catastrophic effects from lightning.

In order to comply with this requirement, the aircraft hydraulic system components and lines shall be bonded and grounded to the aircraft in accordance with ARP1870 or the equivalent OEM's requirements.

4.2 FAR/CS/JAR 25.601 - 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 phases, there shall be emphasis placed on reviewing previous aircraft systems to identify safety problem areas that were encountered and to ensure that they are not repeated on the new design. If, however, it is considered that there are some features that are questionable, then these should be proved by rigorous testing prior to incorporating them on the aircraft.

4.3 FAR/CS/JAR 25.603 - Materials

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

a. Be established on the basis of experience or tests

b. Conform to approved specifications that ensure that the materials 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 referred to herein.

4.4 FAR/CS/JAR 25.1301 - 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:

4.4.1 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.

4.4.2 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 include:

a. The hydraulic fluid used

b. System working pressure

c. Maximum operating temperature

d. Direction of rotation of a pump or motor

4.4.3 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 OEM 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

Hose assemblies per AS1339 should not be used in excess of 3000 psi (20,684 kPa) Design Operating Pressure. Although the hoses shall be impulse tested to 4500 psi (31,026 kPa) peak pressure, this is not an indication that the assemblies may be installed in a system that routinely experiences transient pressures to this level.

4.4.4 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 functional tests conducted on the aircraft for production and maintenance purposes.

4.5 FAR/CS/JAR 25.1309 - 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 this requirement in terms of system redundancy and segregation requirements are discussed in 3.3.

In addition, there are other requirements when FAR/CS/JAR 25.1309 is applied to hydraulic systems that are presented below:

4.5.1 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 shall 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:

1. Qualification testing of components

2. Aircraft and test rig (Iron Bird) testing of the hydraulic system

3. Design analysis

4. Reference to comparable service experience on other aircraft

4.5.2 Hydraulic System Indicators and Warnings

The hydraulic system must incorporate means of providing warnings to the flight crew of failures within the system that:

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, should be designed to minimize crew errors that could create additional hazards. In order to comply with this requirement, hydraulic systems usually provide the following indications and warnings:

1. The supply pressure in each independent hydraulic system

2. Low pressure warnings that notify the flight crew of the loss of a hydraulic system or of a hydraulic pump malfunction

3. High hydraulic fluid temperature by an overheat warning light and/or a temperature gage

4. The quantity of hydraulic fluid in each independent hydraulic system reservoir

5. Low reservoir fluid quantity warning to notify the flight crew of the loss of hydraulic fluid due to a failed tube, seal, etc.

6. 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

The crew drills (check lists) shall utilize the information provided by the hydraulic system indicators and warnings. Therefore, the system operating procedures should 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, shutdown 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, may be handled by the vehicle management system electronic system, if this is fitted to the aircraft.

4.6 FAR 25.943/CS 25.1315/JAR 25X1315 - Negative Accelerations

This requirement calls for the satisfactory operation of systems after being subjected to negative vertical acceleration.

For hydraulic systems, this means ensuring that in the hydraulic reservoir(s), the supply of fluid to the pump(s) does not become interrupted in the event of negative vertical acceleration and thereby permit air to be entrained in the pump(s) which could affect its (their) operation.

In practice, designs that meet this requirement are either:

a. A hydraulic system that is a closed system with no gas/hydraulic fluid interface, incorporating a reservoir that is pressurized hydraulically or by gas with a piston, metal bellows or bladder between the gas and the hydraulic fluid. Hence it would not be possible to uncover the suction connection under negative vertical acceleration conditions.

b. A hydraulic system whose reservoirs have a gas/hydraulic fluid interface that incorporates a chamber around the pump suction connection. This is to ensure that hydraulic fluid flow is not interrupted in the event of negative vertical acceleration conditions.

4.7 FAR/CS/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 that 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 shall 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 shall 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 shall be no warning or caution lights illuminated.

5. SPECIFIC HYDRAULIC SYSTEM AIRWORTHINESS REQUIREMENTS

Each commercial transport hydraulic system shall comply with the requirements of FAR/CS/JAR 25.1435 regulations. This section of the FAR/CS/JAR Part 25 regulations contains the specific requirements for the design and testing of the hydraulic system.

5.1 Part (a) - Element Design

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

Compliance with these requirements for each element is usually demonstrated during qualification testing.

5.1.1 FAR/CS/JAR 25.1435(a)(1)

This requirement states that:

Each element of the hydraulic system must be designed to withstand the proof pressure without permanent deformation that would prevent it from performing its intended functions and the ultimate pressure without rupture.

The proof and ultimate pressures are defined in terms of the design operating pressure (DOP) as stated in Table 1:

TABLE 1 - PROOF AND ULTIMATE PRESSURES

Element	Proof (x DOP)	Ultimate (x DOP)
Tubes and fittings	1.5	3.0
Pressure vessels containing a gas		
High pressure (for example, accumulators)	3.0	4.0
Low pressure (for example, reservoirs)	1.5	3.0
Hoses	2.0	4.0
All other elements	1.5	2.0

5.1.1.1 FAR/CS/JAR 25.1435(a)(1) Additional Information

The DOP for low-pressure elements (for example, return, case-drain, suction, reservoirs, etc.) is the maximum pressure expected to occur during normal user system operating modes. Included are transient pressures that may occur during separate or simultaneous operation of user systems such as slats, flaps, landing gears, thrust reversers, flight controls, power transfer units, etc.

Short term transient pressures, commonly referred to as pressure spikes, which may occur during the selection and operation of user systems (for example, those pressure transients due to the opening and closing of selector/control valves, etc.), may be excluded. This is provided that the fatigue effect of such transients is addressed in accordance with FAR/CS/JAR 25.1435(a)(4).

The following shall be noted:

a. In local areas of systems and elements, the DOP may be different from the above due to the range of normally anticipated airplane operational, dynamic, and environmental conditions. Such differences shall be taken into account.

b. At proof pressure, seal leakage not exceeding the allowed maximum in-service leak rate is permitted. Each element shall be able to perform its intended functions when the DOP is restored.

c. The term 'pressure vessels' is not intended to include small volume elements such as lines, fittings, gages, etc. It may be necessary to use special factors for elements fabricated from non-metallic/composite materials.

5.1.2 FAR/CS/JAR 25.1435(a)(2)

This requirement states that:

Each element of the hydraulic system must be designed to withstand, without deformation that would prevent it from performing its intended functions, the design operating pressure in combination with limit structural loads that may be imposed.

5.1.2.1 FAR/CS/JAR 25.1435(a)(2) Additional Information

Limit structural loads are defined in FAR/CS/JAR 25.301(a). These include, but are not limited to:

a. Flight and ground maneuvers

b. Gust and turbulence conditions

The loads arising in these conditions shall be combined with the maximum hydraulic pressures, including transients that could occur simultaneously.

Where appropriate, thermal effects shall also be accounted for in the strength justification.

For hydraulic actuators equipped with hydraulic or mechanical locking features, such as flight control actuators and power steering actuators, the actuators and other loaded elements shall be designed for the most severe combination of internal and external loads that may occur in use. For hydraulic actuators that are free to move with external loads, i.e., they do not have locking features, the structural loads are the same as the loads produced by the hydraulic actuators.

At limit load, seal leakage exceeding allowed maximum in-service rate is permitted.

5.1.3 FAR/CS/JAR 25.1435(a)(3)

This requirement states that:

Each element of the hydraulic system must be designed to withstand, without rupture, the design operating pressure multiplied by a factor of 1.5 in combination with ultimate structural load that can reasonably occur simultaneously.

5.1.3.1 FAR/CS/JAR 25.1435(a)(3) Additional Information

For compliance, the combined effects of the ultimate structural load(s) as defined in FAR/CS/JAR 25.301 and 25.303 and the DOP, which can reasonably occur simultaneously, shall be taken into account with a factor of 1.5 applied to the DOP. In this case the overall structural integrity of the element shall be maintained. However, it may be permissible for this element to suffer leakage, permanent deformation, operational/functional failure or any combination of these conditions.

Where appropriate, thermal effects shall also be accounted for in the strength justification.

NOTE: For FAR/CS/JAR 25.1435(a)(1), (a)(2), and (a)(3), the pressure and structural loads, as applicable, shall be sustained for sufficient time to enable adequate determination that compliance is demonstrated. Typically, conducting the test for 2 min for proof conditions and 1 min for ultimate condition is considered to be sufficient.

5.1.4 FAR/CS/JAR 25.1435(a)(4)

This requirement states that:

Each element of the hydraulic system must be designed to withstand the fatigue effects of all cyclic pressures, including transients, and associated externally induced loads, taking into account the consequences of element failure.

5.1.4.1 FAR/CS/JAR 25.1435(a)(4) Additional Information

Fatigue, the repeated load cycles of an element, is a significant contributor to element failure. Hydraulic elements are mainly subjected to pressure loads, but may also see externally induced load cycles (for example structural, thermal, etc.). The load cycles for each element shall be defined. The number of load cycles shall be evaluated to produce equivalent fatigue damage encountered during the life of the aircraft or to support the assumptions used in demonstrating compliance with FAR/CS/JAR 25.1309. For example, if the failure analysis of the system allows that an element failure may occur at 25% of aircraft life, the element fatigue life shall at least support this assumption.

Compliance with this requirement is usually demonstrated by impulse testing and/or analysis of those elements that have been identified as being subjected to those loads and this normally takes place during qualification of those elements. The following should be used as a guide for the procedures to be employed when conducting impulse testing:

a. ARP603 - for hose assemblies, tubes and fittings

b. ARP1383 - for hydraulic components

SAE J1927 should be referred to when assessing the life of hydraulic hoses based on the pressure amplitude and number of cycles that they will be subjected to.

5.1.5 FAR/CS/JAR 25.1435(a)(5)

This requirement states that:

Each element of the hydraulic system must be designed to perform as intended under all environmental conditions for which the aircraft is certificated.

5.1.5.1 FAR/CS/JAR 25.1435(a)(5) Additional Information

The aircraft environmental conditions that an element shall be designed for are those under which proper function is required. They may include, but are not limited to:

a. Temperature

b. Humidity

c. Vibration

d. Acceleration forces

e. Icing

f. Ambient pressure

g. Electromagnetic effects

h. Salt spray

i. Cleaning agents

j. Galvanic effects

k. Sand

l. Dust

m. Fungus

They may be location specific (for example, in a pressurized cabin versus in an unpressurized area) or general (attitude). For further guidance on environmental testing, suitable references include, but are not limited to:

1. MIL-STD-810

2. RTCA DO-160

3. ISO7137

AS4941 also gives guidance on the qualification of components.

5.2 Part (b) - System Design

This part provides a series of requirements that are concerned with the design of the hydraulic system.

Design features that shall be considered for the elimination of undesirable conditions and effects are:

a. Design and install hydraulic pumps such that the loss of fluid to or from the pump cannot lead to events that create a hazard that might prevent continued safe operation. For example, engine driven pump shaft seal failure or leakage, in combination with a blocked fluid drain, resulting in engine gear box contamination with hydraulic fluid and subsequent engine failure.

b. Design the system to avoid hazards arising from the effects of abnormally high temperatures, which may occur in the system under fault conditions

5.2.1 FAR/CS/JAR 25.1435(b)(1)

This requirement states that:

Each hydraulic system must have means located at a flightcrew station to indicate appropriate system parameters, if:

a. It performs a function necessary for continued safe flight and landing; or

b. In the event of hydraulic system malfunction, corrective action by the crew to ensure continued safe flight and landing is necessary

5.2.1.1 FAR/CS/JAR 25.1435(b)(1) Additional Information

Appropriate system parameters may include, but are not limited to:

a. Pump or system temperatures and pressures

b. System fluid quantities, and

c. Any other parameters that give indication of the functional level of the hydraulic systems to the pilot

Indication of system pressure is normally provided by:

- A pressure transducer that sends electrical signals to a dedicated gage or is presented on a cathode ray tube (CRT) or flat panel displays, and

- A pressure switch or pressure transducer that gives a warning of low system pressure

Indication of fluid temperature is normally provided by:

- A transducer located in the system reservoir that sends electrical signals to a dedicated fluid temperature indicator or CRT or flat panel displays, and

- A high temperature warning provided by a temperature switch or temperature transducer located either in the hydraulic reservoir or in the pump case drain line(s)

Indication of system fluid quantity is normally provided by:

- A transducer located in the system reservoir that sends electrical signals to a dedicated fluid quantity indicator or CRT or flat panel displays, and

- A low quantity warning provided by a device that operates when the fluid in the reservoir falls below a predetermined level

5.2.2 FAR/CS/JAR 25.1435(b)(2)

This requirement states that:

Each hydraulic system must have means to ensure that system pressures, including transient pressures and pressures from fluid volumetric changes in elements that are likely to remain closed long enough for such changes to occur, are within the design capabilities of each element, such that they meet the requirements defined in FAR/CS/JAR 25.1435(a)(1) through (a)(5).

5.2.2.1 FAR/CS/JAR 25.1435(b)(2) Additional Information

Compliance may be shown by:

a. Designing the systems and elements to sustain the transients without damage or failure

b. Limiting the maximum pressure by:

   1. Providing dampers

   2. Introducing pressure relief devices, etc.

   3. Careful system design between solenoid valves and actuators, etc., to eliminate the possibility of system/component interactions causing large pressure transients

5.2.3 FAR/CS/JAR 25.1435(b)(3)

This requirement states that:

Each hydraulic system must have means to minimize the release of harmful or hazardous concentrations of hydraulic fluid or vapors into the crew and passenger compartments during flight.

5.2.3.1 FAR/CS/JAR 25.1435(b)(3) Additional Information

Harmful or hazardous fluid or vapor concentrations are those that can cause short term incapacitation of the flight crew or long term health effects to the passengers or crew. Compliance may be shown by taking design precautions, to minimize the likelihood of releases and, in the event of a release to minimize the concentrations.

Suitable precautions, based on good engineering judgment, include:

a. Separation of air conditioning and hydraulic systems installations

b. Shut off capability to hydraulic lines

c. Reducing the number of joints and elements, shrouding, etc.

d. If tubes are located in the crew and/or passenger compartments, then there shall be no separable tube joints and means provided to protect against the effects of pipe rupture in these areas

e. When the hydraulic system is installed under the cabin/flight deck floor, then the hydraulic and air systems' design teams shall co-ordinate a combined solution to ensure that no hydraulic mist can:

   1. Emerge in the flight deck or cabin areas, or

   2. Be returned into the airflow that is being re-circulated into the Environmental Control System (ECS).

In case of leakage, sufficient drainage shall be provided.

5.2.4 FAR/CS/JAR 25.1435(b)(4)

This requirement states that:

Each hydraulic system must meet the applicable requirements of FAR/CS/JAR 25.863, FAR/CS/JAR 25.1183, FAR/CS/JAR 25.1185, and FAR/CS/JAR 25.1189 if a flammable hydraulic fluid is used.

5.2.4.1 FAR/CS/JAR 25.1435(b)(4) Additional Information

Unless it has been demonstrated that there are no circumstances that can exist (on the airplane) under which the hydraulic fluid can be ignited in any of its physical forms (liquid, atomized, etc.), the hydraulic fluid shall be considered to be flammable.

Compliance with these requirements shall be by reports that analyze 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.

5.2.4.1.1 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 shall 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 wheel brakes or hot ducting

c. The ability to isolate Engine Driven Pump (EDP) suction lines during an engine fire by shutoff valves that are closed by the operation of the relevant engine fire handle

d. Providing ventilating air to prevent the buildup of vapors

5.2.4.1.2 Precautions for Engine Driven Pump Installations

When EDPs are used, the following precautions shall be taken:

a. The EDP shall be designed to be fire resistant and this shall be demonstrated by suitable testing, for example, in accordance with ISO2685

b. The EDP suction, pressure and case drain tube lines and any couplings that are used in them shall only be constructed from materials that are proven to be fire resistant where they are located in the firezone area

c. Any hoses that are located in the firezone shall have a means of protecting themselves from high temperatures. This is preferably by using integral firesleeves that meet the requirements of TSO C-140 and/or AS1055

5.2.4.1.3 Location of Hydraulic Reservoirs

There shall be no hydraulic reservoirs located in a designated fire zone. There must be at least 0.5 in (12.7 mm) 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.

5.2.4.1.4 Precautions for Electric Motor Driven Pumps

Electric motors that are used to drive hydraulic pumps must be explosion proof and proved by suitable testing. In addition, a locked rotor test shall be conducted on the electric motor pump assembly to check that there is no resulting hazard to the aircraft.

5.2.5 FAR/CS/JAR 25.1435(b)(5)

This requirement states that:

Each hydraulic system must be designed to use any suitable hydraulic fluid specified by the airplane manufacturer, which must be identified by appropriate markings as required by FAR/CS/JAR 25.1541.

5.2.5.1 FAR/CS/JAR 25.1435(b)(5) Additional Information

Compliance with this requirement shall be achieved by making specific references to the hydraulic fluid on labels adjacent to the system fill points and on the components in accordance with ARP1288 or ISO3323. In addition, all documentation concerned with the system or elements within the system shall specifically refer to the fluid where applicable, for example, in qualification reports, inspection, maintenance and overhaul manuals.

If more than one approved fluid is specified, the term “suitable hydraulic fluid” is intended to include acceptable mixtures.

5.3 Part (c) - Tests

The general part of this section states that:

Tests must be conducted on the hydraulic system(s), and/or subsystem(s) and elements, except that analysis may be used in place of, or to, supplement testing where the analysis is shown to be reliable and appropriate. All internal and external influences must be taken into account to an extent necessary to evaluate their effects, and to assure reliable system and element functioning and integration. Failure or unacceptable deficiency of an element or system must be corrected and be sufficiently re-tested, where necessary.

5.3.1 FAR/CS/JAR 25.1435 Part (c) Additional Information

Test conditions shall be representative of the environment that the element, subsystem or system may be exposed to in the design flight envelope. This may include loads, temperatures, altitude effects, humidity, and other influences (electrical, pneumatic, etc.). Testing may be conducted in simulators, stand-alone rigs, integrated laboratory rigs, or on the airplane. The test plan shall describe the objectives and test methods. All interfaces between the airplane elements and the test facilities shall be adequately represented.

5.3.2 FAR/CS/JAR 25.1435(c)(1)

This requirement states that:

The system(s), subsystem(s), or element(s) must be subjected to performance, fatigue, and endurance tests representative of airplane ground and flight operations.

5.3.2.1 FAR/CS/JAR 25.1435(c)(1) Additional Information

Testing for performance shall demonstrate rates and responses required for proper system operation. Testing for fatigue and endurance shall be sufficient to show the assumptions used in demonstrating compliance with FAR/ CS/JAR 25.1309 are correct, but are not necessary to demonstrate airplane design life.

An acceptable test approach for fatigue or endurance testing is to:

a. Define the intended element life

b. Determine the anticipated element duty cycle

c. Conduct testing using the anticipated or an equivalent duty cycle

As part of demonstrating that the element(s), sub-system(s), or system(s) perform their intended functions, the OEM may select procedures and factors of safety identified in:

1. Accepted manufacturing practices

2. National standards

3. Military standards

4. Industry standards

This is contingent upon that it being established that the procedures and factors are suitable for the intended application. Minimum design factors specified in those standards or the regulations may be used unless more conservative factors have been agreed to with the Airworthiness Authorities.

5.3.3 FAR/CS/JAR 25.1435(c)(2)

This requirement states that:

The complete system must be tested to determine proper functional performance and relation to the other systems, including the simulation of relevant failure conditions, and to support or validate element design.

5.3.3.1 FAR/CS/JAR 25.1435 (c)(2) Additional Information

The tests shall include the simulation of hydraulic system failure conditions in order to investigate the effects of those failures, and to correlate with the failure conditions considered for demonstrating compliance with FAR/CS/JAR 25.1309. Relevant failure conditions to be tested are those that cannot be shown to be extremely improbable and have effects assessed to be major, hazardous, or have significant system interaction or operational implications.

5.3.4 FAR/CS/JAR 25.1435(c)(3)

This requirement states that:

The complete hydraulic system(s) must be functionally tested on the airplane in normal operation over the range of motion of all associated user systems. The test must be conducted at the system relief pressure or 1.25 times the DOP if a system pressure relief device is not part of the system design. Clearances between hydraulic system elements and other systems or structural elements must remain adequate and there must be no detrimental effects.

5.3.4.1 FAR/CS/JAR 25.1435 (c)(3) Additional Information

Compliance with FAR/CS/JAR 25.1435(c)(3) can be accomplished by applying a test pressure to the system using airplane pumps or an alternate pressure source (for example, a hydraulic power ground cart). The test pressure to be used shall be just below the pressure required to initiate system pressure relief (cracking pressure). Return and suction pressures are allowed to be those that result from application of the test pressure to the pressure side of the system.

Some parts of the system(s) may need to be separately pressurized to ensure the system is completely tested. Similarly, it may be permissible that certain parts of the system need not be tested if it can be shown that they do not constitute a significant part of the system with respect to the evaluation of adequate clearances or detrimental effects.

6. DESIGN PRACTICES AND GUIDELINES

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

6.1 Pressure Limitations

6.1.1 System Pressure

The maximum transient pressure should not exceed 125% of the design operating pressure in order to minimize potential component and tube line failures. However, the components may be designed to a higher DOP to account for surge pressures greater than 125%.

The hydraulic reservoir pressure should be as low as practical 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 to supply fluid to the pump should be calculated using the guidelines provided 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 shall 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 should also be designed such that malfunctioning of any unit will not render any other subsystem, emergency system, or alternate system inoperative because of back pressure. In addition, consideration shall 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 that 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.

In addition, 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 Fluid Velocity Limitations

Aircraft manufacturers generally have their own guidelines for selecting the fluid velocity limits used for initial tubing sizing. The following fluid velocities can be used for initial tubing sizing if other guidelines are not available:

a. Through high pressure lines - limit to 30 ft/s (9.1 m/s)

b. Through return lines - limit to 15 ft/s (4.6 m/s)

c. Through case drain lines - limit to 10 ft/s (3.0 m/s)

d. Through suction lines - limit to 5 ft/s (1.5 m/s)

Further refinement of the tube line diameters should be conducted using fluid power simulation computer programs in order to optimize the system performance by considering, but not limited to, the following:

1. The allowable pressure drop at minimum required operating temperatures

2. Limit pressure surges, caused by high fluid velocity and fast response valves

3. Prevent inadvertent operation of locking mechanisms within actuators, etc.

4. Limit the back-pressure in return lines as the DOP for return lines is based on the maximum pressure that is expected in normal operation (see 5.1.1.1). In addition, high back pressures may affect brake operation, and pump outlet pressure if the pump senses case drain pressure for regulation purposes

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

6.2.1 Fluid Flow Effects

The system shall 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 multi-pump operation, or reduced engine speed. The system shall 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.

6.3 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 ensure that the subsystem essential to flight operations can still be supplied

6.4 System Filling

Ideally, there should be a built in pump that can transfer fluid from a container into the system. In addition, connections should also be provided to permit the hydraulic system(s) to be filled by low pressure replenishment methods. Self-sealing half couplings or check valves with an AS4396-6 or AS33656-6 end fitting are often used for attachment to the ground filling connection. A dustcap should be provided, with a safety chain, to protect the fill connection when not in use. Each system shall have an easy-to-read fluid quantity indicator that is clearly visible.

Any fluid that enters the system shall be filtered prior to it entering the system return circuit, preferably by a nonbypass type filter with a filtration rating that is equal to or better than the aircraft's system filters.

6.5 Removal of Entrapped Air

Suitable means, such as bleeder valves, shall be provided for the removal of entrapped air. Types of bleeder valves that could be used include those in accordance with AS5169, AS28889, and MIL-V-81940. 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 and not being able to return to the reservoir. This condition can also occur when four-way valves are used, particularly when the length of tubing between the valve and the actuator is long

The bleeder valves shall be so located that they can be operated without necessitating the removal of other aircraft components. The valves shall 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 necessary to install an automatic bleed valve, particularly at the reservoir, to vent undissolved air from the hydraulic system without operator intervention in addition to manual bleed valves. 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 shall 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.

6.5.1 System Air Tolerance

The system shall be designed and configured such that the presence of entrapped air in actuators and motors does not cause a sustained loss of system pressure or degradation of system performance during all conditions of intended performance. When conducting calculations that 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 example, an OEM might use 85,000 to 100,000 psi (586,054 to 689,476 kPa) as the bulk modulus for AS1241 phosphate-ester hydraulic fluid to account for air in the system.

6.6 Subsystem Pressure

Any subsystems which use a pressure lower than the full system pressure shall be designed to withstand and operate under the full pressure or shall 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.

6.7 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 causes major maintenance penalties in the subsequent draining, replenishment or functioning of the systems to transfer the fluid back to the original reservoirs. However, as noted in 3.4, it is acknowledged that acceptable design practices and in-service experience has allowed a deviation from this requirement at the wheel brakes. Two hydraulic sources typically supply a single set of brake pistons due to space and/or weight considerations.

7. COMPONENTS

7.1 General

All components shall be designed and tested in accordance with AS4941 requirements.

7.2 Pumps

AIR1922 provides guidelines for the integration of hydraulic pumps within the aircraft hydraulic system.

Where two (or more) pumps are connected to a common supply line, care must me taken to ensure that there is no interaction between the pumps' compensators. This could result in the loss of pressure control, excessive pressure transients, etc. Refer to AIR4543 for techniques to prevent this problem.

There should be the facility to isolate or depressurize or turn off all the pumps in a system in the event of a system low quantity warning and thereby minimize the effect of fluid loss on the pumps and the system.

In order to preserve shaft seal life and other pump components, the pressure at the case drain connection should be kept to the minimum possible under normal operating conditions. All external leakage from the pump shaft drain should be routed to a collector tank with a vent if practicable; otherwise drain overboard.

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

Although the pump outlet pressure ripple is typically 90 to 110% of the pump average discharge pressure, significantly lower pressure ripple levels should be specified. This is due to the need to:

a. Reduce the vibration levels that can be generated in the pump delivery lines due to the effect of the pressure ripple. This is because the vibration levels can affect the piping installations in the engine pod/pylon areas, such that tubes fail or the fittings loosen to cause hydraulic leaks

b. Reduce the noise that is caused by the pressure ripple

7.2.1 Variable Displacement Pump

Variable displacement, pressure compensated pumps shall be designed and qualified in accordance with AS595, ISO8278, or ISO12334 requirements.

7.2.2 Fixed Displacement Pump

Fixed displacement pumps should not be used as the main source of fluid power in any aircraft hydraulic system, unless the system analysis demonstrates that this type of pump is more effective for the specific application.

7.2.3 Engine Driven Pump (EDP)

Engine driven variable displacement, pressure compensated pumps are usually used as the main power source for hydraulic systems.

The EDP shall be designed and installed such that loss of fluid to it cannot create a hazard that might prevent continued safe flight and landing. This is usually achieved by:

a. The use of a shear section in the pump drive shaft, or

b. To utilize a eutectic drive shaft

Thus, if the pump locked up due to continued running with no fluid, the shaft would fail thereby preventing failures in the power source for the pump, or pump explosions. Care shall be taken to ensure that the broken shaft does not cause any resulting damage to the engine accessory gearbox.

7.2.4 Electric Motor Driven Pump

Electric motor driven variable displacement, pressure compensated pumps can be used for normal, backup, emergency or ground servicing operation of hydraulic systems. AS5994 requirements should be used for guidance in selecting these pumps.

7.2.5 Power Transfer Unit (PTU)

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.

Dependant on the application, the PTU can:

a. Provide hydraulic power in one direction or in both directions

b. Utilize fixed displacement pump and motor or variable displacement, pressure compensated pump/motor with a fixed displacement pump/motor

The principles of construction, installation and operation of a PTU should follow the practices as detailed in ARP1280.

7.2.6 Air Turbine Driven Pump

Air turbine 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 pneumatic system parts of the air turbine driven pump assembly shall comply with the following regulations:

a. FAR/CS/JAR 25.1438 - Pressurization and pneumatic systems

b. FAR/CS/JAR 25.1461 - Equipment containing high energy rotors

These are additional to the FAR/CS/JAR regulations that are applicable for the pump as discussed in Sections 4 and 5. In addition, the air turbine drive pump assembly shall be designed for the unique considerations of:

1. Rapid startup acceleration

2. Number of starts/duty cycle

3. Noise

4. Bleed air duct and turbine burst

5. Overspeed

7.2.7 Manually Operated Pumps

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

a. To act as a backup pump

NOTE: This is a relatively rare application and is only used on small transport aircraft where the power demands are small. Normally, power driven backup pumps are used.

b. To function hydraulic services during ground maintenance and to recharge a parking brake accumulator

c. 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 shall 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 shall be capable of full priming and rated flow at the highest altitude at which pump operation is essential and intended.

A relief valve shall 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 (0.22 kN) 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).

7.3 Reservoirs

Hydraulic reservoirs shall conform to the requirements of AS5586

Each independent system shall have its own reservoir. In addition, if a part of a system is required to be a high integrity part of one of the independent systems such that it requires its own fluid supply, then the fluid can either:

a. Be stored in a dedicated part of the reservoir, or

b. Have its own reservoir that can be filled from the same fill point as for the main reservoir

The fill and vent lines for all hydraulic reservoirs shall be designed such that the rupture of any reservoir, fill or vent lines would not cause fluid exchange between reservoirs or loss of sufficient fluid from any other reservoir to impair system operation. Each reservoir shall be suitably protected by a relief valve to prevent failure or damage when there is a rapid discharge of the fluid from the system to the reservoir. Protection from overpressurization resulting from overfilling shall be incorporated into the reservoir subsystem.

Hydraulic reservoirs shall be designed such that it is not possible 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.

7.3.1 Reservoir Location

It is recommended that the reservoir should be located so that the following conditions are met:

a. A static head of fluid will be supplied to all pump(s) and hand-pump (if fitted and flight operable) in all normal flight attitudes of the aircraft

b. The length of suction line to the pump(s) is the minimum possible

c. Protection is provided from engine burst or tire debris damage

d. There should be ready access to the reservoir depressurizing valve without the need to open cowls or large fairings

7.3.2 Reservoir Venting

If a vent is provided in the reservoir, it shall be arranged so that loss of fluid will not occur through the vent during flight maneuvers or ground operations of the aircraft.

7.3.3 Reservoir Pressurization

7.3.3.1 Pneumatic Pressurization

If the hydraulic reservoir is pressurized by regulated engine bleed air, then the following shall be considered in the system design.

a. Pneumatic System Equipment: Each reservoir should have the following equipment:

   1. An outward (overboard) relief valve to protect the reservoir in the event of:

      - A failure of the pneumatic system regulating valve

      - The buildup of pressure which could occur with an overfilled reservoir, and/or fluid returning to the reservoir with the operation of unbalanced actuators

   2. There should be tubing provided to vent any air from the valve directly overboard and thereby prevent any build up 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 increases and the ambient pressure 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.

   3. 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. When an open line is provided to relieve outside-to-inside differential pressure, a 10-μm nominal vent filter should be provided.

   NOTE: 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.

4. A pressure gage to provide indication of reservoir pressure. This can be used when performing checks on the pneumatic system, or ensuring that the reservoir is correctly pressurized prior to the operation of the hydraulic system pumps.

NOTE: Care shall be taken when designing and installing a gage. This is because gage installations have been potential failure concerns because they can be installed with small size tubing, which in some installations, has resulted in vibration induced failures. It is prudent not to install these gages in numerous places because of this failure potential.

5. A 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 shall 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

6. A means to pressurize the reservoir from a ground rig, via a charge valve

7. 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

b. The pneumatic pressurization system should include the following:

1. Pressure regulating valves that incorporates:

- A regulation mechanism to regulate the air pressure to within the required tolerance of the required setting

- A filter to prevent particulates from the pneumatic source from entering the system

- A relief valve which prevents overpressurization of the reservoir following a failure of the regulation mechanism of the valve

- 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

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

c. 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.

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-engine speed envelope. This particularly relates to the engine stage at which the bleed air is tapped.

It should be noted that reservoir pressurization by bleed air does not generally need many changes in the air charge during a typical flight. One change occurs at start-up and changes also occur when there is a major fluid volume change from unbalanced actuator operation, typically when the landing gear retracts or deploys.

7.3.3.2 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 actual pressure to charge the reservoir shall 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

If the reservoir is pressurized via a charge valve, from a rig, then instructions should be provided that the charge 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 gage

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

The reservoir can also be in the form of a low pressure, maintenance-free accumulator, which is factory pre-charged with gas.

7.3.3.3 Hydraulic Pressurization

An alternative method of pressurizing reservoirs that incorporate a piston is to utilize the system 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 that is isolated from the main system by a check valve or a pressure maintaining 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.

This has the following benefits:

a. It minimizes the possibility of pump cavitation during the 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

7.4 Accumulators

The accumulators should be designed in accordance with ARP4378, ARP4379, or ARP4553 requirements and the standard drawings listed therein.

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

NOTE: Maintenance-free accumulators should be pre-charged with Helium if there are stringent performance requirements.

7.5 General Valve Requirements

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

7.5.1 Directional Control Valves

The installation of directional control valves shall be compatible with the control valve performance such that the system operation will not be affected by:

a. Back pressure

b. Interflow, or

c. Pressure surges

These effects 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.

Valves that are pressure and spring centered are preferable to valves that are only spring-centered.

7.5.2 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. 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. All controls shall be designed to prevent over or under travel of the valve control handle by the use of internal or external stops.

7.5.3 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:

1. Electrical means by the use of microswitches that are independent from those used for valve control

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

7.5.4 Incorrect Use of Check Valves

Check valves shall 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.

7.5.5 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.

7.6 Filters

All vent openings except actuator and valve seal vents or fluid exposed to breathing action should be protected by vent filter/dryers. Line filters, when installed in the aircraft system in close proximity to an accumulator, shall 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.

All filters should 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. It is recommended that the DPI is constructed so that it cannot be reset 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

All filters should incorporate 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.

7.6.1 Filter Element Requirements

Main return and pressure filter elements are commonly rated as 15-µm, 5-µm, or 3-µm absolute. However, filter performance is not constant but varies with flow rates, re-circulation, high and low fluid temperature, vibration, filter construction and other factors. Filters are now rated by the ratio of inlet contaminant measurement to that of egress measurement (Beta ratio) for maximum filter efficiency and protection of components. AIR887 provides a discussion on filter ratings. For commercial transport aircraft the $Beta_{10}$ rating of 75 is recommended.

The element should be the disposable type as it has been found that there are little economic benefits in using a cleanable element, and it is possible that harmful solvents used to clean the element can be introduced into the system. For data on disposable and cleanable elements see AIR787.

7.6.2 Filter Locations

Suction filters shall not 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.

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

7.6.2.1 Pressure Line Installation

A non-bypass 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.

7.6.2.2 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.

7.6.2.3 Pump Case Drain Line Installation

A filter should be fitted in the case drain line for each pump. Although protection of the system can be provided by a single filter, the use of individual case drain filters for each pump means that it is possible to identify which pump is generating contamination and therefore could be subject to incipient failure.

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

7.6.3 Replacement of Filter Elements

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.

7.6.4 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.

7.6.5 Integral Filtration in Components

Filtration should be incorporated in those items whose operation would 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.

Examples of where integral filtration should be used are:

a. Mechanically signaled servovalves that 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

7.7 Flow Regulators

Flow regulators may be used in the hydraulic system to limit the flow rate over a range of specified range of upstream pressures.

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

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

b. 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.

7.8 Snubbers

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

7.9 Relief Valves, System and Thermal Relief

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.

7.9.1 System Relief Valves

Provisions should be made to ensure that pressure in any part of the system does not exceed 125% of the design operating pressure of that part of the system.

Valves should be located in the hydraulic system wherever necessary to accomplish this pressure relief through the bypass of fluid 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.

NOTES:

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

2. The OEM may choose a relief valve setting other than 125% of the DOP, dependant upon other hydraulic system requirements.

7.9.2 Thermal Expansion Relief Valve

Relief valves should be installed as necessary to prevent component and/or system damage resulting from:

a. The thermal expansion of system fluid

b. The rise in gas charge pressure due to thermal effects in an accumulator

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 that the setting of the thermal valves be slightly higher than the system relief valves. 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.

7.10 Motors

All constant displacement motors should be in accordance with ISO9206 or ISO12333 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 motor shaft drain should be connected to a collector tank with a vent.

Where possible, the motor (and associated control valve(s), etc.) should be a line replaceable unit.

7.11 Actuators

The following documents should be used for the specification and testing of actuators:

a. Actuating cylinders, apart from those used for flight control servoactuators - MIL-PRF-5503

b. Flight control servoactuators - ARP1281

c. EHAs - ISO22072

End snubbing should be employed in the actuators if there is a concern of internal damage to the cylinders by the action of the actuator piston bottoming.

Care shall be taken to prevent binding and interference of the actuator ramrod in the rod bearings at the most adverse temperature extremes.

Any restrictors (orifices) that are used to control the rate of actuator speed shall not cause cavitation during any realistic loading condition, including the no load condition and any aiding load condition. Cavitation under these circumstances is defined as causing the pressure in the throat of the restrictor to drop below the vapor pressure of the fluid going through the restrictor. This will result in a two phase flow (fluid and gas bubbles) out of the restrictor instead of single phase flow (fluid only), forming unallowable free air within the hydraulic system. The system designer should provide an analysis of each restrictor to show that cavitation cannot occur.

The actuator shall incorporate a hydraulic or mechanical lock when it is required to hold a flight control surface in position following the loss of the hydraulic system. The lock shall be deactivated by the normal hydraulic system operation. Position locks within actuators (when fitted) should not unlock (or lock) as a function of fluid lubricity.

Where more than one actuator is used to operate a flight control surface, and each actuator is supplied by a different hydraulic system, the following points shall be taken into consideration:

1. Loss of one hydraulic system should not interfere with the operation of the remaining actuator(s).

2. Loss of one or more hydraulic systems should not allow the surface to flutter.

3. Consideration shall be given to minimize force fighting between the actuators. This is because of reduced dynamic performance and reduced actuator and structural life, which can occur if there are significant loads generated as the actuators fight against each other.

7.12 Self-Sealing Couplings

Self-sealing couplings may be used within a hydraulic system to improve the serviceability of the system during a "remove and replace" activity.

Typical locations where self-sealing couplings can be fitted include:

a. At each hydraulic pump in order that the pump can be replaced with minimal fluid loss and air inclusion. When engine driven pumps are used, self-sealing couplings shall also be installed at locations such as the pod/pylon interface in order that the powerplant section can be easily removed and replaced.

b. On all hydraulically operated brake installations where it is necessary to disconnect the brake line or brake unit in order to remove the brake discs or the wheel. This will provide the benefit of minimizing the requirements for bleeding the brakes. Under these circumstances, the self-sealing coupling should be attached to the brake.

c. At all other points in the hydraulic system which require frequent disassembly or, where convenient, to isolate parts of the system such as jacking and servicing one landing gear only. This is in order to reduce/prevent the loss/spillage of a large quantity of hydraulic fluid and/or the introduction of a large volume of air.

It should be noted, however, that the release or coupling torques for large sizes of self-sealing couplings cause them to be difficult to use.

Sufficient clearance should be provided around the coupling to permit connection and disconnection. Self-sealing couplings that are adjacent to each other should be of different size or be otherwise different that inadvertent cross connection of the lines cannot occur. Couplings shall conform to AS1709 or AS1896, as applicable.

7.13 Shuttle Valves

As noted in 6.7, there should not be any point in an aircraft where two or more independent hydraulic systems come together to supply a single service, with the exception of the wheelbrakes.

Shuttle valves should not be used in installations in which a force balance can be obtained on both inlet ports simultaneously which may cause the shuttle valve to restrict flow from the outlet port.

7.14 Pressure Switches

Pressure switches are used in a hydraulic system to provide indications of low system pressure, to control the use of backup pumps(s), etc. Adequate precautions should be taken to prevent chatter of the microswitch. In addition, if a diaphragm type pressure switch is used, a snubber or small orifice should be installed upstream of the switch. This is to protect the diaphragm, whose failure could cause the total loss of a hydraulic system fluid, from transient pressure spikes.

Pressure switches shall conform to the applicable requirements of MIL-DTL-9395.

7.15 Oil Coolers

As part of the design process, there should be a heat load analysis conducted to determine if oil coolers are required in order to prevent system fluid overheating during normal system in-flight and ground operations.

Oil coolers that are typically used on commercial aircraft utilize the following cooling media:

a. Fuel - The oil cooler is installed in the wing tank, fuel feed line or a dedicated fuel cooler pump line.

b. Air - Ambient air is blown or pulled through the oil cooler by a fan, ram air and/or an inducer

c. Exhaust Cabin Air - Air passes through the oil cooler under the action of cabin differential pressure to atmosphere

The cooler size and heat sink medium that is chosen needs to take into consideration the cyclic use of the aircraft and the potential upward creep of temperature due to repeated flights.

8. INSTALLATION PRACTICES AND GUIDELINES

This section describes the general practices used for the installation of hydraulic systems in commercial aircraft and provides guidelines for future aircraft hydraulic system designs.

8.1 General

All installations of components should be designed to accommodate the worst dimensional and operational conditions permitted in the applicable part, component specification, or component part standard.

All components should be installed and mounted to satisfactorily withstand:

a. All expected natural and induced environmental conditions,

b. Acceleration loads

c. Wrench loads

d. Vibration effect

e. Structural bending

f. Salt spray

g. Temperature

h. Pressure

i. Humidity, etc.

This means that the component and tubing mounting brackets and supports, etc., must be designed to ensure that these requirements are met. Of particular importance, therefore, is that the Design Handbook for the Company/aircraft should provide clear guidelines and procedures for the installation of hydraulic elements.

8.2 Installation of Actuators

Hydraulic actuators shall be installed so that they do not interfere with adjacent structure and are readily accessible. If possible, the actuators should be installed in a protected area, or if exposed, be protected from flying debris that may occur during takeoff and landing.

8.3 Installation of Accumulators

Accumulators shall 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 or flight deck.

Where possible, the accumulators should be installed vertically with the gas end below the fluid end. This prevents fluid from being trapped in the gas end and allows fluid leakage across the piston to be monitored and measured if desired.

Space shall be provided around the gas charging valve to permit the easy connection of the gas charging rig for those accumulators that require periodical gas charging.

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

8.4 Location of Hydraulic Tubing

Hydraulic drain and vent lines shall exhaust in areas where the fluid will not be blown into the aircraft, collect in pools in the structure or be blown onto or near exhaust stacks, manifolds or other sources of heat. Ideally, they should be connected to collector tanks with vent lines to go overboard.

Raised barriers or “NO STEP” signs shall be fitted to protect hydraulic lines installed across flat surfaces where they may be stepped on. In addition, tubing shall be located so that damage will not occur due to being used as handholds, or by manipulation of tools during maintenance. Hydraulic tubing should not be used to provide support of other aircraft system installations, such as wiring, other aircraft tubing, or similar installations.

Particular care must be taken in the design of the tubing such that it is protected against chafing by adjacent components, etc.

Where the hydraulic system and other aircraft system(s) are in close proximity to each other, it is recommended that specific precautions be taken in order to prevent possible hazards to the aircraft and/or personnel.

8.4.1 Lines Containing Other Fluids

Hydraulic lines should not be grouped with other lines carrying fluids. This is in order to prevent the possibility of inadvertent cross connection of different systems.

8.4.2 Electrical Systems

Care shall be taken in the routing of the hydraulic tubing with respect to being placed above electrical assemblies in order to minimize the risk of contamination of electrical plugs, components and wiring in the event of any hydraulic fluid leakage from the tubing. Hydraulic tubes should be routed below wire bundles, connectors, etc. In addition, if an electrical wiring clamp fails, the wires should not subsequently contact a hydraulic tube, or, if it does, the current in the electrical conductor must be less than that considered to be able to burn through the hydraulic line.

8.4.3 Environmental Control System (ECS)

The installation of the hydraulic and ECS systems should be such that they do not run close to each other, particularly where ECS ducting is subjected to high bleed air temperatures, etc.

This is in order to prevent:

a. Local heating of the hydraulic system

b. Parts of the ECS system from being contaminated by hydraulic fluid, particularly on ducting that contains high temperature air. If it is not possible to avoid the two systems from being adjacent to each other, then the hydraulic tube lines should be routed below the ECS ducting. Protection should be specified if some of the air conditioning system elements are subjected to temperatures greater than 450 °F (232 °C), either normally or following a failure.

8.4.4 Other Systems/Components

Systems or components that are sensitive to contamination by hydraulic fluid should be located sufficiently away from areas where fluid spillage is possible or else sealing or shielding should be provided.

A check should be made on the compatibility of all materials and finishes that are likely to come into contact with the hydraulic fluid.

8.5 Means of Providing Flexibility in Tube Lines

Means of providing flexibility shall be provided to connect points in a hydraulic pipeline between which relative motion or differential vibration exists. Any of the following should be used, as applicable, in the areas where these conditions can occur:

a. Hoses (see 8.8).

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. Attention shall be taken to the choice of wall thicknesses for the pipes when coiled.

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

d. Swivel joints should only be used in installations where it is not possible to install coiled/bent pipes or hoses as these have superior in-service life compared to swivel joints. Swivel joints shall be designed in accordance with MIL-J-5513 requirements, except that all pressure-to-atmosphere dynamic seal gland design shall be dual unvented. Where lines or fittings are used to drive the swivel joints, they should be adequately supported and be of sufficient strength to ensure a satisfactory operating installation. Rotating joints, that comprise several swivel joints, should be avoided.

NOTE: When using coiled or non-coiled tubing to provide flexibility, the tubing should be qualified by conducting a specific test program. This should comprise the application of angular displacements and pressure cycling on the tubing that would be representative of in-service conditions. The scatter factor to be applied on the number of cycles and angular displacements should be the same as that for a dedicated impulse pressure fatigue test on the tube.

8.6 Tubing

8.6.1 Tubing Materials

The high pressure tubing on the majority of commercial aircraft that are in production at the present time, is fabricated from either titanium alloy Ti 3Al 2.5V to AMS 4944, AMS 4945 or AMS 4946 (for 5080 psi (35,025 kPa) applications) specification or corrosion resistant steel (CRES) 21Cr-6Ni-9Ni to specification AMS 5561. It is recommended that titanium tubing should be used due to its lower weight and superior corrosion resistance compared to 21-6-9 CRES.

On the majority of currently built commercial aircraft, the tubing used in the return and suction parts of the hydraulic system is fabricated from 6061-T6 aluminum alloy to specification AMS-T-7081.

During the fabrication and installation of the tubing, care shall be taken to ensure that:

a. The ovality, wrinkles, scratches, etc. of the tubes at the bends are within limits

b. There are no preloads imposed on the tubing during their installation

This is because these factors can degrade the fatigue life of the tubes.

In addition, the means of attaching sleeves on to the tubes needs to be carefully evaluated. This is because it has been found there has been premature cracking failure of tubes that with some of the methods used.

8.6.2 Tubing Bends and Ovality

All bends should be uniform and conform to AS33611, except when overridden by the individual aircraft constructor's requirements. The minimum bend angle for tubes should not be less than 5 degrees in order to distinguish them from straight pipes. Between two successive tube bends, a straight length of tube should be used; the length of which shall be established by the aircraft designers and production engineers.

The maximum permissible ovality for the tubing materials shall be stated by the aircraft manufacturer for each aircraft program. Typical ovality limits that have been used are 3% for titanium alloys, 5% for corrosion resistant steels, and 10% for aluminum alloys. For tube flatness greater than the AS33611 limits, tubing prestress (autofrettage) using the guidelines of AIR1379 may be used to reduce the flatness to meet the requirements of AS33611 for tube assemblies.

8.6.3 Installation of Small Size Tubing

If tubes that are equal or smaller than 0.25 in (6.35 mm) diameter are used in hydraulic systems, particular care shall be taken to properly install, support and protect them from being used as a handhold.

8.6.4 Straight Tube Lines

Rigid lines routed between, and connected to, fixed components should contain a bend. This will give some degree of flexibility to cope with expansion, contraction and flexing.

8.6.5 Tubing and Fitting Identification

All hydraulic fluid lines shall be permanently marked in accordance with ISO12. A sufficient number of indents should be marked in conspicuous locations throughout the aircraft so that each run of line may be traced. This marking should indicate the unit operated and the direction of flow, such as LANDING GEAR UP ----> or FLAPS DOWN ---->. These markings should be repeated as often as necessary, particularly on lines entering and emerging from closed compartments, to facilitate maintenance work.

Where fittings are located in members, such as bulkheads and webs, each fitting location should be identified (placarded) as to system function, using the same terminology as on its connecting line. Where hydraulic tubes run in fuel tanks, the markings shall be applied using non-adhesive labeling methods.

8.6.6 Tubing Supports

The guidelines given in ARP1897 should be used. All hydraulic tubing should be supported from rigid structure by cushioned steel saddle clamps or by suitable multiple-tube block type clamps.

As noted in 8.4.4, particular attention must be paid to ensure that the cushion materials used in the clamps are compatible with the hydraulic fluid and the tubing. This is because:

a. The fluid can react with the wrong type of cushion material causing it to soften and possibly to disintegrate

b. The cushion material can react with the tubing material to cause corrosion in the tubing

Supports should be placed as near as practicable to bends to minimize the overhang of the tube. Provisions should be made in support locations to accommodate change in tubing length caused by expansion and contraction. Tubing should not be bundled together in order to facilitate their inspection and repair.

8.6.7 Tying

Elastomeric spacers should be used, where necessary, to eliminate the risk of vibration and contact. The angle between two crossed pipes should not exceed 20 degrees.

Tying pipes with tie-threads should be prohibited.

8.7 Design of System Installations

ARP994 should be used as a guide for the design of the installation of tubing and components.

8.7.1 Component Lines

Where two or more tubes are attached to a hydraulic component, there shall be means to prevent incorrect tube connections to the component. In addition, there shall be means within the component to ensure that the correct adapter only can be fitted. An example of how to achieve this is to utilize check valves with a male adapter on one end and a female adapter on the other end.

8.7.2 Pump Suction Lines

If practicable, pump suction lines should be so routed so as to prevent the breaking of the fluid column caused by gravity after engine shutdown and during the parking period. Where such routing is not possible, or where the reservoir cannot be located above the pump, suitable provisions should be installed to maintain the fluid column to the pump after engine shutdown. A swing type check valve in the suction port of the reservoir should normally maintain the fluid column to the pump.

8.7.3 Pump Case Drain Lines

If routing of a pump case drain line cannot be accomplished so that breaking of the fluid column by gravity after engine shutdown is prevented, then a check valve should be incorporated in the line.

8.7.4 Drain Lines

Drain or vent lines coming from the pump, reservoir, or other hydraulic components shall not be connected to any other line or any other fluid system in the aircraft in such manner in order to prevent the mixture of fluids.

8.7.5 Mounting of Lightweight Components

Lightweight components that do not have mounting provisions may be supported by the tubing installation, provided that the component is rigidly installed and does not result in destructive vibration or cause other adverse conditions to the tubing installation. If the unit is mounted between clampblocks, then the distance for spacings between the clampblocks for tubing (as called up by the airframe manufacturer) should be reduced by 20%.

Clamps or similar devices may be used to support such units to structure, provided that nameplates, flow-direction arrows or markings, or other data, are not obscured and that supporting member(s) do not affect the operation of the unit.

The use of saddle type clamps is recommended for supporting in-line components.

8.7.6 Vibration

The complete hydraulic system, including lines and components, should be designed to withstand the effect of vibration, pump pulsation, and shock loads encountered during the service life of the aircraft.

8.7.7 Tubing Clearances

Where tubing is supported to structure or other rigid members, a minimum clearance equal to the cushion thickness shall be maintained with adjacent structure, tubing or other installations. In areas where relative motion of adjacent component or tubing exists, for example, large fuel and pneumatic lines, a minimum clearance of 0.5 in (12.7 mm) for large aircraft (particularly in the pylon area) and 0.25 in (6.35 mm) for smaller aircraft shall be maintained under the most adverse conditions that will be encountered. In addition, clearances must be provided to enable line fittings to be connected or disconnected.

ARP994 provides data on tool clearances required for installation and repair of tubes using various types of fittings.

8.7.8 Corrosion Protection

All tubing in exposed areas, such as wheel wells and wing rear spar areas, should be adequately protected against corrosion. Particular attention should be paid to the protection of aluminum tubing where it goes through grommets (rubber bungs) prior to going into adjacent compartments and/or structure.

It is recommended that all tubes manufactured from aluminum alloy or CRES should be painted in order to prevent long term corrosion.

8.7.9 Manifolds

The reliability of the hydraulic system can be enhanced by the grouping of components of a subsystem, for example, braking, power generation, etc. on a manifold and using internal passageways inside the manifold to connect the components to each other. This has the advantage of eliminating tube connections and thereby reducing the probability of the loss of systems due to external fluid leakage. In addition, the maintainability of the system is enhanced by the grouping of components applicable to one subsystem at one location.

If possible, the manifold and its installation should be designed so as to permit the removal of all the components from the manifold without requiring any of the tubing to be disconnected from the manifold or the manifold to be removed from the aircraft.

The bosses for pipe connections in manifolds shall be in accordance with AS1300, AS5202, or AS5550 (for 5080 psi (35,025 kPa) applications) requirements. If there are holes in the manifold that are to be blanked off, then it is recommended that internally expanded plugs, in accordance with AS3121 to AS3132, shall be used. However, if it is necessary to use a removable plug with an elastomeric seal, then either an AS5169 type plug, wire-locked in position, or a ring locked fluid connection type shall be used.

When manifolds are located in fire zones, the manifolds shall be manufactured from stainless steel.

If the manifolds are installed in any other area, they can be manufactured from other materials (aluminum alloy or titanium) depending on aircraft/system requirements.

8.8 Hoses

Hoses should be used in the following places:

a. Where the hydraulic system operates components that are subjected to large deflections as they actuate devices, for example landing gear actuators, etc.

b. Where there could be installations of components, etc., which would be difficult to install/remove if they were hard piped

c. Where self-sealing couplings are fitted to components in order to either permit easy removal/replacement or to prevent spillage of fluid/ingress of air

8.8.1 Hose Assemblies

AIR1569 provides guidance on the design of the installation of hoses. Hose assemblies shall not be subjected to torsional deflection (twisting) when installed, or during system actuation.

AIR797 provides guidelines for selecting the hose assembly that is appropriate for each application.

High pressure PTFE hoses assemblies shall be qualified to AS604, AS1339, AS4098, TSO C-140 or MIL-H-85800, AS5951 and AS5960 (for 5080 psi (35,025 kPa) applications) requirements. Before specifying lightweight AS1339 hose assemblies in the pump delivery lines, the guidelines contained in AIR4092 should be referred to in order to check if the application of the hoses is suitable.

Hose assemblies used on landing gear assemblies should be the high pressure type for all applications. Hose fittings should be made from stainless steel when high or low pressure assemblies are located in the landing gear bays.

Medium pressure, wire outer braid, polytetrafluoroethylene (PTFE) inner lined hose assemblies shall be qualified to the applicable sections of MIL-DTL-25579 and TSO C-140 requirements.

Convoluted PTFE inner lined hoses may be used in low to medium pressure applications where the installation of the hose requires a tighter bend radius than could be achieved with a standard smooth bore hose. These hoses shall be qualified to AS620 or AS1227 and TSO C-140 requirements.

NOTE: TSO C-140 was issued July 17, 2002 and cancelled both TSO C-53 and C-75.

The above hose assemblies use permanently attached threaded fittings; however, if it is the airframe manufacturer's policy to permit the use of reusable fittings for spares replacements, then space needs to be provided to permit:

a. MIL-DTL-83298 hose and MIL-DTL-83296 fittings for high pressure hoses.

b. MIL-DTL-27267 hose and MIL-DTL-27272 fittings for medium pressure hoses

A carbon additive shall be in the PTFE inner tube wall. This is in order to dissipate any build up of electrostatic charge that is produced as hydraulic fluid flows through the hose. This is needed so as to prevent any pinholes in the PTFE tube being produced by a static charge passing through the inner tube to the hose wirebraiding.

8.8.2 Hose Support

The support of a flexible line should be such that it will never tend to cause deflection of the rigid lines under any possible relative motion that may occur. A flexible hose between two rigid connections may have excessive motion restrained where necessary but should not be rigidly supported as by a tight clamp around the outside diameter of the flexible hose.

Care shall be taken when selecting the type of clamps, etc, to be used and their location on the hose and in the selection and placement of the supports. This is in order to make certain that there is no restriction in the movement of the flexible line and that it does not rub on structure or adjacent members over the full range of its possible movement.

8.8.3 Hose Bend Radii

The minimum radius of the bend of hose assemblies shall be a function of hose size and flexing range to which the hose installation will be subjected. The minimum bend radii for hoses shall be as listed in the applicable hose specification.

8.8.4 Hose Protection

Hoses shall be suitably protected against chafing where necessary to preclude damage to the hose and to adjoining structure, tubing, other hoses, wiring, and other equipment. Integral braided chafe guards are recommended for hoses that are installed in landing gear bays. A metal baffle positioned between the hot surface and the hose should be used to protect any hose that is exposed to extreme hot surfaces such as hot bleed air ducting.

8.8.5 Provisions for Hose Elongation and Contraction

Hose assemblies shall be selected and installed such that elongation and contraction under pressure, within the hose specification limits, will not be detrimental to the installation either by causing strains on the end fittings or excessive binding or chafing of the hose.