NOT MEASUREMENT SENSITIVE

JSSG-2009-2
1 November 2018

SUPERSEDING
JSSG-2009A, Appendix B
20 November 2015

DEPARTMENT OF DEFENSE
JOINT SERVICE SPECIFICATION GUIDE

AIR VEHICLE HYDRAULIC POWER SUBSYSTEM REQUIREMENTS AND GUIDANCE

This specification guide is for guidance only.
Do not cite this document as a requirement.

Comments, suggestions, or questions on this document should be addressed to AFLCMC/EZSS, BLDG 28 RM 133, 2145 MONAHAN WAY, WPAFB OH 45433-7017 USA or e-mailed to engineering.standards@us.af.mil. Since contact information can change, you may want to verify the currency of this address information using the ASSIST Online database at https://assist.dla.mil.

AMSC N/A FSC 15GP

DISTRIBUTION STATEMENT A. Approved for public release. Distribution is unlimited.

FOREWORD

1. This specification guide is approved for use by all Departments and Agencies of the Department of Defense (DoD).

2. This specification guide replaces Appendix B, "Air Vehicle Hydraulic Power Subsystem Requirements and Guidance," in JSSG-2009A, "Air Vehicle Subsystems."

3. The purpose of this Joint Service Specification Guide (JSSG) is to provide guidance for use by Government and Industry program teams in developing program-unique specifications. This document shall not be placed on contract.

CONTENTS

PARAGRAPH PAGE

1. SCOPE

1.1 Scope.

This specification guide provides the requirements, verifications, tailoring guidance, and background information for the hydraulic power subsystem. This specification guide has been developed and coordinated by technical personnel from the Air Force, Navy, and Army and has been approved as an official guide for use by Government personnel for assistance in tailoring the air vehicle subsystems specification for acquisition and model specifications. This specification guide is a mandatory part of the air vehicle subsystem specification. The information contained herein is intended for compliance.

1.2 Structure.

The specification guide structure replicates the structure of the air vehicle subsystems specification except it places each corresponding section 3 requirement and section 4 verification together.

1.3 Overview.

This specification guide provides tailoring guidance and background information for individual paragraphs of the air vehicle subsystems specification. Guidance gives recommendations on how to tailor the specification paragraph. Where (TBS) appears, the guidance paragraph provides recommended values or text that the using service may use to insert in the (TBS). When contractors are expected to complete the (TBS), the guidance paragraph will so state. The using service makes the final decision on whom completes the (TBS) in the specification. Finally, lessons learned are provided to give insight to past events that could affect the tailoring of the specification.

1.4 Deviations.

Projected designs for given applications which will result in improvement of the system performance, reduced life cycle cost, or reduced developmental cost through deviations from this guidance or where requirements of the specification results in compromise in operational capability should be brought to the attention of the using service.

1.5 Environmental impact.

Air vehicle subsystems will be designed such that their operation, maintenance, and repair may be accomplished without violating the most stringent environmental regulations applicable to locations where subsystems are used or supported. Compliance with environmental regulations will not prevent subsystems from achieving and sustaining mission performance capability. Materials, processes, and environmental control equipment necessary to meet these environmental requirements must currently be available in the using service's maintenance and supply system. The design will not use environmentally unsuitable materials such as ozone depleting fluorocarbons, chlorofluorocarbons, and halons, or highly volatile organic compounds in solvents and coatings during development, production, operation, maintenance, or repair. The Environmental Protection Agency maintains an online list of toxic chemicals and hazardous substances on its Ozone Layer Depletion Website at https://www.epa.gov/ozone/snap/ that should be consulted. The Significant New Alternatives Policy (SNAP) Program available thereon identifies substitutes for ozone depleting chemicals.

The contractor will conduct an environmental analysis of air vehicle subsystems.

1.6 Responsible engineering office.

The responsible engineering office (REO) for this specification guide is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL.

2. APPLICABLE DOCUMENTS

2.1 General.

The documents listed in this section are specified in sections 3 and 4 of this guide specification. This section does not include documents cited in other sections of this guide specification or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3 and 4 of this guide specification, whether or not they are listed.

2.2 Government documents

2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

DEPARTMENT OF DEFENSE SPECIFICATIONS

MIL-DTL-5498	Accumulators, Hydraulic, Cylindrical, 3000 PSI, Aircraft
MIL-PRF-6083	Hydraulic Fluid, Petroleum Base, for Preservation and Operation
MIL-DTL-8815	Filter and Filter Elements, Fluid Pressure, Hydraulic Line, 15 Micron Absolute and 5 Micron Absolute, Type II Systems, General Specification
MIL-PRF-46170	Hydraulic Fluid, Ruse Inhibited, Fire Resistant, Synthetic Hydrocarbon Base, NATO Code No. H-544
MIL-PRF-83282	Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Metric, NATO Code Number H-537
MIL-PRF-87257	Hydraulic Fluid, Fire Resistant; Low Temperature, Synthetic Hydrocarbon Base, Aircraft and Missile

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-5522	Test Requirements and Methods for Aircraft Hydraulic and Emergency Pneumatic Systems

(Copies of these documents are available online at https://quicksearch.dla.mil.)

2.3 Non-Government publications.

The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

SAE INTERNATIONAL

SAE AIR1243	Anti Blow-By Design Practice for Cap Seals
SAE AS5440	Hydraulic Systems, Military Aircraft, Design and Installation Requirements for
SAE AS8775	Hydraulic System Components, Aircraft and Missiles, General Specification for
SAE AMS-P-83461	Packing, Preformed, Petroleum Hydraulic Fluid Resistant, Improved Performance at 275˚F (135˚C)

(Copies of these documents are available from https://www.sae.org/.)

2.4 Order of precedence.

Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the 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.

2.5 Streamlining.

The air vehicle subsystems specification has been streamlined. The documents listed in this specification guide that are required for acquisition have the same status as those referenced directly in section 2 (first tier). All other documents referenced through tiering may be used for guidance and information only.

3. REQUIREMENTS

4. VERIFICATIONS

3.1 Definition

4.1 Definition

3.2 Characteristics

4.2 Characteristics

3.3 Design and construction

4.3 Design and construction

3.4 Subsystem characteristics

4.4 Subsystem characteristics

3.4.1 Landing subsystem

4.4.1 Landing subsystem

3.4.2 Hydraulic power subsystem.

The hydraulic power subsystem shall accept power from an energy source internal or external to the air vehicle and thus generate, condition, and distribute hydraulic fluid power to the control and actuation devices of the air vehicle utilizing systems that are dependent upon hydraulic power for normal, alternate, or emergency operation. The hydraulic power subsystems may include components in the other systems dependent upon hydraulic power, such as landing gear or flight controls. The hydraulic power subsystem(s) shall be sized and configured to supply hydraulic power, as required, to the using systems and utility functions in all modes of ground and flight operation.

REQUIREMENT RATIONALE (3.4.2)

The function of the hydraulic power subsystem is to deliver fluid at sufficient flow rates and pressure to the actuating devices in all modes of flight or ground operation. The speed of actuation is a function of fluid flow-rate whereas the actuating force is a function of pressure. Hydraulic fluid power has been found to be the lightest and most efficient method to transmit high horsepower in air vehicles.

REQUIREMENT GUIDANCE (3.4.2)

Important aspects of hydraulic power subsystem operation are fluid quality (absence of dirt, moisture, and air), control of fluid leakage and extreme temperature performance (especially at temperatures lower than -20°F or temperatures higher than +225°F). Sufficient fluid power should be available for all known conditions. Conditions should include:

a. Ground operations
b. Taxi, takeoff, and landing
c. All flight attitudes within structural limitations
d. Zero gravity or negative gravity
e. All altitudes within the flight envelope
f. Structural deflection
g. Loss of all engine propulsive power
h. Emergency and alternate hydraulic power subsystem operation.

Many of the requirements for hydraulic power subsystem design, installation, and general use may be found in the applicable documents in Section 2 (these documents may also be used as a reference source to prepare specific requirements which are appropriate for particular hydraulic power subsystem(s); other inappropriate requirements may be discarded or modified to achieve a "tailored" document).

The hydraulic power subsystem(s) is often oversized to meet a short duration function. For example, the landing gear and brake system on the C-5A, and the gun drive system on the A-10. The hydraulic power subsystem should be divided into a finite number of separate, independent hydraulic power subsystems to meet redundancy requirements for mission performance or emergency use. The separate system(s) may transmit power from one system to another, but should not transmit fluid from one system to another. Experience has shown that one contaminated fluid system can contaminate another.

Standard practice is to use engine-driven pumps (direct or remote gearbox drive) for primary power. The required pump flow (proportional to engine gearbox speed) is often greatest when air vehicle airspeed is lowest, as in the landing phase. Multiple engine air vehicle hydraulic power subsystems using engine-driven pumps should have pumps driven by at least two engines.

Potential growth in flow requirements for hydraulic services should be considered in establishing the pump sizes. Eight-thousand-psi pressure systems are being considered to save space and weight.

Whenever hydraulic power is required for primary flight controls, it is desired that one system is primarily used to power the flight controls. This hydraulic power subsystem should not be used to supply any other system or component in the air vehicle. This hydraulic power subsystem should be as simple as practicable and should contain a minimum number of components.

REQUIREMENT LESSONS LEARNED (3.4.2)

(TBD)

4.4.2 Hydraulic power subsystem.

The verifications (inspections, analyses, demonstrations, and tests) specified shall verify the ability of the hydraulic power subsystems to meet the requirements of section 3 herein. Verification shall encompass planning, procedure preparation, and reporting and shall be accomplished by inspection, analysis, demonstration, or test, or a combination of these methods.

VERIFICATION RATIONALE (4.4.2)

The design and operating characteristics to fulfill the needs of the weapon system should be known before full-scale development.

VERIFICATION GUIDANCE (4.4.2)

The hydraulic power subsystem should be verified incrementally by one or more of the following:

a. Analysis.
    1. A hydraulic power subsystem description and analysis report.
    2. Computer program analysis of steady state and dynamic performance. This is a data item, when required.
b. Laboratory tests.

1. Qualification tests to verify specific component and system design and performance requirements including durability and environmental requirements.
2. Full-scale functional hydraulic power subsystem mockup and simulators.

c. Ground and flight tests.

1. Contractor tests
2. Procuring activity tests

d. Inspection.

1. Conformance to drawing(s)
2. Identification verification

e. Demonstration.

Guidance for qualification tests is contained in component documents listed in primary documents such as SAE AS5440 and SAE AS8775, and legacy documents MIL-H-5440 and MIL-H-8775. Guidance for ground and flight tests is also included in MIL-STD-5522.

VERIFICATION LESSONS LEARNED (4.4.2)

Hydraulic power subsystem design verification is normally the contractor's responsibility. The government on occasion desires to witness or conduct verifications. So for contractual reasons, a statement such as the following is added: "All verifications shall be the responsibility of the contractor but the government reserves the right to witness or conduct any verification."

3.4.2.1 Hydraulic power subsystem general requirements.

4.4.2.1 Hydraulic power subsystem general requirements.

3.4.2.1.1 Fluid selection.

The hydraulic power subsystem(s) fluid shall be (TBS).

REQUIREMENT RATIONALE (3.4.2.1.1)

Fluid selection is critical to the performance of the hydraulic power subsystem. It affects the operation of every component in the system and should be the same as the fluid used in ground support equipment.

REQUIREMENT GUIDANCE (3.4.2.1.1)

TBS should be filled in with a hydraulic fluid based on the hydraulic power subsystem's requirements for various hydraulic fluid properties, such as, thermal and chemical stability, viscosity, oxidation-corrosion inhibition, lubricity, fire resistance, seal and system material compatibility, cost, and logistics. The procuring activity should specify the fluid, unless there are unique performance requirements, which would require a trade study.

REQUIREMENT LESSONS LEARNED (3.4.2.1.1)

The Navy successfully converted all its air vehicles to MIL-PRF-83282 for increased fire resistance. The initial conversion caused problems with initial increased filter replacement due to the better detergent action of MIL-PRF-83282. After a period of time, filter replacement returned to normal. Similar behavior was observed by the Air Force during its conversion of air vehicles to MIL-PRF-83282. Self-contained units, such as dampers and landing gear shock absorbers, were also converted to MIL-PRF-83282. Due to the high viscosity at low temperatures, hydraulic power subsystem temperature is restricted to -40°F. For lower temperature, the air vehicles should be converted to MIL-PRF-5606. The Army similarly requires change of their air vehicle hydraulic fluid from MIL-PRF-83282 to MIL-PRF-5606 at temperatures below -40°F. In the Air Force, those air vehicles, which had extreme low temperature operational requirements, were not converted to MIL-PRF-83282 but are now in the process of converting to MIL-PRF-87257.

Performance Specification MIL-PRF-5606 (formerly MIL-H-5606) petroleum base fluid has been widely used in military air vehicles for about 35 years. It operates in a temperature range of -65˚F to +275˚F and is generally satisfactory. It is non-Newtonian which means its viscosity will change with high rates of fluid shear, as when pumping, and, most importantly, it is also flammable. Because of its flammability, alternate fluids have been developed and are in common usage. These fluids are less flammable. Because of the increased fire resistance of the alternate fluids, MIL-PRF-5606 is no longer used as a design fluid in new air vehicles.

Performance Specification MIL-PRF-83282 is a polyalphaolefin-based synthetic hydrocarbon fluid with an operating temperature range of -40°F to +400°F. It is more fire resistant (200° higher flash and fire points) than MIL-PRF-5606 and has a lower flame propagation rate and greater gunfire ignition resistance. However, it is capable of ignition under certain conditions, such as hot manifold ignition. MIL-PRF-5606 and MIL-PRF-83282 are chemically compatible and physically miscible but do not have the same low temperature fluid characteristics. The viscosity of MIL-PRF-83282 at -40°F is equivalent to that of MIL-PRF-5606 fluid at -65˚F. Therefore, fluid system warm-up procedures with MIL-PRF-83282 fluid may be required at cold temperatures. MIL-PRF-83282, unlike MIL-PRF-5606, is shear stable. Thus, MIL-PRF-83282 can be pumped at 8000 PSI without loss of fluid viscosity.

Phosphate ester hydraulic fluids are used in commercial air vehicles as well as military derivatives, such as the C-9 (DC-9), TA3 (737), E-4 (747), KC-10 (DC-10) and the presidential air vehicle. Phosphate ester fluids are also fire resistant, but are not chemically compatible with many military air vehicle materials, such as hydrocarbon base fluids, MIL-PRF-5606 and MIL-PRF-83282 fluids, elastomeric seals, wire insulation, and paint. The physical properties, such as bulk modulus, also are incompatible with military hydraulic power subsystems. However, the commercial airlines and suppliers have developed materials compatible with phosphate ester fluids, which meet the demanding needs of commercial air vehicle operations. Military air vehicles using phosphate ester hydraulic power subsystems have contract maintenance programs. The fluid is more fire resistant than petroleum base fluids but should be restricted to less than 250°F for long-term operation because of thermal decomposition. Phosphate ester fluid systems should be checked periodically for viscosity change and acid number: an Air Force air vehicle had to have a change of hydraulic tubing because of fluid decomposition and subsequent system corrosion.

Department of Defense Specification MIL-PRF-46170 is the rust-inhibitor version of

MIL-PRF-83282 and was used as a preservative fluid. Defense Specification MIL-PRF-6083 is the rust-inhibitor version of MIL-PRF-5606 and likewise used as a preservative fluid. Neither MIL-PRF-6083 nor MIL-PRF-46170 should be used as a working fluid in air vehicle systems because the sulfonate inhibitor is marginally stable above 250°F, and has been found to precipitate out of solution and form a film on internal surfaces. This precipitate film can cause close-fitting components to jam and lead to component failure.

The newest hydrocarbon hydraulic fluid is MIL-PRF-87257, which is similar to MIL-PRF-83282. This newer fluid has full performance characteristics from -65˚F to 350˚F. It was developed in direct response to the low temperature limits of MIL-PRF-83282 and is completely interchangeable with both MIL-PRF-5606 and MIL-PRF-83282. This fluid has good viscosity to the limit of -65˚F and no replacement is needed for cold weather operation. The fire resistance of MIL-PRF-87257 is between MIL-PRF-5606 and MlL-PRF-83282 but is more like MIL-PRF-83282 than MIL-PRF-5606. It should be used where fire resistance is important and where extreme cold or high temperature operation is critical.

4.4.2.1.1 Fluid selection.

Suitability of the hydraulic fluid selected shall first be verified by analysis and then by hydraulic simulator test, as required. The analysis may include a trade study between different fluids.

VERIFICATION RATIONALE (4.4.2.1.1)

The fluid selected affects every component in the hydraulic system and it should be suitable over the entire air vehicle environment. Analysis and test should show this compatibility.

VERIFICATION GUIDANCE (4.4.2.1.1)

Initial fluid selection should be based on analysis, considering all operational and environmental factors. Final fluid verification should be accomplished with system-level test using flight worthy components. Care should be taken to include all normal as well as abnormal environments. Internal and external corrosion of components by the fluid may cause some fluids to be unsuitable. Fluids with good environmental properties may be toxic to humans and therefore should be unsuitable except in the most extreme conditions. Fluid lubricity is another operational property that is extremely important. It affects the wear and overall life of components. An early test program may be required to establish fluid properties for a unique application. Air vehicle operational environmental may also affect the fluid selection process. Some fluids may be suitable for air vehicle operation but not satisfactory for shipboard use, as in Navy operations, or for desert maintenance operations.

VERIFICATION LESSONS LEARNED (4.4.2.1.1)

Careful testing should precede any fluid change, even if a minor change, for the fluid affects each component in the system. Three development bomber air vehicles used M2V hydraulic fluid, which is similar to the silicate-ester fluid used in the B-58 and B-70 air vehicles. The rotating equipment, hydraulic pumps, and motors in the bomber were designed and qualified to use M2V. However, to reduce costs, the fourth development bomber was designed for use with MIL-H-5606 fluid. Because of the extensive and successful linear actuator testing with MIL-H-5606 fluid, it was decided to conduct a 100-hour test on existing pump and motor designs instead of the 750-hour qualification test.

The pumps showed very high wear rates and had to have some material and geometry (increased clearance) changes to pass a 100-hour test. Hydraulic pumps and motors should be fully requalified when a significant fluid change is to be made. High-speed rotating equipment is especially sensitive to hydraulic fluid characteristics.

Property differences in qualified fluid sources can also affect the fluid performance. A performance-type specification can result in fluid property variations among qualified sources. Hydraulic packing and fluid manufacturers met in the 1950s to establish reference materials to insure control and compatibility of fluids and packings when brought together. For example, elastomer volume change varied about 4 percent (4%) when tested in different qualified fluids. This difficulty was repeated when the Navy changed from MIL-H-5606 to MIL-H-83282 (now MIL-PRF-5606 and MIL-PRF-83282). Different fluid sources for the MIL-H-83282 used different percentages of an ester component. This ester component affected the swell of elastomeric O-rings. Due to seal performance variations with the different qualified sources, the ester component was more tightly restricted to ensure the same seal performance.

3.4.2.1.2 System fluid capacity.

The total fluid volume, including reserves, shall be optimized to accommodate all operating modes of the air vehicle including emergency and normal operation.

REQUIREMENT RATIONALE (3.4.2.1.2)

The total system volume needs sufficient volume to operate all normal and emergency functions. Total fluid volume should provide for system fluid exchanges, compressibility, thermal effects, and leakage. Hydraulic fluid should be available in the reservoir in sufficient quantity to supply the hydraulic pumps under all operational conditions and air vehicle attitudes.

REQUIREMENT GUIDANCE (3.4.2.1.2)

Hydraulic power subsystem operation requires a variable system volume, and the reservoir accommodates these changes in volume to provide more or less fluid as needed. Fluid thermal expansion and contraction, variations in component volumes during operation, and emergency operations cause system volume changes. Guidance for the reservoir volume is given in MIL-DTL-5498 for closed reservoirs. Reservoir volume includes volume exchange for actuators due to unbalanced areas, accumulator charging and discharging, thermal expansion, emergency reserve, and leakage reserve. If not sized properly, changes in the volume can cause fluid to be spilled overboard or the pump to cavitate due to insufficient fluid.

The reservoir should be located so that the following conditions will be obtained:

a. A static head of fluid should be supplied to the hand pump and the power-driven pump or pumps in all normal flight attitudes of the air vehicle.
b. The length of suction line to the pump is a minimum.
c. Protection from combat damage
d. If practicable, suction lines should be so routed as to prevent breaking of the fluid column

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

e. If routing of the pump bypass cannot be accomplished so that breaking of the fluid column by gravity after engine shutdown is prevented, check valves should be incorporated in the lines.

If a vent is provided in the reservoir, it should be arranged so that loss of fluid will not occur through the vent during flight maneuvers or ground operations of the air vehicle. A filter should be incorporated into the vent line if the temperature requirement is suitable. If a filler cap is used, the act of removing the filler cap should automatically vent the reservoir in such manner that the energy contained in the pressurizing air is not dissipated by imparting kinetic energy to either the filler cap or the fluid contained in the reservoir or elsewhere in the system.

REQUIREMENT LESSONS LEARNED (3.4.2.1.2)

Reservoir volume includes volume exchange for actuators due to unbalanced areas, accumulator charging and discharging, thermal expansion, emergency reserve, and leakage reserve. If not sized properly, changes in the volume can cause fluid to be spilled overboard or the pump to cavitate due to insufficient fluid.

4.4.2.1.2 System fluid capacity.

System fluid capacity shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.2)

System fluid capacity factors are based on analytical data, expected operating sequence, as well as experience.

VERIFICATION GUIDANCE (4.4.2.1.2)

TBS: Analysis, inspections, ground and flight tests, and demonstration programs should verify the hydraulic fluid capacity requirements. A hydraulic simulator capable of performing all normal and emergency functions will demonstrate an adequate system fluid capacity. Loss of fluid from the system overboard relief valves should also be checked with the simulator.

Actual operational conditions of the air vehicle should be used for the test verifications. Start up, take off, flight, weapons delivery, return to base, and landing conditions should be included.

VERIFICATION LESSONS LEARNED (4.4.2.1.2)

The UH-1 helicopter incorporated an overboard relief valve in the reservoir to prevent rupture due to overfill. During routine shut down, pressure surges caused fluid to be squirted overboard onto the ground. Routine reservoir servicing was required. The problem was not discovered during tests because not all modes of operation were evaluated. The problem could have been easily corrected during design and manufacture with higher relief valve settings or check valves to prevent pressure surges from reaching the valves.

3.4.2.1.3 System fluid monitoring.

A means shall be provided to monitor hydraulic system fluid quantity.

REQUIREMENT RATIONALE (3.4.2.1.3)

Fluid quantity indication provides a means to detect impending system failure due to fluid loss and is needed to properly fill and service the system.

REQUIREMENT GUIDANCE (3.4.2.1.3)

A means to indicate hydraulic fluid level should be located on or near the hydraulic reservoir.

REQUIREMENT LESSONS LEARNED (3.4.2.1.3)

Reservoir sight gauge - Transparent reservoir level sight gauges can easily be damaged unless they are encased in a protective metal jacket.

4.4.2.1.3 System fluid monitoring.

The means for monitoring system fluid quantity shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.3)

System fluid quantities should be verified for flight operation and servicing.

VERIFICATION GUIDANCE (4.4.2.1.3)

TBS: The hydraulic fluid quantity monitoring system should be verified by inspection and air vehicle ground and flight tests.

VERIFICATION LESSONS LEARNED (4.4.2.1.3)

(TBD)

3.4.2.1.4 System pressure.

The system pressure shall be (TBS) psi.

REQUIREMENT RATIONALE (3.4.2.1.4)

The operating pressure of the hydraulic power subsystem(s) establishes test and design requirements for hydraulic power subsystem components. This requirement is needed for proof and burst pressure tests and for designing components such as hydraulic pumps and motors, relief valves, pressure switches, accumulators, crew station, and flight test instrumentation parameters.

REQUIREMENT GUIDANCE (3.4.2.1.4)

TBS: Pressure selection should be based on air vehicle hydraulic power subsystem weight, reliability, design loads, cost, safety and state-of-the-art. Selection of pressure levels with available components that reduce development, procurement, test, and system support costs should be considered. The availability and development cycle for ground support equipment is also factors.

REQUIREMENT LESSONS LEARNED (3.4.2.1.4)

(TBD)

4.4.2.1.4 System pressure.

System pressure shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.4)

Analyses should support the pressure selection. Tests should supplement the selected operating pressure level(s).

VERIFICATION GUIDANCE (4.4.2.1.4)

TBS: System pressure should be verified by analysis of the contractor design report and drawings, laboratory tests of components, and system tests.

VERIFICATION LESSONS LEARNED (4.4.2.1.4)

(TBD)

3.4.2.1.4.1 Pump inlet pressure.

Pressure at the hydraulic pump(s) inlet shall be (TBS).

REQUIREMENT RATIONALE (3.4.2.1.4.1)

Sufficient pressure should be available at the hydraulic pump inlet port to prevent pump cavitation and degradation in performance at maximum steady-state or transient flow demands. Extreme cold temperatures and high altitude pump startup should be considered.

REQUIREMENT GUIDANCE (3.4.2.1.4.1)

TBS should be filled in with the pump inlet pressure derived for the system.

The airframe contractor and hydraulic pump manufacturers should define values for pump inlet pressures.

Inlet pressure should be provided during system startup, if necessary, to compensate for lack of bleed air pressurization during engine start or lack of bootstrap pressurization during hydraulic power subsystem starts. One should also consider the effect of firewall shutoff valve closure on a windmilling engine-driven hydraulic pump without inlet fluid flow.

REQUIREMENT LESSONS LEARNED (3.4.2.1.4.1)

The use of a portable cart to gas pressurize the reservoir during auxiliary pump startup has been generally unacceptable. Either the ground equipment is not available or it is a maintenance nuisance. The result has been pump cavitation damage. One cargo air vehicle pump suction line is about 100 feet long. When there was sudden flow demand, sufficient fluid flow could not be accelerated to the pump inlet to prevent pump cavitation. A corrective action was to reduce the response time of the pump. Pumps are also unloaded during engine start to reduce drag torque on the engine gearbox.

4.4.2.1.4.1 Pump inlet pressure.

Inlet pressure(s) to the pump(s) shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.4.1)

Pump durability and pump flow characteristics are dependent on pump inlet pressure and flow.

VERIFICATION GUIDANCE (4.4.2.1.4.1)

TBS: The hydraulic pump inlet pressure should be measured and evaluated during the air vehicle ground and flight test program and during the pump qualification tests. Inlet pressure should be provided during system startup, if necessary, to compensate for lack of bleed air pressurization during engine start or lack of bootstrap pressurization during hydraulic system starts. The effect of firewall shutoff valve closure on a windmilling engine-driven hydraulic pump without inlet fluid flow should be considered.

VERIFICATION LESSONS LEARNED (4.4.2.1.4.1)

High-speed pumps - In general, high-speed piston-type hydraulic pumps require higher inlet pressures as compared to lower speed piston-type hydraulic pumps.

3.4.2.1.4.2 System start pressurization.

Sufficient system pressurization, if required, shall be maintained for normal pump operation in the event the normal system start up pressurization source (reservoir bootstrap pressure or other pressurization source) is not available.

REQUIREMENT RATIONALE (3.4.2.1.4.2)

Sufficient pressure should be available at the pump inlet port during startup to prime the pump when the normal system start pressurization source is not available.

REQUIREMENT GUIDANCE (3.4.2.1.4.2)

One method to pressurize the pump inlet, during the transition to normal pressurization, is to use an accumulator.

REQUIREMENT LESSONS LEARNED (3.4.2.1.4.2)

(TBD)

4.4.2.1.4.2 System start pressurization.

System start pressurization shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.4.2)

System start pressurization should be verified. Sufficient pressure should be available at the pump inlet port during startup.

VERIFICATION GUIDANCE (4.4.2.1.4.2)

TBS: Analysis, inspection, and system tests are used to verify this requirement.

VERIFICATION LESSONS LEARNED (4.4.2.1.4.2)

(TBD)

3.4.2.1.4.3 System pressure indication.

Means shall be provided to sense and transmit hydraulic pressure indications in each hydraulic power subsystem.

REQUIREMENT RATIONALE (3.4.2.1.4.3)

Flight crew personnel should know the operating status of the air vehicle hydraulic power subsystems.

REQUIREMENT GUIDANCE (3.4.2.1.4.3)

The system pressure-indicating device should be installed in the air vehicle in a location easily observable to the pilot or other flight personnel.

REQUIREMENT LESSONS LEARNED (3.4.2.1.4.3)

Pressure indicators - Flight station space allotted to hydraulic power subsystem pressure indicators often allows only the use of small size indicators. This makes the indicator hard to read accurately.

4.4.2.1.4.3 System pressure indication.

Availability and measurement of system pressure shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.4.3)

The usefulness of pressure determination(s) should be established.

VERIFICATION GUIDANCE (4.4.2.1.4.3)

TBS: The pressure indicating system should be verified by inspection and test.

The visibility and accuracy of the gage readout should be verified during the air vehicle ground and flight test program.

VERIFICATION LESSONS LEARNED (4.4.2.1.4.3)

(TBD)

3.4.2.1.4.4 System low-pressure warning.

Means shall be provided to indicate low system pressure(s) as follows: (TBS).

REQUIREMENT RATIONALE (3.4.2.1.4.4)

In order to maintain flight safety when a hydraulic power subsystem is lost, air vehicle designs incorporate redundant hydraulic power subsystems. Therefore, essential hydraulic powered flight control is still available when one of the redundant systems has failed. The flight crew should be alerted by a low-pressure warning device (which denotes a failed hydraulic power subsystem if it comes “on”) that the air vehicle may no longer have hydraulic power subsystem redundancy, and that appropriate action should be taken.

REQUIREMENT GUIDANCE (3.4.2.1.4.4)

TBS: The low-pressure warning device should be installed in the air vehicle in addition to the pressure indicating system. It should be installed in a location easily observable to the pilot or other flight personnel.

REQUIREMENT LESSONS LEARNED (3.4.2.1.4.4)

An indicator light that only senses a low needle position on the oil pressure gage can result in erroneous warnings if the gage system fails.

4.4.2.1.4.4 System low-pressure warning.

The low-pressure warning shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.4.4)

The utility of low-pressure indication should be established.

VERIFICATION GUIDANCE (4.4.2.1.4.4)

TBS: The low-pressure warning device should be verified by conducting tests in accordance with appropriate specification(s) and it should be evaluated during the air vehicle ground and flight test program.

VERIFICATION LESSONS LEARNED (4.4.2.1.4.4)

False warnings - Low-pressure warning devices have come “on” due to anomalies in the air vehicle electrical system. Design provisions should be included in the warning device to minimize false warning occurrences due to electrical system anomalies.

3.4.2.1.5 Pressure control.

Overpressure protection shall be provided.

REQUIREMENT RATIONALE (3.4.2.1.5)

Limiting system pressures are needed to prevent malfunctioning of hydraulic components or prevent component structural failures.

REQUIREMENT GUIDANCE (3.4.2.1.5)

Variable-displacement hydraulic pumps incorporate a pressure-sensing device, which controls the pump flow rate into the system as a function of the system pressure. Fixed-displacement hydraulic pumps often use a pressure regulator (unloading valve). System pressure relief valves and thermal relief valves are also used in hydraulic power subsystems to prevent excessive pressures, which could cause component structural failures. For pumps not designed to withstand reverse rotation, the system should be designed so that no single failure will permit reverse rotation.

REQUIREMENT LESSONS LEARNED (3.4.2.1.5)

(TBD)

4.4.2.1.5 Pressure control.

Control of hydraulic pressures shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.5)

Pressure control is necessary as a proof of system safety.

VERIFICATION GUIDANCE (4.4.2.1.5)

TBS: The performance of the hydraulic power subsystem pressure control devices should be verified by analyses, inspections, laboratory tests, and ground tests.

VERIFICATION LESSONS LEARNED (4.4.2.1.5)

(TBD)

3.4.2.1.5.1 Peak pressure.

Peak pressure resulting from any phase of system operation shall not exceed (TBS).

REQUIREMENT RATIONALE (3.4.2.1.5.1)

Peak pressure limits are needed to prevent damage to hydraulic components.

REQUIREMENT GUIDANCE (3.4.2.1.5.1)

TBS: The maximum peak surge pressure during any phase of system operation should not exceed 135 percent (135%) of the system operating pressure unless the system is designed to accommodate higher peak pressures. Peak pressures less than 135 percent (135%) may be required for some hydraulic power subsystems.

REQUIREMENT LESSONS LEARNED (3.4.2.1.5.1)

The use of constant-displacement pumps with unloading valves generates excessive peak pressures in some air vehicles. Free air trapped in a hydraulic fluid system also contributes to excessive peak pressures.

4.4.2.1.5.1 Peak pressure.

Peak pressure characteristics shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.5.1)

Transient peak pressures are a major factor in causing fatigue failures in hydraulic components.

VERIFICATION GUIDANCE (4.4.2.1.5.1)

TBS: Peak pressures can be predicted by computer analysis. Component, mockup, and air vehicle tests should be used to verify the transient pressure characteristics.

VERIFICATION LESSONS LEARNED (4.4.2.1.5.1)

(TBD)

3.4.2.1.5.2 Pressure ripple.

Pressure ripple shall not exceed (TBS).

REQUIREMENT RATIONALE (3.4.2.1.5.2)

Pressure ripple amplitude and frequency generated by high-speed rotating fluid equipment should be identified and attenuated to prevent hydraulic power subsystem instabilities.

REQUIREMENT GUIDANCE (3.4.2.1.5.2)

TBS: Pressure ripple amplitude limits should be expressed as a percentage of nominal system pressure. The military pump specification permits ripple amplitude of ±10 percent (±10%) of system output pressure. The blank should be filled in to limit pressure amplitude to a lesser value and, further, to prevent destructive resonance in the hydraulic distribution system at the range of operating pump speeds.

REQUIREMENT LESSONS LEARNED (3.4.2.1.5.2)

The pressure ripple in the flow output of a piston-type hydraulic pump is transmitted throughout the supply side of the hydraulic power subsystem. The dynamic resistance (impedance) of the hydraulic fluid column creates pressure pulsations throughout the hydraulic supply system.

When the frequency (speed) of the acoustic source (pump) is equal to the natural frequency of the hydraulic fluid column, a resonance condition occurs. Pressure ripple at resonance may be very high, +1000 psi in a 3000-psi system. These resonant conditions are potentially very destructive to the system hardware. In extreme cases, the pressure vessel (lines or components) may reach fatigue failure limits in a few minutes. Hydraulic flow and pressure ripples excite high frequency mechanical motion in lines and components. Excessive motion causes stresses that may result in failure of lines, components, or mounting hardware.

Pump discharge lines are generally the most vulnerable since they are in the area of maximum acoustic energy close to the pump. Dead-end lines to service ports and pressure transmitters are also vulnerable to pulsation-induced damage.

Pressure ripples also occur in the pump inlet and return system. Normally, the inlet system is not a problem because of the low pressure at which it operates. However, thin wall tubing, high installation stresses, and an adverse resonance condition could produce inlet system failures.

The coupling of hydraulic to mechanical resonances is a complex phenomenon, and is a function of line size, configuration (routing), and installation constraints. Total stresses in lines are a combination of hoop stress from internal pressure and bending stress due to installation and induced vibration. Large pump discharge and inlet lines (one inch and above) are particularly vulnerable to high installation stress. Total combined line stress should be low enough to provide infinite fatigue life.

An acceptable level of pressure ripple in one system may not be acceptable in another system due to differences in mechanical response. High frequency line motion induced by pressure ripple cannot be controlled by normal line support techniques (clamps). Clamps should be designed to withstand the line vibration without wearing out the cushion and chafing through the line.
Table I relates central system pulsation level with potential problems.

TABLE I. Pump pressure ripple, peak to peak.

MAXIMUM PULSATIONS	POTENTIAL PROBLEMS
>600 PSI	Rapid failure of pump discharge line due to pressure and vibration stresses. Possible failures of mounting structure and internal functions of central components.
300 – 600 psi	Line clamp cushion wearout, line failure due to clamp chaffing, poor clamp life, frequent inspections required, discharge line check valve wearout.
<150 psi	Trouble free, long-life service.

The first category (>600 psi) is a potential safety of flight situation. The second category is one of nuisance level problems that probably surface only after a considerable amount of operational flight experience. The best approach is to verify acceptable line stresses on the iron bird and the first flight air vehicle to preclude failures of the first category. Pump to filter line lengths or other simple plumbing changes may be identified to relocate resonances away from continuous operating speeds. If stress levels are not acceptable, wideband attenuators or hoses for mechanical decoupling should be considered. Beyond the central system (that is, away from the high acoustic energy of the pumps, gearboxes, and engines), the vibration environments are relatively benign. Good line support and adequate clearances between lines and lines and structure precludes significant vibration related problems.

4.4.2.1.5.2 Pressure ripple.

The required pressure ripple limits shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.5.2)

Pump ripple characteristics should be determined by appropriate high response electronic instrumentation.

VERIFICATION GUIDANCE (4.4.2.1.5.2)

TBS should be filled in by “analysis and test.” A computer program can predict the system dynamics once the hydraulic power subsystem configuration has been modeled. The Defense Specifications for pumps include a test procedure to determine ripple characteristics in a specific test circuit. However, this test circuit may not have the same configuration or impedance as the system being developed. Changing the hydraulic power subsystem impedance could appreciably increase the amplitude of the hydraulic pump pressure ripple. Consequently, if any major changes are made to hydraulic power subsystems such as rerouting hydraulic lines or adding components, tests should be rerun to determine the effects on the pump outlet pressure characteristics.

Pump ripple pressures and peak pressure transients (water hammer) are attenuated at the system pressure filter. Therefore, emphasis should be placed on evaluating system dynamics between the pump outlet and system pressure filter. Pressure-attenuating devices such as Helmholtz resonators, accumulators, and system architecture can reduce pressure amplitudes. Some air vehicles use pumps that incorporate Helmholtz resonators to attenuate output pressures.

VERIFICATION LESSONS LEARNED (4.4.2.1.5.2)

There have been several air vehicles that have experienced tube and tube clamp failures because of resonance. Most failures occur in the engine nacelle area and could have been prevented or corrected if system evaluation tests had been conducted.

Pump pressure ripples in a distribution circuit are damped at the pressure line filter. Therefore, transducer pickups should be placed close to the pump pressure outlet.

3.4.2.1.5.3 Back pressure.

Proper functioning of any unit shall not be affected by back pressure in the system.

REQUIREMENT RATIONALE (3.4.2.1.5.3)

The hydraulic power subsystem back pressure limits should be controlled to preclude degradation and malfunctions from occurring.

REQUIREMENT GUIDANCE (3.4.2.1.5.3)

Legacy Military Specifications MIL-H-5440 and MIL-H-8891, and SAE AS5440 could be used as guides. Factors to consider include reservoir pressurization and hydraulic line loss as a function of fluid viscosity.

The system or systems should also be so designed that malfunctioning of any unit in the system will not render any other subsystem, emergency system, or alternate system inoperative because of back pressure.

Back pressure resulting from the operation of any unit while the air vehicle is on the ground should create no greater back pressure at the brake valve return port than 90 percent (90%) of that pressure which will cause contact of braking surfaces. In addition, supply pressure to the brake system should not drop below the maximum brake-operating pressure during the operation of any other subsystem in the air vehicle during taxiing, landing, or takeoff.

REQUIREMENT LESSONS LEARNED (3.4.2.1.5.3)

Brake system return fluid should go directly to the reservoir instead of another return line. Clogged filter(s) can cause serious back pressure problems. A clogged brakeline filter contributed to a bomber mishap after landing.

4.4.2.1.5.3 Back pressure.

Operating effects from back pressure shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.5.3)

System back pressure characteristics should be identified during development to avoid redesign after full-scale development.

VERIFICATION GUIDANCE (4.4.2.1.5.3)

TBS: The verification of the hydraulic power subsystem back pressure should be by analysis, laboratory tests, and air vehicle ground and flight tests.

VERIFICATION LESSONS LEARNED (4.4.2.1.5.3)

(TBD)

3.4.2.1.6 System level contamination prevention.

There shall be means to remove solid particulate contaminants from hydraulic power subsystem fluid during flight, ground, and filling operations.

REQUIREMENT RATIONALE (3.4.2.1.6)

It is important that particulate contaminants be removed from hydraulic fluid to reduce component wear and prevent contaminant-induced component malfunctions, such as servo valve stiction.

REQUIREMENT GUIDANCE (3.4.2.1.6)

If filters are used, the following should be considered. The filter rating(s) issue for hydraulic power subsystems can be controversial. Most of the controversy is focused on 5- versus 15-micron absolute filtration. A desirable goal is to establish a contamination level that is practical to maintain and still ensure reliable hydraulic power subsystems. The trend has been to go to 5-micron absolute filters in new designs.

REQUIREMENT LESSONS LEARNED (3.4.2.1.6)

Levels of needed filtration have been a controversial subject for years. In the 1950s, the filter element was a 10-micron nominal rating, which did not define the maximum particle size removed by the filter.

In the 1960s, absolute ratings were specified. The MIL-F-8815 filter has a 15-micron absolute rating that essentially means that the largest spherical particle removed is 15 microns, whereas the largest particle removed was undefined in older filter specifications.

Based on early experience with 5-micron absolute filters in improving the pump life on an air vehicle, U.S. Navy personnel recommended the immediate adoption of 5-micron filtration in all systems.

About 1961, the use of 3-micron absolute filters on ground service equipment (GSE) successfully “cleaned” contaminated hydraulic power subsystems on a bomber air vehicle. Thus, the 3- to 5-micron absolute filter became a “standard” for GSE. The contamination in the systems was actually from pumps and reservoirs that were not clean.

Naval Air Development Center laboratory tests for pump wear data indicates decreased pump internal surface damage with the use of finer filters. Five-micron absolute filters were reported to produce 71 percent (71%) less wear than 15-micron absolute filters. The reason is that the finer filter removed more of the smaller abrasive wear particles from the lubricating film thickness separating component-operating surfaces.

Generally, the use of hydraulic-powered flight controls and servo valves do require finer filtration.

The changeover from 25-micron absolute filters to 5-micron absolute filters improved the performance of silt-prone servo valves in a cargo air vehicle.

The use of a 5-micron absolute filter in place of a 10-micron absolute filter improved the performance of the Maverick missile hydraulic power subsystem that uses single stage servo valves.

A large degree of success depends on the system designer and the degree of effort that the user is willing and able to put into the maintenance and filtration control program. A clear fluid is not necessarily a clean fluid. The unaided eye cannot see particles smaller than 40 microns. Education and re-education is critical at all working levels to keep clean hydraulic power subsystems clean.

At one time, reusable (cleanable) wire mesh filter elements were used. However, the cleaning procedure, including ultrasonic bath, did not sufficiently restore the full effectiveness of the metal elements. Experience has shown that the disposable (noncleanable) elements are more efficient and are more cost effective than "cleanable" wire mesh elements.

Experience has shown that filter media migration can occur from sintered bronze filters; that is, bronze particles separate from the filter itself.

Separate pump case drain filters are recommended instead of piping case drain flow upstream of system return line filters. Return lines filter pressure drop and return line system pressure surges can adversely affect case drain line pump seal integrity. In addition, a pump failure causes debris in the case drain line.

4.4.2.1.6 System level contamination prevention.

The means to remove solid particulate contamination shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.6)

Filter characteristics are usually proven by qualification tests on the filter element and filter assembly.

VERIFICATION GUIDANCE (4.4.2.1.6)

TBS: This requirement should be verified by inspection of drawings, and laboratory test data.

VERIFICATION LESSONS LEARNED (4.4.2.1.6)

There is a difference between laboratory tested dirt capacity and actual system filter life. Dirt capacity of a filter element as measured in the laboratory is designed to produce repeatable, relative data demonstrating a filter's ability to remove artificial test contaminant under specific test conditions. System contamination is not the same as the contaminant used in the laboratory. Actual filter life would have to be established by test in the air vehicle system. An experimental test method used to rate a filter is known as Beta X, where X is a particle size, for example X = 10 microns. The filtration ratio for X micron size is determined by obtaining particulate measurement data while recirculating flow with predetermined weight of contaminant added continuously to the test system (also called multipass testing). The dimensionless ratio for Beta X micron particles is equal to the number of particles upstream of the filter greater than X microns, divided by the number of particles downstream greater than X microns. This test is not called out in military filter specifications.

The ability of a finer filter to remove more fine particles than a coarser filter does not necessarily mean that the finer filter will have a shorter life in the system because of dirt holding limitations. The finer filter should remove more of the abrasive smaller particles, which contribute to higher wear rates. This should result in less component surface wear, which should reduce the overall amount of system-generated contamination. The question becomes "How fine a filter is necessary for a given system?"

Pump performance tests at the Franklin Institute resulted in the following:

a. 10-micron size and larger particles were detrimental.

b. Hardness of the particle(s) is a dominant factor in wear.

3.4.2.1.6.1 Contamination control maintainability.

Contamination control assemblies shall be readily accessible and shall be replaceable with no fluid loss other than the fluid in the assembly.

REQUIREMENT RATIONALE (3.4.2.1.6.1)

This is a maintenance-driven requirement. Contamination controls assemblies need to be located where they are easily accessible and prevent fluid loss during maintenance actions.

REQUIREMENT GUIDANCE (3.4.2.1.6.1)

The contamination control assemblies should be located so that maintenance personnel can easily see the contamination control assembly indicator, readily replace contamination control assemblies as needed; and have sufficient working envelope space to allow wrenching and space to remove and replace a contamination control assembly element. During contamination control assembly replacement, fluid should be retained in the hydraulic power subsystem and not be permitted to spill. The function of an automatic shut-off is to prevent fluid from draining out of the system upstream and downstream of the system contamination control assembly during element removal.

REQUIREMENT LESSONS LEARNED (3.4.2.1.6.1)

The following addresses filter assemblies that have historically been used for contamination control.

The location of the filter assemblies also involves environment considerations. A filter on a fighter was located in the aft fuselage near the engine area and was exposed to heat soak. There were leakage problems with the static seal at the filter bowl interface. An air-to-air missile, which used special low viscosity fluid experienced static seal leakage problems, caused by extreme low temperatures during qualification tests; the Buna N O-ring was replaced with a fluorosilicone O-ring.

A special filter for use in a manifold was procured by an air vehicle prime. This resulted in a non-competitive situation that was costly and added to the logistics burden.

When changing a dirty filter element, clean fluid should be placed in the filter bowl with a clean filter element to minimize particle and air contamination ingestion into the hydraulic system during this maintenance action.

4.4.2.1.6.1 Contamination control maintainability.

Accessibility of installed contamination control assemblies for ease of element replacement shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.6.1)

There should be sufficient envelope to remove and replace contamination control assembly elements.

VERIFICATION GUIDANCE (4.4.2.1.6.1)

TBS: A review of contamination control assembly drawings can show the envelope dimensions needed to remove and replace the element. A demonstration on the mock-up and air vehicle is the best way to verify ease of contamination control assembly removal and replacement.

VERIFICATION LESSONS LEARNED (4.4.2.1.6.1)

The following addresses filter assemblies that have historically been used for contamination control:

Some filter differential pressure indicators have given false indications of clogged filter elements on some air vehicles.

These false indications occurred so often that some maintenance personnel chose to ignore the button indicator. Consequently, filter element replacement time was based on air vehicle operating hours in lieu of the indicator for some air vehicles.

3.4.2.1.6.2 Cleanliness level of delivered systems.

Hydraulic particulate contamination shall not exceed (TBS) when the air vehicle is delivered to the procuring activity. Fluid sampling capability shall be available.

REQUIREMENT RATIONALE (3.4.2.1.6.2)

A desired goal is to establish a contamination level that is practical to maintain and still ensure hydraulic power subsystem reliability.

REQUIREMENT GUIDANCE (3.4.2.1.6.2)

TBS: A generally accepted contamination level for delivered air vehicles is NAS 1638, Class 6 or Class 7, depending on the complexity of the hydraulic power subsystem.

REQUIREMENT LESSONS LEARNED (3.4.2.1.6.2)

(TBD)

4.4.2.1.6.2 Cleanliness level of delivered systems.

Hydraulic particulate contamination of delivered air vehicles shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.6.2)

The initial cleanliness level should be measured.

VERIFICATION GUIDANCE (4.4.2.1.6.2)

TBS: Contamination level is determined by analysis of representative fluid samples taken from the air vehicle hydraulic power subsystems. It is recommended that a sampling valve be located upstream of the return line contamination control assembly. Other sampling points, if desired, should be selected by mutual agreement.

VERIFICATION LESSONS LEARNED (4.4.2.1.6.2)

Samples should be taken from a moving fluid stream. A sample of fluid from a static location is of little value. Contamination level of new and cleaned air vehicles may be acceptable, but can build to an unacceptable level within 100 flying hours. Peak contamination levels appear to coincide with component replacement, pump defects, and servicing activities.

Contamination can arise from internal or external sources.

Ground service equipment fluid, which is not clean, contributes to air vehicle system contamination. Ground service equipment should be monitored for fluid cleanliness levels.

Hydraulic pumps generate considerable contamination, especially during wear-in periods, and during a primary failure. Much of the wear-in debris is less than 5 microns. Hydraulic pumps should be procured that have already completed a run-in test.

Consider contamination control assemblies in proportion to the number of components in the system rather than for only maximum pump flow.

Unless conflicting engineering data is available for particular hydraulic power subsystems, it is recommended the following contamination levels in Table II be considered as a maximum limit:

TABLE II. Contamination levels.

NEW FLUID	SEE THE APPLICABLE FLUID SPECIFICATION.
Ground Service Equipment	Class 6, NAS 1638
Delivered Air Vehicles	Class 6 or 7, NAS 1638
In-Service Air Vehicles	Class 8, NAS 1638

3.4.2.1.7 System air removal.

The system shall be designed and configured such that entrained air shall not cause sustained loss of system pressure or degradation of system operational performance during all conditions of intended air vehicle operation. There shall be provisions for bleeding air from the hydraulic fluid at critical points for maintenance purposes.

REQUIREMENT RATIONALE (3.4.2.1.7)

Air in hydraulic power subsystems can cause problems with sluggish response due to lower effective fluid bulk modulus, pump cavitation, or in some cases, the complete loss of hydraulic power due to air lock of the hydraulic pump(s) (free air in the pump inlet line).

There have been cases where fighter air vehicles have lost hydraulic power in one or two hydraulic power subsystems for periods of a few seconds to several minutes or more. Several cases of pump air lock occurred during a flight maneuver and negative "g" mode.

REQUIREMENT GUIDANCE (3.4.2.1.7)

The use of unvented hydraulic power subsystems (that is, the reservoir does not vent to atmosphere) makes it more difficult to remove air from hydraulic fluid. Bleed fittings should be provided in the brake lines. Bleed fittings should be considered at strategic high points in the hydraulic power subsystem.

REQUIREMENT LESSONS LEARNED (3.4.2.1.7)

a. Air vehicle system design. Some examples of designs, which could reduce the air in hydraulic power subsystems, are:

   1. Some system accumulators can be eliminated by providing high-response pumps, backed up by high-response relief valves. This reduces the frequent maintenance associated with accumulator piston seal leakage of gas into the hydraulic fluid.

   2. Using quick-disconnect couplings having low air inclusion on components that require periodic maintenance, and using quick-disconnect fittings at service ports. This results in negligible fluid loss and air entrainment.

b. Ground service equipment. The use of closed hydraulic power subsystems with "bootstrap" type reservoirs has made air bleeding more difficult. Reservoirs of the open or vented design make air bleeding simpler.

   Effective removal of air from air vehicle hydraulic power subsystems is important and can be accomplished with a conventional hydraulic ground cart if it has open loop capability. The cart reservoir should be kept open to the atmosphere to separate air from the air vehicle oil. The actual bleed time depends on the initial air content of the oil, volume of the circuit being cycled, the cart flow rate and the air settling capability of the cart reservoir. Further, if there are multi-hydraulic power subsystems in the air vehicle, the ground cart should have simultaneous multi-hydraulic power subsystem capability with a separate open loop reservoir for each system.

   Never service the air vehicle using a pneumatically pressurized cart reservoir. The oil in the cart reservoir dissolves large amounts of the pressurizing gas that finds its way into the air vehicle system during servicing. Keeping the cart reservoir vented to atmosphere allows the air to come out of solution and separate from the air vehicle oil during open loop bleeding.

c. Reservoir bleed valve. Bleeding of the air vehicle reservoir via the reservoir overboard bleed valve removes a free bubble from the top of an air vehicle reservoir. Momentary reservoir bleeding is a good practice after each long down period and as a preflight activity. However, it is not practical to remove air in this manner from the entire system. Closed loop air removal via a reservoir bleed cannot wash out the air. Detection of free air in a bootstrap type reservoir system can be roughly indicated by reservoir piston sink (the change in reservoir piston position indicator before and after hydraulic power subsystem pressurization).

d. Laboratory tests. Air separation and collection in the reservoir is most effective when oil-flow rate through the reservoir and the reservoir pressure are both low. However, high oil-flow rates are necessary to flush air from remote system locations. Air was adsorbed by oil at normal return pressure (50 psi) and system flows. Bootstrap pressure, combined with high flows necessary to sweep air through the system, actually helps the hydraulic fluid to adsorb the system air. Shutdown of the system causes the air to come out of solution without collecting at the reservoir. Another phenomenon noted was that the pump seemed to homogenize the air within the oil, aiding in air adsorption at high flow conditions.

e. Laboratory and iron bird system tests. Laboratory and iron bird system tests demonstrated system modifications to clear pump air lock independent of temporary system pressure loss. The main objective was the capability to restore pressure to an air locked system in less than four seconds for ingested air volumes of up to 66 cubic inches of free air. The modification consisted of adding a bypass valve, and a check and one-way restrictor relief valve. The bypass valve, which closes when system pressure increases to 600 psi, allows sufficient flow through the reservoir and pump suction line to sweep out the air. It was found necessary to increase the bypass valve orifice flow capacity from the 3-5 gallons per minute (gpm) design goal at a differential pressure of 3000 psi to obtain a satisfactory recovery time. The larger orifice was needed to move the oil in the pump pressure hose at the low differential pressure (about 50 psi) available during the air locked condition, while the pump is acting as an air compressor. The in-line relief valve aids in “trapping” bootstrap reservoir pressure and allows free flow into the reservoir.

   A potential drawback to a bypass valve in this application is the heat that could be generated if the valve were to fail in continuous bypass. However, a thermal switch could be incorporated if operational analysis showed that thermal protection was mandatory.

f. Deaeration devices. A fighter nose gear system incorporates a deaeration device that eliminates nose wheel steering shimmy caused by air in the hydraulic power subsystem. The device can handle the amount of air in this application because nose steering is not a continuous function. An operational test of a deaerator in the main system of a fighter air vehicle showed that saturation occurred because of the system oil flow rates.

g. Air tolerance. Dissolved air measured in a fighter air vehicle was in a range of 14 to 26 percent (26%) by volume. Dissolved air is air in solution in a fluid. Free air is air entrapped in a system but not totally in contact with a fluid. Entrained air is air suspended in a fluid and normally exists in the form of bubbles. MIL-PRF-5606 hydraulic fluid contains about 10 percent (10%) dissolved air by volume at 15 psi. Saturated air volume in solution is proportional to pressure and is inversely proportional to temperature. There is no universal acceptable minimum value for air in a system, but good bleeding and maintenance procedures should reduce the air content. Open loop bleeding can reduce the air vehicle system air content to 14 percent (14%) or less.

h. Deaerated hydraulic fluid. Some missiles are charged with deaerated hydraulic fluid using a vacuum technique.

4.4.2.1.7 System air removal.

Entrained air effects and provisions for air removal shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.7)

It may be necessary to introduce known quantities of free air into a laboratory system (subsystem) to evaluate performance.

VERIFICATION GUIDANCE (4.4.2.1.7)

TBS: Entrained air phenomena can be evaluated in functional test rigs (iron bird). The provisions for air removal should be verified by inspection, demonstration, and tests.

VERIFICATION LESSONS LEARNED (4.4.2.1.7)

(TBD)

3.4.2.1.8 Moisture exclusion.

The hydraulic power subsystem shall be designed to restrict the ingestion and collection of moisture.

REQUIREMENT RATIONALE (3.4.2.1.8)

Moisture in a hydraulic power subsystem can cause malfunctions from corrosion, shorts in electrical devices, and freezing.

REQUIREMENT GUIDANCE (3.4.2.1.8)

Specific water concentration will vary with the fluid system. The limit in new MIL-PRF-5606 fluid is 100 ppm (parts per million) and is 500 ppm in new MIL-PRF-6083 fluid, the preservative version of MIL-PRF-5606 fluid. Consider moisture ingression from moist bleed air reservoir pressurization (if used), from air vehicle washing, and from operating in the rain or snow. Solenoid valves in a low spot can accumulate water and freeze.

REQUIREMENT LESSONS LEARNED (3.4.2.1.8)

Water in conjunction with chlorinated solvents in a hydrocarbon fluid system can cause sticking of slide valves and promote a form of corrosion on low-chromium steels. Experience has shown that chlorine concentration of 200 ppm and 100 ppm of moisture can promote corrosion phenomena. This has occurred on several different air vehicles.

Water running down the landing gear strut wiring entered a “black box” and caused a short. Locate electrical devices related to the hydraulic power subsystem to preclude water ingestion or hermetically seal from moisture.

There is no universal specified maximum limit for moisture content in a hydraulic fluid system. Although it would be desirable to be below 150 ppm, a 300-ppm moisture limit has been considered for one specific hydraulic power subsystem with MIL-PRF-83282 hydraulic fluid.

There have been many cases of adding drilled vent holes in valves after water problems occurred. Furthermore, valves with drilled vent holes should be oriented to drain moisture instead of collecting moisture.

4.4.2.1.8 Moisture exclusion.

Means to restrict ingestion and collection of moisture shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.8)

Operations analysis and systems layout are factors to identify potential moisture problems.

VERIFICATION GUIDANCE (4.4.2.1.8)

TBS: Verification can be by system design analysis, inspection, first article (air vehicle) inspection, and ground and flight test experience.

VERIFICATION LESSONS LEARNED (4.4.2.1.8)

Analyzing air vehicle system fluid samples for water content is not normally done, unless a water-related problem occurs or is suspected. Occasionally, water in GSE hydraulic fluid is transmitted to an air vehicle.

3.4.2.1.9 Leakage control.

Acceptable leakage limits shall be defined for components and systems.

REQUIREMENT RATIONALE (3.4.2.1.9)

External leakage should be minimized to reduce maintenance problems and potential fire hazards. Leakage, even within allowable limits, is a general nuisance.

REQUIREMENT GUIDANCE (3.4.2.1.9)

Static seals should not leak at all. Dynamic seals usually have finite amounts of leakage. Allowable leakage values are normally specified for individual components in contractor-prepared specifications or in Defense Specifications. Leakage values should be evaluated for "reasonableness" and overall performance expectations. O-ring seals are most commonly used, although other specialty seals are often used successfully.

REQUIREMENT LESSONS LEARNED (3.4.2.1.9)

A common cause of leakage is inadequate design squeeze. Use of the largest standard cross section O-ring possible is highly recommended. It is difficult to seal with a "string."

The O-ring seal is affected by changes in physical shape combined with loss of mechanical and physical properties. These are time-dependent functions after the seal is installed. In type I hydraulic power subsystems, the seal is expected to last the life of the air vehicle. However, there is a loss of seal life at fluid temperatures greater than 225°F for Buna N seals in either MIL-PRF-5606 or MIL-PRF-83282 fluid. This was learned in a fighter air vehicle and could be predicted by O-ring specification fluid aging tests for type I (7 days at 160°F) versus 70 hours at 275°F for type II O-ring material. It is recommended that heat exchangers be used to keep hydraulic power subsystem fluid below 225°F if practical and below 250°F if possible, to achieve reasonable seal life. This is reflected in SAE AS5440. Aerospace Material Specification SAE AMS-P-83461 Buna N O-rings should be used in MIL-PRF-5606 and MIL-PRF-83282 hydraulic fluid systems.

O-ring spiral failures occur when there is differential twisting of the O-ring, which results in a spiral cutting failure. The failures have been attributed to several factors, but marginal seal lubrication with rapid stroking duplicated the failure in the laboratory. Side loading a shock strut and completely drying the strut before stroking induced the laboratory failures. Spiral failures have been corrected by using a seal shape that resists rolling in the seal groove.

An in-service leakage problem results when a low squeeze design is used to reduce seal friction, even though the design passed qualification tests. If such a design is contemplated, the absolute worst design conditions should be tested. Experience has shown that a low squeeze design results in unacceptable leakage in service.

Using the O-ring elastomer as a spring to maintain contact between the tetrafluoroethylene (TFE, Teflon®) and the metal rod has used cap strips of TFE to reduce friction or cylinder bore. In certain piston applications a blow-by phenomena has occurred where a pressure reversal separates the TFE cap and cylinder bore interface, allowing a massive pressure drop across the piston. Corrective action was to make notches on the sides of the TFE cap. Blow-by caused the crash of an experimental air vehicle. The failure mode was duplicated in the laboratory. A failure to extend a fighter landing gear was attributed to blow-by of a rod type cap seal, although this could not be duplicated in the laboratory. Additional information on blow-by is found in SAE AIR1243.

The use of dual rod seals can reduce external leakage. The dual rod seals are usually vented to return. Unvented rod seals have been used in the United Kingdom with great success and in several United States air vehicles. The dual unvented seals are usually “specialty” seals that permit some seepage, and furthermore, are not operating in high temperature environments where thermal expansion of trapped fluid can generate extreme high local pressure. Dual unvented seals should not be used when a pressure trap force or friction force between seals is greater than the actuating force, such as spring-loaded devices or free fall actuators.

The fitting boss seal installation has been a problem because separate manufacturers usually make the mating flat metal surfaces. In addition, the axis of the threads should be perpendicular to the fitting hex surface. The absence of a fitting “hex” flat to the mating surface can permit extrusion of the boss fitting O-ring, especially in larger port sizes. Several air vehicles are using the Rosán® boss fitting to prevent the potential service difficulties with the older boss type fitting installation.

4.4.2.1.9 Leakage control.

Acceptable leakage rates shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.9)

Allowable leakage should consider the effects of in-service use as well as leakage from “new” seals.

VERIFICATION GUIDANCE (4.4.2.1.9)

TBS: Use individual component qualification and acceptance requirements, laboratory evaluation(s), air vehicle extreme-temperature tests, and air vehicle flight and service experience

Duplicate the operating conditions as much as practical and consider adverse seal design tolerances.

VERIFICATION LESSONS LEARNED (4.4.2.1.9)

(TBD)

3.4.2.1.10 Emergency operation.

Normal and emergency systems and their controls shall be designed so that the desired function is attained when either is initiated first or when both systems are operated at the same time.

REQUIREMENT RATIONALE (3.4.2.1.10)

The desired function should be accomplished after selection of either a normal mode or an emergency mode of operation.

REQUIREMENT GUIDANCE (3.4.2.1.10)

Operational capability should be considered to avoid any adverse interaction between normal and emergency modes of operation.

Two or more subsystems pressurized by a common pressure source, one of which is essential to flight operation and the other not essential, should be so isolated that the system essential to flight operation will not be affected by any damage to the nonessential system.

Hydraulic pumps required to provide emergency power for direct application to flight controls or other essential hydraulic flight requirements should not be used for any other function.

REQUIREMENT LESSONS LEARNED (3.4.2.1.10)

(TBD)

4.4.2.1.10 Emergency operation.

Intended functional performance with normal and emergency operation shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.10)

The function should not be lost because of an adverse interaction between normal and emergency modes of operation.

VERIFICATION GUIDANCE (4.4.2.1.10)

TBS: Verification should be done by design review(s), subsystem tests, ground demonstration, and flight tests.

VERIFICATION LESSONS LEARNED (4.4.2.1.10)

(TBD)

3.4.2.1.11 Proof pressure.

No component shall fail, take any permanent set, or be damaged in any manner, when subjected to applicable proof pressure of (TBS 1). Systems and components shall satisfy this requirement when subjected to a proof pressure of (TBS 2).

REQUIREMENT RATIONALE (3.4.2.1.11)

The intent of this requirement is to assure that all systems and components are adequately designed and tested for functional and structural integrity.

REQUIREMENT GUIDANCE (3.4.2.1.11)

TBS 1: The system and its components should be designed to withstand the proof pressure requirements without permanent deformation and should be fully functional following the test.

TBS 2: When proof tests are conducted at temperatures other than design temperatures, account for the degradation of material properties at design temperatures in determining the proof pressure. The proof load should be of sufficient magnitude to ensure that the service life requirements are met.

REQUIREMENT LESSONS LEARNED (3.4.2.1.11)

(TBD)

4.4.2.1.11 Proof pressure.

Proof pressure compliance shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.11)

A material factor of safety should be established.

VERIFICATION GUIDANCE (4.4.2.1.11)

TBS: This requirement can only be demonstrated by actual tests on the system and components.

a. System. Proof pressure is applied to the system to prove the integrity of connections at each component.

b. Component. Proof pressure is applied to the component to prove the integrity of the component.

VERIFICATION LESSONS LEARNED (4.4.2.1.11)

(TBD)

3.4.2.1.12 Burst pressure.

No component shall rupture when subjected to an applicable burst pressure of (TBS).

REQUIREMENT RATIONALE (3.4.2.1.12)

The intent of this paragraph is to ensure all components are adequately designed and tested for structural integrity.

REQUIREMENT GUIDANCE (3.4.2.1.12)

TBS: The components should be designed to withstand burst pressure requirements without rupture. Deformation resulting from the test is acceptable and the component need not be functional after the test. When burst tests are conducted at temperatures other than design temperatures, account for the degradation of material properties at design temperature in determining the burst pressure.

REQUIREMENT LESSONS LEARNED (3.4.2.1.12)

(TBD)

4.4.2.1.12 Burst pressure.

Burst pressure compliance shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.12)

The intent is to ensure that all components are adequately designed and tested for structural integrity.

VERIFICATION GUIDANCE (4.4.2.1.12)

TBS: Burst pressure compliance should be verified by tests. Burst pressure is applied to the component to prove the integrity of the component. SAE AS8775 and the legacy document MIL-H-8775 may be used as guides for the test procedure and pressure level.

VERIFICATION LESSONS LEARNED (4.4.2.1.12)

(TBD)

3.4.2.1.13 Low-temperature operation.

The hydraulic power subsystem shall operate at low temperature conditions as follows: (TBS).

REQUIREMENT RATIONALE (3.4.2.1.13)

The low temperature operating conditions should be defined.

REQUIREMENT GUIDANCE (3.4.2.1.13)

TBS: The low temperature operating temperature is normally defined in the weapon system procurement document.

REQUIREMENT LESSONS LEARNED (3.4.2.1.13)

At one time, O-ring seals were aged for 72 hours at -65°F to test for O-ring material crystallization phenomena. Current low temperature tests are performed after stabilizing the component at the desired low temperature plus a 4-to-8-hour low temperature soak, depending on the mass and size of the component.

The O-ring seal properties that enhance low temperature sealing can be in opposition to good seal performance at higher temperatures. For example, high tolerance O-ring cross-section, low tolerance O-ring glands, higher volume change material, and use of “high volume swell” fluid can improve low temperature sealing.

A valuable laboratory test known as temperature retraction (TR) was developed in the 1950s. TR 50-10 denotes the temperature to return an elastomer specimen 10 percent (10%) after the specimen had been stretched 50 percent (50%) and “frozen” in a cold bath. It was determined that an O-ring should pass a -65°F performance test if an oil aged test specimen had a TR 50-10 of -49°F or colder.

Laboratory component tests at -65°F should be conducted with a tolerance of -5°F, +0°F.

4.4.2.1.13 Low-temperature operation.

Low-temperature performance shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.13)

The suitability of low-temperature performance should be verified and information, as required, should be included in the pilot’s handbook and maintenance cold weather operating procedures.

VERIFICATION GUIDANCE (4.4.2.1.13)

TBS should be filled in with analyses and tests. Low temperature tests are performed at the component level and are performed at a system level in the Climatic Hangar at Eglin AFB FL. Low temperature ground and flight tests are performed during operation and test evaluations.

VERIFICATION LESSONS LEARNED (4.4.2.1.13)

A component should be capable of functioning when assembled with adverse tolerance parts without binding at low temperatures. The effect of different materials should be considered in the design stage. The manufacturer can verify this by analysis. In critical applications, a test might be preferred.

3.4.2.1.14 High-temperature operation.

The maximum hydraulic bulk fluid temperature shall be (TBS).

REQUIREMENT RATIONALE (3.4.2.1.14)

The high temperature operating conditions should be defined to ascertain possible fluid cooling needs and general operation.

REQUIREMENT GUIDANCE (3.4.2.1.14)

TBS: The high temperature-operating limit is usually a function of seal life rather than a function of fluid life. Consideration should also be given to heat soak-back after engine shutdown.

REQUIREMENT LESSONS LEARNED (3.4.2.1.14)

A fighter has a thermal switch that diverts hydraulic fluid to the heat exchanger when the fluid temperature exceeds 225°F.

A helicopter had heat degradation of fluid and seals after cumulative ground test operation using the onboard auxiliary power unit (APU). Corrective action was to include an air-fluid heat exchanger.

4.4.2.1.14 High-temperature operation.

High temperature operation shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.14)

The suitability of high temperature performance should be verified.

VERIFICATION GUIDANCE (4.4.2.1.14)

TBS should be filled in with analyses and tests. High temperature tests are performed at the component level. System high temperature performance tests are performed during operation and test evaluations.

VERIFICATION LESSONS LEARNED (4.4.2.1.14)

High temperature component aging should be carefully controlled in an oven (or fluid bath) having uniform temperature throughout. The system maximum fluid temperature is usually in the pump case drain.

3.2.1.14.1 Thermal relief.

Pressure relief for hydraulic fluid thermal expansion shall be provided for all components in hot locations and closed plumbing segments.

REQUIREMENT RATIONALE (3.2.1.14.1)

Temperature and pressure conditions, if not controlled, could cause over pressurization component failures.

REQUIREMENT GUIDANCE (3.2.1.14.1)

Particular emphasis should be placed on the following:

a. Pressure and temperature control
b. Avoiding component location in proximity to hot compartments heats sources and hot surface.

REQUIREMENT LESSONS LEARNED (3.2.1.14.1)

(TBD)

4.4.2.1.14.1 Thermal relief.

Pressure relief for hydraulic fluid thermal expansion shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.14.1)

The pressure relief function should be verified.

VERIFICATION GUIDANCE (4.4.2.1.14.1)

Analysis and inspection of drawings should show protection features. Tests may be required in some instances.

VERIFICATION LESSONS LEARNED (4.4.2.1.14.1)

(TBD)

3.4.2.1.15 Fire and explosion hazard proofing.

Integration of the hydraulic power subsystem in the vehicle shall be in accordance with (TBS).

REQUIREMENT RATIONALE (3.4.2.1.15)

Temperature and pressure conditions, if not controlled, could present a potential fire hazard.

REQUIREMENT GUIDANCE (3.4.2.1.15)

TBS: Particular emphasis should be placed on the following:

a. Pressure and temperature control
b. Keeping combustibles to a minimum
c. Avoiding proximity to ignition sources, hot surfaces, and electrical wiring.

REQUIREMENT LESSONS LEARNED (3.4.2.1.15)

(TBD)

4.4.2.1.15 Fire and explosion hazard proofing.

Fire and explosion resistance shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.15)

Fire and explosion resistance should be verified because it is a critical safety-of-flight issue.

VERIFICATION GUIDANCE (4.4.2.1.15)

Analysis and inspection of drawings should show protection features. Tests may be required in some instances.

TBS: MIL-F-87168 should be used for guidance.

VERIFICATION LESSONS LEARNED (4.4.2.1.15)

(TBD)

3.4.2.1.16 Survivability-Vulnerability (S-V).

The hydraulic power subsystems shall be configured to accept (TBS) by the threat(s) specified in the system or air vehicle specification without loss of flight and mission-essential functions.

REQUIREMENT RATIONALE (3.4.2.1.16)

Air vehicle performance limitations after hydraulic power subsystem(s) damage should be defined.

REQUIREMENT GUIDANCE (3.4.2.1.16)

TBS: Capability should be defined for loss of systems as well as impact by specific threat(s). Refer to the mission completion in a combat environment specification for guidance.

A single failure in the hydraulic power subsystem component or any other subsystem supplying power to the hydraulic power subsystem should not prevent the completion of the air vehicle's primary mission.

The hydraulic system(s) should be configured such that any two fluid system failures due to combat or other damage, which cause loss of fluid or pressure, will not result in complete loss of flight control. For rotary-wing air vehicles, the surviving system(s) should provide sufficient control for return to the intended landing area. Where duplicate hydraulic power subsystems are provided, these systems should be separated as far as possible to obtain the maximum advantage of the dual system with regard to vulnerability from gunfire or engine fires. Where practicable, dual systems should be on opposite sides of the fuselage, the wing spar, or similarly separated.

REQUIREMENT LESSONS LEARNED (3.4.2.1.16)

(TBD)

4.4.2.1.16 Survivability-Vulnerability (S-V).

S-V of the hydraulic power subsystems shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.16)

Performance limitations after hydraulic power subsystem(s) damage should be defined.

VERIFICATION GUIDANCE (4.4.2.1.16)

TBS: Survivability-vulnerability characteristics should be verified by analysis.

VERIFICATION LESSONS LEARNED (4.4.2.1.16)

(TBD)

3.4.2.1.16.1 Resistance to gunfire.

Hydraulic power subsystem pressure vessels shall not fragment from a single impact by (TBS).

REQUIREMENT RATIONALE (3.4.2.1.16.1)

Gunfire damage to a pressure vessel should not result in fragmentation that can injure personnel or cause serious damage to the airframe.

REQUIREMENT GUIDANCE (3.4.2.1.16.1)

TBS: High-pressure vessels have been required to take a single Armor Piercing Incendiary (API) .50-caliber projectile without fragmenting.

Low-pressure vessels may require resistance to a single .30-caliber API projectile.

REQUIREMENT LESSONS LEARNED (3.4.2.1.16.1)

Experience has shown that American Iron and Steel Institute (AISI) Code 4130 steel and comparable steels should not be heat treated above 160,000 psi to preclude fragmentation.

4.4.2.1.16.1 Resistance to gunfire.

Pressure vessel resistance to fragmentation shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.16.1)

Gunfire damage to a pressure vessel should not result in fragmentation that can injure personnel or cause damage to the air vehicle.

VERIFICATION GUIDANCE (3.4.2.1.16.1)

TBS: Resistance to fragmentation should be evaluated by test. Past practice (reference MIL-DTL-5498): For accumulators three inches or less in diameter, the ammunition should be .30-caliber M-2 armor piercing. For all other sizes, the ammunition should be .50-caliber M-2 armor piercing. Muzzle velocity should be 2800 feet per second (fps). The accumulator should be positioned with its longitudinal axis 45° from normal away from the gun position. The projectile should be tumbled so that the .30-caliber shell produces an “in” hole at least ¼ inch wide by ⅝ inch long and the .50-caliber shell should produce an “in” hole at least ½ inch wide by 1½ inches long. The projectile velocity after tumbling should be monitored during the last 10 feet prior to impact. Minimum velocity should be 2300 fps. The accumulator should remain in one piece, and the material of the cylinder should not tear excessively in any one direction.

VERIFICATION LESSONS LEARNED (3.4.2.1.16.1)

(TBD)

3.4.2.1.17 Clearance.

Clearance shall be maintained between hydraulic tubing, moving system components, and structure or other components. This will ensure that no possible combinations of temperature effects, airloads, vibrations, wear, and structural deflections cause binding, rubbing, or jamming. In addition, there shall be adequate clearance for tubing and component installation, removal, and maintenance.

REQUIREMENT RATIONALE (3.4.2.1.17)

The intent of this requirement is to prevent chafing or hydraulic tubing and binding or jamming of components in static or operating modes. In addition, there are minimum clearances necessary to accommodate removal and installation of hydraulic tubing and components.

REQUIREMENT GUIDANCE (3.4.2.1.17)

A minimum clearance of 0.25 inch should be maintained between hydraulic tubing and adjacent structure, tubing, and other installations. Where tubing is supported to structure or other rigid members, it is permissible to deviate from the 0.25-inch clearance as long as a minimum tube to structure clearance equal to the tube clamp thickness is maintained. Other deviations from the 0.25-inch clearance may be allowable such as when a tube is positively clamped from structure, fittings through bulkheads, and adjacent tubing at supported/clamped locations or when two fittings are mounted side-by-side. For parallel tubing runs or tubing run adjacent to rigid structure, less than 0.25 inch may be acceptable as long as 0.25 inch is maintained at the midpoint between supports. The tubing shall not make contact at any time, including most severe maneuvers. Component and tubing installation should have separation clearances that are maintained under all air vehicle-operating modes. There should be clearance for hand tools required for removing and installing hydraulic tubing and components. There should be space to remove and install tubing and components. This may require additional access panels and doors.

REQUIREMENT LESSONS LEARNED (3.4.2.1.17)

Inadequate clearance can cause chafing or rubbing of hydraulic tubing and lead to leakage of hydraulic fluid. Wire chafing against hydraulic tubing can cause arcing, wearing through the wire insulation, and burning through thin-wall hydraulic tubing, thus resulting in a hydraulic fluid leak. The leak may start as a small pinhole, spraying atomized high-pressure hydraulic fluid, which poses a greater fire hazard than pooled hydraulic fluid if an ignition source is present. Furthermore, it can lead to a total loss of a system's hydraulic fluid. On December 11, 2000, a V-22 Osprey aircraft crashed in Jacksonville, North Carolina resulting in total loss of the aircraft. The crash was attributed to a hydraulic line failure caused by chafing from a wire bundle. Several other hydraulic lines were found chafed beyond the established damage limits.

4.4.2.1.17 Clearance.

Compliance with clearance requirements shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.17)

The best way to determine clearance is by close examination of installation mock-up(s) and by examination of the air vehicle before and after flight tests. Tests may be required to demonstrate maintenance of adequate clearances during dynamic operation; such as landing gear, etc., and structural deflections caused by air loads, landing loads, etc.

VERIFICATION GUIDANCE (4.4.2.1.17)

TBS: Separation clearance under all static or operating modes should be verified by analysis, inspection, and test.

VERIFICATION LESSONS LEARNED (4.4.2.1.17)

Newly installed hydraulic tubing should be inspected for rubbing and chafing prior to and during flight-testing, especially if critical clearances less than 0.25 inches exist. Flight loading and maneuvers can reduce static clearances and potentially lead to rubbing and chafing.

3.4.2.2 Interface requirements.

Hydraulic power subsystem and component interfaces shall be identified and controlled to ensure form, fit, and functional compatibility.

REQUIREMENT RATIONALE (3.4.2.2)

Interface baseline design data should be established in the air vehicle development phase to minimize the need for extensive design changes that emerge during air vehicle assembly and test.

REQUIREMENT GUIDANCE (3.4.2.2)

Hydraulic power subsystem interfaces should be identified in hydraulic power subsystem design reports and appropriate contractual documents.

REQUIREMENT LESSONS LEARNED (3.4.2.2)

(TBD)

4.4.2.2 Interface requirements.

Hydraulic power subsystem interface(s) with other air vehicle systems shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.2)

Interface control data is necessary to ensure physical and functional compatibility.

VERIFICATION GUIDANCE (4.4.2.2)

Verification may be accomplished by analysis, demonstration, inspection and tests.

VERIFICATION LESSONS LEARNED (4.4.2.2)

(TBD)

3.4.2.1.16 Electrical power system interface.

All electrical components shall operate with electrical power defined by (TBS).

REQUIREMENT RATIONALE (3.4.2.2.1)

The quality and quantity of available power should be matched to the required needs of the system and component operation(s).

REQUIREMENT GUIDANCE (3.4.2.2.1)

TBS: The electrical power available should be defined at the system and component level. The number of different electrical connectors should be identified and limited to reduce life-cycle costs.

REQUIREMENT LESSONS LEARNED (3.4.2.2.1)

There have been cases where D.C. solenoids would not overcome component forces at minimum voltage.

4.4.2.2.1 Electrical power system interface.

Electrical power system interfaces shall be verified by (TBS).

Physical and functional compatibility with electrical system(s) is paramount for hydraulic power subsystem(s) performance.

VERIFICATION GUIDANCE (4.4.2.2.1)

TBS: Operation of hydraulic power subsystem components at specified power should be verified by system and component tests. Required performance should be demonstrated for all variations permitted by the specification.

VERIFICATION LESSONS LEARNED (4.4.2.2.1)

(TBD)

3.4.2.2.2 Support equipment (SE) interface.

Means shall be provided to mate with the following ground test and service equipment: (TBS).

REQUIREMENT RATIONALE (3.4.2.2.2)

All SE that is in operation and is expected to be compatible with new air vehicle systems should be identified to ensure interface compatibility.

REQUIREMENT GUIDANCE (3.4.2.2.2)

TBS: Identify SE such as hydraulic power carts and fluid filling equipment. Ground service connections for hydraulic power subsystem checkout should be accessible at ground level for maintenance personnel and be so specified. In addition, further identify peculiar fittings to mate with the SE.

System ground test provisions should be so designed that pressurization of any hydraulic power subsystem in the air vehicle is not necessary in order to test another hydraulic power subsystem.

REQUIREMENT LESSONS LEARNED (3.4.2.2.2)

(TBD)

4.4.2.2.2 Support equipment (SE) interface.

The interface of the hydraulic power subsystem with specified SE shall be verified by (TBS).

VERIFICATION RATIONAL (4.4.2.2.2)

Physical and functional interface of support equipment is essential for timely checkout and maintenance.

VERIFICATION GUIDANCE (4.4.2.2.2)

Compatibility of SE should be verified by ground demonstration, analysis, and inspection.

VERIFICATION LESSONS LEARNED (4.4.2.2.2)

(TBD)

3.4.2.2.3 Instrumentation interface(s).

Instrumentation interface(s) shall be identified.

REQUIREMENT RATIONALE (3.4.2.2.3)

The type and quantity of instrumentation needed for a subsystem is dependent upon the desires of the operator and the complexity and flexibility of the subsystem.

REQUIREMENT GUIDANCE (3.4.2.2.3)

As a minimum, the following instrumentation should be provided:

a. Hydraulic power system pressure (each system)

b. Low pressure indicator (each system)

A simple system requires limited instrumentation.

REQUIREMENT LESSONS LEARNED (3.4.2.2.3)

(TBD)

4.4.2.2.3 Instrumentation interface(s).

The presence of required instrumentation shall be verified by (TBS 1). The accuracy and range of the instrumentation shall be verified by (TBS 2).

VERIFICATION RATIONALE (4.4.2.2.3)

The physical and functional interface of instrumentation system(s) is essential to measure the health of the hydraulic power subsystem(s).

VERIFICATION GUIDANCE (4.4.2.2.3)

TBS 1: The presence of the required instrumentation should be verified by inspection and tests.

TBS 2: The accuracy and range of the instrumentation should be verified by component testing and system calibration.

VERIFICATION LESSONS LEARNED (4.4.2.2.3)

(TBD)

5. PACKAGING

5.1 Packaging.

For acquisition purposes, the packaging requirements shall be as specified in the contract or order (see 6.2). When packaging of materiel is to be performed by DoD or in-house contractor personnel, these personnel need to contact the responsible packaging activity to ascertain packaging requirements. Packaging requirements are maintained by the Inventory Control Point's packaging activities within the Military Service or Defense Agency, or within the military service's system commands. Packaging data retrieval is available from the managing Military Department's or Defense Agency's automated packaging files, CD-ROM products, or by contacting the responsible packaging activity.

6. NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

6.1 Intended use.

The hydraulic subsystem descriptions in this specification guide are intended for use in air vehicle systems developed to perform combat and combat-support missions in environments unique to military weapon systems.

6.2 Acquisition requirements.

Acquisition documents should specify the following:

a. Title, number, and date of this specification.

6.3 Definitions.

Inspection: Inspection is defined as visual verification that the system, including system documentation, conforms to the specification requirements. Visual verification can be in the form of inspection of the physical installation, or inspection of drawings showing physical relationships, or review of documents reflecting qualification status with respect to specification requirements.

Analysis: Analysis is defined as verification that specification requirements have been achieved by evaluation of equations, charts, and reduced data, and by comparisons of analytical predictions with available test data, etc. Verification analysis, however, does not include the normal analysis of data generated during ground or flight-testing.

Demonstration: Demonstration is defined as an uninstrumented test where success is determined by observation only, such as fit and function checks and tests that require simple quantitative measurements.

Test: Test is defined as verification of the specification requirements through the application of established test procedures within specified environmental conditions and subsequent compliance confirmation through analysis of the data generated.

Verification by similarity: When verification by similarity is proposed, it should be accomplished by using verification data from previously developed and qualified items. The verification data from the earlier verification should be submitted with design data to substantiate the following items:

a. The equipment is to perform a similar function in the new application as it did in its earlier verification.
b. The environment and operating limits should be no more demanding or degrading than in the earlier operation.
c. The new item does not incorporate differences that would invalidate the criteria of “Inspection” or “Analysis,” above.
d. The equipment meets requirements of its earlier application(s) as indicated by its Mean Time Between Failures (MTBF) and other field failure data.

Considerable effort is expended when similarity claims are made late in a program and rejected by the procuring activity or additional testing is required. Similarity claims should be established early in a program.

6.4 Acronyms.

The following list contains the acronyms/abbreviations contained within this document:

API	Armor Piercing Incendiary
GSE	Ground Service Equipment
SE	Support Equipment
S-V	Survivability-Vulnerability
TFE	Tetrafluoroethylene
TR	Temperature Retraction

6.5 Subject term (key word) listing.

Burst pressure

Contamination

Fluid

Leakage

Moisture

Peak pressure

Pressure

Proof pressure

Pump

6.6 Changes from previous issue.

The margins of this specification guide are marked with vertical lines to indicate where changes from the previous issue were made. This was done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content irrespective of the marginal notations and relationship to the previous issue.

CONCLUDING MATERIAL

Custodians:
Army – AV
Navy – AS
Air Force – 11

Review activity:
Air Force – 70

Preparing activity:
Air Force – 11
(Project 15GP-2018-003)

NOTE: The activities listed above were interested in this document as of the date of this document. Since organizations and responsibilities can change, you should verify the currency of the information above using the ASSIST Online database at https://assist.dla.mil.