



AEROSPACE RECOMMENDED PRACTICE

ARP4752**REV. B**Issued 1994-09
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Superseding ARP4752A

Aerospace - Design and Installation of Commercial
Transport Aircraft Hydraulic Systems

RATIONALE

The changes to ARP4752 at Revision B include:

- a. A limited number of technical changes including removing all references to JAR airworthiness regulations
- b. Editorial changes including updating the references and deleting Appendix A (alphabetical index)

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1. SCOPE

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

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

2. REFERENCES

The majority of the documents referenced in this section are aerospace hydraulic system standards. They include advisory, guidance and certification documentation that can be used for designing, testing and evaluating the design of aircraft hydraulic systems. However, these documents may be added to, or overridden by, specific aircraft and/or airworthiness requirements, particularly when the documents are oriented towards military aircraft requirements. While military and commercial aircraft hydraulic systems generally utilize different fluid types, the intent of Military Specifications (MIL-specs) provides important and relevant requirements and guidelines for commercial aircraft applications.

2.1 Applicable Documents

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

2.1.1 SAE Publications

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

AIR310	Fittings, Catalog of Flared, Flareless, Pipe Threaded, Port, Hose, and Other Type Tube Standard Connectors
AIR737	Aerospace Hydraulic and Pneumatic Specifications, Standards, Recommended Practices, and Information Reports
AIR787	Filter Element Cleaning Methods
AIR797	Hose Characteristics and Selection Chart
AIR887	Liquid Filter Ratings, Parameters and Tests
AIR1379	Prestressing (Autofrettaging) of Hydraulic Tubing Lines
AIR1569	Handling and Installation Practice for Aerospace Hose Assemblies
AIR1922	Aerospace - System Integration Factors That Affect Hydraulic Pump Life
AIR4057	Secondary Filters for Fluid System Reliability
AIR4092	Investigation of PTFE "Melt" Phenomenon for High Pressure Hoses
AIR4150	Inspection of Inservice Airborne Accumulators for Corrosion and Damage
AIR4543	Aerospace Hydraulics and Actuation Lessons Learned
AIR5005	Aerospace - Commercial Aircraft Hydraulic Systems

ARP490	Electrohydraulic Servovalves
ARP584	Coiled Tubing - Corrosion Resistant Steel, Hydraulic Applications, Aerospace
ARP603	Impulse Testing of Hydraulic Hose, Tubing, and Fitting Assemblies
ARP994	Recommended Practice for the Design of Tubing Installations for Aerospace Fluid Power Systems
ARP1280	Aerospace - Application Guide for Hydraulic Power Transfer Units
ARP1281	Actuators: Aircraft Flight Controls, Power Operated, Hydraulic, General Specification For
ARP1288	Placarding of Aircraft Hydraulic Equipment to Identify Phosphate Ester Fluid Compatibility
ARP1383	Aerospace - Impulse Testing of Hydraulic Components
ARP1870	Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety
ARP1897	Clamp Selection and Installation Guide
ARP4146	Coiled Tubing - Titanium Alloy, Hydraulic Applications, Aerospace
ARP4378	Aerospace - Accumulator, Hydraulic, Welded Bellows, Factory Precharged
ARP4379	Aerospace - Accumulator, Hydraulic, Cylindrical, Piston Separated
ARP4386	Terminology and Definitions for Aerospace Fluid Power, Actuation and Control Technologies
ARP4553	Aerospace - Accumulator, Hydraulic, Self-Displacing
ARP4754	Guidelines for Development of Civil Aircraft and Systems
ARP4761	Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment
ARP5376	Methods, Locations and Criteria for System Sampling and Measuring the Solid Particle Contamination of Hydraulic Fluids
AS595	Aerospace - Civil Type Variable Delivery, Pressure Compensated, Hydraulic Pump
AS604	Hose Assembly, Polytetrafluoroethylene, Metallic Reinforced, 3000 psi, 400 °F, Heavyweight, Hydraulic
AS620	Hose Assemblies, Convuluted Polytetrafluoroethylene Metallic Reinforced, High Temperature, Medium Pressure, Aircraft
AS1055	Fire Testing of Flexible Hose, Tube Assemblies, Coils, Fittings, and Similar System Components
AS1227	Hose Assembly, Convuluted Polytetrafluoroethylene, Metallic Reinforced, Low Pressure, Up to 400 °F, Aircraft
AS1241	Fire Resistant Phosphate Ester Hydraulic Fluid for Aircraft
AS1290	Graphic Symbols for Aircraft Hydraulic and Pneumatic Systems
AS1300	Port - Ring Locked Fluid Connection Type, Standard Dimensions for
AS1339	Hose Assembly, Polytetrafluoroethylene, Metallic Reinforced, 3000 psi, 400 °F, Lightweight, Hydraulic and Pneumatic

AS1709	Coupling Assembly, Hydraulic Self Sealing, Quick Disconnect
AS1896	Coupling Assembly, Self-Sealing, One Side Only, Hydraulic
AS3121	Plug, Expansion - Aluminum, 2024-T4 and 2024-T351, Long; Std and .010 Oversize Diameters (UNS A92024)
AS3122	Pin, Expansion - Aluminum, 2024-T4 and 2024-T351, Long (UNS A92024)
AS3123	Plug, Expansion - Aluminum, 2024-T4 and 2024-T351, Short; Std and .010 Oversize Diameters, UNS A92024
AS3124	Pin, Expansion - Aluminum, 2024-T4 and 2024-T351, Short, UNS A92024
AS3125	Plug, Expansion - CRES, 416 or 416SE, Long; Std and .010 Oversize Diameters, UNS S41600/UNS S41623
AS3126	Pin, Expansion - CRES, 416 or 416SE, Long, UNS S41600/UNS S41623
AS3127	Plug, Expansion - CRES, 416 or 416SE, Short; Std and .010 Oversize Diameters, UNS S41600/UNS S41623
AS3128	Pin, Expansion - CRES, 416 or 416SE, Short, UNS S41600/UNS S41623
AS3129	Plug, Expansion - CRES, 303, Long; Std and .010 Oversize Diameters, UNS S30300
AS3130	Pin, Expansion - CRES, 303, Long, UNS S30300
AS3131	Plug, Expansion - CRES, 303, Short; Std and .010 Oversize Diameters, UNS S30300
AS3132	Pin, Expansion - CRES, 303, Short, UNS S30300
AS4059	Aerospace Fluid Power - Cleanliness Classification for Hydraulic Fluids
AS4098	Hose Assembly, Polytetrafluoroethylene, Heavy Duty, Metallic Reinforced, 400 °F, 5000 psi Hydraulic and Pneumatic
AS4396	Fitting End, Bulkhead, Flared, Tube Connection, Design Standard
AS4941	Aerospace - General Requirements for Commercial Aircraft Hydraulic Components
AS5169	Fitting, Port Plug and Bleeder
AS5202	Port or Fitting End, Internal Straight Thread, Design Standard
AS5550	Fitting Assembly, Ring Locked, Adapter, Flareless to Port, Extra Fine Threads, 5080 psi
AS5586	Aerospace - General Requirements for Hydraulic System Reservoirs
AS5951	Hose Assembly, Polytetrafluoroethylene, Para-Aramid Reinforced, 5080 psi (35,000 kPa), 275 °F (135 °C), Aircraft Hydraulic Systems
AS5958	Fittings, Axially Swaged Tube with Flareless Separable, Fluid System for Operating Pressures up to and Including 5080 psi (35 000 kPa), Specification for
AS5960	Hose Assembly, Polytetrafluoroethylene, Metallic Braid Reinforced, 5080 psi (35 000 kPa), 400 °F (204 °C), Aircraft Hydraulic Systems

AS5994	Pump Units, Hydraulic, Electric Motor Driven, Variable Delivery
AS7997	Motors, Aircraft Hydraulic, Constant Displacement General Specification For
AS18280	Fittings, 24° Cone Flareless, Fluid Connection, 3000 psi
AS33611	Tube Bend Radii
AS33656	Fitting End, Standard Dimensions for Flared Tube Connection and Gasket Seal
AMS4944	Titanium Alloy Tubing, Seamless, Hydraulic, 3.0Al - 2.5V, Cold Worked, Stress Relieved
AMS4945	Titanium Alloy Tubing, Seamless, Hydraulic, 3Al - 2.5V, Controlled Contractile Strain Ratio, Cold Worked, Stress Relieved
AMS4946	Titanium Alloy Tubing, Seamless, Hydraulic, 3Al - 2.5V, Texture Controlled Cold Worked, Stress Relieved
AMS5561	Steel, Corrosion and Heat-Resistant, Welded and Drawn or Seamless and Drawn Tubing, 9.0Mn - 20Cr - 6.5Ni - 0.28N, High-Pressure Hydraulic
AMS-T-7081	Tube, Aluminum Alloy, Seamless, Round, Drawn, 6061, Aircraft Hydraulic Quality
J1927	Cumulative Damage Analysis for Hydraulic Hose Assemblies

2.1.2 Airlines for America (A4A) Publications

Available from Airlines for America (A4A), 1301 Pennsylvania Avenue, NW, Suite 1100, Washington, DC 20004, Tel: 202-626-4000, www.airlines.org.

MSG-3 Airline/Manufacturer Maintenance Program Planning Document

2.1.3 Department of Defense Publications

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

MIL-STD-810 Environmental Engineering Considerations and Laboratory Tests

MIL-PRF-5503 Cylinders: Aeronautical, Linear Utility, Hydraulic, General Specification for

MIL-J-5513 Joints, Hydraulic Swivel

MIL-PRF-5606 Hydraulic Fluid, Petroleum Base; Aircraft, Missile and Ordnance

MIL-PRF-6164 Valve, Aircraft, Pneumatic, High-Pressure Charging

MIL-F-8815 Filter and Filter Elements, Fluid Pressure, Hydraulic Line, 15 Micron Absolute and 5 Micron Absolute, Type II Systems, General Specification for

MIL-DTL-9395 Detail Specification, Switches, Pressure, (Absolute, Gage, And Differential), General Specification for

MIL-DTL-25579 Detail Specification Hose Assembly, Polytetrafluoroethylene, High Temperature, Medium Pressure, General Specification for

MIL-DTL-27267 Detail Specification Hose, Polytetrafluoroethylene, 450F, Medium Pressure

MIL-DTL-27272 Fitting, Tetrafluoroethylene, Hose, High Temperature, Medium Pressure, General Requirements for

MIL-V-81940 Valve, Sampling and Bleed, Hydraulic, Type II Systems

MIL-PRF-83282 Hydraulic Fluid, Fire Resistant Synthetic Hydrocarbon Base, Aircraft

MIL-DTL-83296 Detail Specification Fittings, Corrosion Resistant Steel, High Temperature, High Pressure (3000 PSI), Hydraulic And Pneumatic

MIL-DTL-83298 Detail Specification Hose, Polytetrafluoroethylene, High Temperature, High Pressure (3000 psi), Hydraulic And Pneumatic

MIL-H-85800 Hose Assemblies Polytetrafluoroethylene, Aramid Fiber Reinforced, 5000 and 8000 psi, General Specification For

MIL-PRF-87257 Hydraulic Fluid, Fire Resistant, Low Temperature, Synthetic Hydrocarbon Base, Aircraft and Missile

2.1.4 EASA Publications

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

CS-25 Certification Specifications for Large Aeroplanes

2.1.5 FAA Publications

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

14 CFR Part 25 Code of Federal Regulations, 14 CFR 1.1, part 25 Airworthiness Standards, Transport Category Airplanes

TSO C-140 Aerospace Fuel, Engine Oil, and Hydraulic Fluid Hose Assemblies

2.1.6 ISO Publications

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

or if using the Switzerland address:

Available from International Organization for Standardization, 1, rue de Varembe, Case postale 56, CH-1211 Geneva 20, Switzerland, Tel: +41-22-749-01-11, www.iso.org.

ISO 12 Pipelines, Identification Schemes

ISO 2685 Environmental Test Conditions for Airborne Equipment - Resistance to Fire in Designated Fire Zones

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 7137 Aircraft, Environmental Conditions and Test Procedures for Airborne Equipment

ISO 8278 Aerospace, Hydraulic, Pressure Compensated, Variable Displacement

ISO 9206 Aerospace, Constant Displacement Hydraulic Motors, General Specifications

ISO 22072 Electrohydrostatic Actuator (EHA) - Procurement Specifications

ISO 22089 Aerospace – Hydraulic Power Transfer Units – General Specifications

2.1.7 RTCA Publications

Available from RTCA, Inc., 1150 18th Street, NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

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

2.2 Related Publications

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

AS5440 Hydraulic Systems, Military Aircraft, Design and Installation, Requirements For

2.3 Definitions

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

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

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

- a. Reasonable tolerances and transient pressure effects such as may arise from acceptable pump ripple, or
- b. Reactions to system functioning or demands that may affect fatigue

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

- a. One or several actuators
- b. A hydraulic reservoir
- c. A bi-directional, fixed displacement pump driven by a bi-directional, variable speed electric motor
- d. Power electronics to drive the motor in accordance with actuation position demands

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

- a. A mechanical actuator driven by a bi-directional, variable speed electric motor(s) through a gearbox/clutch mechanism
- b. Power electronics to drive the motor in accordance with actuation position demands

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

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

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

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

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

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

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

3. OVERALL HYDRAULIC SYSTEM REQUIREMENTS

3.1 General Requirements

3.1.1 Design

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

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

3.1.2 System Integration

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

3.1.3 System Pressure

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

3.1.4 Hydraulic Fluid

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

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

3.1.4.1 Hydraulic Fluid Properties

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

- a. Fluid particulate classification levels in accordance with AS4059
- b. Chlorinated solvent
- c. Water contamination
- d. Acid number
- e. Kinematic viscosity
- f. Specific gravity limits

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

3.1.5 Temperatures

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

- a. The minimum temperature that the aircraft will likely to be subjected to during an overnight cold soak
- b. The maximum temperature that could occur during high temperature soak backs, for example, in the engine pod area and/or brake lines

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

Operation of the hydraulic services 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.

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

It should be noted that the lower limit for ground cold soak ambient and operating temperatures for aircraft using MIL-PRF-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. However if heating of the hydraulic fluid is provided, then this temperature limit could be reduced.

3.1.6 Schematic Diagram

The graphic symbols and presentation principles should conform to AS1290/ISO 5859, whenever a schematic diagram of a hydraulic system is prepared. This provides the benefit of having a consistent set of symbols/drawing layouts that can be understood by a variety of disciplines/organizations including:

- a. The aircraft hydraulic system engineers
- b. System installation designers
- c. Aircraft customer support engineers
- d. Component suppliers
- e. Airline engineering groups

3.2 Applicable Airworthiness Requirements

Commercial transport aircraft are designed to meet the airworthiness requirements of the Federal Airworthiness Regulations (14 CFR Part 25) for U.S. certified aircraft or the Certification Standards for Large Aeroplanes (CS-25) for European certified aircraft.

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

25.301	Loads
25.303	Factor of safety
25.581	Lightning protection
25.601	Design and construction - general
25.603	Materials
25.611	Accessibility provisions
25.671	Control Systems - general
25.672	Stability augmentation and automatic and power operated systems
25.729	Retracting mechanisms
25.863	Flammable fluid protection
25.863	Flammable fluid protection
25.899**	Electrical bonding and protection against static electricity
25.903	Engines
25.943*	Negative accelerations
25.1182	Nacelle areas behind firewalls and engine pod attaching structures containing flammable fluid lines
25.1183	Flammable fluid - carrying components
25.1185	Flammable fluids

25.1189	Shutoff means
25.1301	Function and installation
25.1309	Equipment, systems and installations
25.1310**	Power source capacity and distribution
25.1315**	Negative accelerations
25.1322	Warning, caution and advisory lights
25.1353	Electrical installations and equipment
25.1541	Markings and placards - general

* 14 CFR Part 25 requirement only

** CS requirement only. 14 CFR 25.1309 includes requirements of CS 25.1310.

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

3.3 Design Concept and Overall Layout Requirements

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

- a. 14 CFR Part 25/CS 25.671
- b. 14 CFR Part 25/CS 25.672
- c. 14 CFR Part 25/CS 25.729
- d. 14 CFR Part 25/CS 25.1309

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

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

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

ARP4761 provides a guide for conducting fault or failure analyses.

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

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

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

3.3.1 Aircraft Utilizing a Single Main Hydraulic System

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

However, if the hydraulic system is the sole power source for retracting/deploying the landing gear, then 14 CFR Part 25/CS 25.729(c) requires that an alternative means of deploying them must be available if they cannot be deployed freefall.

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

- a. A simple auxiliary hydraulic system
- b. A stored gas system
- c. A dedicated electro-mechanical actuator (EMA) or an electro-hydrostatic actuator (EHA)
- d. If the braking system is operated hydraulically, then hydraulic power stored in dedicated accumulators or a separate fluid source and dedicated pump will be required to enable the aircraft to complete its landing run safely following the loss of the normal system.

3.3.2 Aircraft Utilizing Two Independent Hydraulic Systems

Usually, only two independent hydraulic systems are required if:

- a. The aircraft's hydraulic system only supplies a single primary flight control (for example, the rudder) with the remainder of the primary flight controls being non-powered, or
- b. The flight controls are hydraulically powered but they can be operated by other means if there is a total loss of hydraulic power. Examples of other means are:
 - Mechanical operation
 - Powered by EHAs and/or EMAs

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

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

1. Provide more than one supply of power to the brakes
2. Provide an alternative method of deploying the landing gear if freefall is not utilized
3. Provide a second power source (hydraulic or electric) for flaps and/or slats deployment if they are required for safe aircraft operation

3.3.3 Aircraft Utilizing More Than Two Independent Hydraulic Systems

If the aircraft's hydraulic system supplies all the primary and secondary flight controls and there is no manual reversion available, then usually a minimum of three hydraulic systems will be required. This is in order to comply with the requirements of 14 CFR Part 25/CS 25.671 and 25.1309. However, it is noted that:

- a. The use of EHAs or EMAs to supply primary and/or secondary flight controls means that it is possible to use only two hydraulic systems if all the primary and secondary flight controls are powered. This is dependent on having sufficient redundancy within the electrical power generation system such that the probability of failures of electrical and hydraulic systems that could result in the total loss of flight controls is less than 1×10^{-9} /flight hour (see 3.3.4).
- b. If there are a large number of services that are powered hydraulically, four independent hydraulic systems may be a design solution in order to:
 1. Reduce the size of the main and backup pumps
 2. Optimize the redundancy of the supplies to the hydraulic services, etc.
- c. Protective devices that preserve certain hydraulic subsystem capabilities may be required when considering engine burst, tire burst, mid-air collisions, and other system failures, due to the aircraft configuration and/or systems layout, for example.

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

3.3.4 Loss of Electrical Generated Power

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

In addition, the relationship between the electrical supplies to the hydraulic components and the function of the hydraulic components must be carefully reviewed. This is because a potentially catastrophic event might possibly occur due to a combination of single failures of:

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

3.3.5 Directional Control of the Aircraft on the Ground

If the aircraft hydraulic systems supply the services that control the direction of the aircraft on the ground, that is, nosewheel (and/or main gear) steering, differential braking and the rudder, consideration 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, 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 should be given to the level of redundancy of hydraulic power sources within each hydraulic system.

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

If the aircraft has all the primary and secondary flight controls powered by the hydraulic system, then it shall comply with 14 CFR Part 25/CS 25.671(d). This states that the aircraft shall be controllable if all engines fail. In order to meet this requirement, the aircraft can be fitted with a ram air turbine (RAT) when sufficient hydraulic or electrical power is not available from pumps powered by windmilling engines or batteries. The RAT could either power a hydraulic pump or an electrical generator (which would supply an EMP), or both, so that essential flying controls and other services can operate under these conditions.

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

3.3.7 Protection Devices

Consideration 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, or following structural failures (as required in 3.1.1). The following are examples of devices that can be used:

3.3.7.1 Check Valve

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

- a. An accumulator for a limited time and/or cycles
- b. A pump that has its own fluid supply from a separate source than for the main system pump(s)

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

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

3.3.7.2 Pressure Maintaining Valve (PMV)

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

3.3.7.3 Priority Valve

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

3.3.7.4 Fuse

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

3.3.7.5 Electrically Operated Shutoff Valve

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

3.3.7.6 Circuit Breaker (Flow Comparison Device)

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

3.4 Segregation Requirements

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

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

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

3.4.1 Engine Debris Requirements

The effects of non-contained engine bursts, as required by 14 CFR Part 25/CS 25.903(d)(1) shall be considered in the design of the hydraulic system. This is usually accomplished by ensuring that the tubing of each independent system and their respective components are sufficiently physically separated such that a non-contained engine failure could not damage the lines of all systems.

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

It may be necessary to route the plumbing from all the hydraulic systems in a single area to achieve the necessary degree of redundancy. Under these conditions, it could be possible that damage to all of the systems in this area would prevent the aircraft from being controlled. Therefore, consideration 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 14 CFR Part 25/CS 25.729(f). It is required that the design of the tubing installation on landing gears, in landing gear and/or hydraulic bays, etc., is such that only a limited amount of damage is possible, for example, the loss of not more than one system when a redundant system remains functional.

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

3.4.3 Protection against Flailing Shafts

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