AEROSPACE INFORMATION REPORT	AIR1083™	REV. C
	Issued 1969-10 Revised 2012-04 Reaffirmed 2024-04 Superseding AIR1083B	

(R) Airborne Hydraulic and Control System Survivability for Military Aircraft

RATIONALE

AIR1083B has been revised for the following reasons:

a. Deleted Section 3.9 “Non-Ballistic Threats” and added a reference to MIL-HDBK-2069 Aircraft Survivability.

b. Technical changes in terminology have been made to be consistent with the updated references and the deletion of section 3.9

c. Other technical changes to reflect the use of technology which, at Revision B, was under development.

d. The references called out in the document have been updated.

e. Editorial changes have been made to improve the readability of the document.

AIR1083C has been reaffirmed to comply with the SAE Five-Year Review policy.

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1. SCOPE

This SAE Aerospace Information Report (AIR) provides the hydraulic and flight-control system designer with the various design options and techniques that are currently available to enhance the survivability of military aircraft.

The AIR addresses the following major topics:

a. Design concepts and architecture (see 3.2, 3.5, and 3.6)

b. Design implementation (see 3.3, 3.6, and 3.7)

c. Means to control external leakage (see 3.4)

d. Component design (see 3.8)

1.1 Purpose

This document provides the system design engineer with information and design considerations to enhance the airborne hydraulic and control system survivability under combat conditions.

1.2 Field of Application

This AIR will attempt to address the following threats:

a. Typical small arms fire (5.56, 7.62, 12.7, and 14.5 mm AP)

b. Cannon (20, 30, and 40 mm API/HEI)

Protection against missiles and non-ballistic threats is beyond the scope of this AIR. This is because except for electronic counter-measures or evasive maneuvers, no practical technology exists which allows an aircraft control and hydraulic system to survive a direct hit by a missile or large caliber anti-aircraft projectile.

2. REFERENCES

2.1 Applicable Documents

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

2.1.1 SAE Publications

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

ARP584 Coiled Tubing - Corrosion Resistant Steel, Hydraulic Applications, Aerospace

ARP993 Fluidic Technology

AS1241 Fire Resistant Phosphate Ester Hydraulic Fluid for Aircraft

AIR1245 Power Sources for Fluidic Controls

ARP1280 Aerospace - Application Guide for Hydraulic Power Transfer Units

AIR1362 Aerospace Hydraulic Fluids Physical Properties

ARP4146 Coiled Tubing - Titanium Alloy, Hydraulic Applications, Aerospace

ARP4378 Aerospace - Accumulator, Hydraulic, Welded Bellows, Factory Precharged

ARP4379 Aerospace - Accumulator, Hydraulic, Cylindrical, Piston Separated

ARP4553 Aerospace - Accumulator, Hydraulic, Self-Displacing

2.1.2 U.S. Government Publications

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

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

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

MIL-HDBK-2069 Aircraft Survivability

MIL-HDBK-2089 Aircraft Survivability Terms

2.1.3 Other Publications

Aircraft Survivability. Published three times a year by the Joint Aircraft Survivability Program Office (JASPO), 200 12th Street South, Crystal Gateway #4, Suite 1103, Arlington, VA 22202, Tel: (703) 607-3509, https://jaspo.wpafb.af.mil.

2.2 Abbreviations

AP Armor-Piercing

API Armor-Piercing Incendiary

HEI High-explosive Incendiary

3. TECHNICAL REQUIREMENTS

3.1 General

A comprehensive knowledge of the hostile environment to which the air vehicle will be exposed will form the basis upon which the overall design philosophy is formulated. The designer should strive to achieve at the absolute minimum a system which provides the actuation and control capability to meet the minimum acceptable flying quality level to complete the operational mission for which the aircraft is designed; i.e., the aircraft can be controlled and the mission terminated safely, including the landing.

The approach and requirements taken by the military aircraft design team may be different for a fighter versus a transport versus a rotary-wing aircraft, but each must consider the primary modes of failure of the aircraft hydraulic and flight control system due to externally caused damage. Although the main thrust of this document is to design an integrated power generation/flight control system to survive under combat conditions, many of the approaches offered herein can also be used to increase the system reliability in general.

MIL-HDBK-2069 provides general concepts and guidelines for aircraft survivability design. Survivability terms and definitions are contained in MIL-HDBK-2089.

3.2 Design Considerations

3.2.1 Design Concepts

The survivability requirements imposed by the aircraft specification have a major impact on the development of the basic system arrangement. The requirements impact the following:

a. Power source selection

b. System architecture

c. Sub-circuit isolation

d. Supply system

e. Electrical/fiber optic routing

The military aircraft design team must consider that common-mode failures affecting two or more systems are extremely dangerous and may result in the loss of the aircraft. Devices that potentially bridge two or more systems, such as switching valves or multistage actuators, must be designed and installed with this in mind.

3.2.2 Redundancy

System redundancy has long been used to achieve the required system reliability. A high level of mission reliability usually requires increased levels of redundancy. A failure resulting from a ballistic hit can be treated as a regular failure mode and its effect on the overall system reliability can be evaluated. Adding redundancy thus increases mission reliability and the level of survivability. Usually dual or triple redundancy suffices to meet the survivability requirements. Higher levels of redundancy eventually lead to diminishing returns and are usually not practical from a weight, space, and cost consideration.

Furthermore, the degree of redundancy also depends on:

a. The number of flight-essential services to be powered

b. The physical separation of the control elements, availability of any backup control power

c. The availability of alternate control means that may be used to supply the same control capability

The major consideration in using redundancy for survivability reasons is to ensure that there is sufficient separation of the redundant components and/or subsystems. This is in order to avoid multiple damage to several components from a single hit, resulting in component or total system failure. Furthermore, when using redundant components, means must be provided to assure integrity of all portions of the redundancy including dual load path actuator rods and control valves. If this is not done, redundancy becomes illusory.

The use of independent actuation means, such as integrated actuator packages (IAPs), electrohydrostatic actuators (EHAs), or electromechanical actuators (EMAs), can be a means of enhancing survivability where power and space requirements permit such installations. The remote independent hydraulic power source or actuator, or pure electric actuator, provides for actuation redundancy. This is particularly true for aircraft with large distances between the control surfaces and/or the power sources, where a IAP, EHA, or an EMA can substantially reduce the vulnerable area of a system.

The designer must be aware of the impact of the IAPs, EHAs, and EMAs on the electrical system. The overall survivability must be evaluated considering the impact of the choice of devices used on the total aircraft system.

3.2.3 Subsystem Arrangement

Survivability can be enhanced by the judicious arrangements of subsystems in relation to the supply sources. For example, if both speed brakes and flaps are hydraulically powered, an attempt should be made to power them from separate supply sources to assure availability of at least one drag device in the event of a system loss. The same might be applied to normal and emergency operation of critical subsystems.

Consideration should also be given to the secondary effects of damage such as:

a. Linkage or mechanism jams or disconnects

b. Hydraulic fluid loss

c. Open/shorted wiring

The degradation of aircraft performance may result from a loss of a subsystem. To minimize, or eliminate the effect of a subsystem failure on overall aircraft performance, the designer should address this issue when defining the overall system architecture.

Fly-by-wire (FBW) and fly-by-light systems offer the designer an increased flexibility to vary the control laws following a system failure by allowing the designer to reconfigure the system in such a manner as to negate the effect of the failure on the air vehicle controllability. In addition, the use of EMAs should be considered where pure hydraulic redundancy is insufficient to meet survivability goals.

3.2.4 Vulnerable Area Minimization

A basic method of increasing survivability is to minimize the vulnerable area of the hydraulic system. Since a smaller target is harder to hit, it, therefore, has a better chance at survival. The decision on how to accomplish the required area minimization should be made during the initial stages of the system development.

The primary methods of minimizing the vulnerable areas are:

a. Simplification, to reduce the number of required components

b. Increased operating pressure, to minimize line and component size (pressure levels of 5000 psi (35 000 kPa) are now being used in aerospace applications)

c. Packaging of components to keep the total presented area to a minimum (modular packages offer a good solution to reduce the vulnerable area)

d. Component miniaturization

3.2.5 Manual Reversion of Flight Controls

A means of increasing flight control redundancy is to revert to manual control in the event of total hydraulic power loss. This approach is usually limited to slower fixed wing or smaller rotary wing aircraft and cannot be employed on aircraft that are naturally unstable and require a control system to make the aircraft flyable.

Generally some type of retained cylinder damping is needed to maintain full stability of the control surface with loss of all hydraulic power. In the case of fly-by-wire (FBW) controls with direct mechanical reversion to provide redundancy against FBW failures, care must be taken to trim gradually to the pedal/stick position during such a reversion to avoid a damaging sudden step input. This would be particularly important if the aircraft were being flown automatically (for example in a high speed, low level terrain-following mode). In this mode the manual control may not be in an active-stand-by mode and the pilot will have little or no time to correct any pitch down.

NOTES:

1. A mechanical back-up system adds weight and complexity which may outweigh any advantages.

2. Care needs also to be exercised in routing of manual reversion controls to assure that damage cannot result from the event caused by the initial failure.

3.3 Spatial Separation and Isolation

Serious consideration should be given to the needs for spatial separation and the isolation of redundant circuits and/or flight-critical subsystems.

3.3.1 Separation of Redundant Circuits

To obtain the maximum benefits of redundant circuits or subsystems, it is important that they be sufficiently separated to prevent loss of all circuits or subsystems from a single hit. The separation must be analyzed for the maximum threat specified. Ideally, this separation should be in all planes of impact.

One common rule of thumb for separation is to use a minimum distance of 18 in (460 mm). However, caution must be taken to avoid standardization of such separation distances. This is because, when locating redundant lines and components, both separation and standoff distances from predicted detonation points must be considered.

As illustrated in Figure 1, the fragments from a high-explosive shell fan out in two side spray paths approximately 90 degrees apart. This pattern applies to both quick and delayed fuses. As shown in Figure 2, the 18 in (460 mm) separation provides multiple-kill protection from a single hit only for components located within 6 in (150 mm), or further than 30 in (760 mm), from the skin line.

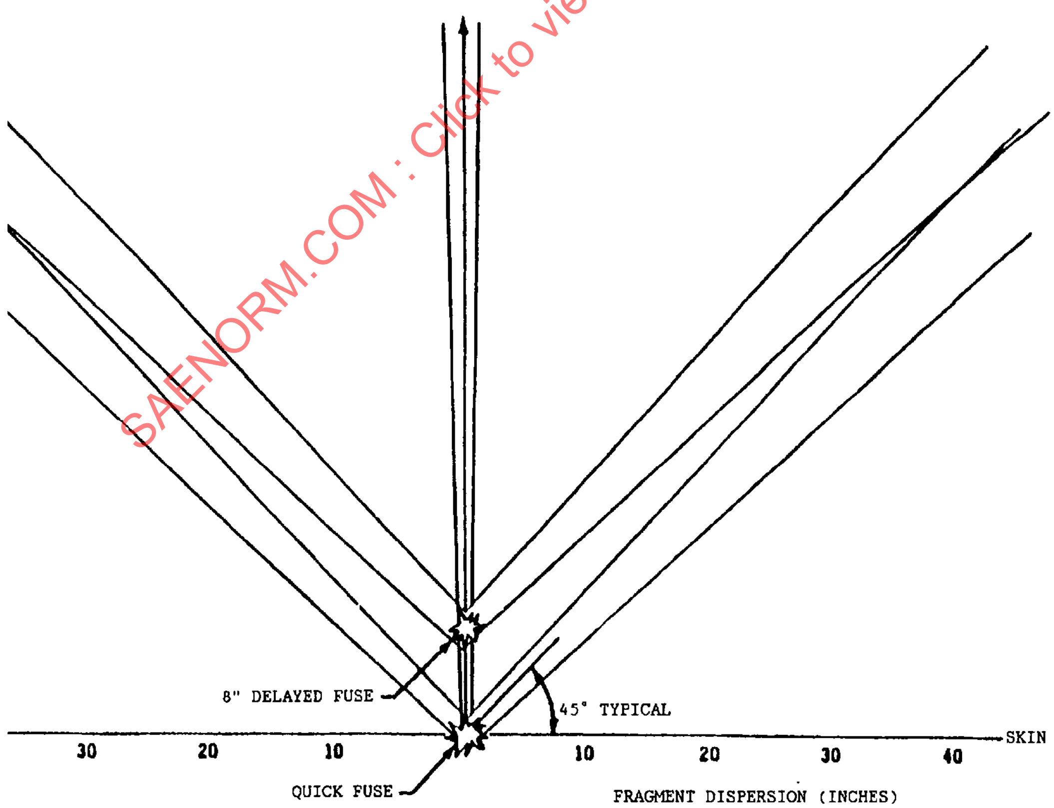


FIGURE 1 - VULNERABLE AREAS FOR HIGH EXPLOSIVE BURSTS

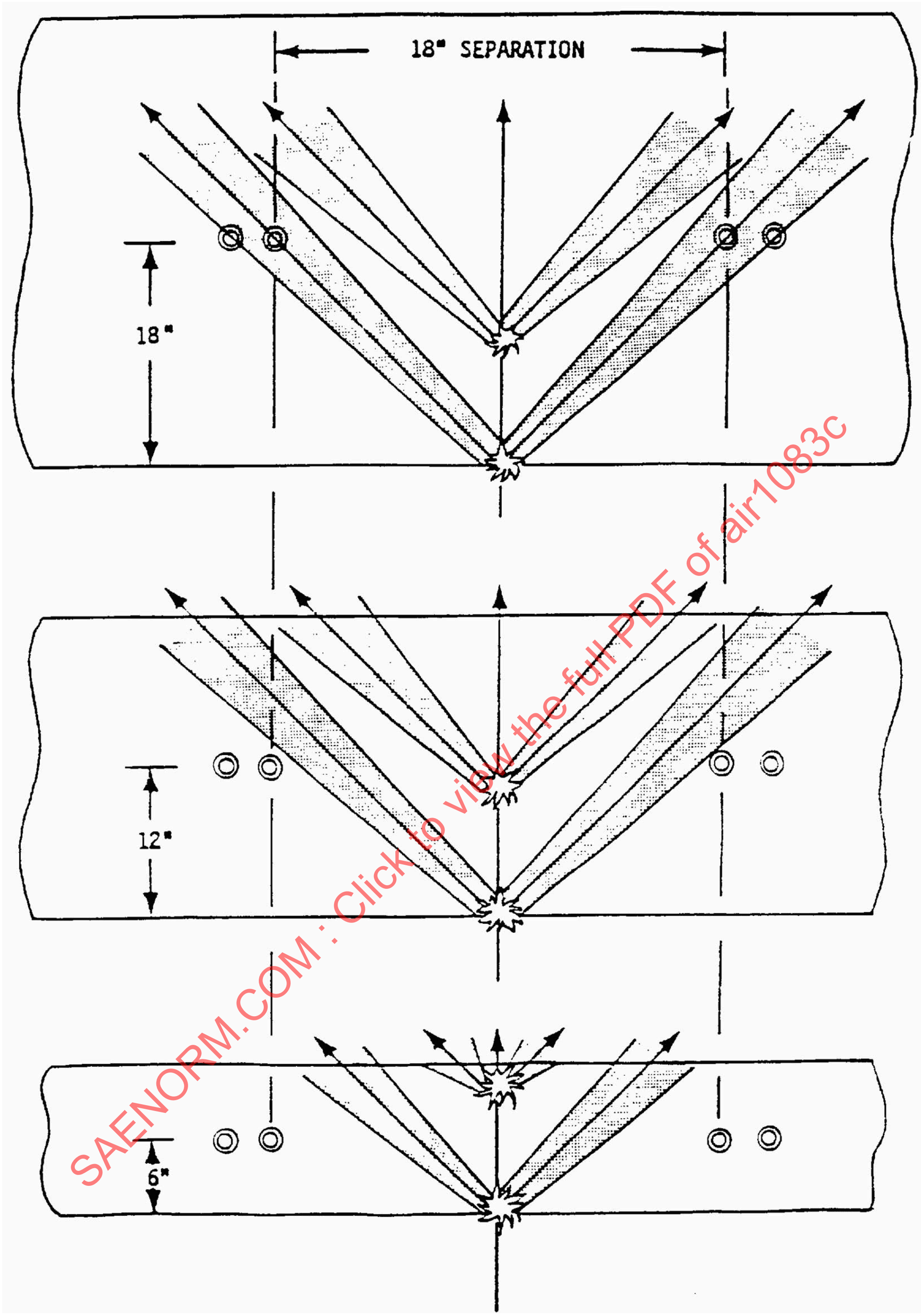


FIGURE 2 - THE HAZARD OF USING CONSTANT SEPARATION DISTANCES BETWEEN TUBE RUNS

Where possible, subsystems/circuits should be separated as far as practical and routed on opposite sides of the fuselage, and on the front and rear spar of the wings and empennage as shown in Figure 3. The maximum separation should be maintained as close to the using function as practical, additional protection can be provided by judicious use of structural shielding and/or armor protection. This is discussed further in the following section.

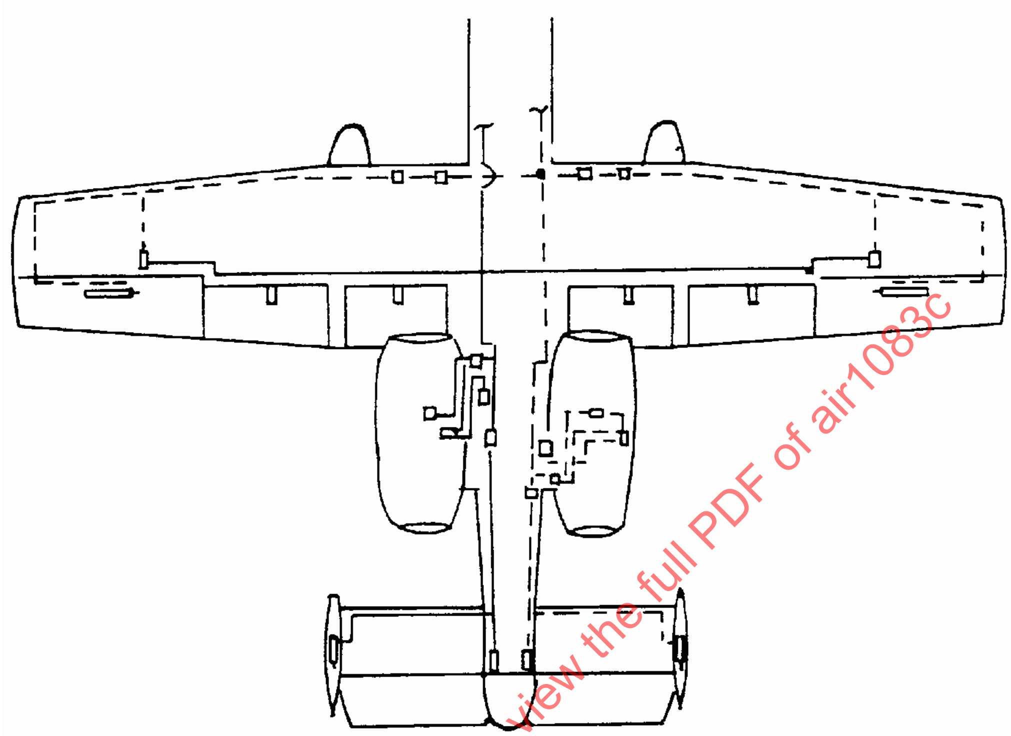
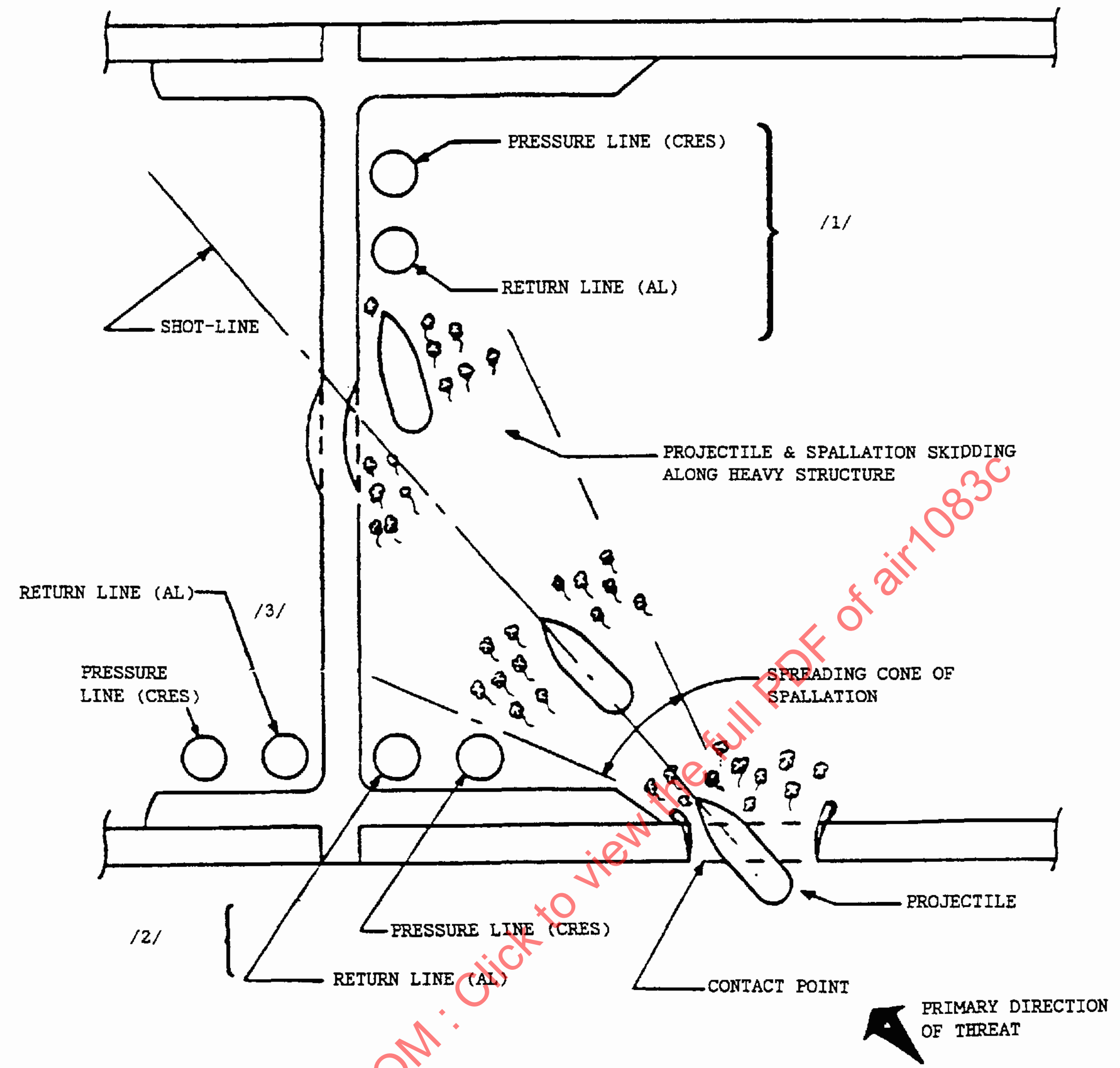


FIGURE 3 - A-10 SKETCH (EXAMPLE) SHOWING PHYSICAL SEPARATION OF HYDRAULIC CIRCUITS

3.3.2 Structural Shielding

Hydraulic lines and electrical power lines for flight control actuation should be routed as close as possible to the heaviest structure of the air vehicle. Landing gear supports and wing and transmissions (gearboxes) and their support frames are typical examples. On multi-engine aircraft, engine driven pumps and electrical generators should be located so they are shielded by the engine and the airframe. Accessory gearboxes should be designed to provide shielding to flight critical components. Non-flight-essential hydraulic and electrical components may be used to shield essential areas. Figure 4 illustrates how the judicious location of system tubing can be used to provide shielding, both from the primary (ballistic) threat, and also from the spallation fragments from the aircraft skin and fracture.



/1/ BAD INSTL: HIGH SPAR LOCATION IN WIDE DISPERSION AREA OF SPALLATION CONE AND LESS IMPACT RESISTANT AL. TUBE SHIELDING CRES TUBE.

/2/ BETTER INSTL: LOW SPAR LOCATION IN NARROW AREA OF SPALLATION CONE AND HIGH IMPACT RESISTANT CRES TUBE SHIELDING AL. TUBE.

/3/ BEST INSTL: LOW SPAR LOCATION BEHIND HEAVY STRUCTURE.

FIGURE 4 - ENHANCEMENT TECHNIQUES AGAINST SPALLATION THREAT

3.3.3 Hydraulic System Isolation Valving

Isolation valves can be used to isolate non-flight-critical hydraulic systems from flight-essential systems. The valves should be fail-safe to the "closed" position in case of electrical power or mechanical failure. A manual override capability may be required at the end of the mission for the emergency operation of non-flight-critical systems such as landing gear extension.

3.4 Leakage Protection

A cause of hydraulic system loss is the depletion of the system fluid due to damage to a line or a component, the probability of which is greatly increased during operation in a hostile environment. Ballistic damage to a hydraulic system will almost always results in depletion of the system fluid.

Furthermore, there always is the threat of ignition of this fluid, as a direct result of the projectile effect. Fire can also ensue from secondary damage to the electrical system with shorts or sparks or due to contact with a hot surface or open flame. This can lead to the loss of the complete aircraft. Accordingly, serious consideration should be given to providing maximum leakage protection to all hydraulic flight-critical systems and components. When using any of the various leakage protection devices described herein, the designer should consider where in the system to locate such a device and how much of the hydraulic fluid will be released before the protection device actuates to shut off the flow.

3.4.1 Line Check Valves

3.4.1.1 Return-Line Check Valves

Check Valves, located at or near the return ports of components and/or return branches of the supply system, can delay the fluid loss in the event of return-line damage. The degree of delay depends upon which subsystem return line is damaged, where it is damaged, how frequently the related subsystem branch operates, and upon the internal leakage of the damaged subsystem components.

3.4.1.2 Pressure-Line Check Valves

Pressure-line check valves may be considered in certain cases where loss of system power allows external flight loads to back drive the control actuator, leading to aircraft instability. The addition of a restrictor check valve at the actuator inlet can eliminate or minimize these effects.

3.4.2 Reservoir Level Sensing

This method monitors the reservoir fluid level to determine the existence of system leakage and subsequently “shut off” the damaged circuit. This isolation technique retains the use of one or more subsystems in the event of fluid loss. One or more distinct fluid level points are used to actuate the shutoff devices controlling the flow to branch circuits. The shutoff logic reactivates an isolated branch in the event that the fluid level continues to drop to the next signal point. The number of branches employed is dependent upon the flight-critical subsystem arrangement and the logic of separation. This principle is generally limited to two or three branch arrangements due to weight and complexity considerations.

The basic principle is illustrated in Figure 5, which depicts a two-branch system design. In this illustration, the reservoir piston shaft would contain two cams that mechanically actuate sensing valves for control of pressure operated shutoff valves. This shutoff sequence can also be controlled electrically using switches and solenoid valves. In the event the shutoff of branch No. 1 does not eliminate the leakage source, the No. 2 branch cam will shut off the second branch and at the same time reopen the No. 1 branch.

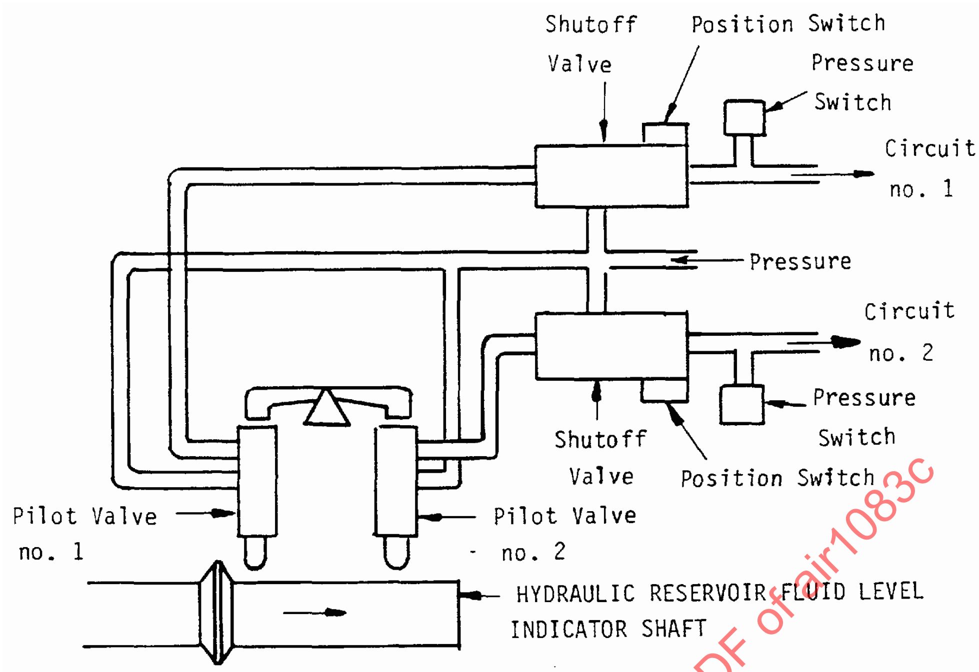


FIGURE 5 - RESERVOIR LEVEL SENSING

Like redundant subsystems, the survivability improvements provided by this technique are dependent on the amount of branch separation and subsystem arrangement. Consideration must be given to the additional circuitry required and its impact on the overall system reliability. Also, it is important to consider shielding or armor protection for the more critical common fluid supply items upstream of the sensing device. Reservoir level indication or branch circuit pressure loss should be annunciated to the flight crew to allow the crew to take possible corrective actions.

3.4.3 Fuses

The fuses of the types described below are for use in non-critical systems and should never be used in flight-essential systems.

3.4.3.1 Volumetric Fuses

Volume measuring fuses may be applied to certain unidirectional circuits to provide leakage (fluid loss) protection. As the name implies, this type of device measures a predetermined volume of fluid. Once this volume is exceeded, the fuseactuates to isolate the subsystem branch or component.

For example, circuits to utility actuators, landing gear, or door actuators might be protected by a fuse of this type. The potential internal leakage of the circuit must be considered in the use of such a device since the rated volume of the fuse is determined with a minimum flow limit. Internal flow rates above this minimum can result in inadvertent shutoff by the fuse. Careful consideration must be given to the possible inadvertent fuse shutoff on the overall aircraft safety.

3.4.3.2 Rate Fuses

Unlike the volumetric fuse, the rate fuse is flow rate sensitive. It is a simple device and is best suited to protect system branches that carry a known flow rate. The rate fuse is relatively insensitive to system operating temperatures except at the extreme low limits. Threshold levels should be carefully set to avoid nuisance shutoff due to flow surges, air or cold start up conditions. Levels of 1.3 to 1.5 times maximum subsystem flow are reasonable values for the threshold settings. Once triggered, these devices remain shut off until the supply pressure is removed. The major drawback of the rate fuse is that it detects only leaks which are in excess of the threshold and which may be large enough to cause rapid system depletion. Leakage flows below the threshold are not detected by this device.

3.4.4 Flow-Differential-Sensing Shutoff Valves

A flow-difference-sensing device works on the basic principle of “what goes in must come out”; i.e., flow into a component must equal the flow out of the component. See Figure 6 for a typical circuit. Adjustments must be made in establishing the detection threshold to account for the effects of unequal area actuators, cold temperature operation, and air. In operation, this device compares the flow rates of the supply and return lines and isolates the circuit or component when the flow rate is unbalanced beyond a preset level. To accommodate all the physical events which occur in a system, such as cold start-up, maintenance induced air, flow transients, etc., startup time delays, and threshold limits must be set high enough to eliminate “false triggering” or “false” shutoff.

Thus each shutoff valve design has a minimum leak detection threshold. Hydro-mechanical devices exhibit higher minimum leak detection thresholds than electro-hydraulic devices.

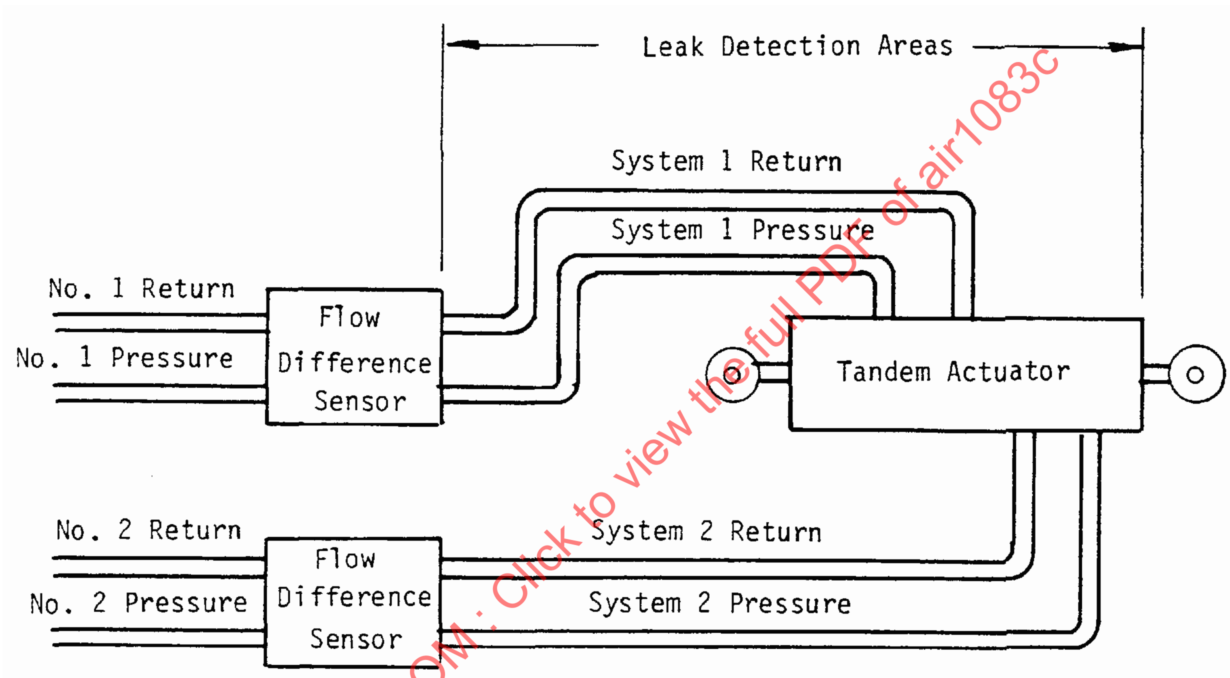


FIGURE 6 - FLOW-DIFFERENCE-SENSING VALVE CIRCUIT

NOTE: For systems that have a reservoir capacity insufficient to handle the threshold leakage rate, the alternative is reservoir level-sensing (RLS).

3.4.4.1 Hydro-mechanical Shutoff Valves

A common method has been to measure the pressure drop across an orifice placed into each leg and use the pressure energy to trigger a shutoff mechanism if the difference between the two flows, or pressure drops, exceeds the predetermined value. Devices have been built which utilize the drop across the metering orifice directly applied across a balance beam or the ends of a valve spool. Hydro-mechanical devices generally operate over limited temperature ranges, are unable to operate with aeration, and exhibit relatively high leakage thresholds.

3.4.4.2 Electro-hydraulic Shutoff Valves

A second approach to flow-differential-sensing shutoff valves uses flow meters to generate electrical signals proportional to the flows. These signals are compared electronically to provide decisions about actuating the shutoff valve. When the “in” and the “out” flows are equal, the sensing elements are in equilibrium, the device is open, and fluid is allowed to flow to the subsystem or component. When a specified difference exists between the “in” and the “out” flows, the equilibrium is upset and “shutoff” occurs. Microprocessor based designs, “smart valves”, offer significantly enhanced performance, because their algorithms allow such options as averaging and totalizing leakage. Electro-hydraulic flow sensing shutoff valves can accommodate aeration, large operating temperature ranges, and large system transients. Current designs can limit total system fluid loss to 23 in^3 (380 cm^3) and have thresholds equal to or lower than 3% of the nominal system flow. Some of these devices are patented or proprietary.

3.5 Hydraulic Backup Means

Backup systems have been used successfully to enhance the reliability/survivability of hydraulic systems. Where the backup power is required for anything but a momentary use, it can be supplied by electric motor pumps (EMPs) or ram air turbine (RAT) driven pumps. EMPs may be either AC or DC powered. Backup power can also be derived from other aircraft systems via transfer (switching) valves or power transfer units (PTUs). Where backup power is required for only short durations, energy storage devices like accumulators or gas generators can be utilized to provide the momentary power.

3.5.1 Means to Transfer Hydraulic Power

This can be achieved using transfer (switching) valves or PTUs. These devices provide back-up power for a primary system in case of a primary system failure. The transfer valve concept will cause fluid interchange between the two systems since it ports two supply systems into a single subsystem. This must be taken into account during the system design formulation. Large quantities of fluid can be interchanged, for example in a system where an accumulator is charged by one system and then could be discharged into another system. PTUs on the other hand, transfer power purely mechanically with no fluid interchange.

3.5.1.1 Transfer Valves

The transfer valve is a device which accepts inputs from either of two or more supply systems and connects one of these systems to the component or subsystem in accordance with the valve, or system, design logic. The transfer valve is usually biased to give priority to one of the supply systems.

The transfer valve can be combined with a system integrity check unit. This type of device, which is an intelligent valve, tests the integrity of the subsystem or components by connecting the pressure and return lines of the downstream branch upon loss of primary pressure, while at the same time inhibiting transfer to the backup system. A small integral accumulator is used to pressurize the downstream branch. If no leak exists, the sensing pressure will not decay, and transfer to the backup system will occur. A built-in timing device limits the duration of the system integrity check prior to transfer.

Attention must be given during the design phase to minimize interstage fluid leakage. The transfer valve design must avoid the loss of both primary and backup power systems due to a single failure in the valve or the downstream subsystem. The valve must be stable under all conditions including supply and return pressure variations, system start-up and run-down and climatic extremes. Systems utilizing large differential area actuators are not well suited to use transfer valves unless precautions can be taken to minimize fluid transfer. If the fluid transfer problem cannot be solved, a PTU should be used.

3.5.1.2 Power Transfer Unit (PTU)

A PTU is used when fluid transfer is prohibited or unavoidable, or where additional transient power requirements dictate the use of such a device. The PTU consists of a hydraulic motor coupled via suitable shafting to a hydraulic pump. Uni- or bi-directional units are available. The purpose of a PTU is identical to the transfer valve, i.e., using the power of one system to provide power to another, except that the transfer is purely mechanical. Sufficient intelligence must be designed into the system using this device to prevent power loss in the primary due to damage in the secondary system branch. Care needs to be exercised in using a PTU to ensure that the differential pressure to accomplish start-up for a PTU must be acceptable for the most critical start-up condition. Consult ARP1280 for additional information about PTUs.

3.6 Control Jam Protection

To enhance the aircraft for flight safety reasons it is necessary to provide aircraft flight control capability following a jammed actuator or control element. This is imperative for operation of the aircraft in a hostile environment.

3.6.1 Mechanical Jam

Compensation for this problem will vary considerably depending on whether the control input is totally FBW or purely mechanical.

For FBW control, compensation can be included in the electronic circuitry and software, with the level of electronic redundancy primarily dependent on system architecture, management, and reconfiguration capability. The jam area in this case would be limited to power actuators, surface pivots, and linkages.

For a mechanical system, the vulnerable area now includes all of the linkages between the pilot controls and the control element. The protection is complicated by the requirement to disconnect the stick or pedals from the input linkage system. This also applies to FBW systems with a mechanical backup. This approach further requires that a detection system be incorporated to provide the pilot with the necessary intelligence to determine what actuator or linkage run is jammed. The signal actuation loads should be above those that might be generated by rapid control motions, but not so high as to require extreme pilot effort. The failure warning indication should incorporate a minimum holding ycle to insure ease of pilot evaluation without retaining the high input loads. To provide the maximum protection, the disconnect devices should be placed as close to the stick or pedal as practical. The disconnect can be designed as a single cycle unit (once disconnected can only be reset after flight) or with a disconnect/connect capability. The latter provides for in-flight familiarization and training and compensation for actuation errors. Consideration should be given to the routing of the mechanical control system to prevent jamming or restriction due to deformation of adjacent structure resulting from ballistic impact.

3.6.2 Hydraulic Lock

Damage to the fluid return circuit of an actuator may result in partial or complete fluid blockage. A partial blockage will restrict the actuator rate to the extent of the amount of return flow restriction until all the fluid is expelled from the low pressure side of the actuator. A complete blockage may result in a complete actuator jam. This condition can be eliminated by the installation of bypass (runaround) check valves at or within the actuator. The check valve is installed between the supply pressure and return ports and will permit runaround flow from return into pressure in the event of a blocked return line. This method will only work if the control valve is still functioning, which cannot always be presumed to be the case.

A better solution to prevent actuator fluid blockage is to install a bypass valve across the actuator ports. This valve interconnects the two cylinder chambers whenever system pressure is below a predetermined value. The interconnection of the cylinder ports can also be connected to return. If the valve spool is of a balanced design, i.e., the spool areas exposed to system and return pressures are equal and the valve is spring-biased to the bypass position, then a blocked return line will automatically place the valve into bypass and interconnect the cylinder chambers. With either approach, check or bypass valves must be incorporated to dispose of the extra volume in the unequal area actuators. Equal-area actuators do not require a return connection, but usually are longer, heavier, and require additional seals.

3.7 Fire Protection

Consideration should be given to minimizing the impact of fire and/or heat on the hydraulic system. All hydraulic fluids, even those that are fire resistant, will burn under environmental conditions that support combustion.

3.7.1 Location of Hydraulic Equipment

The location of the hydraulic equipment should consider the effects of fire and the associated heat of other aircraft systems. Fuel, hydraulic fluid, and electrical short circuits are ignition sources.

Components should not be located in fire zones whenever possible. When this cannot be avoided, suitable shutoff valves should be installed at the fire zone barrier. Only components made from heat resistant materials should be used in fire zones or any other area suspected to generate high temperatures. These components should be qualified as a minimum to survive a 15 mm exposure to 2000 °F (1100 °C). Another consideration is to install temperature sensitive shutoff valves to shut off any fluid line subjected to very high temperatures.

3.7.2 Hydraulic Distribution Elements

3.7.2.1 Tubing Materials

Although aluminum tubing is the lightest aircraft tubing commonly used, it is also the weakest and more prone to failure. Excellent high-strength stainless steel and titanium tubing is available which is significantly superior to aluminum tubing with respect to strength, ability to withstand abuse, and battle damage with a minimal weight penalty. Resistance of tubing and hydraulic lines to ballistic damage and other abuse is also enhanced by the use of heavier-walled titanium or stainless steel tubing, particularly in areas essential to system redundancy. AMS4945 Titanium Tubing and AMS5561 Stainless Steel Tubing is most commonly used in current designs.

It is common practice to prohibit the use of aluminum tubing in areas that are exposed to FOD (foreign object damage) or to high temperatures. Ballistic consideration must address the possibility of a fire caused by ballistic damage; therefore the use of aluminum tubing should be avoided due to the poor fire resistance of the aluminum alloys as compared to steel or titanium.

3.7.2.2 Catering for Relative Motion

In areas of relative motion between components, or components and structure, coiled tubing designed to ARP584 for steel tubing or to ARP4146 for titanium tubing should be considered. The use of hoses should be minimized, but when used should at least be protected with fire shielding.

3.7.2.3 Fittings

Fitting material selection should parallel the tubing material selection for survivability consideration; therefore, aluminum fittings are unsuited for these areas. Permanent type of tube joints should be utilized to the greatest extent possible. Titanium swage-type fittings have successfully passed the 2000 °F (1100 °C), flammability test and have been fully qualified for use on both stainless steel and titanium tubing. In addition, the effects of thermal cycling of components during battle damage should be considered. Fittings made from materials having different coefficients of expansion may experience leakage even after the heat source is eliminated, although this is mostly limited to separable type fittings.

Fittings that employ elastomers as the sealing element should be avoided. Metal-to-metal seals should be considered instead on fittings that could be subjected to high temperature.