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AEROSPACE - DESIGN AND INSTALLATION OF COMMERCIAL TRANSPORT AIRCRAFT HYDRAULIC SYSTEMS

TABLE OF CONTENTS

1. SCOPE . . . 6

1.1 Purpose . . . 6
1.2 Field of Application . . . 6

2. REFERENCES . . . 6

2.1 Applicable Documents . . . 6
2.1.1 SAE Publications . . . 7
2.1.2 FAR Publications from FAA . . . 8
2.1.3 NAS Standards . . . 8
2.1.4 International Standards Organization Standards . . . 8
2.1.5 Air Transport Association of America Documents . . . 9
2.1.6 Joint Aviation Authorities Committee Documents . . . 9
2.1.7 U.S. Government Publications . . . 9

3. OVERALL HYDRAULIC SYSTEM REQUIREMENTS . . . 10

3.1 General Requirements . . . 10
3.1.1 Design . . . 10
3.1.2 System Pressure . . . 11
3.1.3 Hydraulic Fluid . . . 11
3.1.4 Temperatures . . . 11
3.1.5 Seals . . . 12
3.1.6 Schematic Diagram . . . 12
3.2 Applicable Airworthiness Requirements . . . 12
3.3 Design Concept and Overall Layout Requirements . . . 13
3.3.1 Aircraft Utilizing a Single Main Hydraulic System . . . 13
3.3.2 Aircraft Utilizing Two Independent Hydraulic Systems . . . 14

TABLE OF CONTENTS (Continued)

3.3.3 Aircraft Utilizing More Than Two Independent Hydraulic Systems 14
3.3.4 Loss of Electrical Generated Power 14
3.3.5 Directional Control of the Aircraft on the Ground 15
3.3.6 Backup Power Sources 15
3.3.7 Protection Devices 15
3.4 Segregation Requirements 17
3.4.1 Engine Debris Considerations 17
3.4.2 Protection Against Flailing Tires and Tire Debris 17
3.4.3 Protection Against Flailing Shafts 18
3.4.4 Minimizing the Effect of Structural Damage 18
3.5 Maintainability Requirements 18
3.5.1 General 18
3.5.2 Provision of Labels 19
3.5.3 Minimizing the Requirement for Regular Servicing 19
3.5.4 Ease of Conducting Routine Servicing 19
3.5.5 Minimum Use of External Equipment 20
3.5.6 Provision for Ground Carts 20
3.5.7 Ease of Checking Internal Leakage 21
3.5.8 Ease of Filling and Bleeding the System 21
3.5.9 Ease of Flushing/Draining Fluid 21
3.5.10 Minimum Use of Special Tools 21
3.5.11 Use of Pressure Release (Dump) Valves 21
3.5.12 Use of Common Parts 22
3.6 Reliability Requirements 22

4. GENERAL HYDRAULIC SYSTEM AIRWORTHINESS REQUIREMENTS 23

4.1 FAR/JAR 25.581 - Lightning Protection 23
4.2 FAR/JAR 25.601 - General 23
4.3 FAR/JAR 25.603 - Materials 23
4.4 FAR/JAR 25.1301 - Function and Installation 23
4.4.1 Qualification of Each Component 24
4.4.2 Identification of Each Component 24
4.4.3 Installation Limitations 24
4.4.4 Demonstration of Satisfactory Operation 24
4.5 FAR/JAR 25.1309 - Equipment, Systems, and Installations 24
4.5.1 Correct Operation of the Hydraulic System 24
4.5.2 Hydraulic System Indicators and Warnings 25
4.6 JAR 25.1315 - Negative Accelerations 26
4.7 FAR/JAR 25.1322 - Warning, Caution, and Advisory Lights 26

5. SPECIFIC HYDRAULIC SYSTEM AIRWORTHINESS REQUIREMENTS 27

5.1 Part (a) - Design 27
5.1.1 FAR 25.1435(a)(1) 27
5.1.2 FAR 25.1435(a)(2) 27
5.1.3 JAR 25.1435(a) (1) 27
5.1.4 JAR 25.1435(a)(2) 28
5.1.5 FAR/JAR 25.1435(a)(3) 28
5.1.6 JAR 25.1435(a)(4) 28
5.1.7 JAR 25.1435(a)(5) 29

TABLE OF CONTENTS (Continued)

5.1.8 JAR 25.1435(a)(6) 29
5.1.9 JAR 25.1435(a)(7) 30
5.1.10 JAR 25.1435(a)(8) 30
5.1.11 JAR 25.1435(a)(9) 31
5.1.12 JAR 25.1435(a)(10) 31
5.1.13 JAR 25.1435(a)(11) 32
5.2 Part (b) - Tests and Analysis 32
5.2.1 FAR/JAR 25.1435(b)(1) 32
5.2.2 JAR 25.1435(b)(2) 33
5.2.3 FAR 25.1435(b)(2) 34
5.2.4 JAR 25.1435(b)(3) 35
5.3 Part (c) - Fire Protection 35
5.3.1 Prevention of Ignition of Fluid or Vapor 36
5.3.2 Precautions for Engine Driven Pump Installations 36
5.3.3 Location of Hydraulic Reservoirs 36
5.3.4 Precautions for Electric Motor Driven Pumps 36
5.4 Part (d) - Identification of Hydraulic Fluid - JAR Only 37

6. DESIGN PRACTICES AND GUIDELINES 37

6.1 Pressure Limitations 37
6.1.1 System Pressure 37
6.1.2 Back Pressure 37
6.2 Reservoir Pressurization 38
6.2.1 Pneumatic Pressurization 38
6.2.2 Gas Charge Pressurization 40
6.2.3 Hydraulic Pressurization 40
6.3 Fluid Velocity Limitations 41
6.3.1 Fluid Flow Effects 41
6.4 Subsystem Isolation 41
6.5 System Filling 42
6.6 Removal of Entrapped Air 42
6.6.1 System Air Tolerance 43
6.7 Subsystem Pressure 43
6.8 System Interconnections 43
6.9 Component Design 43
6.9.1 Standard Components 44
6.9.2 Fixed Orifices 44
6.10 Accumulators 44
6.11 General Valve Requirements 45
6.11.1 Directional Control Valves 45
6.11.2 Control Valve Actuation 45
6.11.3 Valve Position Indication 45
6.11.4 Incorrect Use of Check Valves 46
6.11.5 Installation of a Shutoff Valve and Check Valve in the Same Subsystem . 46
6.12 Filter Requirements 46
6.12.1 Filter Element Requirements 46
6.12.2 Filter Locations 47
6.12.3 Hydraulic Sequencing 47
6.12.4 Integral Filtration in Components 48
6.13 Flow Regulators 48

TABLE OF CONTENTS (Continued)

6.14 Snubbers 48
6.15 Pumps 48
6.15.1 Variable Displacement Pumps 49
6.15.2 Fixed Displacement Pumps 49
6.15.3 EMPs 49
6.15.4 PTUs 49
6.15.5 Air Turbine Driven Pumps 49
6.15.6 Manually Operated Pumps 40
6.16 Motors 51
6.17 Relief Valves, System and Thermal Relief 51
6.17.1 System Relief Valves 51
6.17.2 Thermal Expansion Relief Valve 51
6.18 Reservoirs 52
6.18.1 Reservoir Location' 52
6.18.2 Reservoir Venting 52
6.19 Actuators 52
6.20 Self-Sealing Couplings 53
6.21 Shuttle Valves 54
6.22 Pressure Switches 54
6.23 Swivel Joints 54
6.24 Oil Coolers 54

7. INSTALLATION PRACTICES AND GUIDELINES 55

7.1 General 55
7.2 Installation of Actuators 55
7.3 Location of Hydraulic Tubing 55
7.3.1 Lines Containing Other Fluids 56
7.3.2 Electrical Systems 56
7.3.3 Environmental Control System (ECS) 56
7.3.4 Other Systems/Components 56
7.4 Tubing 57
7.4.1 Tubing Materials 57
7.4.2 Tubing Bends and Ovality 57
7.4.3 Installation of Small Size Tubing 58
7.4.4 Straight Tube Lines 58
7.4.5 Tubing and Fitting Identification 58
7.4.6 Tubing Supports 58
7.4.7 Tying 58
7.5 Design of System Installations 58
7.5.1 Component Lines 59
7.5.2 Pump Suction Lines 59
7.5.3 Pump Case Drain Lines 59
7.5.4 Drain Lines 59
7.5.5 Mounting of Lightweight Components 59
7.5.6 Vibration 59
7.5.7 Tubing Clearances 59
7.5.8 Corrosion Protection 60
7.5.9 Manifolds 60
7.6 Hoses 60
7.6.1 Hose Assemblies 60

TABLE OF CONTENTS (Continued)

7.6.2 Hose Support 61
7.6.3 Hose Bend Radii 61
7.6.4 Hose Protection 61
7.6.5 Provisions for Hose Elongation and Contraction 62
7.7 Fittings 62
7.7.1 Permanent Fittings 62
7.7.2 Separable Fittings 62

8. NOTES 63

8.1 Intended Use 63
8.2 Key Words 63

1. SCOPE:

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

1.1 Purpose:

The purpose of this document is to provide in one document, information and guidelines to the designers of commercial aircraft hydraulic systems and components and to the engineering staff of airlines, including:

a. Reliability and maintainability requirements

b. Federal Aviation Regulations (FAR)/Joint Airworthiness Requirements (JAR) airworthiness regulations that are applicable to hydraulic systems

c. Design and installation practices

1.2 Field of Application:

This document applies to the hydraulic systems fitted to commercial transport aircraft that are designed to comply with FAR and/or JAR 25 regulations.

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 specification to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this 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, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AIR310	Fittings, Catalog of Flared, Flareless, Pipe Threaded, Port, Hose, and Other Type Tube Standard Connectors
ARP490	Electrohydraulic Flow - Control Servovalves
AS568	Aerospace Size Standard for O-Rings
AS595	Civil Type Aircraft Variable Delivery Hydraulic Pump
AS604	Hose Assembly, Tetrafluoroethylene, 400 °F, 3000 psi Hydraulic, Heavy Braid
ARP584	Coiled Tubing
ARP603	Impulse Testing of Hydraulic Hose Assemblies, Tubing and Fittings
AS620	High Temperature Hose Assembly, Convoluted Tetrafluoroethylene-, for Aircraft
AIR737	Aerospace Hydraulic and Pneumatic Specifications and Standards
ARP819	Fluid System Characteristics Affecting Hydraulic Pump Operation
AIR887	Liquid Filter Ratings, Parameters and Tests
ARP926	Fault/Failure Analysis Procedure
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 Fixed Displacement Aircraft 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
ARP1658	Visual Inspection Guide for Installed Hose Assemblies
AS1709	Coupling Assembly, Hydraulic Self-Sealing, Quick Disconnect
AS1896	Coupling Assembly, Self-Sealing, One Side Only, Hydraulic
ARP1897	Clamp Selection and Installation Guide
AIR1922	System Integration Factors That Affect Hydraulic Pump Life
AS3121	Plug Expansion - Aluminum, 2024-T4, Long, Standard and .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

2.1.1 (Continued):

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
AIR4057	Secondary Filters for Fluid Systems Reliability
AS4059	Aerospace Cleanliness Classification for Hydraulic Fluids
AIR4092	Investigation of PTFE "Melt" Phenomenon for High Pressure Hoses
ARP4146	Coiled Tubing - Titanium Alloy, Hydraulic Applications
AIR4150	Inspection of Inservice Airborne Accumulators for Corrosion and Damage
ARP4268	Aerospace Hydraulic System Sampling Points
ARP4378	Accumulators, Hydraulic, Cylindrical, Aircraft, Maintenance Free, Factory Precharged
ARP4379	Accumulators, Hydraulic Cylindrical, Aircraft
AS4396	Fitting End - Bulkhead Flared Tube Connection, Design Standard
AIR4543	Aerospace Hydraulics and Actuation Lessons Learned
ARP4553	Self Displacing Hydraulic Accumulators
AS4716	Gland Design, O-Rings and Other Elastomeric Seals
AMS 4944	Titanium alloy tubing, Seamless, Hydraulic, 3.0Al-2.5V, Cold Worked and Stress Relieved
AMS 5561	Steel Tubing, Welded and Drawn, Corrosion Resistant Steel, 9.0Mn-20Cr-6.5Ni-0.28N, High Pressure Hydraulics

2.1.2 FAR Publications from FAA: Federal Aviation Administration Documents, 800 Independence Avenue, SW, Washington, DC 20591.

FAR Part 25	Code of Federal Regulations, 14 CFR 1.1, part 25 Airworthiness Standards, Transport Category Airplanes
TSO-C75	Hydraulic Hose Assemblies

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

NAS1613	Packing, Preformed, O-ring, Ethylene Propylene Rubber
NAS1638	Cleanliness of Parts Used in Hydraulic Systems

2.1.4 International Standards Organization Standards: Available from ANSI, 1430 Broadway, New York, NY 10018.

ISO 12	Pipelines, Identification Schemes
ISO 2685	Environmental Test Conditions for Airborne Equipment - Resistance to Fire in Designated Fire Zones

2.1.4 (Continued):

ISO 3323	Aircraft, Hydraulic Components, Marking to Indicate Fluid for Which Component is Approved
ISO 5859	Aerospace, Graphic Symbols for Schematic Drawings of Hydraulic and Pneumatic Systems and Components
ISO 9206	Aerospace, Constant Displacement Hydraulic Motors, General Specifications
ISO 11217	Aerospace, Hydraulic System Fluid Contamination, Location of Sampling Points and Criteria for Sampling
ISO 11218	Aerospace, Cleanliness Classification for Hydraulic Fluids

2.1.5 Air Transport Association of America Documents: Available from The Air Transport Association of America, 1709 New York Avenue, NW, Washington, DC 20006-5206.

MSG-3	Airline/Manufacturer Maintenance Program Planning Document

2.1.6 Joint Aviation Authorities Committee Documents: Available from The Civil Aviation Authority, Printing and Publication Services, Grenville House, Cheltenham, Glos. GL50 2BN, United Kingdom.

JAR 25	Joint Airworthiness Requirements, Large Aeroplanes

2.1.7 U.S. Government Publications: Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-B-5087	Bonding, Electrical and Lightning Protection, for Aerospace Systems
MIL-H-5440	Hydraulic Systems, Aircraft, Design and Installation, Requirements for
MIL-A-5498	Accumulators, Aircraft Hydropneumatic Pressure
MIL-A-5503	Cylinders: Aeronautical, Hydraulic Actuating, General Requirements for
MIL-J-5513	Joints, Hydraulic Swivel
MIL-R-5520	Reservoirs, Aircraft, Hydraulic, Non-separated Type
MIL-H-5606	Hydraulic Fluid, Petroleum Base; Aircraft, Missile and Ordnance
MIL-P-5994	Pump, Hydraulic, Electric Motor Driven, Variable Delivery, General Specification for
MIL-T-7081	Tube, Aluminum Alloy, Seamless, Round, Drawn, 6061, Aircraft Hydraulic Quality
MIL-P-7858	Pump, Hydraulic, Power Driven, Fixed Displacement
MIL-M-7997	Motors, Aircraft Hydraulic, Constant Displacement, General Specification for
MIL-H-8775	Hydraulic System Components, Aircraft and Missiles, General Specification for
MIL-R-8791	Retainer, Packing, Hydraulic and Pneumatic Tetrafluoroethylene Resin
MIL-V-8813	Valves: Aircraft, Hydraulic Pressure Relief, Type II Systems
MIL-F-8815	Filter and Filter Elements, Fluid Pressure, Hydraulic Line, 15 Micron Absolute and 5 Micron Absolute, Type II Systems, General Specification for

2.1.7 (Continued):

MIL-R-8931	Reservoirs: Aircraft and Missile, Hydraulic, Separated Type
MIL-S-9395	Switch Pressure (Absolute Gauge and Differential Specification for
MIL-F-18280	Fittings, Flareless Tube, Fluid Connection
MIL-V-19068	Valves, Shuttle, Hydraulic, Aircraft, Type II Systems
MIL-C-25427	Coupling Assembly, Hydraulic, Self-Sealing, Quick Disconnect
MIL-H-25579	Hose Assembly, Tetrafluoroethylene, High Temperature, Medium Pressure, General Requirements for
MIL-H-27267	Hose Tetrafluoroethylene, High Temperature, Medium Pressure
MIL-H-27272	Fitting, Tetrafluoroethylene, Hose, High Temperature, Medium Pressure, General Requirements for
MIL-R-83248	Rubber, Fluorocarbon Elastomer, High Performance Fluid and Compression Set Resistant
MIL-H-83282	Hydraulic Fluid, Fire Resistant Synthetic Hydrocarbon Base, Aircraft
MIL-H-83296	Fittings, Tetrafluoroethylene Hose, High Temperature, High Pressure (3000 psi), Hydraulic and Pneumatic
MIL-H-83298	Hose, Tetrafluoroethylene, High Temperature, High Pressure (3000 psi), Hydraulic and Pneumatic
MIL-P-83461	Packing, Preformed, Petroleum Hydraulic Fluid Resistant, Improved Performance at 275 °F
MIL-R-83485	Rubber Fluorocarbon Elastomer Improved Performance at Low Temperatures
MIL-STD-1247	Markings, Functions and Hazard Designations of Hose, Pipe and Tube Lines for Aircraft, Missile and Space Systems
MS24391	Plug-Bleeder, Tube, Precision Type
MS33566	Fittings, Installation of Flareless Tube, Straight-Threaded Connectors
MS33649	Bosses, Fluid Connection - Internal Straight Thread
MS33656	Fitting End, Standard Dimensions for Flared Tube Connection and Gasket Seal

3. OVERALL HYDRAULIC SYSTEM REQUIREMENTS:

3.1 General Requirements:

3.1.1 Design: If the aircraft is flyable, it must be controllable under normal operating conditions. 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 must still be controllable.

If the hydraulic system is required for the aircraft to be controllable, then the flight critical hydraulic systems and their components must be designed to operate satisfactorily under all conditions that the aircraft may encounter within its 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.

3.1.2 System Pressure: The normal working pressure used in commercial aircraft hydraulic systems is 3000 psi (20 690 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.

3.1.3 Hydraulic Fluid: Fire resistant phosphate-ester hydraulic fluid conforming to AS1241 is generally used in most commercial aircraft hydraulic systems and should be used for airborne hydraulic systems as well as associated ground support equipment. However, fluid conforming to MIL-H-5606 or MIL-H-83282 can be used under certain circumstances, recognizing the different characteristics of the fluid types. It must be noted that:

a. AS1241 fluids are not mixable or interchangeable with MIL-H-5606 or MIL-H-83282 fluids

b. The seals used for AS1241 fluids are incompatible with the other fluids, and vice versa.

Therefore, hydraulic systems designed for use with AS1241 fluids cannot use MIL-H-5606 or MIL-H-83282 fluids and vice versa.

3.1.4 Temperatures: Each hydraulic system should be designed for operating in ambient temperatures that are dictated by the individual aircraft operating requirements and be nondegraded 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 soakbacks, 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 should 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.

However, it should be noted that the lower limit for ground cold soak ambient and operating temperatures for aircraft using MIL-H-83282 hydraulic fluid should 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.

3.1.5 Seals:

3.1.5.1 Gland Design: Seal gland dimensions should conform to the requirements of **AS4716,** except for specialized proprietary packings.

3.1.5.2 Packings: The elastomer material for O-ring seals should conform to **NAS1613** that are used in systems or components that use AS1241 phosphate-ester hydraulic fluid. If **MIL-H-5606** or **MIL-H-83282** hydraulic fluid is used, then the elastomer material for the O-ring seals should conform to **MIL-R-83248, MIL-P-83461** or **MIL-R-83485.** Wherever possible, the O-rings should conform to aerospace dimensional standards such as **AS568.**

3.1.5.3 Backup Rings: For O-rings with operating pressures above 1500 psi (10 345 **kpa),** backup rings should be installed. Materials in accordance with **MIL-R-8791** are often used for backup rings. **MIL-R-8791/1** provides dimensions for backup rings for many AS568 sizes.

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

3.2 Applicable Airworthiness Requirements:

Modern day commercial transport aircraft are designed to meet the airworthiness requirements of the Federal Airworthiness Regulations (FAR), Part 25 (for US certified aircraft) or the Joint Airworthiness Requirements (JAR), Part 25 (for non-US certified aircraft).

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

25.581 Lightning protection
25.601 Design and construction - general
25.603 Materials
25.671 Control Systems - general
25.672 Stability augmentation and automatic and power operated systems
25.729 Retracting mechanisms
25.863 Flammable fluid protection
25.903 Engines
25.1183 Flammable fluid - carrying components
25.1185 Flammable fluids
25.1189 Shutoff means
25.1301 Function and installation

3.2 (Continued):

25.1309 Equipment, systems and installations
25.1315* Negative accelerations
25.1322 Warning, caution and advisory lights
25.1435 Design of hydraulic systems

* JAR requirement only

The impact of these regulations on the design of commercial transport 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 have to comply with the FAR/JAR requirements of 25.671, 25.672, 25.729 and 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.

Consideration has to 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 effect of a failure, or two failures, on the subsequent degree of difficulty in safely operating the aircraft has to be related to the probability of these failure(s) occurring.

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

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 supply to retracting/deploying the landing gear, then FAR/JAR 25.729(c) requires that an alternative means of deploying them must be available if they cannot be deployed **freefall.** Examples of the alternative means include a simple auxiliary hydraulic system or a stored gas system. 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 nonpowered or

b. The primary flight controls are hydraulically powered but they can be operated mechanically if there is a total loss of hydraulic power.

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:

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

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

c. Provide a second power source (hydraulic or electric) for flap deployment if flaps 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 a minimum of three hydraulic systems will be required. However, if there is a large number of services that are powered hydraulically, four independent hydraulic systems may be a design solution in order to reduce the size of the main and backup pumps, optimize the redundancy of the supplies to the hydraulic services, etc. In addition, more than three systems may be required when considering engine burst, tire burst, mid-air collisions, and other system failures. Nevertheless, the aircraft must still be capable of making a safe landing with only one hydraulic system remaining. 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:

3.3.4 (Continued):

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 should 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, then 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 has to 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 has to comply with FAR/JAR 25.671(d). This states that the aircraft has to be controllable if all engines fail. In order to meet this requirement, the aircraft should 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 should 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. 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:

3.3.7.1 (Continued):

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

b. A pump which 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 the pressurized fluid in 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 should 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 basically 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 nonessential 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 which 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 which could damage the system. Consideration has to 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 Considerations: Consideration has to be given to the effects of **noncontained** engine bursts, as required by FAR/JAR 25.903(d)(l) 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 **noncontained** 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 might have to be installed in the fuel tank areas in the wing with the other systems installed on the wing forward and rear spars. In addition, if the hydraulic bays are all located within the engine burst zones, then the bays should be as far apart from each other as practically possible.

On some occasions, 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 systems in this area would prevent the aircraft from being controlled. Therefore, consideration should 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/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 no more than one system when a redundant system remains functional.

3.4.2 (Continued):

In addition, the tubing in this area should not be manufactured from aluminum alloy. 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 have 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: It is essential to ensure that the damage caused by flailing shafts, for example, a broken flap drive shaft, is limited to, at worst, the loss of a single hydraulic system. In order to ensure this, care must be taken to limit the maximum possible movement of failed driveshafts and to separate independent hydraulic systems near driveshaft locations.

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 should 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 should 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. This can be achieved by avoiding having two or more hydraulic systems in close proximity to each other.

3.5 Maintainability Requirements:

The commercial transport aircraft has to be affordable and be able to operate with acceptable operating costs. Therefore, the hydraulic system has to be easy to maintain. The following are some of the features that should be included:

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.

3.5.1 (Continued):

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. Their installation should be such that it should never be necessary to remove a fully serviceable item or major airframe structure in order to gain access to a defective component or tube. 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.

Defective components should be easily identified, quickly and safely replaced, and be easily checked.

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. Typical labels include:

a. Hydraulic fluid used (see 5.4)

b. Instructions for filling/draining the reservoirs

c. Hydraulic reservoir pneumatic charging instructions (when applicable)

d. Accumulator gas charging instructions (see 3.5.4)

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 7.4.5.

3.5.3 Minimizing the Requirement for Regular Servicing: The system should be designed to require minimum periodic checks and servicing requirements. The need for hydraulic system checks should be derived using the principles laid down in the MSG-3 Airline Manufacturer Maintenance Program Planning document and from the findings of the System Safety Assessment. These checks should be agreed by the airframe manufacturer, airworthiness authorities and the aircraft operators.

Components should utilize on-condition monitoring rather than being removed for overhaul at regular intervals. There should be no parts which require a fixed interval removal and are critical to the safe operation of the aircraft.

3.5.4 Ease of Conducting Routine Servicing: 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.

3.5.4 (Continued):

If accumulators are fitted which are gas charged by ground servicing equipment, there should be a standard charging valve fitted and a permanent pressure gauge attached to the gas side of the accumulators. In the immediate vicinity of the charge valve/pressure gauge, there should be clear, easy-to-read instructions with a charge pressure-ambient temperature chart. These facilities should also be provided for the hydraulic reservoir if it is pressurized by dry air or nitrogen.

If it is required to take fluid samples, then the process should be as easy as possible but ensuring that the samples accurately reflect the condition of the fluid. Fluid sampling valves should be installed in each independent system, be located in a readily accessible area and should allow for the convenient use of sampling containers. ARP4268/ISO 11217 gives guidance regarding sampling valve locations.

For large transport aircraft, there should be a central ground servicing station provided for each independent system that includes connections for the attachment of ground test equipment for system checkout and flushing, reservoir filling (and bleeding if required). At this location, the filters can be monitored for clogging and the reservoirs checked for fluid level, etc.

In addition, it may be possible to centrally charge the gas side of accumulators. However, caution must be taken if the accumulators have different charge pressures.

Smaller transport aircraft should also be provided with a central ground servicing station for the hydraulic system.

3.5.5 Minimum 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.

3.5.6 Provision for Ground Carts: Each hydraulic system should have self-sealing couplings installed to permit the attachment of a hydraulic power ground cart to operate the system during initial installation or component replacement, major overhaul, and for the flushing of contaminated systems. The supply fluid from the hydraulic power carts should pass through the aircraft pressure filter. Fluid returning to the hydraulic cart should pass through a return filter of equal or better filtration capacity than the aircraft system filter.

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

3.5.6 (Continued):

a. Maximum system working pressure
b. Minimum required flow rate
c. Ground cart connections
d. System hydraulic fluid

3.5.7 Ease of Checking Internal Leakage: The system should be designed 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 servoactuator 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.

3.5.8 Ease of Filling and Bleeding the System: The system should be designed such that it is easy to fill the hydraulic system, and should 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.

3.5.9 Ease of Flushing/Draining Fluid: The system should be designed such that it is easy to flush or drain hydraulic fluid from the system in the event that the fluid exceeds the chemical or contamination limits that are specified by the airframe manufacturer. NAS1638 or AS4059/ISO 11218 can be used to specify fluid particulate classification levels. Chlorinated solvent and water contamination, acid number, kinematic viscosity and specific gravity limits should also be specified by the aircraft manufacturer.

3.5.10 Minimum 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.

3.5.11 Use of Pressure Release (Dump) Valves: Where accumulators are installed in subsystems that are isolated from the main system by check valves, pressure release valves should be fitted to depressurize the accumulator without having to operate the subsystem. The pressure release valves should 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 should 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.

3.5.12 Use of 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 which can be used in more than one filter assembly.

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

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

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

In addition, every effort should be made to eliminate the need to have unique designs for opposite side installations.

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 has to be very reliable and has to be designed to meet reliability guarantees as agreed between the airframe manufacturer, aircraft operators and airworthiness requirements. In order to achieve these guarantees, it is essential to make certain that the overall system design is sound. This can be achieved by regular reviews of the system by the system designers, reliability engineers and product support specialist engineers. 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 should be referred to as it provides data on lessons learned from a wide variety of problems.

In addition, the components within the system should be subjected to the same scrutiny. 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 which 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.

No single failure should cause the loss of more than one hydraulic system. Therefore, care should be taken to avoid points in a hydraulic system where two or more different hydraulic systems come together in one housing. This is because a common mode failure, for example, a cracked housing, could result in the loss of these systems. 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.

4. GENERAL HYDRAULIC SYSTEM AIRWORTHINESS REQUIREMENTS:

It should be noted that the comparable FAR and JAR requirements are not always the same. Both the FAR and JAR requirements are discussed where there are differences between them.

The detail design of each commercial transport aircraft hydraulic system has to be such that compliance can be demonstrated with the requirements of FAR/JAR 25.581, 25.601, 25.603, 25.1301, 25.1309, 25.1315 and 25.1322. These are general requirements that have an impact on the hydraulic system.

4.1 FAR/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 should be bonded and grounded to the aircraft in accordance with **MIL-B-5087** or the similar aircraft manufacturer's requirements.

4.2 FAR/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 should be emphasis placed on reviewing previous aircraft systems to identify safety problem areas that were encountered and to try 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/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/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 aircraft manufacturer and the equipment suppliers to ensure the parts are not subjected to conditions that exceed those to which the part has been qualified, for example:

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

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

4.5 FAR/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 which 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 should be considered:

a. Critical environmental conditions including vibration, and acceleration loads

b. The effect of system pressure on the hydraulic system, the equipment and the system installation

4.5.1 (Continued):

This may be demonstrated by:

a. Qualification testing of components
b. Aircraft and test rig (Iron Bird) testing of the hydraulic system
c. Design analysis
d. 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, has to be designed to minimize crew errors which could create additional hazards. In order to comply with this requirement, hydraulic systems usually provide the following indications and warnings:

a. The supply pressure in each independent hydraulic system

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

c. High hydraulic fluid temperature by an overheat warning light and/or a temperature gauge

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

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

f. Valve position indications to inform the flight crew of the ineffective operation of important selector valves such as those for pump and/or system isolation and landing gear retract/deployment.

The crew drills (check lists) shall utilize the information provided by the hydraulic system indicators and warnings. Therefore, the system operating procedures have to be written so that the flight crew are able to correctly diagnose the fault and take the necessary action to isolate hydraulic pumps, operate backup pumps, 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

4.5.2 (Continued):

indications that are provided. This can be achieved, for example, by comparing the pressure indicated on a gage to determine if there is a genuine low system pressure condition or if the pressure switch is defective.

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

4.6 JAR 25.1315 - 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 which 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/JAR 25.1322 - Warning, Caution, and Advisory Lights:

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

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

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

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

4.7 (Continued):

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

5. SPECIFIC HYDRAULIC SYSTEM AIRWORTHINESS REQUIREMENTS:

Each commercial transport hydraulic system has to comply with the requirements of FAR 25.1435 and/or JAR 25.1435 regulations. This section of the FAR/JAR Part 25 regulations contains the specific requirements for the design and testing of the hydraulic system. The JAR requirements are indicated where they are different from, or there is no equivalent FAR requirements.

5.1 Part (a) - Design:

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

5.1.1 FAR **25.1435(a)(1):** This requirement is concerned with the strength of the elements. Each element of the hydraulic system is to be designed to withstand the design operating pressure loads in combination with limit structural loads which may be imposed. No permanent or temporary deformation of the element is permitted under these conditions that would prevent it from performing its intended function.

5.1.2 FAR 25.1435(a)(2): This requirement is also concerned with the strength of the elements. Each element is required to withstand, without rupture, the design operating pressure loads multiplied by a factor of 1.5 in combination with limit (maximum operating) structural loads that can reasonably occur simultaneously. The design operating pressure is the maximum normal operating pressure, excluding transient pressure. It should be noted that it is acceptable to nominate an artificially elevated pressure to account for high surge pressures (see 6.1.1).

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

Some aircraft manufacturers choose to use **MIL-H-5440,** Table II requirements to determine the strength of the elements. The **MIL-H-5440** strength requirements are equivalent to, or exceed, the requirements of FAR **25.1435(a)(l)** and (a)(2).

5.1.3 JAR **25.1435(a)(l):** This requirement is identical to the FAR 25.1435 (a)(l) and (a)(2) requirement except that the term "design operating pressure" is not used. In its place are the terms "the working pressure" **Pw,** for elements other than pressure vessels or "the limit pressure" **Pl,** for pressure vessels. **Pw** and **Pl** are defined as follows:

Pw is the working pressure and should be equivalent to the maximum steady state pressure of the system and is normally the pump working pressure at the maximum tolerance of its nominal set pressure.

5.1.3 (Continued):

P1 is the limit pressure and is the anticipated maximum pressure likely to be experienced in a pressure vessel and should take into account rises in pressure due to thermal effects. An example of this is the rise in pressure that an accumulator can achieve as a result of hot/cold/hot temperature cycle. Under this condition, P1 is typically the accumulator thermal relief valve setting at its maximum tolerance.

5.1.4 JAR 25.1435(a)(2): This requirement is concerned with the flight deck indication of system pressure and fluid quantity for each independent hydraulic system if:

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

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

Indication of system pressure is normally provided by a pressure transducer that sends electrical signals to a dedicated gauge or is presented on a cathode ray tube (CRT) or flat panel displays and a pressure switch that gives a warning of low system pressure.

Indication of system fluid quantity is usually provided by a transducer located in the system reservoir which sends electrical signals to a dedicated fluid quantity indicator or CRT or flat panel displays, and a low quantity warning provided by a switch that operates when the fluid in the reservoir falls below a predetermined level.

5.1.5 FAR/JAR 25.1435(a)(3): There are currently no regulations in the third section of 1435(a) of both the FAR and JAR 25 requirements.

5.1.6 JAR 25.1435(a)(4): This requirement is in two sections and is concerned with the variation of system pressure which can occur during normal and failure conditions.

5.1.6.1 Pump Outlet Pressure Limitations: The first subpart of this requirement is concerned with the pump outlet pressure ripple which shall not exceed 90 to 110% of the pump average discharge pressure for each pump.

It should be noted that the aircraft manufacturers typically specify pumps with significantly lower pressure ripple levels. This can be 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.

5.1.6.2 Maximum Permitted System Pressure: The second subpart of this requirement is concerned with limiting the **maximum pressure** of any part of the system to less than 125% of the operating (FAR) or design working (JAR) pressure at that point in the system. This is concerned with:

a. Transient peak pressures which can occur when fast operating valves open or close, etc.

b. The maximum pressure that will be permitted by the system relief valves in the event of a pump pressure control failure or thermal relief valve operation.

It should be noted that it is acceptable to nominate an elevated working pressure to account for surge pressures that would be otherwise greater than the system operating or working pressure (see 6.1.1).

5.1.7 JAR 25.1435(a)(5): This requirement is in two parts and is concerned with the installation of the hydraulic system in the aircraft.

5.1.7.1 Installation of Each Hydraulic Element: The first part requires that each element be installed and supported to prevent excessive vibration, abrasion, corrosion, mechanical damage and to withstand inertia loads. This means that the component and tubing mounting brackets and supports, etc., must be carefully designed to ensure that these requirements are met. Of particular importance therefore is the Design Handbook for the Company/aircraft which must provide clear guidelines and procedures for the installation of hydraulic elements. In addition, each installation in the aircraft should be carefully scrutinized by the installation designer and the airworthiness authorities prior to the first flight.

5.1.7.2 Liberation (Leakage) of Hydraulic Fluid within the Fuselage: The second part is concerned with the prevention of hazardous or harmful concentrations of hydraulic fluid or vapors in the crew or passenger compartments during flight if the fluid is considered to be harmful to occupants when liberated in any form. It is considered that this particularly applies to AS1241 Phosphate-Ester hydraulic fluids. In order to comply with this requirement, particular precautions have to be taken with the hydraulic system installation in the pressurized part of the aircraft, including pressurized cargo compartments. If tubes are located in the crew and/or passenger compartments, then there should be no separable tube joints in these areas. When the hydraulic system is installed under the cabin/flight deck floor, then the hydraulic and air systems' design teams should co-ordinate a combined solution to ensure that no hydraulic mist can emerge in the flight deck or cabin areas, or be returned into the airflow which is being recirculated into the Environmental Control System (ECS).

5.1.8 JAR 25.1435(a)(6): This requirement calls for the means of providing flexibility to be provided to connect points in a hydraulic **tubeline** between which relative motion or differential vibration exists. In order to comply with this requirement, any of the following should be used, as applicable, in the areas where these conditions can occur:

5.1.8 (Continued):

a. Hoses (see 7.6)

b. Coiled tubing in accordance with ARP584 for steel tubing, ARP4146 for titanium tubing. Looped or straight aluminum tubing should not be used between two connections where there is designed relative motion. Attention should 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°)

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

When using coiled or noncoiled 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 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.

5.1.9 JAR 25.1435(a)(7): This requirement permits the limit of transient pressures to exceed 125% of the design operating pressure, as called up in JAR 25.1435(a)(4)(ii), provided that a survey is conducted on an aircraft or a representative hydraulic rig to determine their magnitude and frequency. Then an analysis or test has to be conducted to substantiate the fatigue strength on that part of the system using the results gained from the survey.

5.1.10 JAR 25.1435(a)(8): This requirement is concerned with the effect of loss of hydraulic fluid to each hydraulic pump and states that each pump must be designed and installed such that loss of fluid to the pump cannot create a hazard that might prevent continued safe flight and landing. This is usually achieved on engine driven pumps by the use of a shear section in the pump drive shaft or to utilize a eutectic drive shaft such that 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 should be taken to ensure that the broken shaft does not cause any resulting damage to the engine accessory gearbox.

In addition, it would be expected that during qualification testing of the pump, it should be demonstrated that an internally failed pump will not cause any external damage or loss of system fluid. It is also recommended that 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.

5.1.11 JAR **25.1435(a)(9):** This requirement calls for the prevention of abnormally high system temperatures in the event of a fault condition such as:

a. High internal leakage caused by a defective component

b. Loss of pump regulation control causing the pump flow to pass through the system relief valve

This is usually achieved by the isolating or **depressurizing** or turning off system pump(s) in the event of a hydraulic system high temperature warning. This is normally provided by a temperature switch which is often located in the main pump suction line at the system reservoir, or in the main pump case drain line, which is where the highest system temperature occurs.

5.1.12 JAR **25.1435(a)(10):** This requirement calls for the ability of all the elements in the hydraulic system to be able to withstand the loads due to the pressures given in Appendix J for the proof condition without leakage or permanent distortion and for the ultimate condition without rupture, at normal operating temperatures.

The Appendix J requirements are as follows:

a. For tubes, ducts and couplings, proof pressure = 1.5 Pw, ultimate pressure = 3.0 Pw.

b. For return line elements, there is no proof pressure requirement; however, ultimate pressure = 1.5 Pf where Pf is the maximum pressure applied during failure conditions.

c. For components other than tubes, couplings, ducts or pressure vessels, proof pressure = 1.5 Pw, ultimate pressure = 2.0 Pw.

d. For pressure vessels fabricated from metallic materials and connected to a line source of pressure, proof pressure = 3.0 Pl or 1.5 Pl; ultimate pressure = 4.0 Pl or 2.0 Pl.

NOTE: The lower values are conditional upon justification by a fatigue endurance test from which a permissible fatigue life is declared, and upon the ultimate load test being made on the test specimen used for the fatigue test.

e. For pressure vessels fabricated from metallic materials and not connected to a line source of pressure (for example, emergency vessels inflated from a ground source), proof pressure = 2.5 Pl or 1.5 Pl; ultimate pressure = 3.0 Pl or 2.0 Pl.

NOTE: The lower values are conditional upon justification by a fatigue endurance test of a suitably factored permissible number of inflation/deflation cycles, including temperature rise cycles if the ambient temperature fluctuation results in a significant variation, and upon the ultimate load test being made on the test specimen used for the fatigue test.

5.1.12 (Continued):

f. For all pressure vessels, the following requirements also apply:

(1) The minimum acceptable conditions for storage, handling and inspection are to be defined in the appropriate manual.

(2) The proof factor is to be sustained for at least 3 min.

(3) The ultimate factor is to be sustained for at least 1 min. The factor having been achieved, the pressure vessel may be isolated from the pressure source for the remaining portion of the test period.

Compliance of this requirement is demonstrated by qualification testing for components and tubing/manifolds, etc. The airworthiness authorities reserve the right to prescribe other factors for proof and ultimate strengths if the elements are constructed from materials other than aluminum alloy or medium strength steel. In all cases, the material used must be chosen to provide resistance to deterioration arising from environmental conditions of the installation, particularly from the effects of vibration.

It should be noted that these values are based on working and limit pressures up to and including 3000 psi (20 690 **kpa).** For higher pressures, the factors to be applied should be agreed between the aircraft manufacturer and the airworthiness authorities.

5.1.13 JAR **25.1435(a)(11):** This requirement calls for adequate allowance to be made for fatigue for those elements which are subjected to repeated internal or external loads. Compliance with this requirement is usually demonstrated by impulse testing and/or analysis of those elements which 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**

5.2 Part **(b) -** Tests and Analysis:

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

5.2.1 FAR/JAR **25.1435(b)(1):** This requirement calls for a once only static pressure test to be conducted on a complete aircraft hydraulic system. This is in order to demonstrate that it can withstand a pressure of 1.5 times the design operating (FAR) or working (JAR) pressure. This is required to show that there is no deformation in any part of the system that would prevent it from performing its intended function. In addition, it has to be demonstrated that there must be adequate clearances between

5.2.1 (Continued):

structural members and hydraulic system elements and there is no permanent deformation. It is recommended that the tests are to be conducted on a development aircraft during the aircraft flight development/certification program.

5.2.2 JAR 25.1435(b)(2): The entire aircraft hydraulic system or appropriate subsystem has to be tested, or an analysis has to be conducted (as appropriate) to demonstrate compliance with FAR/JAR 25.1309. The testing has to be conducted on an aircraft and/or hydraulic rig(s) (iron bird(s)) which is (are) fully representative of the aircraft installation. The tests that are to be conducted include:

5.2.2.1 Function Tests - Normal Operation: Functional tests that investigate normal operating conditions either on an aircraft or hydraulic rig(s) or both. The tests should be carried out to determine that the hydraulic system is functioning correctly and there are no points in the aircraft operating envelope that the hydraulic system does not perform correctly. Checks should be made that there are no interactions between subsystems, for example, and observing that there are no problems when different hydraulic systems are simultaneously operated.

5.2.2.2 Function Tests - Failures: Functional tests that investigate the effect of failures of the system including:

a. Failures of main system pumps such that the backup pumps and accumulators have to operate

b. Loss of hydraulic systems such that the remaining system(s) have to operate on their own

c. The effect of component failures

5.2.2.3 Endurance Tests: Endurance tests that simulate repeated complete flights that could be expected to occur in service. The number of endurance cycles required for the certification of the aircraft has to be agreed with the Airworthiness authorities.

It is recommended that a hydraulic rig or rigs (iron bird(s)) be used for the endurance testing and for some of the failure cases that would be difficult and/or hazardous to conduct on the aircraft. The testing has to take into account flight and ground loads and system working, limit and transient pressures but need not take into consideration loads due to vibration or temperature effects. However, simulation of operating and environmental conditions must be conducted on elements and appropriate portions of the hydraulic system to the extent necessary to evaluate the environmental effects. It is expected that this could be conducted during qualification testing conducted on the elements. Any part which fails during the testing has to be modified in order to have the design deficiency corrected and be sufficiently retested to prove the effectiveness of the modification.

5.2.3 FAR 25.1435(b)(2): This requirement is essentially identical to JAR 25.1435(b)(2) but also requires compliance with FAR 25.1309 to take into account the following.

5.2.3.1 Static and dynamic loads including flight, ground, hydrostatic, **inertially** and thermally induced loads, and combinations thereof: In order to comply with this requirement, a structural analysis is required to determine the loads that could be imposed on all the hydraulic system elements under normal and failure conditions.

The analysis work would be conducted by the aircraft manufacturer and the component suppliers, using data that would be provided by hydraulic system designers and structural load specialists. In order to confirm results of the structural analyses, specific structural strength tests might have to be conducted on selected hydraulic system elements.

5.2.3.2 Motion, Vibration, Pressure Transients, and Fatigue: This requirement is concerned with the need to ensure that the hydraulic system elements can withstand fluctuating loads, from different causes, that can be imposed on them throughout the life of the aircraft.

In order to satisfy this requirement, an analysis of the varying loads should be conducted by hydraulic system designers and the structural load specialists. In order to determine the frequency and magnitude of the loads, it might be necessary to obtain specific data from hydraulic rig or rigs (iron bird(s)) and/or flight testing of the aircraft. The data should then be supplied to the component suppliers in order for them to determine that their parts are able to withstand the varying loads.

It is expected that specific testing (for example, vibration, fatigue) would be required on hydraulic elements in order to confirm that they are able to comply with this requirement.

5.2.3.3 Abrasion, Corrosion, and Erosion: This requirement is concerned with the damage that can occur on hydraulic system elements due to a variety of means during the aircraft lifetime.

The installation of the hydraulic system and the components should take into account the environment that the elements can be subjected to. This is to ensure that they are able to operate reliably and without the need to regularly replace them.

In order to minimize the effects of erosion within the components, the following should be noted:

a. The hydraulic fluid temperature should be such that under normal and failure conditions, they will not cause any erosion of the elements.

b. The design of the components should be such that they are fully compatible with the hydraulic fluid and that internal erosion of the parts would not occur under normal operating conditions.

5.2.3.4 Fluid and Material Compatibility: This requirement is concerned with the need to ensure that the materials chosen for the hydraulic system elements must be compatible with the fluid that the system uses. If the materials and the fluid are not mutually compatible, either on a short or longer term basis, then failures of the element will occur, either through excessive internal or external leakage or due to **nonoperation** of the part.

During the design phases of the hydraulic system, the system design team should consistently and clearly state the hydraulic fluid that the system uses to all the design teams who are involved in the design of the aircraft. The component suppliers must be aware of the fluid so that they can ensure that their components are compatible with the fluid. In addition, the choice of materials for clamp blocks, P-clips, etc. must take into consideration the fluid used. The paint that is used in areas of the aircraft which could be subjected to splash or mist of the hydraulic fluid must also be compatible with the fluid.

5.2.3.5 Leakage and Wear: This requirement is concerned with the need to cater for the effect of leakage and wear that can occur in hydraulic system elements during the service life of the aircraft.

The design of the hydraulic system and its components should allow for the normal degradation which will occur under normal operating conditions. There should be sufficient margins built into the design of the system and the components such that the operation of the hydraulic system will not be degraded to an unacceptable level (for example, slow operation of services, fluid frequently overheating) over the lifetime of the aircraft.

5.2.4 JAR **25.1435(b)(3):** This requirement calls for the identification of those components that, if they fail, will significantly lower the airworthiness or safe handling of the aircraft. This is normally achieved during the reliability assessments of the system that have to be conducted in the form of a Failure Modes and Effects Analysis **(FMEA),** a Fault Tree Analysis **(FTA)** or a System Safety Analysis **(SSA)** that are required in order to demonstrate compliance with 25.671 and 25.1309 requirements. **ARP926** provides a guide for conducting fault or failure analyses. Those components which have been considered to fall into this category have to be qualified by suitable testing with particular emphasis on taking into account the most critical combination of pressures, temperatures and vibration which are applicable to the components.

It is recognized that testing with pressure and temperature cycling is more representative of real usage, and significantly more detrimental, than continuous long-term, single condition testing with little or no cycling.

5.3 Part **(c)** - Fire Protection:

This requirement calls for each hydraulic system that uses flammable hydraulic fluid to meet the applicable requirements of FAR/JAR 25.863, 25.1183, 25.1185 and 25.1189. The fire safety definitions insist that the hydraulic fluid used in modern day hydraulic systems should be considered to

5.3 (Continued):

be flammable even though they might be fire resistant. Compliance with these requirements will be by reports that deal with the fire safety aspects of all regions of the aircraft and which highlight particular design measures/procedures that have been incorporated in the aircraft. The following are examples of the various means that have been used:

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

a. Shrouding the installation where applicable

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

5.3.2 Precautions for Engine Driven Pump Installations: Where EDP's are used, the following precautions should be taken:

a. The EDP should be designed to be fire resistant and this shall be demonstrated by suitable testing, for example, in accordance with ISO 2685

b. The EDP suction, pressure and case drain pipelines and any couplings that are used in them should only be constructed from stainless steel where they are located in the firezone area

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

5.3.3 Location of Hydraulic Reservoirs: There should 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.

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

5.4 Part **(d)** - Identification of Hydraulic Fluid - JAR Only:

This requirement calls for the airframe manufacturer to specify the hydraulic fluid that is to be used in the aircraft. This should be achieved by making specific references to the fluid on labels adjacent to the system fill points and on the components in accordance with **ARP1288** or **ISO** 3323. In addition, all documentation concerned with the system or elements within the system should specifically refer to the fluid where applicable, for example, in qualification reports, inspection, maintenance and overhaul manuals.

6. DESIGN PRACTICES AND GUIDELINES:

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

6.1 Pressure Limitations:

6.1.1 System Pressure: As noted in 5.1.2 and 5.1.6.2, if the maximum hydraulic system working pressure is 3000 psi (20 690 **kpa)** and, in order to comply with JAR **25.1435(a)(4),** the maximum transient pressure should not exceed 3750 psi (25 862 **kpa).** However, the components may be designed to a higher nominal pressure to account for surge pressures greater than 125% of system pressure.

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

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

6.1.2 Back Pressure: The system should be designed such that proper functioning of any unit such as internal actuator locks will not be affected by the back pressure or changes in the back pressure of the system. The system 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 should also be given to the effects of hydraulic fluid with a high viscosity at

6.1.2 (Continued):

low fluid temperatures and/or high flows, on other units/subsystems due to the potentially high back pressures which can be generated under these circumstances.

6.1.2.1 Back Pressure Affecting Brakes: Back pressure resulting from the operation of any unit **while the** aircraft is on the ground should create no greater back pressure at the brake control valve return port than 90% of that pressure which will cause contact of braking surfaces.

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 Reservoir Pressurization:

6.2.1 Pneumatic Pressurization: One of the methods of pressurizing hydraulic reservoirs is by regulated engine bleed air. If this type of system is used, then the following guidelines are recommended.

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

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

(1) A failure of the pneumatic system regulating valve

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

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.

b. An inward relief valve to protect the reservoir if there are conditions where the outside pressure could be greater than the reservoir internal pressure, for example following the loss of the pneumatic pressure.
Both relief valves should have the minimum possible leakage of reservoir air pressure to ambient in order to maintain tank pressure for as long as possible. This is in order to minimize the possibility of pump cavitation during subsequent engine starting and during ground checks.

6.2.1.1 (Continued):

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

NOTE: Care should be taken when designing and installing these gages. This is because gage installations have been in themselves 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.

d. 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 should be taken as to the choice of settings of the switch in order to avoid spurious warnings as it can be possible for the reservoir pressure to decay due to the available bleed pressure being lower than the regulating pressure, particularly during the aircraft descent with the engines at idle settings.

e. A means to pressurize the reservoir from a ground rig.

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

6.2.1.2 The pneumatic pressurization system should include the following:

a. Pressure regulating valves that incorporate:

(1) A regulation mechanism to regulate the air pressure to within the required tolerance of the required setting

(2) A filter to prevent particulates from the pneumatic source from entering the system

(3) A relief valve which prevents overpressurization of the reservoir following a failure of the regulation mechanism of the valve

(4) Incorporate 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

6.2.1.2 (Continued):

b. 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.

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

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.

6.2.2 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 reservoir is pressurized using a charge valve from a rig. Instructions should be provided that the charge should be conducted at a constant temperature. The following guidelines are recommended:

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

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

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

6.2.3 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.

6.2.3 (Continued):

It is recommended that, if possible, the high pressure source be linked to an accumulator which is isolated from the main system by a check 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.

6.3 Fluid Velocity Limitations:

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

a. The allowable pressure drop at minimum required operating temperatures

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

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

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

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

6.4 Subsystem Isolation:

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

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

6.4 (Continued):

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.

6.5 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 MS33656-6 or AS4396-6 fitting end 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 should have an easy-to-read fluid quantity indicator which is clearly visible.

Any fluid that enters the system should be filtered prior to it entering the system return circuit, preferably by a nonbypass type filter with a filtration rating that is at least equivalent to the aircraft's system filters. It is not recommended to fill the system by direct pouring of the fluid into the reservoir. This is because of the ease of introducing contaminants into the system by this method.

6.6 Removal of Entrapped Air:

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

Particular areas of the system where bleeding is required are:

a. Brakes

b. Hydraulic reservoirs (if a separated type)

c. Pump suction and/or case drain lines

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

6.6 (Continued):

It may be desired to install an air removal device, 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 should not be such as to cause the loss of the hydraulic system. The automatic bleed function can be combined with the manual bleed and reservoir relief valves.

6.6.1 System Air Tolerance: The system should be designed and configured such that the presence of entrapped air in actuators and motors does not cause sustained loss of system pressure or degradation of system performance during all conditions of intended performance. When conducting calculations which include bulk modulus, an allowance for the effect of entrained air in the fluid should be made in the value assigned for the bulk modulus (for example, an OEM might use 85 000 to 100 000 psi (586 045 to 689 464 kpa) as the bulk modulus for AS1241 phosphate-ester hydraulic fluid to account for air in the system).

6.7 Subsystem Pressure:

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

6.8 System Interconnections:

For those aircraft where there are two or more independent hydraulic systems, there should not be any point in the system where they come together, even though they might be separated by shuttle or control valves. This is because, under these circumstances, there is always the possibility of fluid transfer from one system to another. This causes major maintenance penalties in the subsequent draining, replenishment or functioning of the systems to transfer the fluid back to the original reservoirs. However, it is acknowledged that acceptable design practices and in-service experience has allowed a deviation from this requirement at the wheelbrakes. Two hydraulic sources typically supply a single set of brake pistons due to space and/or weight considerations.

6.9 Component Design:

It is recommended that the components used in the hydraulic system conform to the general requirements contained in MIL-H-8775 and the applicable component specifications identified in this document and AIR737, with modifications as necessary to suit the hydraulic fluid and other differences applicable to commercial aircraft.

6.9 (Continued):

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

a. Install them incorrectly
b. Be able to have the wrong tubes connected to them
c. Tamper with adjustable features during general aircraft servicing

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

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

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

6.10 Accumulators:

Accumulators should be installed with the utmost consideration given to the protection of the flight and ground crew, passengers and critical parts of the aircraft in the case of structural failure or loss of the accumulator end cap. The accumulator must not be mounted so that a structural failure will propel failed parts into the cabin or flight deck. The accumulators should be designed in accordance with MIL-A-5498, 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.

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

6.10 (Continued):

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

6.11 General Valve Requirements:

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

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

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

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

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

b. To assist system troubleshooting

Valve position indication can be provided by:

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

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

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

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

6.12 Filter Requirements:

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

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

a. Incorporate a differential pressure indicator (DPI) or an electronic type to provide a warning that the filter element is nearly or fully clogged. There should be a surge damper incorporated in the DPI mechanism if the DPI is sensitive to sudden flow surges. 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

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

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

6.12.1 Filter Element Requirements: The rating of the element should be chosen according to the requirements of the system equipment that it is designed to protect, and to maintain the cleanliness of the fluid to the level that is specified by the system designer. Typically, for commercial aircraft, the filter elements with a Beta10 of 75 or greater should be used. See AIR887 for a discussion of filter ratings.

6.12.1 (Continued):

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

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

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

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

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

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

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

6.12.2.3 Pump Case Drain Line Installation: A filter should be fitted in the case drain line for each pump that runs continuously or occasionally during every flight. Although protection of the system can be provided by a single filter, the use of individual case drain filters for each pump 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.

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

6.12.4 Integral Filtration in Components: Filtration should be incorporated in those items whose operation 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. ARP4057 provides guidelines for secondary filters.

Examples of where integral filtration should be used are:

a. Mechanically signalled servovalves which use close tolerance spool and sleeve assemblies

b. Electrohydraulic servovalves

c. Solenoid valves which incorporate small bore pilot holes

d. Single direction flow restricting orifices

6.13 Flow Regulators:

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

One typical application of a flow regulator is to limit the available hydraulic flow to the motor of a 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.

6.14 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.

6.15 Pumps:

All hydraulic pumps should be designed for long life. ARP819 should be referred to for selecting each pump. The pump should be integrated within the aircraft hydraulic system using the guidelines as detailed in AIR1922.

6.15 (Continued):

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 shaft seal should be routed to a collector tank with a vent if practicable; otherwise drain overboard.

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

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

a. Sufficiently high to ensure effective pump cooling so that it achieves its required life

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

6.15.1 Variable Displacement Pumps: Variable displacement pumps should be designed and qualified in accordance with AS595 requirements.

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

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

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

6.15.5 Air Turbine Driven Pumps: Air driven pumps are mounted to an air turbine housing that contains a pneumatic turbine, shutoff and speed control valving, gearing and a lubrication system. The turbine is driven by the engine compressor bleed air. Air driven pumps can be used as a normal, backup emergency or ground servicing source of hydraulic system power. However, typically, an air driven pump is intermittently activated for

6.15.5 (Continued):

additional hydraulic flow capacity during high system demand loads such as landing gear extension/retraction, or as a redundant source following power loss of the normal hydraulic power source. The pump should meet the requirements of AS595 and should also comply with the following regulations:

a. FAR/JAR 25.1438 - Pressurization and pneumatic systems
b. FAR/JAR 25.1461 - Equipment containing high energy rotors

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

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

a. To act as a backup pump

NOTE: This is a relatively rare application and is only used on small transport aircraft where the flow 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 should be used in the suction line of the pump. The suction line should be of a suitable diameter and length to ensure priming and obtaining full-rated flow within a few full pump strokes. The pump circuit should be capable of full priming and rated flow at the highest altitude at which pump operation is essential and intended.

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

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

6.16 Motors:

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

6.17 Relief Valves, System and Thermal Relief:

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

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

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

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

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

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

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

6.17.2 Thermal Expansion Relief Valve: Relief valves should be installed as necessary to prevent pressure rise exceeding 125% of system working pressure and system damage resulting from the thermal expansion of system fluid and, in the case of an accumulator, the rise in gas charge pressure due to thermal effects. The valve should relieve fluid to the low pressure side of the system. Internal leakage should not be considered as an acceptable method of thermal relief. It is preferable 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.

6.18 Reservoirs:

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

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

Each independent system should have its own reservoir. However, 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 be stored in a dedicated part of the reservoir or have its own reservoir which can be filled from the same fill point as for the main reservoir. The fill and vent lines for all hydraulic reservoirs should 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. Reservoirs should be suitably protected by a relief valve to prevent failure or damage when rapid discharge of the fluid from the system to the reservoirs is encountered. Protection from **overpressurization** resulting from overfilling should be incorporated into the reservoir subsystem.

6.18.1 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.**

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

6.19 Actuators:

Actuating cylinders, apart from those used for primary flight control, should conform to guidelines contained in **MIL-A-5503.** The flight control actuators should conform to the guidelines contained in **ARP1281.**

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

6.19 (Continued):

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 should be taken into consideration:

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

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

c. Consideration should 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.

The actuator should 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 should be deactivated by the normal hydraulic system operation.

6.20 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 should 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 almost make them prohibitive for use.

6.20 (Continued):

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 should conform to MIL-C-25427, AS1709 or AS1896, as applicable.

6.21 Shuttle Valves:

As noted in 6.8, 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.

Shuttle valves should conform to the applicable requirements of MIL-V-19068.

6.22 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 should conform to the applicable requirements of MIL-S-9395.

6.23 Swivel **Joints:**

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 should be designed in accordance with MIL-J-5513 requirements, except that all pressure-to-atmosphere dynamic seal gland design should 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.

6.24 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.

6.24 (Continued):

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 or fuel feed 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.

7. INSTALLATION PRACTICES AND GUIDELINES:

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

7.1 General:

All installations of standard parts of components should be designed to accommodate the worst dimensional and operational conditions permitted in the applicable part, component specification, or standard. All components should be installed and mounted to satisfactorily withstand all expected natural and induced environmental conditions, acceleration loads, wrench loads, vibration effects, structural bending, salt spray, temperature, pressure, humidity, etc.

7.2 Installation of Actuators:

Hydraulic actuators should 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.

7.3 Location of Hydraulic Tubing:

Particular attention should be given to preclude hydraulic tubing from being installed in the flight deck or in the cabin. Hydraulic drain and vent lines should 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. Tubing should be located so that damage will not occur due to being stepped on, 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

7.3 (Continued):

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 should be taken in order to prevent possible hazards to the aircraft and/or personnel.

7.3.1 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.

7.3.2 Electrical Systems: Care should 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.

7.3.3 Environmental Control System (ECS): The installation of the hydraulic and ECS systems should be such that they should not run close to each other, particularly where ECS ducting that 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 pipelines 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.

7.3.4 Other Systems/Components: Systems or components which 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 at some stage during the life of the aircraft.