SAE International™ SURFACE VEHICLE RECOMMENDED PRACTICE

SAE J1779 | REV. AUG2003

Issued 1978-03
Revised 2003-08

Supersedes J1779 OCT1992

(R) Ship Systems and Equipment – Hydraulic System Design Criteria for Marine Vehicles

FOREWORD—This recommended practice is intended as a guide toward a standard practice. Because it covers such a wide variety of marine vehicles, it is intended for use as a guide in the development of a detailed system specification or as a supplement to a design specification.

1. Scope

1.1 Scope—The marine environment differs greatly from other environments in which hydraulics are used. This Recommended Practice provides hydraulic design considerations and criteria for the marine environment and is applicable to commercial vessels, military ships, and submersible vehicles. This document may be used for manned and un-manned vehicles.

2. References

2.1 Applicable Publications—The following publications form a part of the specification to the extent specified herein. Unless otherwise indicated the latest revision of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001, www.sae.org, telephone 724-776-4970.

AMS4943—Titanium Alloy Tubing, Seamless, Hydraulic, 3.0Al - 2.5V, Annealed (UNS R56320)
AMS4944—Titanium Alloy Tubing, Seamless, Hydraulic, 3.0Al - 2.5V Cold Worked, Stress Relieved (UNS R56320)
AMS4945—Titanium Alloy Tubing, Seamless, Hydraulic, 3.0Al - 2.5V, Controlled Contractile Strain Ratio, Cold Worked, Stress Relieved (UNS R56320)

ARP994—Recommended Practice for the Design of Tubing Installations for Aerospace Fluid Power Systems

AS19692—Pumps, Hydraulic, Variable Delivery; General Specifications for

J1273—Recommended Practices for Hydraulic Hose Assemblies
J1776—Marine Vehicles - Hydraulic Pumps - Design and Specification Guide
J1777—General Environmental Considerations for Marine Vehicles
J1778—Ship Systems and Equipment - Recommended Practice for Hydraulic Fluid Selection
J1780—Diagrams and Associated Tables for Hydraulic Systems of Marine Vehicles

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

J1781—Materials for Fluid Systems of Marine Vehicles
J1782—Ship Systems and Equipment - Hydraulic Systems - Noise Control
J1783—Ship Systems and Equipment - Selection of Hydraulic Directional Control Valves
J1942—Hose and Hose Assemblies for Marine Applications
J2321—Ship Systems and Equipment - General Specification for Filter Elements - Hydraulic and Lube Oil Service
J2333—Ship Systems and Equipment - Hydraulic System Filters - Selection Parameters
J2470—Hydraulic Fluid Power - Valves - Methods for Assessing Lock Sensitivity to Contaminants
J24714—Fluid Systems - Connector Tubes - General Specification and Part Standard

2.1.2 ASTM PUBLICATIONS—Available from American Society for Testing and Materials, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, www.astm.org, telephone 610-832-4585.

ASTM D 6304—Standard Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fisher Titration

2.1.3 ISO PUBLICATIONS—Available from International Organization for Standardization, 1 rue de Varembe, 1211 Geneva 20, Switzerland. (Also available from American National Standards Institute, 11 West 42nd Street, New York, NY 10036 and National Fluid Power Association, 3333 North Mayfair Road, Milwaukee, WI 53222-3219.)

ISO 4406—Hydraulic fluid power - Fluids - Method of coding level of contamination by solid particles
ISO 4413—Hydraulic fluid power - General rules relating to systems
ISO 5598—Fluid Power Systems and Components - Vocabulary
ISO18413—Hydraulic Fluid Power - Cleanliness of parts and components - Inspection document and principles related to sample collection, sample analysis, and data reporting

2.1.4 NATIONAL FLUID POWER ASSOCIATION (NFPA) PUBLICATIONS—Available from the National Fluid Power Association, Inc., 3333 North Mayfair Road, Milwaukee, WI 53222-3219, www.nfpa.com, telephone 414-607-3345.

NFPA T2.6.1—Method for Verifying the Fatigue and Establishing the Burst Pressure Ratings of the Pressure Containing Envelope of a Metal Fluid Power Component
NFPA T2.9.15—Hydraulic Fluid Power - Cleanliness of Components - Inspection document and methods of sample collection, sample analysis, and data reporting
NFPA T2.24.1—Hydraulic Fluid Power - Systems Standard for Stationary Industrial Machinery Supplement to ISO 4413; 1998 - Hydraulic Fluid Power - General Rules Relating to Systems to be Used in Conjunction with ISO 4413; 1998
NFPA T3.4.9—Recommended practice - Hydraulic fluid power - Application guideline for accumulators

2.1.5 DEPARTMENT OF DEFENSE PUBLICATIONS—Available from Standardization Documents Order Desk, Building 4D, 700 Robbins Ave., Philadelphia, PA 19111-5094, http://assist.daps.mil, telephone 215-697-2179.

2.1.5.1 Military Standards

MIL-STD-167-1—Mechanical Vibrations of Shipboard Equipment (Type I - Environmental and Type II - Internally Excited)
MIL-STD-438—Schedule of Piping, Valves, Fittings and Associated Piping Components for Submarine Service
MIL-STD-777—Schedule of Piping, Valves, Fittings, and Associated Piping Components for Naval Surface Ships
MS 18282—Relief Valve Operating Characteristics Versus Maximum Operating Pressure for Liquid Service

2.1.5.2 Military Specifications

MIL-S-901—Shock Tests, H.I. (High Impact) Shipboard Machinery, Equipment, and Systems, Requirements for
MIL-P-17869—Pumps and Motors, Power, Oil Hydraulic (Naval Shipboard Use)
MIL-PRF-83282—Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Aircraft

2.1.5.3 Military Handbooks

MIL-HDBK-2193—Hydraulic System Components, Ship

2.1.5.4 Other Defense Publications

"Handbook of Fluid-Filled, Depth/Pressure Compensating Systems for Deep Ocean Applications" by Thomas H. Mehnert, compiled by the David Taylor Naval Ship Research and Development Center, Annapolis, Maryland (DTIC No. AD 894-795)
"Handbook of Hydraulic Systems for Deep Ocean Applications" by William E. Schneider and John Sasse, compiled by David Taylor Naval Ship Research and Development Center, Annapolis, Maryland (DTIC No. ADB062-769L)
SS800-AG-MAN-010/P-9290—"System Certification Procedures and Criteria for Deep Submergence Systems" Available from the Naval Sea Systems Command (Request from the appropriate contracting officer)

2.1.6 OTHER PUBLICATIONS

American Bureau of Shipping, Rules for Building and Classing Underwater Vehicles, Systems, and Hyperbaric facilities, 1990; ABS Plaza, 16855 Northcase Drive, Houston TX 77060 USA
American Bureau of Shipping, Rules for Building and Classifying Steel Vehicles; ABS Plaza, 16855 Northcase Drive, Houston TX 77060 USA
Det Norske Veritas: Rules for Classification of Ships, Veritasveien 1, N-1233 Høvik, Norway; www.dnv.com
Lloyd's Register: Rules and Regulations for the Classification of Ships, 71 Fenchurch Street, London, EC3M 4BS; www.lr.org

3. Definitions—Refer to ISO5598 for definitions not listed below.

3.1 Fatigue Pressure Rating—The maximum pressure that a component's pressure containing envelope has been verified to sustain a rated number of pressure cycles using pressure excursions derived from rated pressure, without failure.

3.2 System Proof Pressure Test—The system proof pressure is the hydrostatic test pressure to which components and piping are subjected after system installation to verify integrity and the absence of leaks.

3.3 System Tightness Test—A system tightness test is a hydrostatic test up to the nominal system operating pressure and is meant to verify that there is no leakage from mechanical joints.

3.4 Heat Recoverable Couplings—Heat recoverable couplings are cryogenically cooled fittings that shrink to form an interference fit when warmed to ambient temperature.

3.5 Critical—Critical, as used in this document, refers to the importance of the component/system's function in the ship. Those components/systems that are essential to the safety of the ship, its crew, and its passengers are defined as critical. The procuring activity may broaden this definition as appropriate [e.g., mission critical components/systems are those that are required for the ship/vehicle to complete its mission.]

4. ***Design Criteria and Considerations***—Unless otherwise specified herein, the general requirements of ISO 4413 as supplemented by NFPA T2.24.1 shall be used for guidance. ISO 4413 provides general rules relating to hydraulic systems for machinery in industrial manufacturing processes that are generally applicable to all systems.

For deep ocean applications, the "Handbook of Hydraulic Systems for Deep Ocean Applications" provides guidance on design practices and component selection.

4.1 **Function—**The function of a hydraulic system on a marine vehicle is to provide power for the operation of equipment. Examples of applications operated by hydraulic fluid power are rudders, trim control surfaces, large valves, cranes, winches, hatch operators, elevators, propeller pitch control, and retractable masts. Hydraulic systems provide for the generation of fluid power, conducting the fluid power to and from the application, and the appropriate control of the fluid power in operating the application.

4.2 **System Arrangement—**The designer must comply with the applicable government and classification body's rules and regulations in designing the vessel. In regard to hydraulic systems, the rules are usually general in nature although specific rules may apply for systems such as steering. Requirements of the USCG may be found in Title 46 of the Code of Federal Regulations. The following parts are particularly applicable: Part 56 - Piping Systems and Appurtenances; Part 57 - Welding and Brazing; Part 58 - Main and Auxiliary Machinery and Related Systems. Some requirement documents of the major classification bodies are listed in 2.6. Unless specific specifications are provided for the design of the hydraulic system, the guidance herein should be followed in addition to the requirements of government regulatory agencies and the applicable classification body.

The primary method of assuring reliable operation of critical components is through redundancy. The degree of redundancy in fluid power supplies should be part of the vessel specifications. In the absence of specifications, applications critical to the safe operation of the vessel, such as steering gear, and/or personnel safety, such as damage control valves, should have, at a minimum, two separate power supply sources (i.e., pump, reservoir, and piping loop) and controls for the application. Should one source fail, then the other source shall provide the necessary fluid power for the safe operation of the application. Operation at a reduced rate in this emergency condition may be acceptable if the safety of the vessel or personnel is not compromised. These fluid power supply sources shall have separate electrical/mechanical power supplies. Where practical, a manual operation mode should be provided for improved safety and reliability.

For other applications not critical to the safe operation of the vessel, the failure mode of each application shall be determined and the application controls designed to provide the appropriate failure mode. Examples of failure modes are "fail as is," "fail close," and "fail operational."

Typically, marine components, such as winches, elevators, and capstans have dedicated power plants. However, weight and volume are critical aspects of hydraulic system design on marine vehicles. Due consideration should be given to the use of a central hydraulic system to minimize the weight and volume of power plants where a large number of components are relatively close to one another. However, if critical and non-critical applications are served by the same central hydraulic power plant, provision must be made to ensure the operation of the critical components is not compromised by operation of or casualty to non-critical equipment.

Stored energy should be considered to minimize the number of pumps and to reduce pump cycling.

Reliability and safety of the fluid power supplies can be improved through the use of relief valves, reservoir level monitors, and filtration.

Critical systems should have sufficient redundancy and isolation valves so that operation can continue after a component failure or system leak. On military ships, additional system isolation and replenishment features may be required for survivability. On unmanned vehicles, redundancy may be reduced.

4.2.1 HYDRAULIC POWER PLANT PACKAGE—The hydraulic system power plant should be designed, where possible, as a package unit capable of being readily removed from the vehicle for repair and test.

4.3 Pressure Level—System pressure level shall be selected on the basis of minimum equipment weight, maximum reliability and least life cycle cost. Higher pressures tend to minimize weight but the number of components rated above 21 MPa (3000 psi) is limited and development costs may be significantly greater for higher pressure systems. For impact of higher pressure on acoustic characteristics of hydraulic systems, see SAE J1782. For intermittent duty subsystems, such as engine start subsystems, high pressures, up to 35 MPa (5000 psi), are often used to minimize weight. Variable displacement pressure compensated pumps are often used for pressure regulation of central hydraulic systems where the maximum operating pressure of the system is the pump cutout pressure.

4.3.1 PRESSURE COMPENSATION—On submersibles, hydraulic systems must often work against very high ambient sea pressures. A common method of overcoming the problems of this high external pressure is to pressure compensate the system. This is a method of keeping the internal pressure in the reservoir and return side of the system slightly above the sea pressure by referencing the system operating pressure to sea pressure. The "Handbook of Fluid-filled, Depth/Pressure Compensating Systems for Deep Ocean Applications" provides descriptions of various types of pressure compensated systems (see 2.1.5.4).

4.4 Pressure Test Requirements

4.4.1 FATIGUE PRESSURE TEST—Rated fatigue life and the need for fatigue testing may be a design concern for components which have an expected service life of 100,000 or more pressure cycles with a magnitude in excess of 50% of their rated operating pressure. Where required, components are to be subjected to an impulse fatigue test. See paragraph 4.20 for fatigue rating and testing requirements.

4.4.2 SYSTEM PROOF PRESSURE TEST—For parts not covered by a specification or standard, the contracting or design activity shall specify the required proof pressure. A proof pressure test shall be conducted to verify the integrity of permanent joints (for example, welding, brazing, swaging, etc.) and should be conducted after the completion of the joining process. The amount of piping subjected to the test need only include the affected section of pipe. The following guidance shall be used in determining the minimum proof pressure:

a. Typically, the system proof pressure is approximately equivalent to 150 percent of the system pressure [e.g., 31 MPa (4500 psig) in a 20.6 MPa (3000 psig) system.
b. For suction ports the proof pressure shall be not less than 200 kPa gage (29 psig).
c. For the high pressure portion of the system the proof pressure shall not be less than the maximum operating pressure under conditions of hydraulic shock considering, but not necessarily limited to, such factors as rapid valve closing, overhauling and suddenly applied loads, and relief valve response time.
d. For return ports the proof pressure shall be at least 135% of the maximum return line pressure considering maximum flow rates and minimum fluid temperatures. If a stop valve is installed in a return line, the requirements for pressure and cylinder ports shall also apply upstream of the stop valve and the proof pressure must be at least equal to that developed with full flow through any relief valve protecting the return line.
e. For unbalanced cylinders and other components which can be subjected to pressure multiplication, the proof pressure for ports subjected to the multiplication shall be not less that the nominal system pressure times the multiplication factor based on area ratios.
f. For submersible vehicles, all components which may be subjected to submergence pressure shall be subject to an external proof pressure of at least 135% of the pressure at the maximum operating depth of the vehicle. Components always compensated to sea pressure may have the compensating pressure applied during the external proof test.

4.4.3 System Tightness Test—For components, piping, tubing and fittings which are proof tested prior to installation and are mechanically connected, a proof test is not normally required after installation if a tightness test is conducted at system operating pressure. A system tightness test shall be conducted after initial installation of a component(s) and after reinstallation of a component(s). The extent of testing need only be sufficient to check all mechanical joints affected by removal and reinstalltion.

4.5 Pressure Regulation—Constant pressure systems are recommended for primary controls where fast response is required. Constant pressure systems are best suited for central hydraulic systems serving multiple actuators. Variable pressure hydraulic systems with open center directional control valves, servo pump controlled systems, and hydrostatic drive systems are normally limited to single purpose applications.

The minimum cracking pressure of relief valves shall be at least 110% of the maximum normal operating pressure but above any pump ripple pressures. See MS 18282 for guidance on in-line relief valve operating characteristics and settings. When adjustable relief valves are used, means should normally be provided to protect against inadvertent adjustment. This can be done by lockwire or by using in-line valves which must be disconnected from the line for adjustment. Since back-pressure at the outlet of the relief valve is additive to the setting, care must be exercised in systems where back-pressure may be significant. The maximum pressure in the system developed under full flow conditions of the relief valve must not exceed the proof pressure of the system.

4.6 Environmental Considerations—There are many performance and non-performance issues to consider in hydraulic system design. Several factors can indirectly influence hydraulic system design, such as temperature, possibility of high impact shock, vibration, corrosion, safety, and the system impact on the environment.

4.6.1 External Temperature—Ambient temperatures must be considered in selecting system fluid and sizing piping and components. SAE J1777 provides guidance on various environmental operating conditions for marine vehicles. When seawater is used for cooling, seawater temperatures range from –2 to 29 °C (28 to 85 °F) on the open sea and 35 °C (95 °F) in the Persian Gulf.

If operation in Arctic regions is required, the hydraulic system should be capable of starting with a temperature of -40 °C (-40 °F). While maximum performance is not required at cold temperatures, the cold temperatures should not significantly increase the time for the vehicle to get underway. The equipment should be designed for a nonoperating temperature of -54 °C (-65 °F) to assure that no damage will occur during shipping and storage.

Other temperatures to be considered are:

a. Maximum dew point of compressed air used for pressurization should be as dry as the ambient temperature, typically -29 °C (-20 °F).
b. Maximum safe fluid temperature where personnel may touch uninsulated piping (+52 °C (125 °F))
c. Minimum flash point of the system fluid (refer to SAE J1778 for fire resistance)
d. Viscosity characteristics of system fluid (refer to SAE J1778)

Effects of fluid expansion/contraction due to environmental and operating temperature changes should be considered, particularly on small closed systems.

4.6.2 High Impact Shock and Vibration—Naval ships must consider operations and damage mitigation in order to maintain some level of combat capability. Military ships typically have to meet the requirements of shock (MIL-S-901) and vibration (MIL-STD-167-1).

4.6.3 Corrosion—See paragraph 4.13.

4.6.4 Safety—Operational safety and equipment use are to be considered in addition to various failure modes. Failure modes can impact local area needs and overall operational capabilities. Manual overrides, backup systems, and re-routing of systems shall be examined. Additionally, provisions shall be made to depressurize the hydraulic system prior to performance of maintenance. If designed to permit maintenance without full system depressurization, hydraulic systems shall be designed to have a minimum of two valve protection between pressurized and de-pressurized portions of the system wherever practical. If not practical, detail instructions shall be provided to advise maintenance personnel of means to assure that the system is truly isolated.

4.6.5 IMPACT ON ENVIRONMENT—The environmental impact of hydraulic systems in the design, operation, and disposal shall be considered. Materials with a detrimental impact on the environment should be avoided. This includes coatings, system fluid, and insulation. Where practical, means shall be provided to contain spilt hydraulic fluid. Also, provision should be made for the storage of contaminated and spilt fluid until it can be disposed of properly.

4.7 Fluid Cleanliness—Cleanliness is essential for reliable operation of any high performance hydraulic system. The marine environment itself poses a hazard to maintenance of cleanliness by the possibility of seawater leakage into the system. For this reason, critical components, such as servovalves, should be of types which are tolerant of contamination and possess chip shearing capability. The following guidelines should be followed in regard to cleanliness:

a. Chlorinated solvent shall not be used to clean hydraulic systems or components. Should chlorinated solvent contamination be suspected, the fluid should be tested by the gas chromatographic technique and should not contain more than 200 ppm total chlorinated solvent. Excessive solvents can be removed by techniques such as vacuum dehydration.
b. For non-water based hydraulic fluids, no free, undissolved water should be permitted in the hydraulic fluid since it may affect the fluid properties and characteristics and it may result in corrosion. For the commonly used MIL-PRF-83282 fluid, water contamination should be limited to 300 ppm. Total water content may be determined by Karl Fischer Reagent Method ASTM D 6304.
c. Fluid cleanliness levels should be established based on component requirements for long life and reliable performance. Cleanliness requirements should be specified based on the cleanliness classes identified in ISO 4406. SAE J2333 identifies recommended cleanliness levels for various types of systems and components. The cleanliness class depends upon the contamination sensitivity of individual components. SAE J2470 provides a procedure to measure the contamination sensitivity of hydraulic valves.
d. Component cleanliness can be controlled by adhering to one of the methods described in NFPA T2.9.15 or ISO 18413. Component cleanliness shall be maintained during assembly, test and installation. System cleanliness shall be maintained throughout system fabrication.
e. To minimize seawater contamination, hydraulic reservoirs and return lines may be pressurized higher than the water pressure acting on the system cooler and submerged actuators. See 4.3.1 for further information.
f. Reservoirs which are vented to atmosphere can be protected with particulate and moisture control devices. Such devices are capable of controlling particulates in the air well below the filtration rating of system filters. Devices are available which are capable of reducing the moisture content of incoming air by 80%. Care must be given to the selection of breather devices so that the back pressure of air passing through the breather under adverse operating conditions does not result in the over pressurization of the reservoir.

4.8 Hydraulic Fluid—Factors governing the selection of hydraulic fluid for marine vehicles and the physical properties of some of the commonly used fluids are described in SAE J1778. Fluids shall be selected using these factors with full consideration given to viscosity changes that will occur over the operating temperature and pressure ranges of the system. Seawater has not been an acceptable fluid for vehicle hydraulic systems. Rust inhibitors operating on the water coagulation principle are used in some preservative fluids. Failure to drain fluid from components containing preservative fluid with these inhibitors can result in the clogging of filters. Similarly, barium additives in preservative fluids have caused valve sticking when the preservative fluid has not been drained prior to installation.

4.9 Hydraulic Diagrams—Hydraulic diagrams and associated tables should be prepared in accordance with the requirements of SAE J1780, unless otherwise approved by the procuring activity.

4.10 Components—Component selection can be from those covered by industry and military specifications for both aerospace and marine hydraulic components, commercially available hydraulic components, and specially developed and tested hardware. Factors limiting applicability of aerospace components to marine use are maximum available size, lack of corrosion resistance, electrical insulation, and other special requirements as described in this report. Many of these limitations also apply to commercially available components. The suitability of a particular component must be evaluated by the designer for his specific application. Refer to SAE J1777 for environmental considerations for marine components.

4.10.1 PUMPS—Variable displacement, pressure compensated hydraulic pumps are often used because of their low energy requirements during periods of low usage. SAE AS19692 provides general guidelines for these types of pumps. MIL-P-17869 covers various types of pumps qualified for Navy shipboard use. In many cases it may be necessary to design and procure a pump to suit the requirements of the system. SAE J1776 provides guidance for preparing a detailed specification for hydraulic system pumping components on marine vehicles. This document allows one to set forth the pump environmental and performance considerations, establish service life and reliability requirements, and define the specific evaluation tests for the particular application.

It is often desirable to be able to reduce the load during start-up of the ship service unit. This may be accomplished by bypassing pump output to return or depressurization of the pump compensator. Pumps should be installed with a positive static head, if possible, to avoid air locks and cavitation. This is particularly important when using high speed aircraft type pumps. Inlet pressurization may be obtained by means of a boost pump or by a pressurized reservoir.

Pumps and motors for deep submersibles shall be constructed of materials that will resist corrosion as the result of salt water contamination of the hydraulic fluid. Refer to SAE J1781. Shaft seals should be designed to withstand vacuum filling of the component if required. Care must be taken in the selection of pumps and motors to ensure that no uncompensated volume occurs during any part of the operating cycle.

4.10.2 RESERVOIRS—Reservoirs should be constructed of corrosion resistant materials compatible with the hydraulic fluid. The use of coatings to obtain corrosion protection is not recommended. The hydraulic reservoir shall have sufficient capacity to accommodate hydraulic actuator differential volumes, accumulator volumes, thermal expansion of the fluid plus a leakage reserve adequate for the longest service interval. A relief valve is required for overpressure protection of non-vented reservoirs. The relief valve should be designed to handle both air and hydraulic fluid.

Reservoirs for marine vehicles that are below decks are often filled from a fitting (and connecting piping) located on the weather deck which is some elevation above the reservoir. Consideration must be given to both the over pressurization of the reservoir during filling from such things as blocked reservoir vents and containment of excess fluid if over filled. The deck fitting must also be designed for filling the reservoir without spillage.

Each reservoir shall be equipped with a drain connection. The reservoir shall be designed such that the entire contents of the reservoir can be drained when the vehicle is on an even keel. The reservoir shall also be designed such that pockets are not created from which fluid cannot drain. As an option, connections to this drain and the reservoir can be added to provide for a recirculating loop with some form of filtration/ purification for cleaning of the reservoir contents.

Reservoir pressurization is often necessary and may be obtained by means of a bootstrap piston with start-up accumulator or by directly pressurizing the reservoir with a compressed gas, usually air. When pressurizing with air, care should be taken to provide clean, dry air. If the air source contains moisture, it will be necessary to provide a means of removing the moisture to prevent condensation within the reservoir. The reservoir must be designed to minimize air entrainment in the fluid. Due consideration must be given to the design of the tank return and tank suction to prevent air entrainment. Return and suction lines should be below the lowest fluid level in the tank under all conditions of list, roll, trim, and pitch to prevent splashing and air entrainment. Dissolved air can come out of solution in portions of the hydraulic system where pressure is reduced below reservoir air pressure or in localized areas, such as at sharp edges in the flow path, which will result in cavitation. Separated free air can cause reduced bulk modulus and other problems.

Warning plates shall be installed adjacent to and readily visible at each fluid filling opening of each reservoir. Each plate shall indicate the type of fluid to be used in the reservoir. For example, "USE ONLY MIL-PRF-83282 FLUID".

Reservoirs for submersibles: If the electric motor is not compatible with the system fluid or electrical arcing could cause fluid contamination, the hydraulic reservoir should be designed to have two separate pressure compensated compartments. One compartment containing dielectric oil should house the electric motor to drive the pump while the other compartment should be filled with system fluid and house the pump and associated components. (See SAE J1778 for guidance in selecting dielectric oil and system fluid.) A mechanical shaft seal should be provided which will preclude the interchange of fluids between the compartments.

Reservoirs, except for shallow diving vehicles, should be located outside of the pressure hull. The reservoir installation shall be designed for ease of cleaning and maintenance of components contained therein. Means should be provided for removing water from the hydraulic system fluid by recycling fluid from the reservoir through test connections to an external purification unit. The number of external connections should be kept to a minimum.

Reservoir compensation for submersibles: Each compartment of the reservoir should be pressure compensated to maintain the hydraulic system pressure above sea pressure at all times. A readily removable cover plate(s) should be provided in the outer shell of the vehicle to permit ready access to the compensator(s) for inspection and system filling. The compensator(s) shall be arranged to provide compensation to all portions of the system. Subcircuits of sections of the system that may be isolated by the closing of valves during normal operation should contain separate pressure compensating/relief features such as relief valves and check valves.

4.10.3 FILTERS—As a minimum filters shall be installed in the discharge lines of all hydraulic pumps, with the possible exception of hand pumps. Return line filters are recommended for systems serving more than one compartment or more than five actuators. Systems employing pumps and motors with case drains shall employ either case drain filters or return line filters to filter case drain flow. Last chance (secondary) filter/strainers should be installed when necessary to protect contamination sensitive components.

For detailed recommendations regarding filter selection, including filter location, use of filter bypass relief valves, filtration efficiency, dirt capacity, element condition indicators, maintenance practices, and operating costs see SAE J2333. SAE J2321 covers recommended filter elements.

All filters should be equipped with an indicator or differential pressure gage to indicate when servicing is required. Indicators are not required for strainers and last chance filters. Flexible transparent covers for pop-up indicators should be considered to protect the mechanism from contamination and corrosion. Large capacity filters are usually more cost effective but weight considerations may override this consideration, especially on deep submersibles. In any event, sufficient dirt capacity should be provided to limit servicing to no more frequently than once a week. Filters shall be located so that they are readily accessible for servicing without significant loss of fluid.

4.10.4 TEMPERATURE CONTROL—Hydraulic fluid will break down if fluid temperature exceeds the limits prescribed for the fluid. Fluid temperature has a direct effect on fluid viscosity which in turn can affect system and component performance. Non-metallic materials may also be affected by heat. Therefore, fluid temperature must be kept within the design parameters for the fluid, system/components, and non-metallic materials used to ensure long life and proper system operation.

Hydraulic fluid coolers must be sized to meet the most adverse environmental conditions (i.e., temperatures in the tropics, Persian Gulf, etc.) and the most significant heat input [e.g., continuous system standby (no flow) at full system pressure].

Fuel, air, and seawater are possible heat sinks for control of hydraulic fluid temperature. Selection criteria include availability, fouling, and corrosion. Marine air contains salt spray which is extremely corrosive and as a result can rapidly impair heat transfer. Seawater cooled fluid coolers are available which resist fouling and corrosion. Plate-fin and immersion type coolers are lighter weight but often less maintainable than shell and tube coolers. Plate-and-frame types that are easy to clean and have high efficiency should be considered.

For submersible vehicles, supplemental cooling units are not usually required. Cooling of the hydraulic package can usually be accomplished by locating the hydraulic reservoir in direct contact with sea water. However, supplemental cooling may be required for long periods of operation without vehicle movement or if operation of the system is required when not immersed in the water.

When fluid temperatures are expected to exceed 125 °F (52 °C), shielding or insulation must be provided for system piping and components to prevent personnel injury. Consideration should be given to insulate/shield control devices which consume large amounts of pressure to control associated equipment. For example, a servo valve maintaining speed of a light load (in one operating scenario) consumed a significant portion of system pressure. Pressure was converted to heat causing downstream return piping to reach dangerous temperature levels. Consideration should also be given to high temperatures generated by pumps and motors.

4.10.5 RELIEF, DIRECTIONAL CONTROL, AND FLOW CONTROL VALVES—The function of pressure relief valves is to limit the magnitude of transients or protect the system in the event of compensator or regulator failure. Relief valves must be sized and set to permit the full output of the pump or system to pass through the valve without developing pressures that would exceed the proof pressure of lines and components. Generally, the minimum reseat pressure should not be less than the nominal system operating pressure to ensure that the system can return to normal operating conditions without a decrease in operating pressure.

Means shall be provided to control overhauling loads and the pressures they generate. Use of pressure compensated flow control or counter balance valves should be considered. Relief valves are sometimes used between an actuator and a blocked center directional control valve to limit the pressures that can be developed due to overhauling loads. However, there may be poor control of the load once the relief lifts (cracks), particularly if the relief valve is oversized.

Refer to SAE J1783 for the selection of directional control valves, including proportional valves and servo valves.

4.10.6 ACCUMULATORS—Accumulators are used to store hydraulic energy. This stored energy provides an emergency source of power and can be used to reduce pump size and response requirements for transient loads. ISO 4413 provides requirements for hydraulic systems with gas-loaded accumulators. NFPA T3.5.49 provides application guidelines for accumulators.

Where feasible, systems with accumulators shall automatically vent the accumulated liquid pressure when the system is shut-off and de-pressurized, or provisions made to positively isolate the accumulator when the system is shut-off and de-pressurized. When this is not feasible, instructions for safe servicing of the system must be posted along with a warning label “CAUTION - System contains accumulator(s). Depressurize accumulator(s) before maintenance.” Gas loaded accumulators are normally charged with nitrogen or other inert gases. Although air loaded accumulators have been used in some ship systems, the use of air-loaded accumulators is not recommended and shall not be used without specific approval of the procuring activity. Use of air loaded accumulators is usually limited to very large accumulators with special designs to minimize the possibility of compressive explosion of an oil/air mixture.

4.10.7 ACTUATORS—Actuators perform mechanical work utilizing the energy in the hydraulic system. This group of components includes continuous rotary devices (hydraulic motors), partial turn rotary devices (rotary actuators), and linear devices (cylinders).

Refer to SAE J1781 for material considerations for marine actuators.

Refer to MIL-HDBK-2193 for design and performance guidelines.

When determining the output requirements for actuators in the marine environment, particular attention must be given to ship motion and its affect on the device being powered by the actuator. Wave motion and wind can cause the loads to vary significantly during operation.

4.11 Hydraulic Lines—Hydraulic tubing (either customary U.S. or metric units) is preferred over piping (NPS) but piping may be used for larger diameters if tubing is not available. In larger sizes, piping may be less costly than tubing but incur significant weight penalties. For lines up to 1-1/2 in (38 mm) outside diameter, installation per ARP994 is recommended. Mixture of piping and tubing should be minimized to facilitate logistic support.

4.11.1 LINE MATERIALS—Hydraulic lines should be designed on the basis of service pressures, durability, compatibility with the adjacent materials, standardization, and lightweight.

SAE J1781 provides guidance on the selection of materials and their corrosion resistance. For Navy submarines and surface ships respectively, MIL-STD-438 and MIL-STD-777 identify the materials and specifications for piping, valves, and fittings. When determining minimum pipe/tube wall thickness, consideration must be given to allowances for fabrication (e.g., bending, welding), pressure (including water hammer), temperature, in-service physical damage, thickness tolerances, erosion (for high velocity streams) and corrosion (based on environment). For pipe/tube exposed to sea water, the corrosion allowance normally added is 1.25 mm (0.05 in) for nonferrous materials and 1.65 mm (0.065 in) for ferrous materials. (Note 6.2 has additional information.)

4.11.2 CONNECTIONS—Where it is necessary or desirable to remove hydraulic line sections from the craft for maintenance or replacement, such sections should be installed with mechanically assembled joints. The number of mechanical joints shall be held to a minimum by means of manifolds and modules, and permanent connections (permanently swaged, welded, or heat recoverable couplings). The use of brazed joints is generally not recommended due to their susceptibility to melting during a fire. Where fire is unlikely, brazing can provide reliable joints in small diameter lines. Use SAE ARP994, MIL-STD-438, and MIL-STD-777 as applicable for guidance in selection and installation of tubing and fittings.

The use of mechanical joints in sea water should be minimized since the joints often result in sea water contamination of the system. A technique that can be used to minimize the possibility of sea water contamination is to use double seals with a leakoff between the seals. This leakoff can be piped to a location where any leakage can be monitored. On submersibles where monitoring is not possible, the leakoff can be connected to the compensation system. If a seal fails it will be compensating system fluid rather than sea water which leaks into the system.

Fitting installation shall be in accordance with manufacturer's recommended practice. Fittings with national pipe threads (NPT) shall not be used.

For subplate mounted components, the use of short connector tubes with diametrical seals are preferred to face seals for ships designed to withstand high impact loads. Connector tubes shall be in accordance with SAE J24714. If face seals are used, utmost caution is required as to flatness, smoothness, lack of steps, and inherent stiffness in mating parts to ensure a satisfactory seal. Gaskets molded into metal washers may also be considered.

Flexible connections should be used for mounting components subject to motion, vibration, or frequent removal such as pumps, motors, and actuators. Tube coils, flexible hoses, and swivel joints may be used for this purpose. Flexible connections shall not be used to compensate for poor piping installation or system alignment procedures.

Flexible hoses shall meet the requirements of SAE J1942 and installation shall comply with SAE J1273. Flexible hose length shall be as short as possible consistent with the flexibility requirements of the application. Hose assemblies with two hoses connected by an elbow are commonly used when large relative displacements occur.

Galvanic isolating fittings or hose are required where dissimilar metals are exposed to seawater.

4.11.3 PENETRATIONS—Penetrations through watertight boundaries require watertight sealed unions or fittings. This includes the hull, weather decks, and watertight subdivisions. Firewall penetrations should have means for shutting off the flow of combustible hydraulic fluid to the fire zone. Within the zone, fire sleeves should be provided on hoses or coiled tubing used. Care must be exercised to avoid the introduction of elastic loads on bulkheads or tubing, as well as to avoid mechanical vibration coupling.

4.12 Hydraulic Noise Control—Refer to SAE J1782 for the control of noise in hydraulic systems.

4.13 Component Corrosion Protection

4.13.1 For components internal to the ship, protective painting is an adequate defense against corrosion.

4.13.2 Components exposed to salt spray or to intermittent submersion in sea water require careful material selection, coating selection, and possibly cathodic protection. Refer to SAE J1781.

4.13.3 Components continuously submerged in sea water also require careful selection of material and coatings. Due consideration must be given to the total environment of the component. For example, the interaction of zinc anodes with large exposed areas of corrosion resistant alloys has caused scaling on NiCuAl hydraulic cylinder rods which in turn has caused failure of the wipers and seals on the hydraulic cylinder. Refer to SAE J1781.

4.13.4 Oil coolers circulating seawater may be copper nickel. If so, they shall be galvanically isolated from the hull and shall have a sacrificial anode. Titanium may be used without anodes.

4.14 Bearings—Actuator bearings exposed to seawater shall not depend on grease lubrication which may be washed away. For example, self-aligning spherical bearings may have a titanium ball with a ceramic coating to offer a sliding surface which resists pitting by seawater corrosion. The bearing race may be reinforced plastic, with tetrafluoroethylene (TFE) or other dry film lubricant. Fatigue life shall be the sizing criterion. Clearance should be allowed for swelling of plastic in contact with water.

4.15 Electric Indicators—Advanced marine vehicles generally require remote automatic sequencing of mechanisms and remote infinitely variable positioning of hydrodynamic control surfaces. All of the controls which are electrical require protection from seawater to avoid shorts to ground and mechanical corrosion damage to working parts.

It is essential to keep wiring dry. Means of excluding moisture by simple passive means have been disappointing in the past. In order to be effective, future designs shall be equal to or better than the examples quoted herein:

a. Utility actuators can and should be controlled by means of remote controlled valves located inside the machinery compartments. Rotary position switches may be used in protected locations. Some position-sensing switches however, may have to be in exposed locations. To avoid corrosion, the switches should be magnetically actuated and should have no external working parts. Reed switches or variable induction type proximity sensors may be used. Switches should be sealed to the end of watertight cables to avoid shorts. Control valves remotely operated by solenoids or electric motors should have manual overrides on manned vehicles.
b. Infinitely variable positioning actuators require a position transducer. In protected locations any convenient linear or rotary transducer may be used. In exposed locations a linear transducer housed inside the cylinder end cap and within the hollowed out piston rod is recommended. Servovalves should likewise be housed under a hard cover or in a cavity in the actuator body external to the hull. A pressurized conduit should be used to connect the electrical actuator cavities to a sealed junction box inside the hull. The conduit should be pressurized with dry compressed air to a pressure of 50 KPa (0.5 atmosphere) above ambient. Pressurizing air must continuously be replenished to make up for unavoidable air leakage. Care shall be taken that the pressurizing air does not become a source of water condensation. Dedicated air dryers are needed for reducing dew point below minimum ambient temperature. Hydraulic fluid can drip through imperfect seals into electrical cavities and may have to be drained periodically.

4.16 Solenoids—Solenoids for control valves shall be designed for operation in the system fluid or be dry coil solenoids enclosed by welded or brazed housings capable of preventing external fluid intrusion. On submersible vehicles, where the solenoid is exposed, solenoids are usually required to operate satisfactorily when immersed in sea water and subjected to a pressure equivalent to at least 135% of the ambient pressure at the operating depth of the vehicle. Unpotted coil insulation must be compatible with any compensating and system fluid which may be present.

4.17 Service Provisions—Consideration should be given in the design of hydraulic systems of marine vehicles to system checkout and servicing with:

a. On-board auxiliary power
b. Shoreside hydraulic service cart (water and particulate removal)
c. On-board electric pump

Hydraulic filters should have indicators activated by differential pressure drop to signal the need for maintenance.

Hydraulic reservoirs located within the vehicle shall normally have local sight gauges and fluid sampling valves in addition to any remote level indicators installed.

Hydraulic pump operating status shall be displayed at the pump controls by a remote indicating light unless the operator can easily determine status without a light. Consideration should be given to providing operating status indication to ship operators for critical systems such as steering gear.

Hydraulic accumulators shall have gas pressure indicating gauges if recharging the accumulators can be accomplished during the mission. Accumulators without gas pressure indicating gages should have provisions for connection of a gage.

Sufficient pressure test stations and vents shall be provided for system checkout and air removal. The system should be designed so that entrapped and entrained air will be bled back to the system reservoir as the system is operated. Readily accessible vent(s) should be installed for venting this air. Provision should also be made for ease of bleeding and, if necessary, vacuum filling during the initial charge of the system or using an air separator to remove air from the fluid during operation. Air removal is particularly important on submersible vehicles with pressure compensation (see 4.3.1). If air is present in the system, the volume of fluid required in the reservoir to achieve compensation is increased. With too much air it may not be possible to obtain full compensation. Vacuum dehydration is an effective means of reducing the air content of the service fluid.

Drains shall be provided at system low spots unless an alternative means of draining is available. Means shall be provided for detecting and removing water from the system. Connections on the reservoir or the compensator should be provided to permit the connection of an external purification unit for removal of water.

There shall be provisions for isolating damaged branch lines. Shutoff valves in pressure lines should be used in combination with check valves in return lines. Automatic shutoff and volumetric or rate fuses should be used only after thoroughly considering the effects of an unwarranted shutdown.

To aid in servicing, double seals with leak offs may be used for mechanical joints in seawater so that the failed seal can be readily identified (see 4.11.2).

4.18 System Support—Advanced marine vehicles having high performance hydraulic systems require adequate logistic support. Servicing equipment should be provided to remove moisture and solvents as well as solid particle contaminants from the hydraulic fluid. Equipment may range from drain and refill to purifiers including a vacuum/spray dryer, depending on economic reasons. Operation from remote facilities requires operations and maintenance information, spare parts, clean test benches, and standard mechanics tools as well as special tools. Use of special tools should be held to a minimum. Information shall include labels, placards, technical manuals, detailed procedures, and directives.

a. Hydraulic lines and check valves should be marked with flow arrows to indicate direction of flow. Components shall have manufacturer's identification plates. Labels indicating function on a schematic diagram shall be posted at or near components to be serviced. Instruction and warning plates shall be written in a manner the crew can understand and shall be posted where they can be seen and read.
b. Crew training aides and technical manuals shall be provided. The information shall include at least how to find a failed component and what the replacement part is called by part number.
c. Detailed procedures shall be provided for flushing, initial start-up, and checkout after parts replacement.

4.19 Certification of Submersible Vehicles—SS800-AG-MAN-010/P-9290 presents a set of guidelines for the designer and/or builder of Manned Deep Submergence Systems including any noncombat submersible intended for use by the U.S. Navy. This certification procedures and criteria manual is not intended to provide rigid procedures for construction. The objective of the certification process is to verify that a Deep Submergence System provides acceptable levels of personnel safety throughout the specified operating range of the vehicle when used in accordance with approved operating and maintenance procedures.

4.20 Life Requirements—The life requirements for hydraulic system components must be based on the mission and life requirements of the vehicle. In general, components should be designed to have a life at least equivalent to the major overhaul schedule of the vehicle.

Recognizing that nothing lasts forever, the system designer should understand the most probable failure modes [e.g., bearing failure, seal failure] for components in the system and the consequences of failure. The onset of failure must also be considered [i.e., graceful degradation versus catastrophic failure].

For those applications where personnel safety or ship safety is involved, a more rigorous engineering investigation is necessary to ensure system/component designs are safe. Particular emphasis should be placed on the load conditions and the duty cycle of the system/component along with the design factors of safety. In these, cases, consultation with component suppliers is highly recommended. For those components for which there is no back up or safety device [such as a brake], some form of certification is necessary. Certification shall be in the form of previous testing, proven performance in a similar application, or a rigorous test program. Applicable regulatory body [e.g., U.S. Coast Guard] and classification society [e.g., DNV, Lloyd's] specifications should be reviewed for requirements. The following guidance is provided for the system designer to develop a certification program:

Fatigue Pressure Rating – The requirement for fatigue rating of components shall be based on the magnitude and number of pressure cycles. For applications expecting to see 100,000 to 1,000,000 pressure cycles during their life, the system designer should consider selecting fatigue rated components. For applications expecting to see 1,000,000 or more pressure cycles during their life, the system designer shall select fatigue rated components if the pressure cycles are above 50% of system pressure. Fatigue rating shall be accomplished in accordance with NFPA T2.6.1. This rating applies to the pressure envelope only.

Load test – A static load test of such things as winches, capstans, and cranes is required to certify that the component is able to hold rated loads.

Endurance test – The purpose of the endurance test is to certify that the component will function without failure for a certain number of load cycles at rated conditions. The U.S. Navy often requires a 50,000 cycle endurance test.

Refer to paragraph 6.3 for examples of service life related failures.

5. Summary—Design criteria for hydraulic systems on advanced marine surface and submersible craft are sufficiently well understood so that acceptable designs can be attained by sound engineering practice and judicious usage of existing specifications. This Recommended Practice provides guidance as to the preferred ways to meet these criteria.

Systems must work and keep working reliably. Minimum performance and reliability are not negotiable. The bottom line when evaluating system trade-offs is weight versus total life cycle cost, including design, development, construction, operation, and maintenance costs.

6. Notes

6.1 The (R) is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. If the symbol is next to the report title, it indicates a complete revision of the report.

6.2 The following information provides lessons learned from a Boeing hydrofoil program related to hydraulic line selection and design, and is retained for information.

Copper ions leached onto aluminum hull plating can cause severe damage. Aluminum thin walled tubing often is not durable in the shipboard environment. The preferred materials are stainless steel and titanium. Among the stainless steels, the alloy 21Cr-6Ni-9Mn (AMS 5561) is preferred over AISI 304 on the basis of strength to weight ratio. However, AISI 304 is recommended when shipboard replacement of tubing is required since it is easier to fabricate. Pitting of 21-6-9 tubing was a severe problem in the tropics on Boeing JETFOILs where the fluid temperature exceeded 50 °C (120 °F). The problem was solved by applying two coats of epoxy resin base zinc chromate to the tubing and installing heat shrinkable polyolefin sleeves sealed with polysulfate rubber at all joints. However, for new designs titanium tubing and titanium alloy fittings should be used since the coating of the stainless steel tubing is labor intensive for initial installation and maintenance. Among the titanium alloys, 3Al-2.5V (AMS 4943, AMS 4944, and AMS 4945), is preferred for strength and ease of fabrication.