

MIL-STD-1522A(USA

28 MAY 1984

SUPERSEDING

MIL-STD-1522 (USAF)

1 JULY 1972

MILITARY STANDARD

STANDARD GENERAL REQUIREMENTS
FOR SAFE DESIGN AND OPERATION
OF PRESSURIZED MISSILE AND
SPACE SYSTEMS



NO DELIVERABLE DATA REQUIRED BY THIS DOCUMENT

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MIL-STD-1522A (USAF)
28 MAY 1984

DEPARTMENT OF AIR FORCE
Washington, D.C. 20301

Standard General Requirements for Safe Design and Operation of
Pressurized Missile and Space Systems

MIL-STD-1522A (USAF)

1. This military standard is approved for use by the Department of the Air Force, and is available for use by all departments and agencies of the Department of Defense.
2. Beneficial comments (recommendations, additions, or deletions) and any pertinent data which may be of use in improving this document should be addressed to:

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MIL-STD-1522A (USAF)
28 MAY 1984

FOREWORD

This standard establishes the basic system safety criteria for pressurized systems used on Missiles and Space System-Aerospace Vehicle Equipment (AVE) and its related Ground Support Equipment (GSE). It is applicable to all AVE and GSE which contain pressurized systems, subsystems or components. All criteria listed herein are mandatory design criteria when this standard is placed on contract. Each criterion will be reviewed for specific applicability to the projected new design, and when systems are approved for modification. Specific approval of the procuring activity is required prior to the exclusion, modification or revision of any criterion listed in this standard during the generation of design specifications for items of AVE and GSE which contain pressurized systems, subsystems or components thereof.

MIL-STD-1522A (USAF)
28 MAY 1984

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CONTENTS

	<u>PAGE</u>
1. SCOPE.	1
1.1 Purpose	1
1.2 Application	1
2. REFERENCED DOCUMENTS	3
2.1 Issues of Documents	3
2.2 Other Publications.	4
3. DEFINITIONS.	5
3.1 "A" Basis Allowables.	5
3.2 Acceptance Tests.	5
3.3 Applied Load (Stress)	5
3.4 "B" Basis Allowables.	5
3.5 Brittle Fracture.	5
3.6 Burst Factor.	5
3.7 Components.	5
3.8 Composite Material.	5
3.9 Critical Condition.	6
3.10 Critical Stress Intensity	6
3.11 Critical Flaw	6
3.12 Damage Tolerance.	6
3.13 Design Burst Factor	6
3.14 Destabilizing Pressure	6
3.15 Detrimental Deformation	6
3.16 Ductile Fracture.	6
3.17 Factor of Safety.	6
3.18 Fatigue	6
3.19 Fittings.	7
3.20 Flaw.	7
3.21 Fracture Control.	7
3.22 Fracture Mechanics.	7
3.23 Fracture Toughness.	7
3.24 Hazard.	7
3.25 Hydrogen Embrittlement.	7
3.26 Initial Flaw.	7
3.27 Leak-Before-Burst	7
3.28 Limit Load.	7
3.29 Lines	8
3.30 Load Spectrum	8
3.31 Margin of Safety.	8
3.32 Maximum Allowable Working Pressure.	8
3.33 Maximum Operating Pressure.	8
3.34 Pressure Cycle.	8
3.35 Pressure Vessel	8
3.36 Pressurized Structure	11
3.37 Pressurized System.	11

MIL-STD-1522A (USAF)
28 MAY 1984

CONTENTS (Cont)

	<u>PAGE</u>
3.38	11
3.39	11
3.40	11
3.41	11
3.42	11
3.43	11
3.44	11
3.45	12
3.46	12
3.47	12
3.48	12
3.51	12
3.52	12
3.53	12
3.54	12
3.55	12
 4.	 13
4.1	13
4.1.1	13
4.1.2	13
4.2	14
4.2.1	14
4.2.2	14
4.2.3	15
4.2.4	15
4.2.5	16
4.2.6	17
4.2.7	17
4.3	17
4.3.1	17
4.3.2	18
4.3.3	18
4.4	19
4.5	19
4.6	20
4.6.1	20
4.6.2	21
4.6.3	21
4.6.4	22
4.7	22
4.7.1	22
4.7.2	22
4.7.3	23
4.7.4	23
4.7.5	23

CONTENTS (Cont)

	<u>PAGE</u>
4.7.6 Documentation	24
4.8 Special Requirements	24
4.8.1 Re-Activated Pressurized Hardware . . .	24
4.8.2 Multiple Proof Tests	25
4.8.3 Test Fluids	25
5. DETAILED REQUIREMENTS	27
5.1 Non-composite Pressure Vessels	27
5.1.1 Pressure Vessels with Non-Hazardous Leak-Before-Burst Failure Mode (AVE)	29
5.1.1.1 Factor of Safety Requirements . . .	29
5.1.1.2 Safe-Life Analysis Requirements . .	29
5.1.1.3 Qualification Test Requirements . .	29
5.1.1.4 Acceptance Test Requirements . . .	31
5.1.1.5 Re-Certificate on Test Requirements.	31
5.1.2 Pressure Vessels with Brittle Fracture Failure Mode (AVE).	32
5.1.2.1 Factor of Safety Requirements . . .	32
5.1.2.2 Safe-Life Demonstration Requirements	33
5.1.2.3 Qualification Test Requirements . .	34
5.1.2.4 Acceptance Test Requirements . . .	34
5.1.2.5 Re-Certification Test Requirements.	35
5.1.3 Pressure Vessels Designed Employing Strength of Materials (AVE)	35
5.1.3.1 Factor of Safety Requirements . . .	35
5.1.3.2 Safe-Life Analysis Requirements . .	35
5.1.3.3 Qualification Test Requirements . .	35
5.1.3.4 Acceptance Test Requirements . . .	35
5.1.3.5 Re-Certification Test Requirements.	35
5.1.4 Pressure Vessels Designed Employing the ASME Boiler Code (AVE & GSE). . .	35
5.1.4.1 Qualification Test Requirements . .	36
5.1.4.2 Acceptance Test Requirements . . .	36
5.1.4.3 Re-Certification Requirements (GSE)	36
5.2 Composite Pressure Vessels	36
5.2.1 Composite Pressure Vessels with Non- Hazardous Leak-Before-Burst Failure Mode (AVE).	37
5.2.1.1 Factor of Safety Requirements . . .	37
5.2.1.2 Safe-Life Analysis Requirements . .	37
5.2.1.3 Qualification Test Requirements . .	37
5.2.1.4 Acceptance Test Requirements . . .	37
5.2.1.5 Re-Certification Test Requirements.	37
5.2.2 Composite Pressure Vessels with Brittle Fracture or Hazardous Leak- -Before-Burst Failure Mode (AVE). . .	37

MIL-STD-1522A (USAF)
28 MAY 1984

CONTENTS (Cont)

		<u>PAGE</u>
5.2.2.1	Factor of Safety Requirements . . .	37
5.2.2.2	Safe-Life Requirements.	38
5.2.2.3	Qualification Test Requirements . .	38
5.2.2.4	Acceptance Test Requirements. . . .	38
5.2.2.5	Re-Certification Test Requirements.	38
5.2.3	Composite Pressure Vessels Designed Employing Strength of Materials (AVE)	38
5.2.4	Composite Pressure Vessels Designed Employing the ASME Boiler Code (AVE & GSE)	38
5.2.4.1	Qualification Test Requirements . .	38
5.2.4.2	Acceptance Test Requirements. . . .	38
5.3	Components.	38
5.3.1	Factor of Safety Requirements. . . .	38
5.3.2	Safe-Life Analysis Requirements. . .	39
5.3.3	Qualification Test Requirements. . .	39
5.3.4	Acceptance Test Requirements	39
5.3.5	Re-Certification Test Requirements . .	39
6.	PRESSURIZED SYSTEM REQUIREMENTS.	41
6.1	General Pressurized System Requirements .	41
6.1.1	Design Features.	41
6.1.1.1	Assembly.	41
6.1.1.2	Routing.	41
6.1.1.3	Separation.	41
6.1.1.4	Shielding.	41
6.1.1.5	Grounding.	41
6.1.1.6	Handling.	41
6.1.1.7	Special Tools	42
6.1.1.8	Test Points	42
6.1.1.9	Common-Plug Test Connectors	42
6.1.1.10	Individual Pressure and Return Test Connectors.	42
6.1.1.11	Threaded Parts.	42
6.1.1.12	Friction Locking Devices.	42
6.1.1.13	Internally Threaded Bosses.	42
6.1.1.14	Retainer or Snap Rings.	42
6.1.1.15	Snubbers.	42
6.1.2	Component Selection.	42
6.1.2.1	Connections	42
6.1.2.2	Fluid Temperature	43
6.1.2.3	Actuator Pressure Rating.	43
6.1.2.4	Pressure Service Ratings.	43
6.1.2.5	Pump Selection.	43
6.1.2.5	Fracture and Leakage.	43
6.1.2.7	Oxygen System Components.	43

CONTENTS (Cont)

	<u>PAGE</u>
6.1.2.8	43
6.1.2.9	43
6.1.2.10	43
6.1.3	44
6.1.3.1	44
6.1.3.2	44
6.1.3.3	44
6.1.3.4	44
6.1.3.5	44
6.1.4	44
6.1.4.1	44
6.1.4.2	44
6.1.4.3	44
6.1.5	45
6.1.5.1	45
6.1.5.2	45
6.1.5.3	45
6.1.6	45
6.1.7	45
6.1.7.1	45
6.1.7.2	45
6.1.7.3	45
6.1.7.4	45
6.1.7.5	46
6.1.8	46
6.1.8.1	46
6.1.8.2	46
6.1.8.3	46
6.1.8.4	46
6.1.8.5	46
6.1.8. 5.1	46
6.1.8. 5.2	46
6.1.8.6	47
6.1.8.7	47
6.1.8.8	47
6.1.8.8.1	47
6.1.8.8.2	47
6.1.8.9	47
6.1.8.10	47
6.1.9	47
6.1.9.1	48
6.1.9.1.1	48
6.1.9.1.2	48
6.1.9.1.2.1	48
6.1.9.1.2.2	48
6.1.9.2	49
6.1.9.2.1	49
6.1.9.2.2	49

MIL-STD-1522A (USAF)
28 MAY 1984

CONTENTS (Cont)

	<u>PAGE</u>
6.1.9.2.3	Filler Cap Bleed. 49
6.1.10	Control Devices. 49
6.1.10.1	Directional Control Values. 49
6.1.10.2	Overtravel. 49
6.1.10.3	Pressure and Volume Control Stops . 49
6.1.10.4	Manually Operated Levers. 50
6.1.10.5	Limit Torque. 50
6.1.11	Accumulators 50
6.1.11.1	Accumulator Design. 50
6.1.11.2	Accumulator Gas Pressure Gages. . . 50
6.1.11.3	Accumulator Identification. 50
6.1.12	Flex Hose. 50
6.1.12.1	Installation. 50
6.1.12.2	Restraining Devices 51
6.1.12.3	Flex Hose Stress. 51
6.1.12.4	Temporary Installations 51
6.2	Hydraulic System Requirements 52
6.2.1	Hydraulic System Components. 52
6.2.1.1	Component Integrity 52
6.2.1.1.1	Component Selection 52
6.2.1.2	Cycling. 52
6.2.1.3	Actuators 52
6.2.1.4	Shutoff Valves. 52
6.2.1.5	Variable Response 52
6.2.1.6	Fire Resistant Fluids 52
6.2.1.7	Accumulators. 52
6.2.1.8	Adjustable Orifices 52
6.2.1.9	Lock Valves 53
6.2.1.10	Hydraulic Reservoir 53
6.2.2	Pressure Limits. 53
6.2.3	Cavitation 53
6.2.3.1	Inlet Pressure. 53
6.2.3.2	Fluid Column. 53
6.2.4	Redundancy 53
6.2.5	Hydraulic Lockup 54
6.2.5.1	Emergency Disengage 54
6.2.5.2	Emergency By-Pass 54
6.2.6	Hydraulic System Pressure Relief . . . 54
6.2.6.1	Pump Pressure Relief. 54
6.2.6.2	Thermal Pressure Relief 54
6.2.6.3	Location. 54
6.3	Pneumatic Systems Requirements. 54
6.3.1	Pneumatic System Components. 54
6.3.1.1	Component Integrity 54
6.3.1.2	Configuration 55
6.3.1.3	Compressors 55
6.3.1.4	Actuators 55
6.3.1.5	Adjustable Orifice Restrictors. . . . 55
6.3.2	Controls. 55
6.3.2.1	Manual Takeover 55

FIGURES

			<u>PAGE</u>
Figure	1	Total Energy Contained in a Pressure Vessel	9
	2	Pressure Vessel Design Verification Approach	28

TABLES

			<u>PAGE</u>
Table	I	Stored Energy in a Pressure Vessel . .	10
	II	Qualification Test Requirements	32
	III	System Safety Factors	39
	IV	Open Line Force Calculation Factor . .	51
APPENDIX		57

MIL-STD-1522A (USAF)
28 MAY 1984

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MIL-STD-1522A (USAF)
28 MAY 1984

SECTION 1 SCOPE

1.1 PURPOSE - This standard establishes requirements for the design and test of all pressurized systems for missiles, space vehicles and ground support equipment. These requirements, when implemented on a particular pressurized system, will assure a high level of confidence in achieving safe operation and mission success.

1.2 APPLICATION - All the requirements listed herein are mandatory requirements when this standard is placed on contract. Specific approval of the procuring activity is required prior to the exclusion, modification or revision of any requirement listed in this standard when design specifications are generated for pressurized systems, subsystems and components. When the system is intended for use on a launch test range, specific approval for exclusion of any requirement must be obtained by the procuring activity and the appropriate launch or test range approval authority.

MIL-STD-1522A (USAF)
28 MAY 1984

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MIL-STD-1522A (USAF)
28 MAY 1984SECTION 2
REFERENCED DOCUMENTS

2.1 ISSUES OF DOCUMENTS - The following documents of the issue in effect on the date of invitation for bids or request for proposal, form a part of this standard to the extent specified herein.

SPECIFICATIONS
MILITARY

MIL-E-6051	Electromagnetic Compatibility Requirements Systems
MIL-S-8512	Support Equipment, Aeronautical, Special, General Specification for the Design of

STANDARDS
MILITARY

MIL-STD-1540	Test Requirements for Space Vehicles
MIL-STD-1472	Human Engineering Design Criteria for Military Systems, Equipment, and Facilities

HANDBOOKS
MILITARY

MIL-HDBK-5	Metallic Materials and Elements for Aerospace Vehicle Structures
MIL-HDBK-17	Plastic for Aerospace Vehicles Part 1 Reinforced Plastics

PUBLICATIONS
FEDERAL

Title 49 Code of Federal Regulation	Transportation DOT (Department of Trans- portation) CFR
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MIL-STD-1522A (USAF)

28 MAY 1984

OTHER

AFML-TR-68-115 Aerospace Structural Metals Handbook

MCIC-HB-01 Damage Tolerant Design Handbook, Air
Force Materials Laboratory, Air Force
Flight Dynamics Laboratory

(Copies of specifications, standards, drawings, and publications required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other Publications. The following documents form a part of this standard to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

PUBLICATIONS

Codes

ASME Boiler and Pressure Vessel Codes, Section VIII,
Division 1 and 2

ASME Boiler and Pressure Vessel Code: Section X.

(Applications for copies should be addressed to ASME
Order Department P.O. Box 3199, Grand Central
Station, New York New York, 10163.)

The Standards of the Hydraulic Institute

(Applications for copies should be addressed to
Hydraulic Institute, 712 Lakewood Center N, 14600
Detroit Ave., Cleveland, Ohio 44107.)

SECTION 3
DEFINITIONS

The following definitions of significant terms are provided to insure precision of meaning and consistency of usage. In the event of a conflict, the definitions listed herein apply.

- 3.1 "A" BASIS ALLOWABLE - The "A" basis allowable of a material are the minimum mechanical strength values guaranteed by the material producers/suppliers such that at least 99% of the material they produce/supply will meet or exceed the specified properties with a 95% confidence level.
- 3.2 ACCEPTANCE TESTS - Acceptance tests are the required formal tests conducted on hardware to ascertain that the materials, manufacturing processes, and workmanship meet specifications and that the hardware is acceptable for delivery.
- 3.3 APPLIED LOAD (STRESS) - The actual applied load (stress) on a structure is the load (stress) imposed on the structure in the design environment.
- 3.4 "B" BASIS ALLOWABLES - The "B" basis allowable of a material are mechanical strength values specified by material producers/suppliers such that at least 90% of the materials they produce/supply will meet or exceed the specified properties with a 95% confidence level.
- 3.5 BRITTLE FRACTURE - Brittle fracture is a type of catastrophic failure in structural materials that usually occurs without prior plastic deformation and at extremely high speed. The fracture is usually characterized by a flat fracture surface with little or no shear lips (slant fracture surface) and at average stress levels below those of general yielding.
- 3.6 BURST FACTOR - The burst factor is a multiplying factor applied to the maximum expected operating pressure (MEOP) to obtain the design burst pressure. Burst factor is synonymous with ultimate pressure factor.
- 3.7 COMPONENTS - Components for purposes of this standard, are all elements of a pressurized system.
- 3.8 COMPOSITE MATERIAL - Composites are combinations of materials differing in composition or form on a macroscale. The constituents retain their identities in the composite. Normally the constituents can be physically identified and there is an interface between them.

MIL-STD-1522A (USAF)
28 MAY 1984

3.9 CRITICAL CONDITION - The critical condition is the most severe environmental condition in terms of loads, pressures and temperatures, or combination thereof imposed on structure, systems, subsystems, and components during service life.

3.10 CRITICAL STRESS INTENSITY - The stress intensity at which unstable fracture occurs.

3.11 CRITICAL FLAW - The critical flaw in a structural material is a flaw of sufficient size and shape that unstable growth will occur under the specific operating load and environment.

3.12 DAMAGE TOLERANCE - The damage tolerance of a structure is its ability to resist failure due to the presence of flaws, cracks, or other damage for a specified period of unrepaired usage.

3.13 DESIGN BURST PRESSURE - The design burst pressure is a test pressure that pressurized components must withstand without rupture to demonstrate design adequacy in a qualification test. It is equal to the product of the maximum expected operating pressure, burst factor, and a factor to account for the difference in material-properties between test and design temperatures.

3.14 DESTABILIZING PRESSURE - Any pressure that produces compressive stresses in pressurized structure.

3.15 DETRIMENTAL DEFORMATION - Detrimental deformations include all structural deformations, deflections, or displacements that prevent any portion of the structure from performing its intended function, or that reduce the probability of successful completion of the mission.

3.16 DUCTILE FRACTURE - Ductile fracture is a type of failure in structural materials generally preceded by large amounts of plastic deformation and in which the fracture surface is inclined to the direction of the applied stress.

3.17 FACTOR OF SAFETY - The factor of safety of a structure is the ratio of the allowable load to the limit load.

3.18 FATIGUE - Fatigue is the progressive localized permanent structural change that occurs in a material subjected to repeated or fluctuating loads at stresses having a maximum value less than the ultimate tensile strength of the material. Fatigue may culminate in cracks or fracture after a sufficient number of fluctuations.

MIL-STD-1522A (USAF)
28 MAY 1984

3.19 FITTINGS - Fittings are local elements of a pressurized system utilized to connect lines, components and/or vessels within the system.

3.20 FLAW - A flaw is a local discontinuity in a structural material, such as a scratch, notch, crack or void.

3.21 FRACTURE CONTROL - Fracture control is a set of policies and procedures involving the application of analysis and design methodology, manufacturing technology and operating procedures to prevent structural failure due to the initiation of and/or propagation of flaws or crack-like defects during fabrication, testing, and service life.

3.22 FRACTURE MECHANICS - Fracture mechanics is an engineering concept used to predict flaw-growth and fracture behavior of materials and structures containing cracks or crack-like flaws.

3.23 FRACTURE TOUGHNESS (K_{IC}) - Fracture toughness is a material characteristic which reflects flaw tolerance and resistance to fracture and is equal to the value of the stress intensity factor at flaw instability. Fracture toughness is dependant on the environment, geometry and loading rate.

3.24 HAZARD - An existing or potential condition that can result in an accident.

3.25 HYDROGEN EMBRITTLEMENT - Hydrogen embrittlement is a mechanical- environmental failure process that results from the initial presence or absorption of excessive amounts of hydrogen in metals, usually in combination with residual or applied tensile stresses.

3.26 INITIAL FLAW - An initial flaw is a flaw in a structural material before the application of load or environment.

3.27 LEAK-BEFORE-BURST (LBB) - A fracture mechanics design concept in which it is shown that any initial flaw will grow through the wall of a pressure vessel and cause leakage rather than burst (catastrophic failure).

3.28 LIMIT LOAD - The limit load is the maximum anticipated load, or combination of loads, which a structure may be expected to experience during the performance of specified missions in specified environments. Since the actual loads that are experienced in service are in part random in nature, statistical methods for predicting limit loads are employed wherever appropriate.

MIL-STD-1522A (USAF)
28 MAY 1984

3.29 LINES - Lines are tubular elements of a Pressurized system provided as a means for transferring fluids between components of the system. Included in this definition are flex hoses.

3.30 LOAD SPECTRUM - The load spectrum on a structure is a representation of the cumulative static and dynamic loadings anticipated for the structure under all expected operating environments.

3.31 MARGIN OF SAFETY - The margin of safety of a structure is the increment by which the allowable load (or stress) exceeds the applied load (or stress), for a specific design condition, expressed as a fraction of the applied load (or stress).

$$\text{Margin of Safety} = \frac{\text{ALLOWABLE LOAD (OR STRESS)}}{\text{APPLIED LOAD (OR STRESS)}} = 1$$

3.32 MAXIMUM ALLOWABLE WORKING PRESSURE (MAWP) - The maximum pressure at which a component can continuously operate based on allowable stress values and functional capabilities. MAWP is synonymous with MDOP (Maximum Design Operating Pressure) or "Rated Pressure".

3.33 MAXIMUM OPERATING PRESSURE (MOP) (MEOP) - The maximum pressure at which the system or component actually operates in a particular application. MOP is synonymous with MEOP (Maximum Expected Operating Pressure) or maximum working pressure. MOP includes the effects of temperature, transient peaks, vehicle acceleration, and relief valve tolerance.

3.34 PRESSURE CYCLE - A pressure cycle is a pressure increase greater than the threshold pressure (P_{TH}) followed by a pressure decrease greater than the P_{TH} unless otherwise specified.

3.35 PRESSURE VESSEL A pressure vessel is a component of a pressurized system designed primarily as a container that stores pressurized fluids and:

- (1) Contains stored energy of 14,240 foot-pounds (19,310 joules) or greater based on adiabatic expansion of a perfect gas, Figure 1; Table I; or
- (2) Contains a gas or liquid which will create a mishap (accident) if released; or
- (3) Will experience a design limit pressure greater than 100 psi.

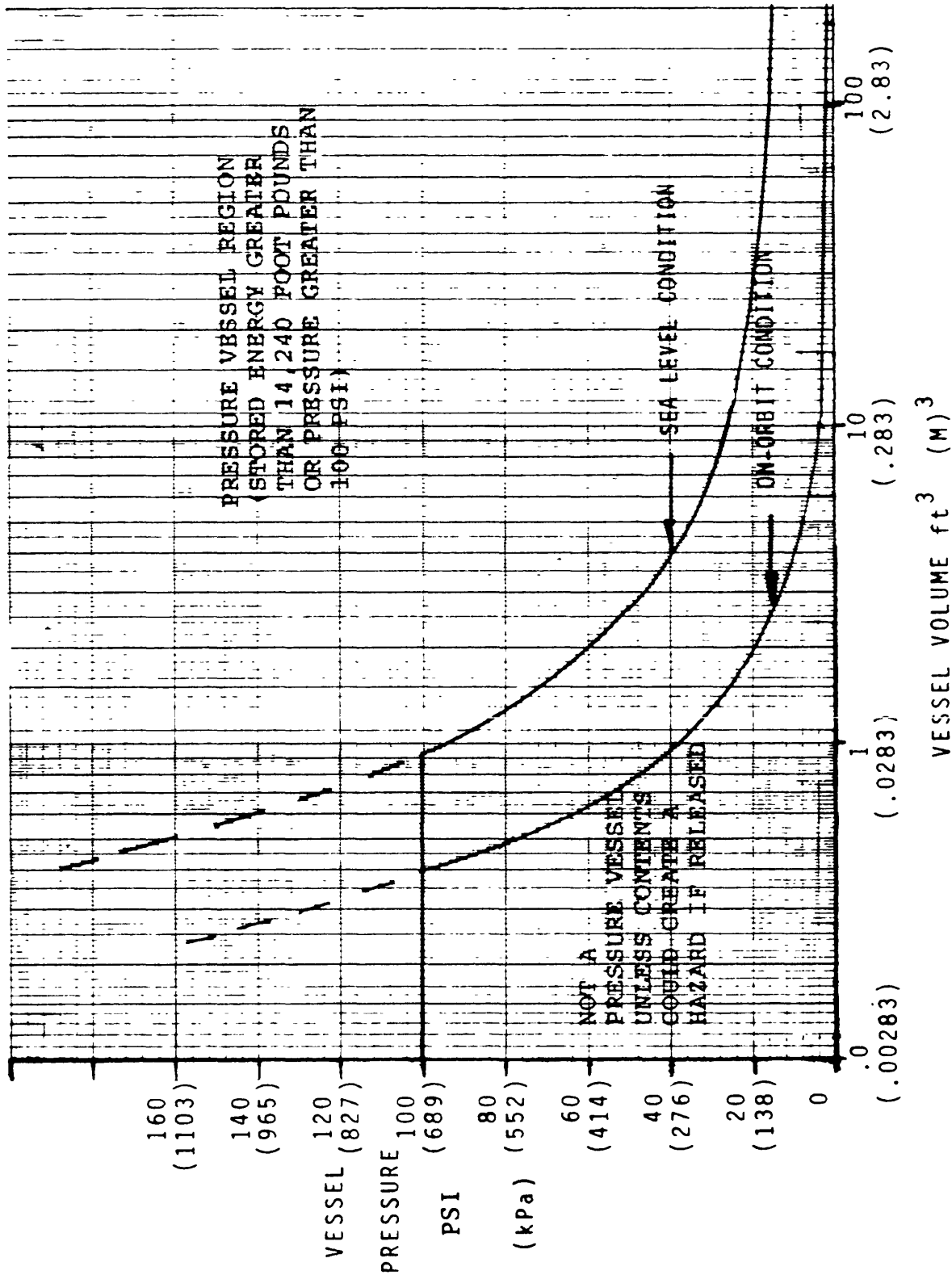


FIGURE 1. Total Energy Contained in a Pressure Vessel

MIL-STD-1522A (USAF)
28 MAY 1984

TABLE I. Stored Energy in Pressure Vessel

PRESSURE VESSEL PRESSURE	ENERGY EQUIVALENT PER CUBIC FOOT OF PRESSURE VESSEL
PSIA	ft lbs
20	606
30	1991
40	3582
50	5313
60	7148
70	9066
80	11051
90	13093
100	15184
200	37849
300	62376
400	87968
500	114286
600	141146
700	168433
800	196070
900	224001
1000	252185
2000	543111
3000	843691
4000	1149784
5000	1459636
6000	1772296
7000	2087167
8000	2403851
9000	2722059
10000	3041575
20000	6283809
30000	9576045

NOTE: To obtain the pressure vessel equivalent, multiply the energy equivalent per cubic foot by the vessel volume in cubic feet.

3.36 PRESSURIZED STRUCTURE - A pressurized structure is a structure designed both to carry internal pressure and vehicle structural loads.

3.37 PRESSURIZED SYSTEM - A pressurized system, as addressed in this document, comprises the pressure vessels or pressurized structure, lines, fittings, valves, etc., that are exposed to and designed by the pressure within these components. It does not include electrical control devices, etc., required to operate the system.

3.38 PROOF FACTOR - The proof factor is a multiplying factor applied to the limit load or MEOP to obtain proof load or proof pressure, for use in acceptance testing.

3.39 PROOF PRESSURE - The proof pressure is the test pressure that pressurized components shall sustain without detrimental deformation. The proof pressure is used to give evidence of satisfactory workmanship and material quality, and/or establish maximum initial flaw sizes. It is equal to the product of maximum expected operating pressure, proof pressure design factor, and a factor accounting for the difference in material properties between test and design temperature.

3.40 QUALIFICATION TESTS - Qualification tests are formal contractual demonstrations that the design, manufacturing, and assembly have resulted in hardware conforming to specification requirements.

3.41 RESIDUAL STRESS - Residual stress is a stress which remains in a detail part as a result of manufacturing processing, testing and operation.

3.42 SAFE-LIFE - Safe-life of a structure is the period during which the structure is predicted not to fail in the expected operating environment.

3.43 SERVICE LIFE - The service life of a component or space vehicle is the total life expectancy of the item. The service life starts with the manufacture of the structure and continues through all acceptance testing, handling, storage, transportation, launch operations, orbital operations, refurbishment, retesting, reentry or recovery from orbit, and reuse that may be required or specified for the item.

3.44 STABILIZING PRESSURE - Any pressure which produces tensile stresses in a pressurized structure is a stabilizing pressure.

MIL-STD-1522A (USAF)
28 MAY 1984

3.45 STIFFNESS - The stiffness of a structure is its resistance to deflection under an applied load.

3.46 STRESS-CORROSION CRACKING - Stress-corrosion cracking is a mechanical-environmental induced failure process in which sustained tensile stress and chemical attack combine to initiate and propagate a flaw in a metal part.

3.47 STRESS INTENSITY FACTOR (K_I) - The stress intensity factor is a parameter that describes the elastic stress field in the vicinity of a crack tip.

3.48 THRESHOLD PRESSURE (P_{TH}) - Threshold pressure is a pressure change great enough to induce a stress which affects the flaw growth in a pressure vessel.

3.49 THERMAL STRESS - Thermal stress is a structural stress arising from temperature gradients and/or differential thermal deformation in or between structural components, assemblies, or systems.

3.50 THRESHOLD STRESS INTENSITY FACTOR (K_{TH}) - The threshold stress intensity factor is the maximum value of the stress intensity factor below which environmentally induced flaw-growth, under sustained static tensile stress, does not occur for a given material in a specified environment.

3.51 ULTIMATE LOAD - The ultimate load is the product of the limit load and the ultimate factor of safety. It is the maximum load which the structure must withstand without rupture or collapse in the expected operating environments.

3.52 ULTIMATE FACTOR OF SAFETY - The ultimate factor of safety of structure is the ratio of the ultimate load to the limit load.

3.53 ULTIMATE PRESSURE - The ultimate pressure is the product of the MEOP and the ultimate pressure factor. It is the maximum pressure which the structures must withstand without rupture in the expected operating environment.

3.54 ULTIMATE PRESSURE FACTOR - The ultimate pressure factor is a multiplying factor applied to the MEOP to obtain ultimate pressure.

3.55 VERIFICATION/RE-CERTIFICATION TESTS - Verification/re-certification tests are tests conducted to verify/recertify the integrity of structures after some specific period of operation or storage or after exposure to some adverse conditions.

SECTION 4
GENERAL REQUIREMENTS

This section presents general requirements for the analysis, design and verification of pressure vessels and pressurized structures. Included are requirements on system analysis, structural design, material selection, safe operating stress levels, fracture control, quality assurance and other special requirements.

Pressure vessels and pressurized structures shall comply with the requirements specified in Section 4. Pressure vessels and pressurized structures designed fabricated, inspected, and tested in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII Divisions 1 or 2, Section X; or (for GSE only) Title 49 Code of Federal Regulation shall comply with system analysis requirements (Section 4.1) only.

4.1 SYSTEM ANALYSIS REQUIREMENTS

4.1.1 System Analysis. Perform a detailed system functional analysis to determine that the operation, interaction, or sequencing of components shall not lead to unsafe conditions which could cause personnel injury or major damage to the vehicle, its booster, or associated ground equipment. The analysis shall identify any single malfunction or personnel error in operation of any component that will create conditions leading to an unacceptable risk to operating personnel or equipment. The analysis shall also evaluate any secondary or subsequent occurrence, failure, or component malfunction which, initiated by a primary failure, could result in personnel injury. Such items identified by the analysis shall be designated safety critical and will require the following considerations.

- a. Specific Design Action
- b. Special Safety Operating Requirements
- c. Specific Hazard Identification and Proposed Corrective Action
- d. Special Safety Supervision

4.1.2 Systems analysis data. Systems analysis data will show that:

- a. The system provides the capability of maintaining all pressure levels in a safe condition in the event of interruption of any process or control sequence at any time during test or countdown.

MIL-STD-1522A (USAF)
28 MAY 1984

- b. Redundant pressure relief devices have mutually independent pressure escape routes.
- c. In systems where pressure regulator failure may involve critical hazard to the crew or mission success, regulation is redundant and where passive redundant systems are specified includes automatic switchover.
- d. When the hazardous effects of safety critical failures or malfunctions are prevented through the use of redundant components or systems, it shall be mandatory that all such redundant components or systems are operational prior to the initiation of irreversible portions of safety critical operations or events.

4.2 GENERAL DESIGN REQUIREMENTS

4.2.1 Loads, Pressures and Environments. The entire anticipated load-pressure-temperature history and associated environments throughout the service life shall be determined in accordance with specified mission requirements. As a minimum, the following factors and their statistical variations shall be considered :

- a. The environmentally induced loads and pressures.
- b. The environments acting simultaneously with these loads and pressures with their proper relationships.
- c* The frequency of application of these loads, pressures, environments and their levels and duration.

These data shall be used to define the design spectra which shall be used for both design analysis and testing. The design spectra shall be revised as the structural design develops and the loads analysis matures.

4.2.2 Strength Requirements. All pressure vessels and pressurized structures within the structural system shall possess sufficient strength to withstand limit loads and internal pressures in the expected operating environments throughout their respective service lives without experiencing detrimental deformation. They shall also withstand ultimate loads and internal pressures in the expected operating environments without experiencing rupture or collapse.

MIL-STD-1522A (USAF)
28 MAY 1984

Pressure vessels and pressurized structures shall be capable of withstanding ultimate external loads and ultimate external pressures (destabilizing) without collapse or rupture when internally pressurized to the minimum anticipated operating pressure.

All pressure vessels and pressurized structures shall sustain proof pressure without incurring gross yielding or detrimental deformation and shall sustain design burst pressure without rupture. When proof tests are conducted at temperatures other than design temperatures, the change in material properties at the proof temperature shall be accounted for in determining proof pressure.

Pressurized structures subject to instability modes of failure shall not collapse under ultimate loads nor degrade the functioning of any system due to elastic buckling deformation under limit loads. Evaluation of buckling strength shall consider the combined action of primary and secondary stresses and their effects on general instability, local or panel instability, and crippling. Design loads for buckling shall be ultimate loads, except that any load component that tends to alleviate buckling shall not be increased by the ultimate design factor. Destabilizing pressures shall be increased by the ultimate design factor, but internal stabilizing pressures shall not be increased unless they reduce structural capability.

The margin of safety shall be positive and shall be determined by analysis or test at design ultimate and design limit levels, when appropriate, at the temperatures expected for all critical conditions.

4.2.3 Stiffness Requirements. Pressure vessels and pressurized structures shall possess adequate stiffness to preclude detrimental deformation at limit loads and pressures in the expected operating environments throughout their respective service lives. The stiffness properties of pressure vessels and pressurized structures shall be such as to prevent all detrimental instabilities of coupled vibration modes, minimize detrimental effects of the loads and dynamics response which are associated with structural flexibility, and minimize adverse interaction with other vehicle systems.

4.2.4 Thermal Requirements. Thermal effects, including heating rates, temperatures, thermal stresses and deformations, and changes in the physical and mechanical properties of the materials of construction shall be considered in the design of all pressure vessels and pressurized structures. These effects shall be based on temperature extremes which simulate those predicted for the operating environment plus a design margin as specified in MIL-STD-1540.

MIL-STD-1522A (USAF)
28 MAY 1984

4.2.5 Stress Analysis Requirements. A detailed and comprehensive stress analysis of each pressure vessel and pressurized structure shall be conducted under the assumption of no crack-like flaws in the structure. The analysis shall determine stresses resulting from the combined effects of internal pressure, ground or flight loads, temperature and thermal gradients. Both primary membrane stresses and secondary bending stresses resulting from internal pressure shall be calculated to account for the effects of design discontinuities, design configuration and structural support attachments.

Loads shall be combined by using the appropriate limit or ultimate safety factors on the individual loads and comparing the results to material and/or geometric capabilities. Safety factors on internal pressures shall be as determined in Section 5.0. Safety factors on external (support) loads shall be as assigned to primary structure supporting the pressurized system.

Classical solutions are acceptable if the design geometries and loading conditions are sufficiently simple and the results are sufficiently accurate to warrant their application. Finite element or finite difference structural analysis techniques shall be used to calculate the stresses, strains and displacements for complex design geometries and loading conditions. Local structural models shall be constructed, as necessary, to augment the overall structural model in areas of rapidly varying stresses.

Minimum material gage as specified in the design drawings shall be used in calculating stresses. The allowable material strengths shall reflect the effects of temperature, thermal cycling and gradients, processing variables, and time associated with the design environments.

Minimum margins of safety associated with the parent materials, weldments and heat-affected zones shall be calculated and tabulated for all pressure vessels and pressurized structures along with their locations and stress levels. The margins of safety shall be positive against the strength and stiffness requirements of Section 4.2.2 and 4.2.3, respectively.

Records of the stress analysis shall be maintained. The analysis shall include the input parameters, data, assumptions, rationales, methods, references, and a summary of significant analysis results, and safe-life analysis. The analysis shall be revised and updated to maintain currency for the life of the program.

4.2.6 Malfunction. Pressure vessels and pressurized structures are not required to withstand loads, pressures, or environments due to malfunctions that could create conditions outside the maximum expected mission requirements.

4.2.7 Miscellaneous Requirements. The structural design of all pressure vessels and pressurized structures shall employ proven processes and procedures for manufacture and repair. The design shall emphasize the need for access, inspection, service, replacement, repair and refurbishment. For all reusable pressure vessels and reusable pressurized structures, the structural design shall permit these structures to be maintained in and refurbished to a flightworthy condition. Repaired and refurbished structures shall meet all stipulated conditions of flightworthiness.

4.3 MATERIALS REQUIREMENTS

4.3.1 Material Selection. Materials shall be selected on the basis of proven environmental compatibility, material strengths, fracture properties, and service life consistent with the overall program requirements. Material "A" allowable values shall be used for pressure vessels, and pressurized structures where failure of a single load path would result in loss of structural integrity. For redundant pressurized structures in which failure of a structural element would result in a safe redistribution of applied loads to other load-carrying members, material "B" allowable may be used. The fracture toughness shall be as high as practicable within the context of structural efficiency and damage tolerance.

For pressurized systems to be analyzed with linear elastic fracture mechanics, fracture properties shall be accounted for in material selection. These properties include fracture toughness; threshold values of stress intensity under sustained loading; subcritical flaw-growth characteristics under sustained and cyclic loadings; the effects of fabrication and joining processes; the effects of cleaning agents, dye penetrants, coatings and proof-test fluids; and the effects of temperature, load spectra, and other environmental conditions.

Materials which exhibit a low threshold stress intensity value, K_{TH} , in the expected operating environments shall not be used in pressure vessels and pressurized structures unless adequate protection from the operating environments can be demonstrated by tests. If the material has a threshold stress intensity factor, K_{TH} , of less than 60% of the critical stress intensity factor, K_{Ic} , under the conditions of its application, it shall be mandatory to show, by a "worst case" fracture mechanics analysis, that the low allowable threshold stress intensity factor will not precipitate premature structural failure.

MIL-STD-1522A (USAF)
28 MAY 1984

4.3.2 Material Evaluation. The materials selected for design shall be evaluated with respect to material processing, fabrication methods, manufacturing operations, refurbishment procedures and processes, and other pertinent factors which affect the resulting strength and fracture properties of the material in the fabricated as well as the refurbished configurations. (Reference Section 4.5)

The evaluation shall ascertain that the mechanical properties, strengths and fracture properties used in design and analyses will be realized in the actual hardware and that these properties are compatible with the fluid contents and the expected operating environments. Materials which are susceptible to stress-corrosion cracking or hydrogen embrittlement shall be evaluated by performing sustained threshold-stress-intensity tests when applicable data are not available.

4.3.3 Material Characterization. The allowable mechanical properties, strength and fracture properties of all materials selected for pressure vessels and pressurized structures shall be characterized in sufficient detail to permit reliable and high confidence predictions of their structural performance in the expected operating environments unless these properties are available from reliable sources such as MIL-HDBK-5, MIL-HDBK-17, ASTM Standards, AFML/AFFDL Damage Tolerant Design Handbook, MIL Specifications, Aerospace Structural Metals Handbook, and other sources approved by the procuring agency. Where material properties are not available, they shall be determined by test methods approved by the procuring agency. As a minimum, the characterization shall produce the following strength and fracture properties for the parent metals, weldments and heat-affected zones as a function of the fluid contents, loading spectra, and the expected operating environments, including proof-test environments:

- a. Uniaxial tensile yield stress, σ_{ys} , and ultimate stress, σ_u ;
- b. Fracture toughness K_{Ic} and K_{TH} ;
and, for pressurized systems to be analyzed with linear elastic fracture mechanics:
- c. Sustained-stress flaw-growth data, da/dt vs ΔK ;
- d. Cyclic-stress flaw-growth data, da/dn vs ΔK and load ratio, R ; and,
- e. Empirical constants associated with the chosen flaw-growth models.

MIL-STD-1522A (USAF)
28 MAY 1984

Uniform test procedures shall be employed for determining material fracture properties as required. These procedures shall conform to recognized standards, such as test specifications of the American Society for Testing and Materials, and the Society of Automotive Engineers. The test specimens and procedures utilized shall provide valid test data for the intended application.

Enough tests shall be conducted so that meaningful nominal values of fracture toughness and flaw-growth rate data corresponding to each alloy system, temper, product form, thermal and chemical environments and loading spectra can be established to evaluate compliance with service life requirements of Section 4.4. Test plans and results shall be approved by the procuring agency.

4.4 SAFE-LIFE REQUIREMENTS

The safe-life shall be determined by analysis, test, or both and shall be at least four times the specified service life for those pressure vessels and pressurized structures which are not accessible for periodic inspection and repair.

For those pressure vessels and pressurized structures which are readily accessible for periodic inspection and repair, the safe-life, as determined by analysis and test, shall be at least four times the interval between scheduled re-certification.

All pressure vessels and pressurized structures which require periodic refurbishment to meet safe-life requirements shall be re-certified after each refurbishment by the same techniques and procedures used in the initial certification, unless an alternative re-certification plan has been approved by the procuring agency.

4.5 FABRICATION AND PROCESS CONTROL REQUIREMENTS

Proven processes and procedures for fabrication and repair shall be used to preclude damage or material degradation during material processing, manufacturing operations, and refurbishment. In particular, special attention shall be given to ascertain that the melt process, thermal treatment, welding process, forming, joining, machining, drilling, grinding, repair and rewelding operations, etc., are within the state-of-the-art and have been used on similar hardware.

The fracture toughness, mechanical and physical properties of the parent materials, weldments and heat-affected zones shall be within established design limits after exposure to the intended fabrication processes. The machining, forming, joining,

MIL-STD-1522A (USAF)
28 MAY 1984

welding, dimensional stability during thermal treatments, and through-thickness hardening characteristics of the material shall be compatible with the fabrication processes to be encountered.

Fracture control requirements and precautions shall be defined in applicable drawings and process specifications. Detailed fabrication instructions and controls shall be provided to insure proper implementation of the fracture control requirements. Special precautions shall be exercised throughout the manufacturing operations to guard against processing damage or other structural degradation. In addition, procurement requirements and controls shall be implemented to insure that suppliers and subcontractors employ fracture control procedures and precautions consistent with the fabrication and inspection processes intended for use during actual hardware fabrication.

4.6 QUALITY ASSURANCE REQUIREMENTS

A quality assurance program, based on a comprehensive study of the product and engineering requirements, such as drawings, material specifications, process specifications, workmanship standards design review records, and failure mode analysis, shall be established to assure that the necessary non-destructive inspections and acceptance tests are effectively performed to verify that the product meets the requirements of this document. The program shall insure that materials, parts subassemblies, assemblies, and all completed and refurbished ~~ri~~ are conform to applicable drawings and process specifications; that no damage or degradation has occurred during material processing, fabrication, inspection, acceptance tests, shipping, storage, operational use and refurbishment; and that defects which could cause failure are detected or evaluated and corrected. As a minimum, the following consideration shall be included in structuring the quality assurance program.

4.6.1 Inspection Plan. An inspection master plan shall be established prior to start of fabrication. The plan shall specify appropriate inspection points and inspection techniques for use throughout the program, beginning with material procurement and continuing through fabrication, assembly, acceptance proof test, operation, and refurbishment, as appropriate. In establishing inspection points and inspection techniques, consideration shall be given to the material characteristics, fabrication processes, design concepts, structural configuration and accessibility for inspection. Designs employing fracture mechanics techniques shall also include inspection for flaws. The flaw geometries shall encompass defects commonly encountered, including surface crack, corner crack, through-the-thickness crack at the edge of

MIL-STD-1522A (USAF)
28 MAY 1984

fastener hole, surface crack at the edge of bolt hole, and surface crack at the root of intersecting prismatic structural elements. Acceptance and rejection standards shall be established for each phase of inspection, and for each type of inspection technique.

4.6.2 Inspection Techniques. The selected non-destructive inspection (NDI) techniques must have the capability to determine the size, geometry, location and orientation of a flaw or defect; to obtain, where multiple flaws exist, the location of each with respect to the other and the distance between them; and to differentiate among defect shapes, from tight cracks to spherical voids. Two or more NDI methods shall be used for a part or assembly that cannot be adequately examined by only one method.

The flaw detection capability of each selected NDI technique shall be based on past experience on similar hardware. Where this experience is not available or is not sufficiently extensive to provide reliable results, the capability, under production or operational inspection conditions, shall be determined experimentally and demonstrated by tests approved by the procuring agency on representative material product form, thickness, and design configuration. The flaw detection capability shall be expressed in terms of detectable crack length, crack depth, or crack area. To minimize the possibility of proof test failure in pressure vessels the selected NDI technique(s) should be capable of detecting flaws smaller than critical size with a 90% probability of detection at a 95% confidence level.

The most appropriate NDI technique(s) for detecting commonly encountered flaw types shall be used for all pressure vessels along with their flaw detection capabilities.

The following criteria shall apply in defining the characteristics of part-through initial flaws in the event the selected NDI technique measures either the flaw length or the flaw depth, but not both. The depth of initial flaw shall be assumed to be one-half ($1/2$) the flaw length if the NDI technique measures only the flaw-length; whereas, for an NDI technique which measures only flaw-depth, the length of flaw shall be assumed to be twenty (20) times the depth.

4.6.3 Inspection Data. Inspection data in the form of flaw histories shall be maintained throughout the life of the pressure vessel and pressurized structure. These data shall be periodically reviewed and assessed to evaluate trends and anomalies associated with the inspection procedures, equipment

MIL-STD-1522A (USAF)
28 MAY 1984

and personnel, material characteristics, fabrication processes, design concept and structural configuration. The result of this assessment shall form the basis of any required corrective action.

4.6.4 Acceptance Test. Every pressure vessel, and pressurized structure shall be proof-pressure tested in accordance with the requirements of Section 5.1, 5.2, and 5.3 as applicable to verify that the hardware has sufficient structural integrity to sustain the subsequent service loads, pressure, temperatures and environments. The temperature of the vessel shall be consistent with the critical use temperature, or, as an alternative, tests may be conducted at an alternate temperature if the test pressures are suitably adjusted to account for temperature effects on strength and fracture toughness.

Accept/reject criteria shall be formulated prior to acceptance test. Every pressure vessel and pressurized structure shall not leak, rupture or experience gross yielding during acceptance testing.

4.7 OPERATIONS AND MAINTENANCE REQUIREMENTS.

4.7.1 Operating Procedures. Operating procedures shall be established for each pressure vessel. These procedures shall be compatible with the safety requirements and personnel control requirements at the facility where the operations are conducted. Step-by-step directions shall be written with sufficient detail to allow a qualified technician or mechanic to accomplish the operations. Schematics which identify the location and pressure limits of relief valves and burst disc shall be provided, and procedures to insure compatibility of the pressurizing system with the structural capability of the pressurized hardware shall be established. Prior to initiating or performing a procedure involving hazardous operations with pressure systems, practice runs shall be conducted on non-pressurized systems until the operating procedures are well rehearsed. Initial tests shall then be conducted at pressure levels not to exceed 50% of the normal operating pressures until operating characteristics can be established and stabilized. Only qualified and trained personnel shall be assigned to work on or with high pressure systems. Warning signs with the hazard(s) identified shall be posted at the operations facility prior to pressurization.

4.7.2 Safe Operating Limits. Safe operating limits shall be established for each pressure vessel and each pressurized structure based on the appropriate analysis and testing employed in its design and qualification per Section 5.0.

MIL-STD-1522A (USAF)
28 MAY 1984

These safe operating limits shall be summarized in a format which will provide rapid visibility of the important structural characteristics and capability. The desired information shall include, but not be limited to, such data as fabrication materials, critical design conditions, MEOP, nominal operating or working pressure, proof pressure, burst pressure, pressurization and depressurization sequence, operational cycle limits, design and operating temperatures, operational system fluid, cleaning agent, NDI techniques employed, permissible thermal and chemical environments, minimum margin of safety and potential failure mode. For pressurized systems with potential brittle fracture failure mode, the critical flaw sizes and maximum permissible flaw sizes shall also be included. Appropriate references to design drawings, detail analyses, inspection records, test reports, and other back-up documentation shall be indicated.

4.7.3 Inspection and Maintenance. The results of the appropriate stress, and safe-life, analyses shall be used in conjunction with the appropriate results from the structural development and qualification tests to develop a quantitative approach to inspection and repair. Allowable damage limits shall be established for each pressure vessel and pressurized structure so that the required inspection interval and repair schedule can be established to maintain hardware to the requirements of this document. NDI technique(s) and inspection procedures to reliably detect critical structural defects and determine flaw size under the condition of use shall be specified. Detailed repair procedures shall be developed for use in field and depot levels. Procedures shall be established for recording, tracking, and analyzing operational data as it is accumulated to identify critical areas requiring corrective actions. Analyses shall include prediction of remaining life and reassessment of required inspection intervals.

4.7.4 Repair and Refurbishment. When inspections reveal structural damage or detects exceeding the permissible levels, the damaged hardware shall be repaired, refurbished, or replaced, as appropriate. All repaired or refurbished hardware shall be re-certified after each repair and refurbishment by the applicable acceptance test procedure for new hardware to verify their structural integrity and to establish their suitability for continued service.

4.7.5 Storage Requirements. When pressure vessels and pressurized structures are put into storage, they shall be protected against exposure to adverse environments which could cause corrosion or other forms of material degradation. In addition, they shall be protected against mechanical damages resulting from scratches, dents, or accidental dropping of the

MIL-STD-1522A (USAF)
28 MAY 1984

hardware. Induced stresses due to storage fixture constraints shall be minimized by suitable storage fixture design. In the event storage requirements are violated, re-certification shall be required prior to acceptance for use.

4.7.6 Documentation. Inspection, maintenance, and operation records shall be kept and maintained throughout the life of each pressure vessel and each pressurized structure. As a minimum, the records shall contain the following information:

- a. Temperature, pressurization history, and pressurizing fluid for both tests and operations.
- b. Number of pressurizations experienced as well as number allowed in safe-life analysis.
- c. Results of any inspection conducted, including: inspector, inspection dates, inspection techniques employed, location and character of defects, defect origin and cause.
- d. Storage condition.
- e. Maintenance and corrective actions performed from manufacturing to operational use, including refurbishment.
- f. Sketches and photographs to show areas of structural damage and extent of repairs.
- g. Acceptance and re-certification test performed, including test conditions and results.
- h. Analyses supporting the repair or modification which may influence future use capability.

4.8 SPECIAL REQUIREMENTS

4.8.1 Re-activated Pressurized Hardware. Pressure vessels and pressurized structures which are re-activated for use after an extensive period in either an unknown, unprotected, or unregulated storage environments shall be re-certified to ascertain their structural integrity and suitability for continued service before commitment to flight. Re-certification tests for pressurized hardware shall be in accordance with the appropriate Re-Certification Test Requirement (5.1.1.5, 5.1.2.5).

4.8.2 Multiple Proof Tests. Multiple proof tests are generally not required or recommended except in special circumstances, as described below:

- a. Re-activated pressurized hardware as described in Section 4.8.1.
- b. Refurbished or repaired hardware (Section 4.7.4).
- c. Hardware modification after the initial proof test.
- d. Re-certification of hardware for additional service after it has been in service for its intended safe-life.
- e. Re-certification of hardware designed for safe-life between regularly scheduled inspection.
- f. Component testing prior to final assembly.
- g. Proof test limitation resulting from inability of a single proof test to envelope the critical operational pressure, temperature, and external loading combinations.
- h. Proof test limitation resulting from inability of the initial proof test to verify the entire service life capability of the hardware.

4.8.3 Test Fluids. Proof-test fluids shall be compatible with the structural materials in the pressure vessels and pressurized structures. Proof test fluids shall not pose a hazard to test personnel. If such compatibility data is not available, required testing shall be conducted to demonstrate that the proposed test fluid does not have a deleterious effect on the article to be tested.

MIL-STD-1522A (USAF)
28 MAY 1984

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MIL-STD-1522A (USAF)
28 MAY 1984

SECTION 5 DETAILED REQUIREMENTS

Four approaches for the design, analysis and verification of pressure vessels are offered as illustrated in Figure 2. Selection of the approach to be used is dependent on the desired efficiency of design coupled with the level of analysis and verification testing required. Final selection shall be coordinated and/or defined by the procuring agency and the appropriate launch or test range approval authority.

Approach A, Figure 2, illustrates the steps required for verification of a pressure vessel designed with a burst factor equal to 1.5 or greater. This approach is not acceptable for the design and verification of ground support equipment. Based on the results of the failure mode determination, one of two distinct verification paths must be satisfied: 1) Leak-Before-Burst with leakage of the contents not creating a condition which could lead to a mishap (such as toxic gas venting or pressurization of a compartment not capable of the pressure increase), and 2) Brittle failure mode or Leak-Before-Burst in which, if allowed to leak, the leak causes a hazard. The verification requirements for path 1 are delineated in Sections 5.1.1 and 5.2.1, and the verification requirements for path 2 in Sections 5.1.2 and 5.2.2.

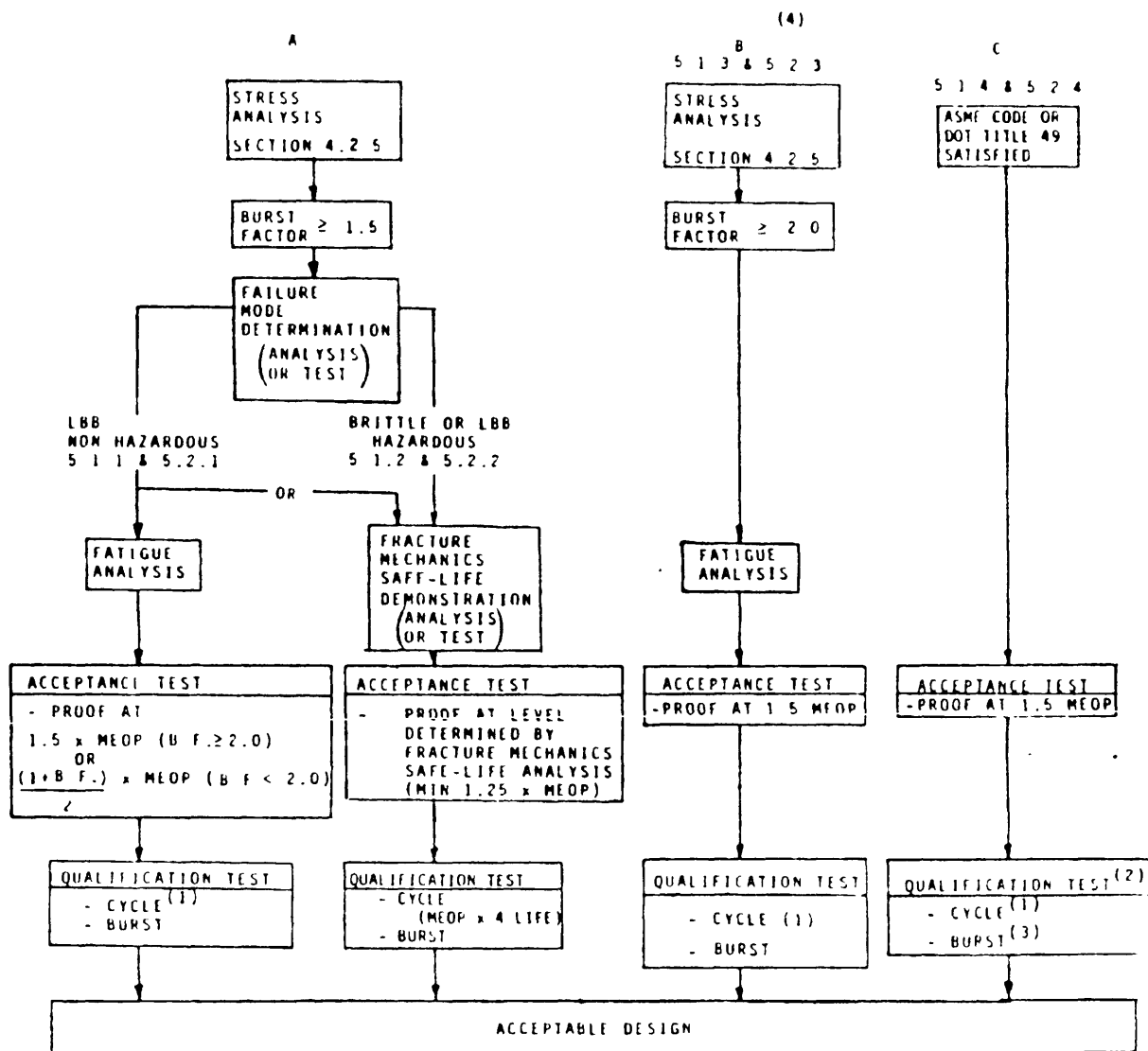
Approach B, Figure 2, illustrates the steps required for verification of a pressure vessel designed with a burst factor equal to 2.0 or greater. This approach is not acceptable for USAF/SD use, or design and verification of ground support equipment. Verification requirements for this approach are delineated in Sections 5.1.3 and 5.2.3.

Approach C, Figure 2, illustrates the steps required for verification of a pressure vessel designed employing the ASME Boiler and Pressure Vessel Code. This approach is the only acceptable approach for ground support equipment. Additional requirements for airborne vehicle equipment and ground support equipment are delineated in Sections 5.1.4 and 5.2.4.

5.1 NON-COMPOSITE PRESSURE VESSELS

This section is intended primarily for application to metallic pressure vessels but may be used for certain non-metallics with the approval of the procuring agency (for fiber reinforced composite pressure vessels, see Section 5.2).

MIL-STD-1522A (USAF)
28 MAY 1984



- NOTES
- (1) CYCLE TEST AT EITHER MEOP x 4 LIFE OR 1.5 MEOP x 2 LIFE
 - (2) GROUND SUPPORT EQUIPMENT REQUIRE FUNCTIONAL TEST ONLY
 - (3) BURST OR DISPOSITION VESSEL WITH APPROVAL OF THE PROCURING AGENCY
 - (4) APPROVAL IS NOT ACCEPTABLE FOR USAF/SD USE

FIGURE 2. Pressure Vessel Design Verification Approach

MIL-STD-1522A (USAF)
28 MAY 1984

5.1.1 Pressure Vessels with Non-Hazardous Leak-Before-Burst(LBB) Failure Mode (Aerospace Vehicle Equipment, AVE). The LBB failure mode shall be demonstrated analytically or by test showing that an initial flaw of any size, considering a flaw shape range of $.05 \leq a/2c \leq .5$, will propagate through the thickness of the pressure vessel before becoming critical. (See the Appendix for an acceptable analytical approach).

5.1.1.1 Factor of Safety Requirements. Pressure vessels which satisfy the LBB failure mode criterion may be designed conventionally, wherein the design factors of safety and test factors are selected on the basis of successful past experience or specified by codes and specifications. Unless otherwise specified, the minimum Design Burst Factor shall be 1.5.

5.1.1.2 Safe-Life Analysis Requirements. In addition to the stress analysis conducted in accordance with the requirements of-section 4.2.5, conventional fatigue-life analysis shall be performed, as appropriate, on the unflawed structure to ascertain that the pressure vessel, acted upon by the spectra of maximum expected operating loads, pressures and environments will meet the safe-life requirements of Section 4.4. Nominal values of fatigue-life characteristics of the structural materials shall be taken from reliable sources such as MIL-HDBK-5, ASTM Standards, MIL Specifications, the Aerospace Structural Metals Handbook, or other sources approved by the procuring agency. Safe-life requirements are met when Minor's rule, expressed as

$$\sum_{i=1}^k \frac{n_i}{N_i} \leq 0.8$$

is satisfied. In this equation, n_i = 4 times the number of cycles applied at stress level i , N_i = the number of cycles to failure at stress level i , and k = number of stress levels considered in the analysis. The LBB failure mode criteria accepts the possibility of propagation of an existing flaw, through the thickness of the vessel wall, allowing leakage of the contained gas or liquid. In the event that this leakage would present a hazard, fracture mechanics analysis shall be required. (See Section 5.1.2.2)

5.1.1.3 Qualification Test Requirements. Qualification tests shall be conducted on flight-quality hardware to demonstrate structural adequacy of the design. The test fixtures, support structures, and methods of environmental application shall not induce erroneous test conditions. The types of instrumentation and their locations in qualification

MIL-STD-1522A (USAF)
28 MAY 1984

tests shall be based on the results of the stress analysis of Section 4.2.5. The instrumentation shall provide sufficient data to ensure proper application of the accept/reject criteria, which shall be established prior to test. The sequences, combinations, levels, and duration of loads, pressure and environments shall demonstrate that design requirements have been met.

Qualification testing shall include demonstration of the leak-before-burst failure mode by pre-flawed specimen testing, fatigue life by cycle testing and random vibration testing and ultimate strength by burst testing. The following delineates the required tests:

a. Leak before burst testing

The test may be conducted on coupons which duplicate the materials (parent material, weldment, and HAZ) and thicknesses of the pressure vessel or on a pressure vessel representative of the flight hardware. Test specimens shall be pre-flawed and cycled through the design spectrum to demonstrate stable flaw growth completely through the wall thickness. A sufficient number of tests is to be conducted to establish that all areas (thicknesses) and stress fields will exhibit a leak-before-burst mode of failure.

This test may be partially or completely omitted if available materials data, directly applicable to the materials and methods of construction, are available to substantiate an analytical demonstration of the leak-before-burst failure mode.

b. Pressure Testing

Required qualification pressure testing levels are shown in Table II. Requirement for application of external loads in combination with internal pressures during testing must be evaluated based on the relative magnitude and/or destabilizing effect of stresses due to the external load. If limit combined tensile stresses are enveloped by test pressure stresses, the application of external loads shall not be required. If the application of external loads is required, the load shall be cycled to limit for four times the predicted number of operating cycles of the most severe design condition (eg. destabilizing load with constant minimum internal pressure or maximum

additive load with constant maximum expected operating pressure). Qualification test procedure shall be approved by the procuring agency and the appropriate launch or test range approval authority.

c. Random Vibration Testing

Random Vibration qualification testing shall be performed per requirements of MIL-STD-1540 unless it can be shown the vibration requirement is enveloped by other qualification testing performed.

5.1.1.4 Acceptance Test Requirements. Acceptance tests shall be conducted on every pressure vessel before commitment to flight. Accept/reject criteria shall be formulated prior to tests. The test fixtures and support structures shall be designed to permit application of all test loads without Jeopardizing the flightworthiness of the test article. The following are required as a minimum.

- a. Non-Destructive Inspection. A complete inspection by the selected non-destructive inspection (NDI) technique(s) shall be performed prior to proof pressure test to establish the initial condition of the hardware. All pressurized hardware which requires periodic refurbishment to meet safe-life requirements shall undergo a complete post-refurbishment inspection prior to additional proof pressure tests.
- b. Proof Pressure Test. Every pressure vessel shall be proof-pressure tested to verify that the materials, manufacturing processes, and workmanship meet design specifications and that the hardware is suitable for flight. The proof pressure shall be equal to:

$$P_{\text{proof}} = (1 + \text{Burst Factor})/2 \times \text{MEOP} \text{ or } 1.5 \times (\text{MEOP}) \text{ whichever is lower}$$

5.1.1.5 Re-Certification Test Requirements. All refurbished pressure vessels shall be re-certified after each refurbishment by the acceptance test requirements for new hardware to verify their structural integrity and to establish their suitability for continued service before commitment to flight. Pressure vessels which have exceeded the approved storage environment (temperature, humidity, time etc.) shall also be re-certified by the acceptance test requirements for new hardware.

MIL-STD-1522A (USAF)
28 MAY 1984

TABLE II. Qualification Test Requirements

Test Item	No yield after	No Burst at(1)
Vessel #1(2)	-	Burst Factor x MEOP
Vessel #2	Cycle at 1.5 x MEOP for 2 x predicted number of operating cycles. (50 cycles minimum) or Cycle at 1.0 x MEOP for 4 x predicted number of operating cycles. (50 cycles minimum)	Burst Factor x MEOP
(1) After demonstrating no burst at the defined test level, increase pressure to actual burst of vessel. Record actual burst pressure.		
(2) Test may be deleted at discretion of procuring agency.		

5.1.2 Pressure Vessels with Brittle Fracture or Hazardous Leak-Before-Burst (LBB) Failure Mode (AVE)

5.1.2.1 Factor of Safety Requirements. Safe-life design methodology based on fracture mechanics techniques shall be used to establish the appropriate design factor of safety and the associated proof factor for pressure vessels which exhibit brittle fracture or hazardous leak-before-burst failure mode. The loading spectra, material strengths, fracture toughness and flaw-growth rates of the parent material and weldments, test program requirements, stress levels, and the compatibility of the structural materials with the thermal and chemical environments expected in service shall be taken into consideration. Nominal values of fracture toughness and flaw-growth rate data corresponding to each alloy system, temper and product form shall be used along with a life factor of four on specified service life in establishing the design factor of safety and the associated proof factor. Unless otherwise specified the minimum burst factor shall be 1.5.

5.1.2.2 Safe-life Demonstration Requirements. In addition to the stress analysis conducted in accordance with the requirements of Section 4.2.5, safe-life analysis of each pressure vessel covering the maximum expected operating loads and environments, shall be performed under the assumption of pre-existing initial flaws or cracks in the vessel. In particular, the analysis shall show that the pressure vessel with flaws placed in the most unfavorable orientation with respect to the applied stress and material properties, of sizes defined by the acceptance proof test or NDI and acted upon by the spectra of maximum expected operating loads and environments, will meet the safe-life requirements of Section 4.4. Nominal values of fracture toughness and flaw-growth rate data associated with each alloy system, temper, product form, thermal and chemical environments, and loading spectra shall be used along with a life factor of four on specified service life in all safe-life analyses.

Pressure vessels which experience sustained stress shall also show that the corresponding applied stress intensity (K_I) during operation is less than the threshold stress intensity (K_{TH}) in the appropriate environment

$$K_{TH} > K_I$$

If the above cannot be shown: then analysis must show flaw growth to failure or .9t, whichever is less, will not occur during four times the time interval for which the pressure vessel is a hazard (eg. pressurized in the STS cargo bay).

The safe-life analysis shall be included in the stress analysis of Section 4.2.5. In particular, the fracture mechanics data, loading spectra and environments, flaw-growth model, initial flaw sizes, proof factors, strength and other input data, analysis assumptions, rationales, methods, references, summary of significant results, shall be clearly presented.

Testing of structure under fracture control in lieu of safe-life analysis is an acceptable alternative, provided that, in addition to following a quality assurance program (Section 4.6) for each flight article, a qualification test program is implemented on pre-flawed specimens representative of the structure design. These flaws shall not be less than the flaw sizes established by the acceptance proof test or the selected NDI method(s). Safe-life requirements of Section 4.4 are considered demonstrated when the pre-flawed test specimens successfully sustain the limit loads and pressures in the expected operating environments for the specified test duration without rupture.

MIL-STD-1522A (USAF)
28 MAY 1984

5.1.2.3 Qualification Test Requirements. Qualification tests shall be conducted on flight-quality hardware to demonstrate structural adequacy of the design. The test fixtures, support structures, and methods of environmental application shall not include erroneous test conditions. The types of instrumentation and their locations in qualification tests shall be based on the results of the stress analysis of Section 4.2.5. The instrumentation shall provide sufficient data to ensure proper application of the accept/reject criteria, which shall be established prior to test. The sequences, combinations, levels, and duration of loads, pressure and environments shall demonstrate that design requirements have been met.

Qualification testing shall include life cycle testing, random vibration testing, and burst testing. The following delineates the required tests:

a. Pressure Testing

Required qualification pressure testing levels are shown in Table II. Requirement for application of external loads in combination with internal pressures during testing must be evaluated based on the relative magnitude and/or destabilizing effect of stresses due to the external load. If limit combined tensile stresses are enveloped by test pressure stresses, the application of external loads shall not be required. If the application of external loads is required, the load shall be cycled to limit for four times the predicted number of operating cycles of the most severe design condition (e.g., destabilizing load with constant minimum internal pressure, or maximum additive load with constant maximum expected operating pressure). Qualification test procedure shall be approved by the procuring agency and the appropriate launch or test range approval authority.

b. Random Vibration

Random vibration qualification testing shall be performed per requirements of MIL-STD-1540 unless it can be shown the vibration requirement is enveloped by other qualification testing performed.

5.1.2.4 Acceptance Test Requirements. The acceptance test requirements for pressure vessels which exhibit brittle fracture, or hazardous LBB, failure mode are identical to those with ductile fracture failure mode as defined in Section 5.1.1.4 except that the test level shall be that defined by the fracture

MIL-STD-1522A (USAF)
28 MAY 1984

mechanics analysis. Cryo-proof acceptance test procedures may be required to adequately verify initial flaw size. The pressure vessel shall not rupture or leak at the acceptance test pressure.

5.1.2.5 Re-certification Test Requirements. All refurbished pressure vessels shall be re-certified after each refurbishment by the acceptance test requirements for new hardware to verify their structural integrity and to establish their suitability for continued service before commitment to flight. Pressure vessels which have exceeded the approved storage environment (temperature, humidity, time etc.) shall also be re-certified by the acceptance test requirements for new hardware.

5.1.3 Pressure Vessels Designed Employing Strength of Materials (AVE). Pressure vessels may be designed and verified utilizing the following criteria which does not employ fracture mechanics techniques. Pressure vessel failure mode demonstration is not required. The DoD user of this approach should be aware that this approach is not acceptable for USAF/SD use. The pressure vessel is to be designed, analyzed and verified as defined in Section 5.1.1 with the following exceptions or changes to criteria.

5.1.3.1 Factor of Safety Requirements - The pressure vessel is to be designed to a minimum Proof Pressure = $1.5 \times \text{MEOP}$ and a minimum Design Burst Pressure = $2.0 \times \text{MEOP}$.

5.1.3.2 Safe-Life Analysis Requirements - Requirements per Section 5.1.1.2.

5.1.3.3 Qualification Test Requirements - Requirements per Section 5.1.1.3 except that Leak Before Burst testing is deleted.

5.1.3.4 Acceptance Test Requirements - Requirements per Section 5.1.1.4 except that proof test shall be conducted at $1.5 \times \text{MEOP}$.

5.1.3.5, Re-Certification Test Requirements- Requirements per Section 5.1.1.5.

5.1.4 Pressure Vessels Designed Employing the ASME Boiler Code (AVE & GSE). Pressure vessels may be designed and manufactured per the rules of the ASME Boiler and Pressure Vessel Code, Section VIII, Divisions 1 or 2.

MIL-STD-1522A (USAF)
28 MAY 1984

5.1.4.1 Qualification Test Requirements - (For airborne systems required to satisfy Space Transportation System Safety Requirements). Qualification testing shall consist of the cycle testing defined in Section 5.1.1.3b.

5.1.4.2 Acceptance Test Requirements - As specified in Code. AVE pressure vessels shall be proof pressure tested at 105 x MEOP. This test may be accomplished when satisfying code requirements.

5.1.4.3 Re-Certification Requirements (GSE) - When no data is available concerning existing ground system pressure vessel or history of use, or if the origin of data is uncertain, perform a detailed investigation to determine the utility of the vessel. This investigation shall, as a minimum, include the following:

- (a) Paint removal and thorough internal and external surface cleaning including removal of corrosion.
- (b) Thorough internal and external surface inspection to determine extent of corrosion or any handling damage or cracks.
- (c) Accurate measurement of minimum vessel wall thickness.
- (d) Identification of construction materials.
- (e) Determination of operating stress levels using proposed system maximum expected operating pressure.
- (f) Analysis to determine the operating safety factor based on corrosion or other existing damage.
- (g) Hydrostatic test to 150% of proposed maximum expected operating pressure.
- (h) The using activity shall maintain reports of the above investigation as a part of the system records.

5.2 COMPOSITE PRESSURE VESSELS

Pressure vessels fabricated of composite materials must satisfy the non-composite requirements of Section 5.1 with the following exceptions applicable to each design verification analysis approach.

MIL-STD-1522A (USAF)
28 MAY 1984

Composite vessels with metallic liners may be designed employing either of the two approaches. Composite vessels without a load carrying metallic liner may only be designed by the ASME code, (section 5.2.3 of this standard). The leak-before-burst or brittle failure mode designation for a metal lined composite vessel shall be based on the characteristics of the liner. Fracture mechanics methodology is not applicable to the composite overwrap.

5.2.1 Composite Pressure Vessels with Non-Hazardous Leak-Before-Burst (LBB) Failure Mode (AVE). Applicable fracture mechanics analysis and/or tests of metal lined composite pressure vessels shall verify the leak-before-burst failure mode of the metal liner.

5.2.1.1 Factors of Safety Requirements. Requirements per Section 5.1.1.1.

5.2.1.2 Safe-Life Analysis Requirements. Requirements per Section 5.1.1.2.

5.2.1.3 Qualification Test Requirements. Qualification testing shall consist of the leak-before-burst demonstration of the liner and cycle/burst testing of the composite vessel as defined in Section 5.1.1.3. In particular the effects of the liner sizing operation on the fracture mechanics characteristics of the liner should be accounted for in the LBB evaluation.

5.2.1.4 Acceptance Test Requirements. Acceptance tests shall be conducted as defined in Section 5.1.1.4. The substitution of the metal liner sizing operation for acceptance test is acceptable provided the requirements of Section 5.1.1.4 are satisfied.

5.2.1.5 Re-Certification Test Requirements. Requirements per Section 5.1.1.5. (NOTE) Alternate re-certification procedure may be approved by the procuring and safety agencies.

5.2.2 Composite Pressure Vessels with Brittle Fracture or Hazardous LBB Failure Mode (AVE). This section is applicable only to composite pressure vessels with metal liners which exhibit brittle fracture or hazardous leak-before-burst failure mode.

5.2.2.1 Factor of Safety Requirements. Unless otherwise specified, the minimum burst factor shall be 1.5.

MIL-STD-1522A (USAF)
28 MAY 1984

5.2.2.2 Safe - Life Demonstration Requirements.

Requirements of Section 5.1.2.2 shall apply to the metal liner. Conventional fatigue life analysis of the composite overwrap must verify the liner is the critical safe-life component. Analysis shall show the safe-life of the overwrap to be a factor of 10 longer than the safe-life of the liner.

5.2.2.3 Qualification Test Requirements. Requirements per Section 5.1.2.3.

5.2.2.4 Acceptance Test Requirements. Acceptance test requirements shall be as defined in Section 5.1.2.4. The substitution of metal liner sizing operation for an acceptance test is acceptable provided the requirements of Section 5.1.2.4 are satisfied. The metal liner shall not leak at the proof test pressure. An additional Cryo type proof test of the liner, prior to composite overwrap, may be required to adequately verify the largest allowable initial flaw size present in the liner.

5.2.2.5 Re-certification Test Requirements. The re-certification test requirements for all refurbished composite pressure vessels are as defined in Section 5.1.1.5.

5.2.3 Composite Pressure Vessels Designed Employing Strength of Materials (AVE). Composite pressure vessels, both load bearing metal lined and all composite, may be designed and verified utilizing the criteria of Section 5.1.3 which does not employ fracture mechanics techniques.

5.2.4 Composite Pressure Vessels Designed Employing the ASME Boiler Code (AVE & GSE). Composite pressure vessels may be designed and manufactured per the rules of the ASME Boiler and Pressure Code, Section X.

5.2.4.1 Qualification Test Requirements. (For airborne systems required to satisfy Space Transportation System Requirements). Qualification testing shall consist of the cycle testing defined in Section 5.1. 1.3b and random vibration testing defined in Section 5.1.1.3c,

5.2.4.2 Acceptance Test Requirements. As specified in Code. AVE pressure vessels shall be proof pressure tested at $1.5 \times \text{MEOP}$. This test may be accomplished when satisfying code requirements.

5.3 COMPONENTS

5.3.1 Factors of Safety Requirements - Components excluding pressure vessels are to be designed to the minimum factors given in Table III.

MIL-STD-1522A (USAF)
28 MAY 1984

TABLE III. Systems Safety Factors

	PROOF	DESIGN BURST	
		Ave	GSE
Lines and fittings dia < 1.5 in.	1.5	4.0	4.0
dia ≥ 1.5 in.	1.5	2.5	4.0
Fluid Return Sections	1.5	3.0	4.0
Fluid Return Hose	1.5	5.0	4.0
Other Components (Except Pressure Vessels)	1.5	2.5	4.0
Components subject to low or negative pressures shall be evaluated for a minimum external pressure of 50 psig.			

5.3.2 Safe-Life Analysis Requirements. Not required.

5.3.3 Qualification Test Requirements. Not required on lines and fittings. Internal/external pressure testing shall be conducted on all other components to demonstrate no failure at the design burst pressure.

5.3.4 Acceptance Test Requirements. Acceptance test requirements shall be satisfied by completion of leak and/or proof test requirements for the assembled pressurized system as dictated by the applicable range safety documentation, and or procuring agency, requirements.

5.3.5 Re-Certification Test Requirements. Re-certification of lines, fittings and components shall be as delineated in Section 5.3.5 as applied to the refurbished systems.

MIL-STD-1522A (USAF)
28 MAY 1984

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MIL-STD-1522A (USAF)
28 MAY 1984

SECTION 6 PRESSURIZED SYSTEM REQUIREMENTS

Requirements which apply to all types of pressurized systems are in section 6.1. Additional detail requirements applicable to specific system types are in the sections following.

6.1 GENERAL PRESSURIZED SYSTEM REQUIREMENTS

6.1.1 Design Features

6.1.1.1 Assembly. Design components so that, during the assembly of parts, sufficient clearance exists to permit assembly of the components without damage to O-rings or backup rings where they pass threaded parts or sharp corners.

6.1.1.2 Routing. Avoid straight tubing and piping runs between two rigid connection points. Where such straight runs are necessary, provisions shall be made for expansion joints, motion of the units, or similar compensation to insure that no excessive strains will be applied to the tubing and fittings. Use line bends to ease stresses induced in tubing by alignment tolerances and vibration.

6.1.1.3 Separation. Physically separate redundant pressure components and systems from main systems for maximum safety advantage in case of damage or fire.

6.1.1.4 Shielding. Shield pressure systems from other systems when required to minimize all hazards caused by proximity to combustible gases, heat sources, electrical equipment, etc. Any failure in any such adjacent system shall not result in combustion or explosion of pressure fluids or components. Shield or separate lines, drains, and vents from other high-energy systems; for example, heat, high voltage, combustible gases, and chemicals. Drain and vent lines will not be connected to any other lines in any way that could generate a hazardous mixture in the drain/vent line, or allow feedback of hazardous substances to the components being drained or vented. Shield or isolate pressure fluid reservoirs from combustion apparatus or other heat sources.

6.1.1.5 Grounding. Electrically ground hydraulic system components and lines to metallic structures.

6.1.1.6 Handling. Provide fixtures for safe handling and hoisting with coordinated attachment points in the system structure, for equipment that cannot be hand-carried. Handling and hoisting loads shall be in accordance with MIL-S-8512.

MIL-STD-1522A (USAF)
28 MAY 1984

6.1.1.7 Special Tools. Design safety critical pressure systems so that special tools shall not be required for removal and replacement of components unless it can be shown that the use of special tools is unavoidable.

6.1.1.8 Test Points. Provide test points if required, such that disassembly for test is not required. The test points shall be easily accessible for attachment of ground test equipment.

6.1.1.9 Common-Plug Test Connectors. Common-plug test connectors for pressure and return sections shall be designed to require positive removal of the pressure connection prior to unsealing the return connections.

6.1.1.10 Individual Pressure and Return Test Connectors. Individual pressure and return test connectors shall be designed to positively prevent inadvertent cross-connections.

6.1.1.11 Threaded Parts. All threaded parts in safety critical components shall be securely locked to resist uncoupling forces by acceptable safe design methods. Safety wiring and self-locking nuts are examples of acceptable safe design. Torque for threaded parts in safety critical components shall be specified.

6.1.1.12 Friction Locking Devices. Avoid friction-type locking devices in safety critical applications. Star washers and jam nuts shall not be used as locking devices.

6.1.1.13 Internally Threaded Bosses. The design of internally threaded bosses shall preclude the possibility of damage to the component or the boss threads because of screwing universal fittings to excessive depths in the bosses.

6.1.1.14 Retainer or Snap Rings. Retainer or snap rings shall not be used in pressure systems where failure of the ring would allow connection failures or blow-outs caused by internal pressure.

6.1.1.15 Snubbers. Snubbers shall be used with all Bourdon type pressure transmitters, pressure switches, and pressure gages, except air pressure gages.

6.1.2 Component Selection

6.1.2.1 Connections. Design or select components to assure that hazardous disconnections or reverse installations within the subsystem are not possible. Color codes, labels, and directional arrows, are not acceptable as the primary means for preventing incorrect installation.

MIL-STD-1522A (USAF)
28 MAY 1984

6.1.2.2 Fluid Temperature. Estimate the maximum fluid temperature early in design as part of data for selection of safety critical components, such as system fluid, pressurizing gas, oil coolers, gaskets, etc.

6.1.2.3 Actuator Pressure Rating. Specify components that are capable of safe actuation under pressure equal to the maximum relief valve setting in the circuit in which they are installed.

6.1.2.4 Pressure Service Ratings. Pumps, valves/regulators, hoses, and all such prefabricated components of a pressure system shall have proven pressure service ratings equal to or higher than the limit-load (maximum expected operating pressure) and rated service life of the system.

6.1.2.5 Pump Selection. Apply "The Standards of the Hydraulic Institute" in evaluating safety in pump selection.

6.1.2.6 Fracture and Leakage. Where leakage or fracture is hazardous to personnel or critical equipment, design so that failure occurs at the outlet threads of valves before the inlet threads or body of the valve fails under pressure.

6.1.2.7 Oxygen System Components. Specify valves and other components for oxygen systems of 3000 psi or higher that are slow opening and closing types to minimize the potential for ignition of contaminants. Such systems shall also require electrical grounding to eliminate the possibility of the build-up of static electrical charges.

6.1.2.8 Pressure Regulators. Select pressure regulators to operate in the center 50 percent of their total pressure range, or design to avoid creep and inaccuracies at either end of the full operating range.

6.1.2.9 Flareless Tube Fittings. In all cases flareless tube fittings shall be properly preset prior to pressure application.

6.1.2.10 Manual Valves and Regulators. Design manually operated valves and regulators so that over torquing of the valve stem or regulator adjustment cannot damage soft seats to the extent that failure of the seat will result.

6.1.2.10.1 Valve designs which utilize uncontained seats are unacceptable and shall not be specified.

MIL-STD-1522A (USAF)
28 MAY 1984

6.1.3 Design Pressures

6.1.3.1 Over Pressure. Specify warning devices to indicate hazardous over or under pressures to operating personnel. These devices shall actuate at predetermined pressure levels designed to allow time for corrective action.

6.1.3.2 Back Pressure. Safety critical actuations of pneumatic systems shall not be adversely affected by any back pressure resulting from concurrent operations of any other parts of the system under any set of conditions.

6.1.3.3 Pressure Isolation. Components or lines that can be isolated and contain residual pressure shall be equipped with gage reading and bleed valves for pressure safety check. Bleed valves shall be directed away from operating personnel. Fittings or caps for bleeding pressure are not acceptable.

6.1.3.4 Gas/Fluid Separation. Specify pressurized reservoirs that are designed for gas/fluid separation with provision to entrap gas that may be hazardous to the system or safety critical actuation, and prevent its recirculation in the system. This shall include the posting of instructions adjacent to the filling point for proper bleeding when servicing.

6.1.3.5 Compressed Gas Bleeding. Bleed compressed gas emergency systems directly to the atmosphere away from the vicinity of personnel, rather than to reservoir. If the gas is combustible, consideration should be given to methods for reducing the potential for accidental ignition or explosion.

6.1.4 Design Loads

6.1.4.1 Acceleration and Shock Loads. Specify installation of all lines and components to withstand all expected acceleration and shock loads. Shock isolation mounts may be used if necessary to eliminate destructive vibration and interference collisions.

6.1.4.2 Torque Loads. Specify the mounting of components, including valves, on structures having sufficient strength to withstand torque and dynamic loads, and not supported by the tubing. However, light-weight components that do not require adjustment after installation (for example, check valves), may be supported by the tubing, provided that a tube clamp is installed on each such tube near the component.

6.1.4.3 Vibration Loads. Support tubing by cushioned steel tube clamps or by multiple-block type clamps that are suitably spaced to restrain destructive vibration.

MIL-STD-1522A (USAF)
28 MAY 1984

6.1.5 Controls

6.1.5.1 Interlocks. Specify interlocks where necessary to prevent a hazardous sequence of operations and provide a fail-safe capability at all times. For example, the "open" position of remotely controlled valves that can hazardously pressurize lines leading to remotely controlled (or automatic) disconnect couplings shall be interlocked to preclude the "open" valve position coincident with the disconnected condition of the couplings.

6.1.5.2 Multiple Safety Critical Functions. Pressure systems that combine several safety critical functions shall have sufficient controls for isolating failed functions, for the purpose of safely operating the remaining functions.

6.1.5.3 Critical Flows and Pressures. All pressure systems shall have pressure indicating devices to monitor critical flows and pressures marked to show safe upper and lower limits of system pressure. The pressure indicators shall be so located as to be readily visible to the operating crew.

6.1.6 Protection. Protect all systems for pressure above 500 psi in all areas where damage can occur during servicing or other operational hazards. Hazardous piping line routes that invite use as handholds or climbing bars, shall be avoided. Shield pressure lines and components of 500 psi or higher that are adjacent to safety critical equipment to protect such equipment in the event of leakage or burst of the pressure system.

6.1.7 Electrical.

6.1.7.1 Hazardous Atmospheres. Electric components for use in potentially ignitable atmospheres shall be demonstrated to be incapable of causing an explosion in the intended application.

6.1.7.2 Radio Frequency Energy. Electrically energized hydraulic components shall not propagate radio-frequency energy that is hazardous to other subsystems in the total system, or interfere in the operation of safety critical electronic equipment (Reference MIL-E-6051).

6.1.7.3 Grounding. Electrically ground pressure system components and lines to metallic structures.

6.1.7.4 Solenoids. All solenoids shall be capable of safely withstanding a test voltage of not less than 1500 V rms at 60 cps for 1 minute between terminals and case at the maximum operating temperature of the solenoid in the functional envelope.

MIL-STD-1522A (USAF)
29 MAY 1984

6.1.7.5 Electric Motor Driven Pumps. Electric motor driven pumps used in safety critical systems shall not be used for ground test purposes unless the motor is rated for reliable continuous and safe operation. Otherwise, the test parameters may perturb reliability calculations.

6.1.8 Pressure Relief

6.1.8.1 Requirement. Specify pressure relief devices on all systems having a pressure source which can exceed the maximum allowable pressure of the system, or where the malfunction/failure of any component can cause the maximum allowable pressure to be exceeded. Relief devices are required downstream of all regulating valves and orifice restrictors unless the downstream system is designed to accept full source pressure. On space systems, where operational or weight limitations preclude the use of relief valves, and systems will operate in an environment not hazardous to personnel, they can be omitted if the ground or support system contains such devices and they cannot be isolated from the airborne system during the pressurization cycle and the space vehicle cannot provide its own protection.

6.1.8.2 Flow Capacity. Specify that all pressure relief devices shall provide relief at full flow capacity at 110% of the MEOP of the system, or lower.

6.1.8.3 Sizing. Specify the size of pressure relief devices to withstand maximum pressure and flow capacities of the pressure source, to prevent pressure from exceeding 110% of the MEOP of the system.

6.1.8.4 Unmanned Flight Vehicle Servicing. Where a ground system is specifically designed to service an unmanned flight vehicle, pressure relief protection may be provided within the ground equipment, if no capability exists to isolate the pressure relief protection from the flight vehicle during the pressurization cycle.

6.1.8.5 Automatic Relief.

6.1.8.5.1 Low Safety Factor. Where safety factors less than 2.0 are used in the design of pressure AVE vessels, provide a means for the automatic relief, depressurization, and pressure verification of safety critical vessels for the event of launch abort.

6.1.8.5.2 Confinement. Whenever any pressure volume can be confined and/or isolated by system valving, provide an automatic pressure relief device. Pop-valves, rupture discs,

MIL-STD-1522A (USAF)
28 MAY 1984

blow-out plugs, armoring, and construction to contain the greatest possible overpressure that may develop are examples of corrective measures for system safety in cases not covered by the above paragraphs.

6.1.8.6 Venting. Vent pressure relief devices for toxic or inert gases to safe areas or scrubbers, away from the vicinity of personnel.

6.1.8.7 Relief Valve Isolation. Shut-off valves for maintenance purposes on the inlet side of pressurized relief valves are permissible if a means for monitoring and bleeding trapped pressure is provided and the requirements of ASME Code for unfired pressure vessels, Appendix M, paragraph UA-354, and the provisions for valve design in paragraph 6.1.2 are met. It is mandatory that the valve be locked open when the system is repressurized.

6.1.8.8 Negative Pressure Protection.

6.1.8.8.1 Testing. Hydrostatic testing systems for vessels which are not designed to sustain negative internal pressure shall be equipped with fail-safe devices for relief of hazardous negative pressure during the period of fluid removal. Check valves and valve interlocks are examples of devices which can be used for this purpose.

6.1.8.8.2 Storage and Transportation. Thin walled vessels which can be collapsed by a negative pressure shall have negative pressure relief and/or prevention devices for safety during storage and transportation.

6.1.8.9 Reservoir Pressure Relief. Design pressurized reservoirs so that ullage volumes shall be connected to a relief valve that shall protect tune reservoir and power pump from hazardous overpressure or back pressure of the system.

6.1.8.10 Air Pressure Control. The air pressure control for pressurized reservoirs shall be an externally nonadjustable pressure regulating device. If this unit also contains a reservoir pressure relief valve, design the unit so that no failure in the unit will permit overpressurization of the reservoir.

6.1.9 Contamination. The following contamination related considerations shall be addressed in the design of pressurized systems. Contamination includes solid, liquid and gaseous material.

- a. Prevent contamination from entering or developing within the system.

MIL-STD-1522A (USAF)
28 MAY 1984

- b. Design the system to include provisions to detect contamination.
- c. Design the system to include provisions for removal of contamination. Include provisions for initial purge with fluid or gas which will not degrade future system performance.
- d. Design the system to be tolerant of contamination.

6.1.9.1 Filtering. All pressurizing fluids entering safety critical systems will be filtered through a 10 micron filter, or finer, before entering the system.

6.1.9.1.1 Fluid Filters.

- a. All pressure systems shall have fluid filters in the system, designed and located to reduce the flow of contaminant particles to a safe minimum.
- b. All of the circulating fluid in the system shall be filtered downstream from the pressure pump, or immediately upstream from safety critical actuators. Entrance of contamination at test points or vents shall be minimized by downstream filters. The bypass fluid or case drain flow on variable displacement pumps shall be filtered.
- c. When clogging of small orifices could cause a hazardous malfunction or failure of the system, they shall be protected by a filter element designed to prevent clogging of the orifice. Note that this includes servo valves.
- d. Do not use filters or screens in suction lines of power pumps or hand pumps of safety critical systems.

6.1.9.1.2 Air Filters.

6.1.9.1.2.1 Pressurized Reservoirs. Specify air filters for hydraulic reservoir air pressurization circuits and locate air filters to protect the pressure regulating equipment from contamination. Specify dry compressed air for hydraulic reservoir pressurization. Specify a moisture removal unit to protect the pressure regulation lines and equipment.

6.1.9.1.2.2 Unpressurized Reservoirs. Unpressurized hydraulic reservoirs shall have filters and dessicant units at the breather opening to preclude introduction of moisture and contaminants into the reservoir.

MIL-STD-1522A (USAF)
28 MAY 1984

6. 1.9.2 Bleed Ports

6. 1.9.2.1 Location - Provide bleed ports where necessary to remove accumulations of residue or contaminants. Provide high point bleed ports where necessary for removal of trapped gases. The bleed valve shall be directed away from operating personnel and possible ignition sources.

- a. Equip components, cavities, or lines that can be isolated, with bleed valves which can be used to release retained pressure, or will indicate that continued pressure exists in the system.
- b. Bleed valves used for reducing pressure on systems containing hazardous fluids shall be routed to a safe disposal area.

6.1.9.2.2 Auxiliary Bleed Ports. Provide auxiliary bleed ports where necessary to allow bleed off for safety purposes. Locate bleeder valves so that they can be operated without removal of other components, and shall permit the attachment of a hose to direct the bled off fluid into a container.

6.1.9.2.3 Filler Cap Bleed. Reservoir filler caps shall include design provisions which shall automatically bleed the reservoir on opening, so that possible ullage pressure can not impart hazardous kinetic energy to either the filler caps, the fluid in the reservoir, or the system.

6.1.10 Control Devices

6.1.10.1 Directional Control Valves. Design safety critical pressure systems incorporating two or more directional control valves to preclude the possibility of inadvertently directing the flow or pressure from one valve into the flow or pressure path intended for another valve, with any combination of valve settings possible in the total system.

6.1.10.2 Overtravel. Design control devices to prevent overtravel or undertravel that may contribute to a hazardous condition, or damage to the valve.

6.1.10.3 Pressure and Volume Control Stops. All pressure and volume controls shall have stops, or equivalent, to prevent settings outside their nominal safe working ranges.

MIL-STD-1522A (USAF)
28 MAY 1984

6.1.10.4 Manually Operated Levers.

- a. Components that have integrated manually operated levers shall provide levers and stops capable of withstanding the limit torques specified by MIL-STD-1472.
- b. Provide levers and stops on remote controls, capable of withstanding a limit torque of 1800 lb-in.
- c. Because jamming is possible, do not use sheathed flexible-actuators for valve controls in safety critical pressure systems; for example, push-pull wires, torque wires, etc., that are sheathed are not acceptable.

6.1.10.5 Limit Torque. Control components that have integral manually operated levers shall provide levers and stops capable of withstanding the following limit torques.

<u>Lever Radius (R)</u>	<u>Design Torque</u>
Less than 3 inches	50 x R lb-in.
3 to 6 inches	75 x R lb-in.
over 6 inches	150 x R lb-in.

6.1.11 Accumulators

6.1.11.1 Accumulator Design. Design accumulators in accordance with the pressure vessel standards for ground systems and locate for minimal probability of mechanical damage and for minimum escalation of material damage or personnel injury in the event of a major failure such as tank rupture.

6.1.11.2 Accumulator Gas Pressure Gages. Accumulator gas pressure gages shall not be used to indicate system pressure for operational or maintenance purposes.

6.1.11.3 Accumulator Identification. Gas type and pressure level shall be posted on, or immediately adjacent to the accumulator.

6.1.12 Flexhose

6.1.12.1 Installation. Use flexhose between any two connections where relative motion can be expected to fatigue metal tube or pipe. Design flexhose installation to avoid abrasive contact with adjacent structure or moving parts. Rigid supports shall not be used on flexhose.

MIL-STD-1522A (USAF)
28 MAY 1984

6.1.12.2 Restraining Devices. Design flexhose installation which are six feet long or greater so that restraint is provided on both the hose and adjacent structure at no greater than six-foot intervals and at each end to prevent whiplash in the event of a burst. Restraining devices shall be designed and demonstrated to contain a force not less than 1.5 X openline pressure force. (See Table IV) The design safety factor shall be not less than 3. Sand or shot bags placed on top of flexible hose is not an acceptable restraint. Do not use hose clamp type restraining devices.

6.1.12.3 Flexhose Stress. Design flexhose installations that shall not produce stress or strain of any nature in the hard lines or components. Include stresses induced because of dimensional changes caused by pressure or temperature variations, or torque forces induced in the flexhose.

6.1.12.4 Temporary Installations. Temporary installations using chains or cables anchored to substantial fixed points, lead ingots or other weights, are acceptable providing they meet the requirements of paragraph 6.1.2.1. Protect flexhose from kinking or abrasive chafing from the restraining device or damage from adjacent structure or moving parts that may cause reduction in strength.

TABLE IV. Open Line Force Calculation Factor

DIAMETER OPENING (INCH)	CALCULATED FORCE FACTOR FOR EACH PSI OF SOURCE PRESSURE (LB)
1/8	0.18506
1/4	0.2832
3/8	0.3814
1/2	0.4796
5/8	0.5777
3/4	0.6759
7/8	0.7741
1	0.8723
NOTE: To calculate the force acting on line opening, select applicable diameter and multiply righthand column by the source pressure (psi).	

MIL-STD-1522A (USAF)
28 MAY 1984

6.2 HYDRAULIC SYSTEM REQUIREMENTS

6.2.1 Hydraulic System Components

6.2.1.1 Component Integrity. When the system pressure profile is indeterminate; perform safety tests at pressure no lower than 67 percent of the maximum allowable working pressure for components rated up to 3000 psig and no lower than 80 percent of the maximum allowable working pressure for components rated above 3000 psig.

6.2.1.1.1 Component Section. Select components which are compatible with and rated for the viscosity of the hydraulic fluid to be used.

6.2.1.1.2 Cycling. Cycling capability for safety critical components shall be not less than 400% of the total number of expected cycles, including system tests, but not less than 2000 cycles. For service above a temperature of 160°F, an additional cycling capability equivalent to the above shall be required as a maximum.

6.2.1.1.3 Actuators. Safety critical hydraulic actuators shall have positive mechanical stops at the extremes of safe motion.

6.2.1.1.4 Shutoff Valves. Hydraulic fluid reservoirs and supply tanks shall be equipped with shutoff valves, operable from a relatively safe location in the event of a hydraulic system emergency.

6.2.1.1.5 Variable Response. Do not use shuttle valves in safety critical hydraulic systems where the event of a force balance on both inlet ports may occur, thus causing the shuttle valve to restrict flow from the outlet port.

6.2.1.1.6 Fire Resistant Fluids. Where system leakage can expose hydraulic fluid to potential ignition sources or is adjacent to a potential fire zone and the possibility of flame propagation exists, fire resistant or flame proof hydraulic fluid shall be used.

6.2.1.1.7 Accumulators. Hydraulic systems incorporating accumulators shall be Interlocked to either vent or isolate accumulator fluid pressure when power is shutoff.

6.2.1.1.8 Adjustable Orifices. Do not use adjustable orifice restrictor valves in safety critical hydraulic systems.

MIL-STD-1522A (USAF)
28 MAY 1984

6.2.1.9 Lock Valves.

- a. When two or more hydraulic actuators are mechanically tied together, only one lock valve shall be used to hydraulically lock all the actuators.
- b. Do not use hydraulic lock valves for safety critical lockup periods likely to involve extreme temperature changes, unless fluid expansion and contraction effects are safely accounted for.

6.2.1.10 Hydraulic Reservoir. Whenever possible, the hydraulic reservoir should be located at the highest point in the system. If this is not possible in safety critical systems, procedures must be developed to detect air in actuators or other safety critical components and to assure that the system is properly bled prior to each use.

6.2.2 Pressure Limits. Hydraulic systems installations will be limited to a maximum pressure of 15,000 psig.

NOTE

There is no intent to restrain development of systems capable of higher pressures, however, the employment of such systems must be preceded by complete development and qualification that includes appropriate safety tests.

6.2.3 Cavitation.

6.2.3.1 Inlet Pressure. Specify the inlet pressure of hydraulic pumps in safety critical systems to prevent cavitation effects in the pump passages or outlets.

6.2.3.2 Fluid Column. Safety critical hydraulic systems shall have positive protection against breaking the fluid column in the suction line during standby.

6.2.4 Redundancy. Hydraulic systems for primary flight control of marine vehicles shall have redundant features for all major aspects of operation and control and be essentially independent of systems non-critical to safety.

NOTE

Provision may be made for a safety critical system to draw power from a non-critical system, provided that no single failure can cause loss of both systems because of this connection.

MIL-STD-1522A (USAF)
28 MAY 1984

6.2.5 Hydraulic Lockup.

6.2.5.1 Emergency Disengage. Hydraulic systems that provide for manual takeover shall automatically disengage or allow by-pass of the main hydraulic system upon the act of manual takeover.

6.2.5.2 Emergency By-Pass.

- a. Safety critical hydraulic systems or alternate by-pass systems provided for safety shall not be rendered inoperative because of back pressure under any set of conditions.
- b. Design the system so that a hydraulic lock resulting from an unplanned disconnection of a self-seating coupling or other component shall not cause damage to the system or to adjacent property, or injury to personnel.

5.2.6 Hydraulic System Pressure Relief

6.2.6.1 Pump Pressure Relief. Hydraulic systems employing power operated pumps shall include a pressure regulating device and an independent safety relief valve.

6.2.6.2 Thermal Pressure Relief. Thermal expansion relief valves shall be installed as necessary to prevent system damage from thermal expansion of hydraulic fluid, as in the event of gross overheating. Internal valve leakage not be considered an acceptable method of providing thermal relief. Thermal relief valve setting shall not exceed 150 psi above the value for system relief valve setting. Vents shall outlet only to areas of relative safety from fire hazard. Hydraulic blow-out fuses (soft plugs) shall not be used in systems having temperatures above 160°F.

6.2.6.3 Location. Pressure relief valves shall be located in hydraulic systems wherever necessary to assure that the pressure in any part of a power system shall not exceed the safe limit above the regulated pressure of the system.

6.3 PNEUMATIC SYSTEMS REQUIREMENTS

6.3.1 Pneumatic System Components.

6.3.1.1 Component Integrity. Pneumatic components (other than tanks) for safety critical systems shall exhibit safe endurance against hazardous failure modes for not less than 400% of the total number of expected cycles including system test. Pneumatic ground support emergency system components shall have safe endurance of a minimum of 5000 cycles.

MIL-STD-1522A (USAF)
28 MAY 1984

6.3.1.2 Configuration - The configuration of pneumatic components shall permit bleeding of entrapped moisture, lubricants, particulate material, or other foreign matter hazardous to this system.

6.3.1.3 Compressors. Select compressors which are designed to sustain not less than 2.5 X delivery pressure, after allowance for loss of strength of the materials equivalent to not less than that caused by 1000 hours aging at 275°F.

6.3.1.4 Actuators. Safety critical pneumatic actuators shall have positive mechanical stops at the extremes of safe motion.

6.3.1.5 Adjustable Orifice Restrictors. Adjustable orifice restrictor valves shall not be used in safety critical pneumatic systems.

6.3.2 Controls.

6.3.2.1 Manual Takeover. Provide for automatic disengagement or by-pass for pneumatic systems that provide for manual takeover in the event of a hazardous situation. Provide positive indication of disengagement.

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MIL-STD-1522A (USAF)
28 MAY 1984

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APPENDIX

FAILURE MODE DETERMINATION

The following is an acceptable approach for failure mode determination. This approach is not mandatory. An alternate approach may be used if approved by the procuring agency and appropriate launch or test range approval authority.

The results of the stress analysis of Section 4.2.5 shall be used to determine potential failure modes of the pressure vessel and pressurized structure in terms of leakage (ductile fracture failure mode) or complete fracture (brittle fracture failure mode). The structure is considered to exhibit a ductile fracture failure mode when

$$\frac{K_{Ic}}{\sigma_{op}} \geq 2 a \sqrt{t} \quad (a \sigma_{op} \leq \sigma_{ys}, a > 1)$$

where K_{Ic} is the plane strain fracture toughness of the material, σ_{op} is the operating stress level, a is the proof factor, σ_{ys} is the yield stress of the material, and t is the material thickness at the location of σ_{op} . Under this condition, further fracture mechanics analysis is not required. These pressurized systems shall be designed and tested in accordance with the requirements of Section 5.1.1.

When

$$\frac{K_{Ic}}{\sigma_{op}} < 2 a \sqrt{t}$$

the pressurized system shall be designed and tested in accordance with established linear elastic fracture mechanics methodology, as delineated in Section 5.1.2.

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