METRIC/INCH-POUND

KSC-DE-512-SM
Revision M-1

GROUND SYSTEMS DEVELOPMENT STANDARD

Export Control Determination

January 15, 2025

Engineering Directorate

National Aeronautics and
Space Administration

John F. Kennedy Space Center

KSC FORM 16-12 (REV. 6/95) PREVIOUS EDITIONS ARE OBSOLETE (CG 11/95)
KDP-KSC-T-5407 Rev Basic

RECORD OF REVISIONS/CHANGES

REV LTR	CHG NO.	DESCRIPTION	DATE
		Basic issue.	January 1983
A		General revision.	March 1986
	A-1	Added requirements for SCAPE suit operations and EMI compatibility.	February 20, 1987
B		General revision.	June 1988
	B-1	Added requirements for marking of test weights.	July 26, 1991
C		General revision.	March 10, 1993
D		Miscellaneous changes.	August 5, 1994
	D-1	Added requirements for design of facility premises wiring.	December 15, 1994
E		Added requirements for instrumentation calibration and quick release pins.	June 1, 1995
F		Revised miscellaneous references.	August 5, 1996
G		Updated miscellaneous references and text.	December 18, 1998
H		Updated miscellaneous references and text.	September 14, 2000
	H-1	Revised 3.3.3.2.13.	May 30, 2002
J		Updated miscellaneous references and text. Incorporated change H-1.	October 15, 2002
K		Updated miscellaneous references and text. All pages reformatted.	September 30, 2004
L		Complete rewrite and align with NASA-STD-5005.	February 29, 2012
	L-1	Updated reference documents, abbreviations, and terms.	February 28, 2013
	L-2	Updated reference documents, abbreviations, and terms.	June 23, 2014
	L-3	Permitted the use of cleaning standards that are functionally equivalent to ISO 14952.	July 29, 2014
	L-4	Updated reference documents, abbreviations, and terms.	August 3, 2015
	L-5	Updated reference documents, abbreviations, and terms.	July 20, 2016
M	Interim	General revision to retitle the standard, incorporate Changes L-1 through L-5, and restructure the requirements by engineering discipline.	March 18, 2019
M		Update incorporating comments from KSC staffing.	November 9, 2021

REV LTR	CHG NO.	DESCRIPTION	DATE
	M-1	Updated reference documents, abbreviations, and terms.	January 15, 2025

FOREWORD

KSC-DE-512-SM establishes overall requirements and best design practices to be used at the John F. Kennedy Space Center (KSC) for developing ground systems (GS) in support of operations at launch, landing, and retrieval sites. These requirements apply to the design and development of hardware and software for ground support equipment (GSE) and ground support systems (GSS) used to support the KSC mission for transportation, receiving, handling, assembly, test, checkout, servicing, and launch of space vehicles and payloads and selected flight hardware items for retrieval.

During the 1950s and early 1960s, the Missile Firing Laboratory (later renamed to the Launch Operations Directorate) was the launch operations arm of Redstone Arsenal and the Army Ballistic Missile Agency. The Missile Firing Laboratory used Army specifications and standards for its design and development of GS. KSC's effort to develop standards began with GP-863, *General Criteria for Design of New Equipment and Facilities,* which was released in July 1970 and updated three years later. GP-863 focused on operability, reliability, maintainability, useful life, environmental, transportability, human performance, safety, logistics, documentation, and quality assurance. KSC-DE-512-SM, *Facility Systems, Ground Support Systems, and Ground Support Equipment, General Design Requirements,* replaced GP-863 in 1983. The early revisions of KSC-DE-512-SM contained requirements, along with guidance for accomplishing detailed designs. Later revisions became more formal and the "shall" statement became the phrase to identify each requirement. The document title was changed to "development" to emphasize that the standard covers design, fabrication, qualification, and testing.

This standards manual represents a tailored version of NASA-STD-5005 to include KSC-site-specific and local-environment requirements. KSC-DE-512-SM is a single, complete document for the design and development of KSC GS for use at launch, landing, and retrieval sites.

These requirements and practices are optional for equipment used at manufacturing, development, and test sites.

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ABBREVIATIONS, ACRONYMS, AND SYMBOLS

μF	microfarad
σ	sigma
°C	degree Celsius
°F	degree Fahrenheit
A	ampere
A&E	architect and engineering
AC	alternating-current
AISC	American Institute of Steel Construction
ASD	acceleration spectral density
ASME	American Society of Mechanical Engineers
Btu	British thermal unit
CG	center-of-gravity
CGA	Compressed Gas Association
COPV	composite overwrapped pressure vessel
COTS	commercial off-the-shelf
dB	Decibel
DC	direct-current
DCR	Design Certification Review
DOT	Department of Transportation
ECS	Environmental Control System
EEE	electrical, electronic, and electromechanical
e.g.	for example
EMC	electromagnetic compatibility
EMI	electromagnetic interference
ESD	electrostatic discharge
etc.	and so forth
ETFE	ethylene tetrafluoroethylene
FOD	Foreign Object Debris
ft	foot
g	gravity
GO_2	gaseous oxygen
GRMS	gravity root mean squared acceleration
GS	ground systems
GSE	ground support equipment
GSS	ground support systems
HVAC	heating, ventilation, and air conditioning
Hz	hertz
i.e.	that is
in.	inch
IP	Importance Factor

kPa	kilopascal
KSC	John F. Kennedy Space Center
ksi	one thousand pounds per square inch
lb	pound
LO_2	liquid oxygen
LRFD	load and resistance factor design
M&P	materials and processes
MAPTIS	Materials and Processes Technical Information System
MAWP	maximum allowable working pressure
MEOP	maximum expected operating pressure
MHz	megahertz
MOTS	modified off-the-shelf
MPa	megapascal
MUA	Material Usage Agreement
MUP	Material Usage Permit
N_2O_4	nitrogen tetroxide
NASA	National Aeronautics and Space Administration
NDE	nondestructive evaluation
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
OSHA	Occupational Safety and Health Standards
Pa	Pascal
Pb	lead
PCTFE	polychlorotrifluoroethylene
PFA	plastic film, foam, and adhesive tape
pH	potential of hydrogen
PHE	propellant handler’s ensemble
PLC	programmable logic controller
PLD	programmable logic device
PQR	procedure qualification record
PSD	Power Spectral Density
psi	pound per square inch
psia	pound per square inch absolute
psig	pounds per square in gauge
PTFE	polytetrafluoroethylene
PVS	pressure vessels and pressurized systems
RF	radio frequency
RoHS	Restriction of Hazardous Substance
S	second
S&MA	KSC Safety and Mission Assurance Directorate
SCAPE	self-contained atmospheric protective ensemble
SCC	stress corrosion cracking
sigma	standard deviation
SMACNA	Sheet Metal and Air Conditioning Contractors’ National Association
Sn	tin

STE	special test equipment
UL	Underwriters Laboratory
UNS	Unified Numbering System
UTS	ultimate tensile strength
V	volt
VAB	Vehicle Assembly Building
VAC	volts alternating current
VDC	volts direct current
vs.	versus
WPS	welding procedure specification

1. SCOPE

1.1 Purpose

This document establishes requirements and guidance for the design and fabrication of ground systems (GS), which includes ground support equipment (GSE) and ground support systems (GSS), to provide uniform methods and processes for the design and development of robust, safe, reliable, maintainable, supportable, and cost-effective GS in support of space flight and institutional programs and projects. This standards manual is intended to supplement the minimum requirements of NASA-STD-5005 by applying more site-specific, stringent, restrictive, or demanding requirements applicable to the specific Kennedy Space Center (KSC) environment and to ensure compatibility with existing systems. This standards manual also provides requirements for GSS which are not covered by NASA-STD-5005.

1.2 Applicability

This document applies to all GS designed for use at KSC and design projects managed by KSC for other launch, landing, and recovery locations. This document may be invoked by a program or project for testing facilities, laboratories, flight hardware manufacturing facilities, or other applications. The applicability of KSC-DE-512-SM relative to other building codes, NASA, KSC, and industry design standards is shown in Figure 1.

a. This standards manual applies to all new and modified GS for programs and projects assigned to KSC. The Program may specify the use of this standards manual to other applications (e.g., test hardware or facility projects).

b. KSC-DE-512-SM establishes minimum design requirements for GS, as defined herein, for NASA programs and projects assigned to KSC. This standards manual is intended to establish uniform engineering best practices and methods in the design, analysis, documentation, procurement, fabrication, assembly, test, and installation of GS to support KSC operations.

c. This standards manual is required for use by KSC design entities and their support contractors and may be cited in contracts, projects, and other documents as necessary to provide a technical requirement.

d. Rationale and guidance are provided in italic text after the requirement where more definition is needed.

e. The requirements of this standards manual are optional for hardware used only at manufacturing, development, or test sites but are mandatory for hardware used at launch, landing, and retrieval sites.

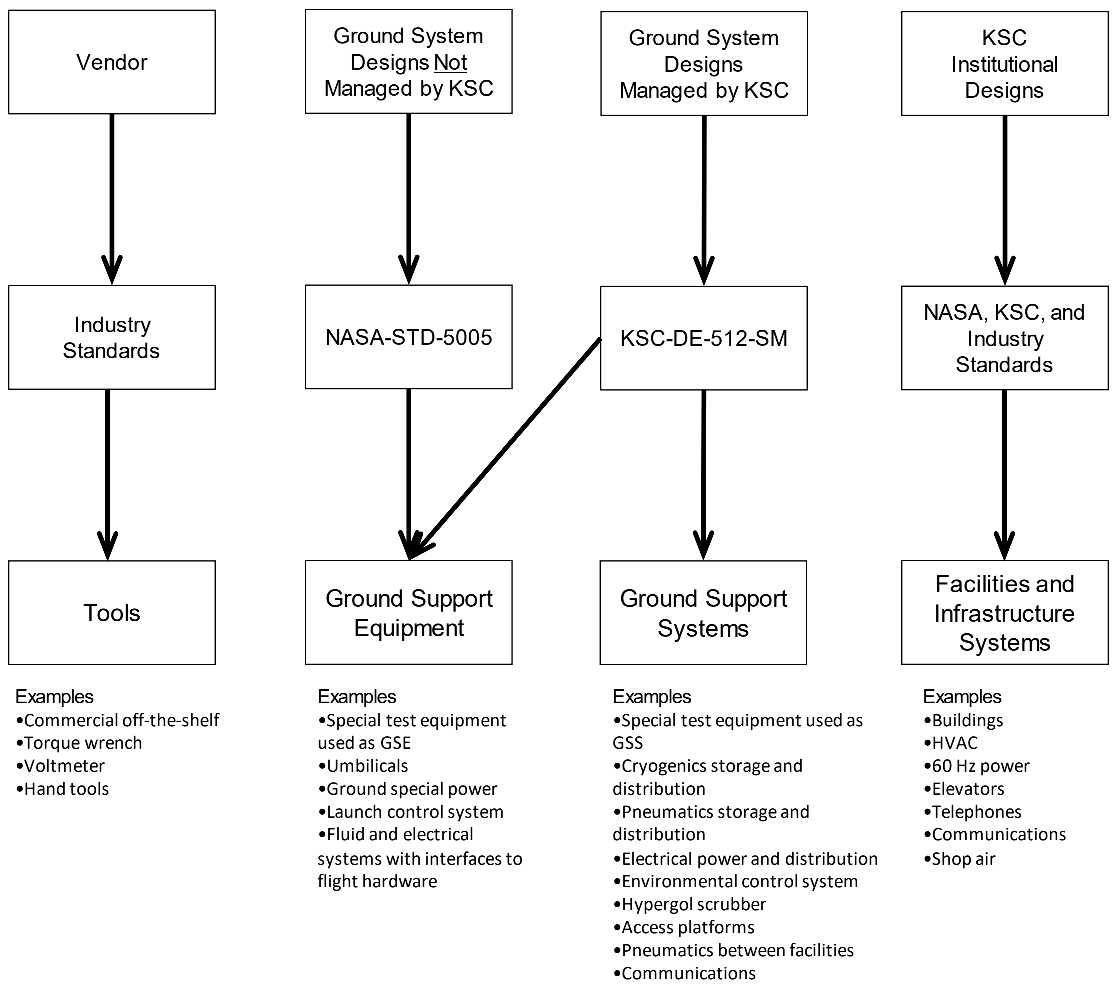

Figure 1. KSC-DE-512-SM Applicability

f. A program may invoke additional requirements that differ from the requirements stated herein. These requirements will be evaluated and approved for use by the KSC Engineering Technical Authority. See KSC-PLN-5400 and 1.3.

g. The Program may elect to manufacture GS or components of GS to NASA flight hardware requirements if the design meets Programmatic functional requirements. The requirements of this document are satisfied by the requirements of NASA flight hardware design and manufacturing standards. NASA and KSC safety requirements for GS are not intrinsically satisfied by NASA flight hardware standards and must be addressed in full.

It would not normally be cost effective to design ground equipment to flight hardware standards. There are certain cases where it would be advantageous. One is when existing flight hardware is available to be used as GS. Another, where a structural interface with flight hardware requires the lower flight hardware safety factors for dimensional compatibility. When designing GS to flight hardware standards, ALL flight hardware requirements are applicable. This *includes A-basis material properties, bonded storage of materials, material traceability, testing, fracture control, etc.*

h. KSC Directorates are responsible for invoking this standards manual for the design and development of GS. KSC Directorates have responsibilities described as follows:

- KSC Engineering and KSC Safety and Mission Assurance (S&MA) have the responsibility to determine categories or types of GS (e.g., critical vs. noncritical) and any additional requirements resulting from these categories or types.
- The KSC Authority Having Jurisdiction has the responsibility and authority to define hazardous areas and approve designs that provide equipment to these areas.

i. This standards manual applies to the following:

- GSE,
- GSS,
- facility GSS,
- special test equipment (STE),
- selection and qualification of commercial off-the-shelf (COTS) equipment, and
- modifications to commercial off-the-shelf (i.e., modified off-the-shelf [MOTS]).

j. NASA-STD-5005 may be applied by the governing program for GSE provided by entities other than KSC.

k. This standards manual does not apply to the following:

- flight hardware,
- tools (standard shop),
- facilities and utilities (in-house and architect and engineering [A&E] firms), or
- design and fabrication of COTS equipment (the application and usage of COTS equipment in GSE designs must meet the requirements of this standard).

KSC-DE-512-SM does not cover the design and fabrication of tools, facilities and utilities, or COTS equipment. However, other KSC standards and industry standards may apply to these designs.

The Technical Authority determines the classification of equipment listed in 1.2.i, 1.2.j., and 1.2.k.

1.3 Tailoring and Waivers

Individual provisions of this standards manual should be and are intended to be tailored (i.e., modified or deleted) to meet specific program and project needs. All tailoring is required to be evaluated for use by the KSC Engineering Technical Authority (see KSC-PLN-5400). Waivers to institutional requirements will follow the process in KDP-KSC-P-1865.

1.4 Use of Shall, May, Should, and Will

In this standards manual, the auxiliary verb "shall" denotes mandatory actions (i.e., requirements) that are verified. "May" denotes discretionary privilege or permission. "Should" denotes a good practice that is recommended but is not required. The terms "must" and "will" denote an expected outcome, a requirement levied by others, or a requirement that does not have mandated verification. When this standards manual is placed on a contract, the "will" statements in this standards manual are equivalent to "shall" statements for the purposes of the contract.

Requirements denoted by "shall" require formal evidence for closure. "Will" is a formal requirement which is verified during design reviews and certification meetings, but does not require formal documented evidence tied to that requirement.

2. APPLICABLE DOCUMENTS

The following documents form a part of this document to the extent specified herein. When this document is used for procurement, including solicitations, or is added to an existing contract, the specific revision levels, amendments, and approval dates of said documents should be specified in an attachment to the Solicitation/Statement of Work/Contract.

The applicable documents are accessible via the NASA Standards and Technical Assistance Resource Tool at http://standards.nasa.gov or may be obtained directly from the standards developing organizations or other document distributors.

Citations of applicable documents are hyperlinked to their appearance in 2.1 and 2.2. Citations of reference documents, which are listed in Appendix A, are not hyperlinked.

2.1 Government Documents

120E3100003	Electrical Cable Fabrication Requirements
29 CFR 1910	Occupational Safety and Health Standards
29 CFR 1910.120, Appendix B	Occupational Safety and Health Standards, Subpart H: Hazardous Materials, Hazardous waste operations and emergency response, Appendix B: General description and discussion of the levels of protection and protective gear
29 CFR 1926	Safety and Health Regulations for Construction
49 CFR	Title 49 - Transportation
79K07491	Installation of Purge Hardware
AFSPCMAN 91-710	Range Safety User Requirements Manual, Volume 3, Launch Vehicles, Payloads, and Ground Support Systems Requirements

FAA-HF-STD-001	Human Factors Design Standard (HFDS)
KDP-KSC-P-1865	Institutional Requirement Deviation/Waiver Process
KNPR 1840.19	Kennedy Space Center Industrial Hygiene Program
KNPR 8700.2	KSC System Safety and Reliability Analysis Methodology Procedural Requirements
KNPR 8715.3-1	KSC Safety Practices Procedural Requirements, Volume 1, Safety Procedural Requirements for Civil Servants/NASA Contractors
KNPR 8730.1	KSC Metrology and Calibration Procedural Requirements
KNPR 8730.2	KSC Quality Assurance Procedural Requirements
KSC-DF-107	Technical Documentation Style Guide
KSC-E-165	Electrical Ground Support Equipment Fabrication, Specification For
KSC-E-166	Installation and Assembly, Electrical Ground Support Equipment (GSE), Specification for
KSC-GP-425	Fluid Fitting Engineering Standards
KSC-GP-435	Engineering Drawing Practices, Vol. I of II: Aerospace and Ground Support Equipment
KSC-GP-864	Electrical Ground Support Equipment Cable Handbook
KSC-GP-986	Design Criteria for Reusable Space Vehicle Umbilical Systems
KSC-NE-9187	Sensors, Transducers and Signal Conditioning Systems Selection Guidelines
KSC-PLN-5400	Technical Authority Implementation Plan
KSC-PLN-5406	Design and Development Electrical, Electronic, Electromechanical (EEE) Parts Plan
KSC-SPEC-E-0002	Modular Electrical Enclosures, Racks, Consoles, and Accessories, Specification for
KSC-SPEC-P-0027	Tubing, Superaustenitic Steel, Corrosion Resistant, UNS N08367 and UNS S31254, Seamed, Bright Annealed, Passivated, Specification for
KSC-SPEC-Z-0008	Fabrication and Installation of Flared Tube Assemblies and Installation of Fittings and Fitting Assemblies, Specification for
KSC-SPEC-Z-0009	Lubrication, Thread, Corrosion-Resistant Steel and Aluminum Alloy Tube Fittings, Specification for

KSC-STD-132	Potting and Molding Electrical Cable Assembly Terminations, Standard for
KSC-STD-141	Load Test Identification and Data Marking, Standard for
KSC-STD-152-2	Graphical Symbols for Drawings: Part 2: Ground Support Equipment, Standard for
KSC-STD-164	Environmental Test Methods for Ground Support Equipment, Standard for
KSC-STD-E-0002	Hazardproofing of Electrically Energized Equipment, Standard for
KSC-STD-E-0004	Pneumatic and Hydraulic Mechanical Components, Electrical Design, Standard for
KSC-STD-E-0011	Electrical Power Receptacles and Plugs, Standard for
KSC-STD-E-0015	Standard for Marking of Ground Support Equipment
KSC-STD-E-0022	Bonding, Grounding, Shielding, Electromagnetic Interference, Lightning and Transient Protection, Design Requirements for Ground Systems
KSC-STD-S-0033	Kennedy Space Center Fall Protection Standard
KSC-STD-Z-0005	Pneumatic Ground-Support Equipment, Design of, Standard for
KSC-STD-Z-0006	Design of Hypergolic Propellants Ground Support Equipment, Standard for
KSC-STD-Z-0008	Design of Ground Life Support Systems and Equipment, Standard for
KSC-STD-Z-0009	Cryogenic Ground Support Equipment, Design of, Standard for
MIL-DTL-22992	Connectors, Plugs and Receptacles, Electrical, Waterproof, Quick Disconnect, Heavy Duty Type, General Specification for
MIL-DTL-24308	Connectors, Electric, Rectangular, Nonenvironmental, Miniature, Polarized Shell, Rack and Panel, General Specification for
MIL-DTL-38999	Connectors, Electrical, Circular, Miniature, High Density, Quick Disconnect (Bayonet, Threaded or Breech Coupling), Environment Resistant with Crimp Removable Contacts or Hermetically Sealed with Fixed, Solderable Contacts, General Specification for
MIL-HDBK-17	Department of Defense Composite Materials Handbook

MIL-PRF-39012	Connectors, Coaxial, Radio Frequency, General Specification for
MIL-STD-101	Color Code for Pipelines and for Compressed Gas Cylinders
MIL-STD-202	Test Method Standard, Electronic and Electrical Component Parts
MIL-STD-810	Environmental Engineering Considerations and Laboratory Tests
MIL-STD-889	Dissimilar Metals
MSFC-SPEC-3635	Pyrotechnic System Specification
MSFC-STD-3029	Guidelines for the Selection of Metallic Materials for Stress Corrosion Cracking Resistance in Sodium Chloride Environments
NASA/TM-2008-215633	Terrestrial Environment (Climatic) Criteria Guidelines for Use in Aerospace Vehicle Development
NASA-STD-4003	Electrical Bonding for NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment
NASA-STD-5005	Standard for the Design and Fabrication of Ground Support Equipment
NASA-STD-5008	Protective Coating of Carbon Steel, Stainless Steel, and Aluminum on Launch Structures, Facilities, and Ground Support Equipment
NASA-STD-5009	Nondestructive Evaluation Requirements for Fracture-Critical Metallic Components
NASA-STD-6001	Flammability, Offgassing, and Compatibility Requirements and Test Procedures
NASA-STD-7009	Standard for Models and Simulation
NASA-STD-8719.9	Lifting Standard
NASA-STD-8719.12	Safety Standard for Explosives, Propellants, and Pyrotechnics
NASA-STD-8719.17	NASA Requirements for Ground-Based Pressure Vessels and Pressurized Systems (PVS)
NASA-STD-8719.26	NASA Requirements for Ground Based Non-Code Metallic Pressure Vessels
NASA-STD-8739.1	Workmanship Standard for Polymeric Application on Electronic Assemblies
NASA-STD-8739.4	Crimping, Interconnecting Cables, Harnesses, and Wiring

NASA-STD-8739.5	Workmanship Standard for Fiber Optic Terminations, Cable Assemblies, and Installation
NPR 1800.1	NASA Occupational Health Program Procedures
NPR 2810.1	Security of Information Technology
NPR 6000.1	Requirements for Packaging, Handling, and Transportation for Aeronautical and Space Systems, Equipment, and Associated Components
NPR 7150.2	NASA Software Engineering Requirements
NPR 8705.2	Human-Rating Requirements for Space Systems
NPR 8715.1	NASA Safety and Health Programs
NPR 8715.3	NASA General Safety Program Requirements
OSHA 1910.111	Storage and Handling of Anhydrous Ammonia

2.2 Non-Government Documents

ASCE Pre-standard	ASCE Standard for Load & Resistance Factor Design (LRFD) of Pultruded Fiber Reinforced Polymer (FRP) Structures
ASHRAE Fundamentals IP Handbook	ASHRAE Handbook Fundamentals – I-P Edition
ASHRAE HVAC Applications IP Handbook	ASHRAE Handbook Heating, Ventilating, and Air-Conditioning Application Inch-Pound Edition
ASHRAE HVAC Systems and Equipment IP Handbook	ASHRAE Handbook HVAC Systems and Equipment I-P Edition
ADM	Aluminum Association Aluminum Design Manual
AISC 325	Steel Construction Manual
API STD 620	Design and Construction of Large, Welded, Low-Pressure Storage Tanks
ASCE-7	Minimum Design Loads for Buildings and Other Structures
ASME B31.3	Process Piping
ASME B31.5	Refrigeration Piping and Heat Transfer Components
ASME B31.8	Gas Transmission and Distribution Piping Systems
ASME BPVC-II	ASME Boiler & Pressure Vessel Code, Section II, Materials

ASME BPVC-VIII	ASME Boiler & Pressure Vessel Code, Section VIII, Division 1: Rules for Construction of Pressure Vessels, Division 2: Alternative Rules, Division 3: Alternative Rules
ASME BPVC-X	ASME Boiler & Pressure Vessel Code, Section X, Fiber-Reinforced Plastic Pressure Vessels
ASME BPVC-XII	Boiler and Pressure Vessel Code, Section XII: Rules for Construction and Continued Service of Transport Tanks
ASME Y14.100	Engineering Drawing Practices
ANSI/ASSP Z359	Fall Protection and Fall Restraint Standards
ASTM A213	Standard Specification for Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes
ASTM A249	Standard Specification for Welded Austenitic Steel Boiler, Superheater, Heat-Exchanger, and Condenser Tubes
ASTM A262	Standard Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels
ASTM A269	Standard Specification for Seamless and Welded Austenitic Stainless Steel Tubing for General Service
ASTM A312	Standard Specification for Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes
ASTM A967	Standard Specification for Chemical Passivation Treatments for Stainless Steel Parts
ASTM B152	Standard Specification for Copper Sheet, Strip, Plate, and Rolled Bar
ASTM D4174	Standard Practice for Cleaning, Flushing, and Purification of Petroleum Fluid Hydraulic Systems
ASTM D4470	Standard Test Method for Static Electrification
ASTM D7194	Standard Specification for Aerospace Parts Machined from Polychlorotrifluoroethylene (PCTFE)
ASTM E426	Standard Practice for Electromagnetic (Eddy Current) Examination of Seamless and Welded Tubular Products, Titanium, Austenitic Stainless Steel and Similar Alloys
ASTM E1548	Standard Practice for Preparation of Aerospace Contamination Control Plans

ASTM F3125	Standard Specification for High Strength Structural Bolts, Steel and Alloy Steel, Heat Treated, 120 ksi (830 MPa) and 150 ksi (1040 MPa) Minimum Tensile Strength, Inch and Metric Dimensions
ASTM F3148	Standard Specification for High Strength Structural Bolt Assemblies, Steel and Alloy Steel, Heat Treated, 144ksi Minimum Tensile Strength, Inch Dimensions
ASTM G93	Standard Practice for Cleaning Methods and Cleanliness Levels for Material and Equipment Used in Oxygen-Enriched Environments
ASTM MNL 36	Safe Use of Oxygen and Oxygen Systems: Handbook for Design, Operation, and Maintenance
AWS C3.3	Recommended Practices for the Design, Manufacture, and Examination of Critical Brazed Components
AWS D17.1	Specification for Fusion Welding for Aerospace Applications
CGA C-7	Guide to Classification and Labeling of Compressed Gases
CGA S1.1	Pressure Relief Device Standards Part 1 – Cylinders for Compressed Gases
CGA S1.2	Pressure Relief Device Standards Part 2 – Portable Containers for Compressed Gases
CGA S1.3	Pressure Relief Device Standards Part 3 – Stationary Storage Containers for Compressed Gases
EU 97/23/EC	Directive of the European Parliament and of the Council on the Approximation of the Laws of the Member States Concerning Pressure Equipment
ESD S20.20	For the Development of an Electrostatic Discharge Control Program for – Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)
IEC 60807-1	Rectangular connectors for frequencies below 3 MHz
IEC 61131-2	Programmable controllers – Part 2: Equipment requirements and tests
IEC 61131-3	Programmable controllers – Part 3: Programming languages
IPC J-STD-001	Requirements for Soldered Electrical and Electronic Assemblies, Performance Class 3

IPC J-STD-001(S)	Joint Industry Standard, Space Applications Electronic Hardware Addendum to IPC J-STD-001, Requirements for Soldered Electrical and Electronic Assemblies
IPC 2221	Generic Standard on Printed Board Design
IPC 2222	Sectional Design Standard for Rigid Organic Printed Boards
IPC 2223	Sectional Design Standard for Flexible/Rigid-Flexible Printed Boards
IPC 2252	Design Guide for RF/Microwave Circuit Boards
IPC 6011	Generic Performance Specification for Printed Boards
IPC 6012	Qualification and Performance Specification for Rigid Printed Boards
IPC 6013	Qualification and Performance Specification for Flexible/Rigid-Flexible Printed Boards
IPC 6018	Qualification and Performance Specification for High Frequency (Microwave) Printed Boards
IPC/WHMA-A-620	Requirements and Acceptance for Cable and Harness Assemblies
IPC/WHMA-A-620-S	Space Applications Electronic Hardware Addendum
ISO 1219	Fluid power systems and components - Graphical symbols and circuit diagrams
ISO 4126	Safety devices for protection against excessive pressure
ISO 17491	Protective clothing – Test methods for clothing providing protection against chemicals
	Part 1: Determination of resistance to outward leakage of gases (internal pressure test)
	Part 2: Determination of resistance to inward leakage of aerosols and gases (inward leakage test)
	Part 3: Determination of resistance to penetration by a jet of liquid (jet test)
ISO/TR 10771-2	Hydraulic fluid power – Fatigue pressure testing of metal pressure-containing envelopes – Part 2: Rating methods
NEMA HP 7	Electrical and Electronic PVC, PVC/Nylon, and PE/Nylon 105ºC Hook-Up Wire, Types B, C, D, BN, CN, and DN (600, 1000, and 3000 V), and Types J and JN 75ºC (600V)

NFPA 59A	Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)
NFPA 70	National Electrical Code
NFPA 70E	Standard for Electrical Safety in the Workplace
NFPA 496	Standard for Purged and Pressurized Enclosures for Electrical Equipment
NFPA 497	Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas
NFPA 1991	Standard on Vapor-Protective Ensembles for Hazardous Materials Emergencies and CBRN Terrorism Incidents
NFPA T2.6.1	Fluid power components – Method for verifying the fatigue and establishing the burst pressure ratings of the pressure containing envelope of a metal fluid power component
SAE AMS 2759	Heat Treatment of Steel Parts, General Requirements
SAE AMS 2759/9	Hydrogen Embrittlement Relief (Baking) of Steel Parts
SAE AMS 2774	Heat Treatment Wrought Nickel Alloy and Cobalt Alloy Parts
SAE AMS-DTL-23053/5	Insulation Sleeving, Electrical, Heat Shrinkable, Polyolefin, Flexible, Crosslinked
SAE AMS-H-6875	Heat Treatment of Steel Raw Materials
SAE ARP 1658	Hose Assemblies, Installed, Visual Inspection Guide For
SAE AS 22759	Wire, Electrical, Fluoropolymer-Insulated, Copper or Copper Alloy
SAE AS 50151	Connectors, Electrical, Circular Threaded, AN Type, General Specification for
SAE AS 50861	Wire, Electric, Polyvinyl Chloride Insulated, Copper or Copper Alloy
SAE AS 5942	Marking of Electrical Insulating Materials
SAE CMH-17	Composite Materials Handbook-17
SAE J518	Hydraulic Flanged Tube, Pipe, and Hose Connections, 4-Screw Flange Connection

SMACNA 1958	Sheet Metal and Air Conditioning Contractors' National Association HVAC Systems Duct Design
UL 207	UL Standard for Safety Refrigerant-Containing Components and Accessories, Nonelectrical

2.3 Order of Precedence

This standards manual does not supersede or waive established Agency requirements found in other documentation. Conflicts between this standards manual and applicable documents cited herein will be resolved by the responsible Technical Authorities. The following is the order of precedence:

1. Federal, state, and local laws and regulations
2. Agency and Center Directives
3. Agency mandatory standards

3. DEFINITIONS

For the purpose of this document, the following definitions apply.

analysis: use of calculations, numerical simulations, tools, techniques, and physics/engineering-based modeling to determine that the requirement is satisfied.

Rationale: Engineering analysis proceeds by (1) separating the engineering design into the components and disciplines, (2) analyzing or estimating each component of the operation or failure mechanism separately, and (3) recombining the components in accordance with physics and engineering principles. The methods selected must be supported by appropriate technical rationale and be documented in detail.

brittle metal: metallic material with an elongation at the maximum load in a standard tensile test of less than 5.0% at both the design temperature and the testing temperature.

Note that this is NOT the elongation at failure/elongation at fracture in the standard tensile test. That is the value that is typically reported and tabulated. The elongation at maximum load/maximum engineering stress is the basis of the criteria (ASTM refers to this as the Uniform Elongation).

catastrophic failure: failure that results in serious injury, damage to flight hardware, loss of mission, or major damage to a significant ground asset.

certified: having successfully completed a program-approved Design Certification Review (DCR) process with documented evidence to satisfy a set of specific design requirements and functional/performance requirements approved by the cognizant Technical Authority.

Rationale: Certification remains valid only if the supporting documentation demonstrates that the design meets all the original design requirements (KSC-DE-512-SM, *NASA-STD-5005, etc.) and performance requirements (weight, load capacity, flow rate, interface, etc.) of its original certification. Any waivers will be reevaluated against current requirements by the current Technical Authority.*

commercial off-the-shelf (COTS): equipment, including hardware and associated software, that is commercially available from a vendor and built to industry specifications. This includes items purchased as a standard off-the-shelf part with options available to any purchaser. Items purchased against a Government design specification or drawing, or custom-made by a vendor for NASA, are not COTS. The selection of COTS for use in GS is required to meet the design requirements of this standards manual and the performance and safety requirements of the system.

Rationale: The design and fabrication of COTS is not covered by this standards manual. However, utilization of COTS in GSE systems is covered in Section 4. Design activities, such as writing a specification or statement of work or creating drawings, do not fall under the definition of COTS because the procuring agency—not the commercial entity— is then taking responsibility. Commercial items or components should be used when they satisfy the GS function and will not degrade the safety or reliability of the ground or flight system. Requirements should be specified in terms of functionality or performance rather than design. To qualify as COTS, equipment must not be modified (see MOTS).

conventional structures: structures composed predominately of standard structural shapes and connections typical of commercial or residential construction, such as office buildings, warehouses, machine shops, and other facilities whose structures are characterized by well-established design precedents and loading conditions. Conventional structures typically comprise facility structures, permanent launch pad structures, mobile launcher towers, mobile launcher base/platforms, and GSS structures.

corrosive environment: a marine (seacoast) or launch-induced environment that causes accelerated degradation of materials as a result of oxidation or chemical reaction.

Rationale: In the corrosive marine (seacoast) environment at KSC, the most common sources of corrosion are moisture and sodium chloride. The launch-induced environment also introduces hydrochloric acid, which exacerbates the corrosive effects of the marine environment.

critical: loss of function or improper performance could result in serious injury, damage to flight hardware, loss of mission, or major damage to a significant ground asset.

Rationale: GSE systems are typically considered to be critical.

criticality: a program-defined measure of the consequences of a failure mode.

Rationale: Criticality of a GS is determined by an S&MA or KSC Engineering analysis of the equipment's function and application. The classifications assigned to the GS will guide the design team in determining which specifications and standards to apply, which materials to select, and how to document the GS.

demonstration: a verification method that determines the properties on an end item by observation of its operation. This method is generally employed where qualitative operational performance is to be verified. A demonstration must be witnessed and documented.

design life: the operational life of equipment (to include storage life, installed life in a nonoperating mode, and operational service life), after which the equipment will be replaced or recertified. It is the responsibility of the program/project to determine recertification requirements, which may include refurbishment, analysis, or test.

ductile metal: metallic material with an elongation at the maximum load in a standard tensile test of greater than 5.0% at both the design temperature and the testing temperature.

facility: land, buildings, structures, and other real property improvements, including facility systems (utility systems and collateral equipment). Facility systems include heating, ventilation, and air conditioning (HVAC); 60 hertz (Hz) power; potable water; elevators; lighting; shop air; etc. Facility systems may support or have interfaces with GS. The term *facility* does not include GSE, GSS, facility GSS, tools, or special test equipment.

factor of safety: a constant that has been defined for yield and ultimate design criteria and that is the ratio of the yield or ultimate design loads to the limit load (the maximum allowable design load). If the factor of safety is defined in terms of stress, it is the ratio of the ultimate or yield stress to the maximum design stress. In fatigue design, it is the ratio of the calculated fatigue life to the allowable design life. This standards manual specifies the minimum factor of safety for GS for specific structural applications (e.g., pressure vessels, threaded fasteners, and aluminum structures).

Rationale: This definition is consistent between ground hardware and flight hardware. This definition is inherently load-based. It reduces to the traditional stress-based definition in the simplest case.

find number: a reference number assigned to designate an item on the field of the drawing, in lieu of using the item's part or identifying number. It is entered as a cross-reference to the line of the parts list where the item's actual part or identifying number and description are given.

Reference designations for electrical and electronic parts and equipment, in accordance with ASME Y14.44, may be used as find numbers.

flight hardware: hardware intended for launch into space, including boosters, engines, payloads, and manned or unmanned components.

form, fit, or function: a collection of physical attributes that fully define the interface with outside entities. Form, fit, and function are defined together because of their effect on GS certification. Form is the outer shape where it can interface with facilities, other GS, flight hardware, or human operators. Fit is related to form but includes dimensional tolerance and compatibility. The form and fit of GS include outer shape, dimensional tolerance, connections (structural, mechanical and electrical connections), and every other externally measurable feature. Function is the description of the behavior of the GS including force, speed, timing, voltage, current, flow, pressure, safety factor, overcurrent protection, grounding, software, etc.

Changes to form, fit, or function define when GS certification in invalidated or requires an updated certification for use.

fracture-critical: classification of hardware where a crack could lead to a failure that results in serious injury, damage to flight hardware, loss of mission, or major damage to a significant ground asset.

ground support equipment (GSE): nonflight equipment, systems, or devices specifically designed and developed for a direct physical or functional interface with flight hardware.

Rationale:

- *Production equipment used during the manufacturing of flight hardware is not considered to be GSE. Each program defines when manufacturing ends and processing of the flight hardware begins. If production equipment is to be used for flight hardware processing, it must be designed to meet GSE requirements.*

- *GSE does not include tools that are designed for general use and not specifically for use on flight hardware. Examples: ratchets and sockets, multimeters, screwdrivers, etc. (see "tool" definition in this document).*

- *Equipment that has a physical interface; but not a functional interface with flight hardware; may be exempted from GSE design, fabrication, and certification requirements by the Technical Authority. Examples: dust covers, inspection tools, bolt alignment guides, etc.*

- *Any item that makes physical contact with flight hardware requires evaluation for material compatibility, electrostatic discharge (ESD), and other materials and process (M&P) requirements from the processing M&P authority and the flight hardware M&P authority.*

ground support system (GSS): equipment or infrastructure (portable or fixed) that provides functional or physical support to GSE. It does not directly interface with flight hardware, although it may supply commodities, power, or data that eventually reaches the flight hardware after being conditioned or controlled by GSE.

Rationale: Design standards for GSS may be similar to or, at the discretion of the program/project, identical to the design standards for GSE. Protective features designed into the GSE prevent failures from propagating to flight hardware.

ground systems (GS): GSE, GSS, and facility GSS.

inspection: measurement or examination of one or more characteristics of a product or service and comparison with specified requirements to determine conformity.

limited-life item: equipment or component that degrades as a result of operating time, cycling, or material aging and that has a shorter lifetime than the system's design life. Limited-life items require periodic replacement or refurbishment, which must be defined in design and maintenance documents. This does not include items that require periodic calibration or are replaced as part of normal maintenance and wear-and-tear.

modified off-the-shelf (MOTS): commercially available equipment, including hardware and associated software and procedures, modified for a specific application in GS.

Rationale: Modification of COTS voids the design intent of the original equipment and places responsibility for performance, functionality, and reliability on the designer.

M&P, M&P Technical Authority: NASA or NASA-approved cognizant engineer/scientist with authority to approve deviations from materials and processes requirements in this standards manual. In general, the phrase, M&P Approval, refers to the cognizant materials and processes engineer who approves design drawings and documents. The M&P Technical Authority is the single materials and processes engineer with delegated technical authority from the KSC Chief Engineer.

Rationale: This standards manual includes many specific requirements that may be modified or interpreted by the NASA M&P engineer or the NASA M&P Technical Authority (M&P Chief Engineer).

nonconventional structures: structures that are not within the scope of voluntary consensus standards for structural design such as standards issued by American Institute of Steel Construction (AISC), the Aluminum Association, or American Society of Mechanical Engineers (ASME). Nonconventional structures are experimental in nature and employ members and connections that are predominantly atypical to commercial structures. Structures are nonconventional if the primary loading is outside the scope of commercial standards or is difficult to accurately define, such as launch acoustics, pyrotechnic, launch vibration, rocket exhaust, T-0 release. Nonconventional structures lack established design precedent in commercial codes and are subject to frequent modifications to support changes in the operational requirements. Nonconventional structures typically comprise hold down posts/vehicle support posts, umbilical connections to flight hardware, umbilical mechanisms, GSE structures, and GSE mechanisms. Umbilical swing arm structures, tilt-up arm structures, tail service mast arm structures, etc., may be conventional or nonconventional depending on design member and joint details and the dominant loading.

Rationale: The transition region between conventional and nonconventional structures should be designed to meet the criteria for both types of structure.

oxygen-enriched: containing more than 23.5 percent oxygen.

Rationale: Other standards such as those published by the National Fire Protection Association (NFPA) or the Occupational Safety and Health Administration (OSHA) differ from the definition in their specification of oxygen concentration (22%). Dry air is approximately 21% oxygen.

safe working load: the maximum assigned load the device or equipment can operationally handle and maintain. This value is marked on the device, indicating maximum working capacity. This is also the load referred to as "rated load" or "working load limit". If the device has never been downrated, this also is the "manufacturer's rated load".

special test equipment (STE): equipment designed for limited or one-time use in a variety of applications. STE is classified as GSE or GSS and is designed to the requirements of this standards manual.

Rationale: Although its use is limited, STE has the potential to cause damage to flight hardware or injury to personnel. STE includes equipment traditionally known as shop aids.

successful history of prior use: NASA or NASA contractor experience without structural failures for the service life of a fluid system or the length of the program supported by the system. Alternatively, "successful history" is successful experience used in support of NASA programs by commercial entities.

Technical Authority: a NASA employee, at a delegated level of authority, who provides independent oversight of programs and projects in support of safety and mission success. Technical Authority delegations are formal and traceable to the NASA Administrator. Technical Authorities are funded independently of a program or project.

testing: an activity that determines an item's ability to meet specified requirements by subjecting the item to a set of physical, chemical, environmental, or operating actions or conditions. It includes measurements taken with certified and calibrated tools in accordance with generally accepted scientific or engineering principles.

tools: standard off-the-shelf items, not specifically designed by or for NASA, used to service ground or flight systems that are not integral to the system being serviced. Items custom-made or modified to meet NASA specifications are not tools, are considered GSE or GSS, and are subject to the design requirements of this standards manual.

Rationale: Tools are not designed to specifically interface with flight hardware, nor are they designed to perform a function specific to flight hardware. Their design and general use in industry include a variety of applications that may be required on flight hardware or GSE. Tools are intended for use by trained technicians and facilitate manual operations, such as torqueing fasteners, cutting wire, checking electrical continuity, or verifying surface clearances. Examples of tools include torque wrenches, ratchets, sockets, voltmeters, go/no-go gages, screwdrivers, wire cutters, and pliers.

traceability: the data, reports, and records that document the history of a product or component from the point of origin to final use.

Rationale: Documentation may include the origin of materials and parts and certification of personnel and processes during fabrication, assembly, procurement, installation, activation, verification, and validation.

validation: a two-part process to confirm first that the design requirements comply with the stakeholders' expectations and second that the final product complies with operational requirements.

Rationale: Validation answers the question, "Does it do what the stakeholders/users/customers want it to do?"

verification: proof of compliance with design solution specifications and descriptive documents. Verification may be determined by a combination of test, analysis, demonstration, and inspection.

4. GENERAL REQUIREMENTS

In order to meet customer requirements, individual system and equipment design projects may need to meet criteria that are more stringent than those specified herein. In such cases, these criteria should be determined by the responsible design organization in consultation with the customer and other stakeholders (e.g., users and operators).

4.1 Use of Alternative Equipment in Ground Systems

4.1.1 Use of COTS Equipment in Ground Systems Design

COTS equipment should be used to the maximum extent possible when (1) it satisfies the intended function, (2) it will not degrade the safety or reliability of the flight or GS, and (3) it provides a cost savings that exceeds possible cost increases that may result from unique maintenance or logistics requirements, modifications, or an increase in the complexity of the interfacing equipment.

4.1.1.1 COTS M&P Requirements

COTS shall be evaluated for acceptability from an M&P standpoint and in its intended environmental conditions (temperature, humidity, etc.).

4.1.1.2 COTS Rating

COTS incorporated into GS shall be used within the manufacturer's specified limits.

COTS incorporated into pressure vessels and pressurized systems (PVS) is required to meet requirements of NASA-STD-8719.17.

4.1.1.3 COTS Documentation

Vendor documentation shall be provided as evidence that the requirements of this standards manual have been met.

Vendor or contractor documentation and supporting test data should be incorporated into system control documents.

4.1.1.4 COTS Qualification

Qualification tests and inspections shall be indicated in the engineering documentation to satisfy electromagnetic compatibility (EMC), vibration, and acoustic requirements that are not satisfied by vendor documentation.

Program and project EMC, vibration and acoustic requirements apply to COTS equipment utilized in GS. When program requirements exceed vendor specifications for vibration, acoustics and electromagnetic interference (EMI), mitigations must be taken. Mitigations such as EMI rated enclosures and shielded cabling should be utilized to meet EMI requirements. Vibration isolation should be used to meet vibration and acoustic requirements.

4.1.1.5 Modifications to COTS

Modifications to COTS shall be performed in accordance with this standards manual.

Modification to PVS is required to meet NASA-STD-8719.17 and may no longer be considered COTS.

4.1.2 Use of Flight Hardware in Ground Systems

Flight hardware will be considered acceptable to use as GS or as a component within GS if it meets all NASA flight hardware requirements.

Note that there are additional requirements in NASA-STD-8719.17 and NASA-STD-8719.26 for PVS converted from flight to ground use.

4.1.3 Use of Flight Hardware Design Standards for Ground Systems

GS or components in GS designed in full compliance with NASA flight hardware standards are considered to be in accordance with this standards manual.

Those GS or components are designed as if they are flight hardware with all required inspections, lot traceability, testing, etc. Verification of the flight hardware requirements would then occur during the certification just as the ground requirements are verified during the GS certification (System Acceptance Review or DCR).

4.1.4 Rotational or Production GSE

Rotational GSE or flight hardware production equipment used as GSE shall be approved by the KSC Engineering Technical Authority before use at KSC if the equipment was not designed and certified in accordance with NASA-STD-5005 or this standards manual.

GSE designed to NASA-STD-5005 or an Office of Primary Responsibility-Designee approved tailored version of NASA-STD-5005 does not require approval.

4.2 Design for Operational Requirements

The GS design will support the program/project-specific operational requirements of flight systems.

In addition to operational requirements, GS should be designed for ease of production, manufacturing, construction, and inspection. GS should be designed to minimize the complexity and frequency of maintenance. Close manufacturing tolerances should be avoided unless required by design and performance.

4.3 Ground System Degradation and Contamination

GS shall not degrade, contaminate, electronically interfere with, or otherwise damage flight systems, other GS, subsystems, or experiments while it is being used, checked out, serviced, or otherwise handled.

4.4 GS Design for Access

GS design will include access provisions for handling, servicing, calibrating, maintaining, and replacing components and limited-life items.

GS design should provide for ease of operation, maintenance, local isolation valves, servicing, cleaning, and inspection of hardware and software. GS fault detection and isolation should be considered based on criticality and cost of failures.

4.5 Interfaces

a. GS will meet the requirements of all interfaces with new or existing hardware or software as documented in interface control documents or any other documentation that controls interface requirements.

Interfaces should be verified by test, analysis, or both. As a design goal, the number of connections at interfaces should be minimized.

b. Fluid, mechanical, or electrical connections in close proximity will be designed to prevent cross-connections.

Unique design configurations and clear identification marking should both be used to minimize the probability of incorrectly mating connections. Design configurations include threads, flanges, sizes, orientation (male/female, left-hand, right-hand), pins, and keys. Identification marking (see 4.8) should indicate function, commodities, pressure, reference designator, etc.

c. GS will be compatible with all facility interfaces.

An assessment may be necessary in order to determine whether it is more cost-effective to modify the facility interface or design the GS to meet the existing facility interface. Some GS interfaces directly to the facility and some GS interfaces to GSS.

4.6 Design Life and Heritage Hardware

4.6.1 Design Life

GS will be designed for the operational life specified by program or mission requirements and identified in design drawings and maintenance documents.

Engineering documentation should specify maintenance requirements to meet design life.

4.6.2 Heritage Hardware

Existing GS verified to meet the GS requirements of a previous NASA program shall be considered acceptable for use without further verification against the requirements of this standards manual.

GSE requirements for previous NASA programs are defined in SW-E-0002, NASA-STD-5005, SSP 50004, or a previous edition of this standards manual. The design life limitations of the heritage equipment still apply. This requirement is verified by documentation of the previous verification/certification (DCR).

4.7 Limited-Life Items

Items with limited life shall be identified in design documentation and annotated with the specific limitation to the life of the item.

Use of items with a projected lifetime that is less than the design life of the GS for which the items are intended should be avoided whenever possible. Elapsed time or cycle indicators should be employed to accumulate operational time or cycles for limited-life items. The age of items that are installed in a nonoperating mode should also be tracked.

4.8 Identification, Marking, and Labeling

4.8.1 Colors

The colors in Appendix B shall be used for GS designed and painted for NASA/KSC.

If the equipment is COTS, the colors in Appendix B should be used as guidance to make equipment consistent with other GS.

4.8.2 Marking and Labeling

a. GS shall be identified and marked in accordance with KSC-STD-E-0015.

GS and line replaceable units should be marked in accordance with KSC-STD-E-0015. There are several reasons a part should not be marked: the part number will not fit on the part using 1/8 in. characters; the marking will be damaged during assembly; it is part of an inseparable assembly. Marking of individual assembly parts is at the discretion of the designer.

b. GS for PVS shall be identified and marked in accordance with KNPR 8715.3-1.

4.8.3 Load Capacity Marking

GS used for transportation, handling, and personnel access shall be conspicuously marked to indicate the maximum safe working load in accordance with KSC-STD-E-0015 and for lifting equipment with NASA-STD-8719.9.

4.8.4 Serial Numbers

Serial numbers or other unique identifiers shall be marked on those parts, components, or assemblies that contain limited-life items or that require periodic inspection, checkout, repair, maintenance, servicing, or calibration (e.g., pressure relief devices, pressure transducers or gages).

Reference designators (A-numbers) are used to identify location or function and cannot be used as unique identifiers.

4.9 Interchangeability

Hardware assemblies, components, and parts with the same part number will be physically and functionally interchangeable.

4.10 Safety and Health

All GS will be designed and fabricated in accordance with 29 CFR 1910, 29 CFR 1926, NPR 8715.3, NPR 8715.1, and NPR 1800.1.

4.10.1 Hazard Analysis

A hazard analysis will be conducted in accordance with program-defined methodology as part of the GS design process to identify, mitigate, and control hazards. In the absence of a program-defined methodology, KNPR 8700.2 will be used.

4.10.2 Safety and Health Requirements on KSC Property

GS to be used at KSC will meet the safety requirements of KNPR 8715.3-1 and the health requirements of KNPR 1840.19.

4.10.3 Safety Requirements on Air Force and Space Force Property

GS to be used on Air Force and Space Force property will meet the requirements of AFSPCMAN 91-710.

4.10.4 Safety Requirements on Other NASA Property

GS to be used at other NASA facilities will meet the safety requirements of those facilities.

4.10.5 Caution and Warning Indications

GS shall provide caution and warning indications to alert personnel of impending or existing hazards.

GS should be designed to allow efficient implementation of applicable lockout/tagout requirements per 29 CFR 1910.147.

GS caution and warning indications (e.g., indicator lights, warning signals, labels, placards, etc.) should be designed in accordance with FAA-HF-STD-001.

4.10.6 Fall Protection

GS designs shall incorporate fall protection as required by 29 CFR 1910, 29 CFR 1926, NPR 8715.1, KSC-STD-S-0033 and ANSI/ASSP Z359.

4.10.7 Hazmat Suits

Hazmat suits, also known as self-contained atmospheric protective ensemble (SCAPE) suits and propellant handler's ensemble (PHE), shall conform to NFPA 1991, Level A, or to ISO 17491 (-1, -2, or -3), and as required by 29 CFR 1910.120, Appendix B.

4.11 Reliability

GS should be designed to minimize the probability of system failure and reduce the severity of the failure effect of the system, including failures caused by operator errors and human-system interaction.

Procedures and instructions to perform and document analyses, such as Failure Mode and Effects Analysis/Critical Items List or sneak circuit analysis, will be in accordance with Program requirements or KNPR 8700.2.

4.11.1 Redundancy

a. Critical redundant hardware systems, subsystems, or components shall be physically oriented or separated such that the failure of one will not prevent the other from performing its intended function.

b. Critical redundant hardware and software systems, subsystems, or components shall be designed such that common-cause failures (e.g., contamination, vibration, EMI) do not simultaneously eliminate redundancy.

c. The design of critical redundant hardware systems shall provide methods for verifying each redundant element without compromising the reliability of the redundant system.

Simultaneous failure of identical components is not considered a credible failure of redundancy unless the failure is a result of a simultaneous effect such as contamination, launch vibration, software, or EMI. Common software used across redundant strings is vulnerable to common cause failure. However, rigorous verification testing may reduce the risk to acceptable levels.

4.11.2 Failure Tolerance

a. GS; except primary structure and the pressure boundary of piping, tubing, and vessels; shall be designed to sustain a failure without causing loss of life or damage to support equipment, facilities, or flight hardware (fail-safe).

Failure tolerance is not possible for primary structure and the pressure boundary of piping, tubing, and vessels. The safety of these systems is achieved by applying design requirements contained in this standards manual and Design for Minimum Risk.

More stringent fault-tolerance requirements (e.g., two-fault tolerance for loss of flight crew) may be applicable depending on program requirements. GS should be designed such that no single failure/inadvertent operator action results in injury or in damage to or loss of ground equipment, flight equipment, or facilities. Failure modes/inadvertent operator actions are controlled using a systematic application of approved standards and design margins.

GS may be designed to terminate operations autonomously after the first failure or inadvertent operator action and in time to preclude any scenario that results in loss of life. This approach is consistent with the historical use of the term "fail-safe" in GS design.

b. GS shall be designed to sustain a failure and still perform its basic function (fail-operational) when necessary to meet safety or operational requirements.

Purges, ground special power, and launch release systems are examples of systems that interface with other systems whose loss would propagate failures. Requirements for availability of system functions during launch processing may necessitate fail-operational design.

c. GS failure modes/inadvertent operator actions with the potential for loss of flight crew will be addressed in accordance with NPR 8705.2.

4.11.3 Failure Propagation

GS shall be designed such that failures will not be propagated to the flight systems.

The design of GS should consider how flight hardware/software failures could propagate through the GS and affect other flight systems (vent systems, etc.).

4.11.4 System Safety and Reliability Analysis

System Safety and Reliability Analyses will be performed concurrently with GS designs in accordance with Program-defined methodology or KNPR 8700.2.

4.11.5 Modeling and Simulation of Critical GSE

When invoked by a program, NASA-STD-7009 will be used for mathematical modeling and simulation of critical GSE that is not verified by the results of testing.

This requirement applies to physics-based modeling and simulations only (e.g., finite element analysis and computational fluid dynamics) and does not apply to descriptive modeling such as computer-aided design models, visualization models, or software models.

4.12 Environments

GS shall be designed to perform in the natural and artificial environments to which it will be subjected during its life cycle.

4.12.1 Natural Environment

4.12.1.1 Natural Environment Specification

GS used or stored in an exterior environment shall be designed to function after exposure to the natural environment at its respective geographical location as specified in NASA/TM-2008-215633 or a Program specified natural environments document.

Specifications in NASA/TM-2008-215633 may be tailored to reflect program-defined risk and exposure times, including operation within the launch commit criteria of the vehicle. Purging enclosures to protect GS components from the natural environment should be considered essential, in addition to purging enclosures in hazardous areas as required in 9.14. Programs may substitute a specific document for natural environments based on their own requirements.

Wind loading for facility type GS should be designed for wind loads using ASCE-7.

4.12.1.2 Solar Natural Environment

In the absence of either a Program specified document or a specific calculation of solar heating, the following surface temperature increments shall be used to calculate the effects of direct solar heating:

	Bare Metallic Surface or Dark Painted Surface	White Painted Surface
Peak Temperature for Exposure	Ambient +36C (+65F)	Ambient +19C (+35F)
Average Surface Temperature for Heat Transfer	Ambient +22C (+40F)	Ambient +14C (+25F)

These are the maximum temperatures for a high temperature loads case. For minimum temperature cases, it is typically conservative to assume no solar heating. Peak temperature is the highest temperature at a point on the surface. It would be used for exposure limits or for *material allowable stress. Average surface temperature is spatially averaged around a cylinder where one side is exposed to maximum solar radiation and the remaining surface is exposed to background diffuse solar radiation. Average Temperature is used for heat transfer calculations.*

4.12.2 Interior Environment

GS designed to function within a controlled interior environment shall be designed to either the specified design environment for its installation and use location or the following temperature and humidity requirements:

- Continuous: Temperature range of +15 °C (60 °F) to +28 °C (82 °F) and humidity nominally 55%, within a range of 30% to 80%.
- Outage: Temperature range of +11 °C (52 °F) to +40 °C (104 °F) with up to 95% noncondensing humidity for a maximum of 4 hours.

Some uncontrolled interior environments exceed the most severe exterior environment (e.g., an enclosed trailer or shed or an unconditioned mobile launcher base). An uncontrolled interior environment may be 11 °C (20 °F) above the temperature for the exterior natural environment with the humidity of the natural environment.

Note that HVAC systems should be designed to the ASHRAE Fundamentals IP Handbook, ASHRAE HVAC Applications IP Handbook, and ASHRAE HVAC Systems and Equipment IP Handbook.

4.12.3 Vehicle Assembly Building Environment

GS stored and used in the Vehicle Assembly Building (VAB) or similar KSC facilities without HVAC shall be designed for the following environmental conditions:

- The exterior humidity environment, 20% relative humidity to 99% noncondensing relative humidity in the absence of a Program requirement
- No rain or solar heating
- The extreme temperature range for short-term exposure and storage from 4 °C (38.8°F) to 34 °C (93.4 °F)
- For thermal and heat transfer calculations, the minimum and maximum temperatures of 8 °C (46.4 °F) to 30.5 °C (87.2 °F) for durations greater than one hour

These temperatures are based on twelve consecutive years of collected data. NASA TM-2014-281335 contains historical VAB temperature and humidity data and may be used for specific operations and to extract the diurnal temperature profile for long-duration thermal calculations.

4.12.4 Fire/Explosion Hazardproofing

If GS is operated in locations where fire or explosion hazards exist, as defined by NFPA 70, Article 500, it shall be hazardproofed in accordance with the requirements in KSC-STD-E-0002.

Hazardous commodities are classified in NFPA 497. Oxidizers used in spaceflight programs are not classified. Nitrogen tetroxide (N_2O_4) should be treated as Class I, Group C. Oxygen should be treated as Class I, Group D.

Rooms containing GSE with a hazardproofing positive pressure should be designed for 750 Pa (3 in. of water) pressure to account for degradation in seals, corrosion, changes in temperature, etc., over the life of the design to guarantee a positive pressure per 9.14.d.

4.12.5 Environmental Test Methods

Test methods and conditions required for testing and qualification of GS components for natural environments shall be in accordance with KSC-STD-164.

MIL-STD-810 covers most environmental test methods. The technical authority decides which tests apply to individual components or subsystem.

4.12.6 Seismic Environment

GS used in a seismically active areas shall be designed to resist the location-specific effects of a seismic event using the criteria and guidelines in ASCE-7.

KSC and Cape Canaveral Space Force Station are not considered to be in a significantly seismically active area. Seismic design methods can be useful in designing and selecting facility systems within the Pad to account for launch-induced environments.

4.13 Launch Induced Environments

4.13.1 Launch-Induced Environment and Launch Loads

Launch induced environments and launch loads include vibration and acoustics created by engine ignition, buildup, launch, and also from GSE function such as umbilical arm retraction, pyrotechnic devices release, etc.

a. GS required to function during or after exposure to the launch-induced environment shall be designed to withstand the environment defined in program-specific documents.

b. Testing of GS for launch-induced environment shall be applied in accordance with KSC-STD-164.

The technical authority decides which tests apply to individual components or the subsystem.

c. GS not required to function after exposure to the launch-induced environments or after launch loads shall not cause damage, generate FOD, or create a hazard to flight hardware, facilities, other GS, personnel, or the environment.

4.13.2 Launch Vibration Loads

In the absence of a Program-specified vibration load requirement, GS shall be designed to withstand the predicted launch vibration environment in accordance with one of the following methods:

This requirement applies to GSS and GSE subsystems, not primary launch pad or mobile launcher structures.

- Full response analysis using the predicted power spectral density (PSD) from 2 to 2000 Hz for structural GS.
- Static analysis using the structural requirements of this standards manual with an applied load of three times the gravity root mean squared acceleration (also known as GRMS) from the predicted PSD from 2 to 2000 Hz for structural GS.
- Vibration test with the predicted PSD plus an additional 3dB from 2 to 2000 Hz for a duration of 10 seconds for one planned launch plus 5 seconds per additional launch in the GS design life per axis/direction or a Program-specified duration for structural GS or for active GS components.

If the predicted PSD is based on a small data set or is predicted without measurement, the 3dB value should be changed to 6dB to cover the added uncertainty. If the Program provided PSD is a qualification level PSD, then the test is performed at the provided PSD level without the addition of 3dB. The response analysis and equivalent static analysis would then use the qualification PSD minus 3dB or the value used to create the qualification PSD. The PSD in the units of g^2/Hz is the acceleration spectral density (ASD) for a vibration test.

The Technical Authority may approve alternate methods that meet the intent of the launch-induced loading.

Active components require vibration testing or qualification by similarity to other tested components. Active components include valves, filters, relays, circuit boards, terminal blocks, mechanisms, etc.

4.13.3 Launch Acoustic Loads

In the absence of a Program-specified vibration load requirement, GS components and assemblies shall be designed to withstand the predicted launch acoustic environment in accordance with one of the following methods:

Primary structure does not respond to acoustic loading. This requirement applies to GSS and GSE subsystems, pneumatic panels, electrical enclosures, or other lightweight structural assemblies with large collector areas. Individual components may be susceptible to acoustic *loads. Determining which components are susceptible requires insight into the construction of the component.*

- Individual components that are susceptible to acoustic loads are tested at the predicted acoustic level for a duration of 10 seconds for one planned launch plus 5 seconds per additional launch in the GS design life or a Program-specified duration.
- Complete systems and structures have a full response analysis using the predicted PSD above 2000 Hz.
- In the absence of an acoustic load analysis, subsystems and subsystem structures exposed to launch environments are designed for an equivalent static load of 2 psi pressure.

The 2 psi screening load has been used successfully for several NASA programs for structures small enough to react coherently to acoustic loads, such as pneumatic panels and frames and sheet metal enclosures. This load may be applied as a net load, but is generally applied as a pattern of +2 psi and −2 psi loads that create no net force on the structure's foundation or supports.

The Technical Authority may approve alternate methods that meet the intent of the launch-induced loading.

4.13.4 Launch Vibration and Acoustic Loads for Facility-Type Systems

Facility-type systems located within a launch environment will be selected and designed to account for the launch-induced environment.

To account for launch induced environments, facility systems located within the Pad perimeter should be selected and designed to the seismic requirements of ASCE-7 for the worst case location in the continental United States, classified as either non-building structures or nonstructural components, site class D with Importance Factor, Ip=1.5.

Equivalent static loads for facility type systems should use the following values:

- *Pad surface: +/-3.0 g in any direction.*
- *Mobile launcher base or tower, Launcher access tower: +/-5.0 g in any direction.*
- *Mobile launcher zero deck (blast deck) or within 5 feet of exhaust hole: +/-10.0 g in any direction.*

4.14 Human Factors

a. GS shall comply with human factors criteria established from FAA-HF-STD-001 based on human interaction with the system.

b. GS will comply with 29 CFR 1910.

Human factors criteria may be established by the design organization as a checklist or other simplified implementation of the FAA-HF-STD-001 standard.

4.15 Documentation

Documentation in Appendix C should be released and made available to the user.

4.15.1 Drawings and Specifications

a. Drawings and specifications required for the fabrication, construction, installation, modification, test, operation, maintenance, sustaining, and use of GS shall be prepared in accordance with drawing practices equal to or more stringent than the engineering drawing practices of ASME Y14.100 and KSC-GP-435, Vol. I.

For facility-format drawings (typically provided by A&E firms), the above requirement is met by applying KSC-GP-435, Vol. II, and the United States National CAD Standard from the National Institute for Building Sciences.

b. Fluid system schematics shall use symbols from KSC-STD-152-2 Revision C or ISO 1219.

c. Before beginning fabrication or contract award, drawings and specifications for fabrication shall be approved by the Technical Authority and put under configuration control.

Completed drawings and specifications in an unapproved state may be used for bidding purposes only.

4.15.2 Technical Documentation

Technical documentation (e.g., manuals and reports) will be prepared using KSC-DF-107 as a guide.

4.16 Spares and Limited-Life Items

a. GS design documentation shall identify limited-life items, spare parts, components, and materials necessary to support construction, fabrication, installation, test, and operation.

b. Limited-life items shall be controlled from the date of their manufacture through turnover, including the time they are in storage.

c. GS design documentation shall provide instructions for replacement of those parts, components, and materials.

4.17 Qualification

All critical components used in GS will undergo qualification to verify performance in their intended environment.

KSC-STD-G-0003 should be used for the qualification testing. Specific testing requirements for EMI, vibration, etc., are listed in other sections in this document. The lead designer is responsible to identify credible failure modes which then require qualification. Those decisions *are reviewed by both the Technical Authority and the Safety organization as part of the design review process. Approval of the engineering documentation is a record of this acceptance.*

4.18 Quality Assurance

Quality assurance is the function that verifies the compliance of hardware and software with specified requirements. Quality assurance includes quality engineering and quality inspection. KSC minimum requirements and best practices are given in KNPR 8730.2.

4.18.1 General

GS design will incorporate quality requirements in accordance with the program's/project's S&MA Plan.

4.18.2 Definition of Quality Requirements

Quality requirements shall be defined on the engineering drawings or in other technical documents that are included in the design, fabrication, or installation contract.

The design documentation should include special quality-related requirements, such as any special processes, certification of personnel or special testing that should be conducted, and any other special requirements that are necessary to produce a quality product.

4.18.3 Personnel Training

Certification documentation for required training of personnel performing processes during fabrication, assembly, installation, and testing of GS shall be maintained and made available as requested. Documentation includes but is not limited to welder qualification records, NDE personnel qualification records, performance continuity records, tubing fabrication training, etc.

4.18.4 Testing

a. Testing requirements shall be specified in engineering documentation.

b. Testing will verify compliance with the applicable specifications and the ability of the GS to perform its required design functions.

c. Test documentation, data, and results will be produced, maintained, and archived in accordance with KNPR 8730.2 and program or project requirements.

4.18.5 Metrology and Calibration

Metrology and calibration of the following will be in accordance with KNPR 8730.1:

a. All test equipment and tools used in support of fabrication, assembly, installation, and test of GS.

b. Instrumentation used for measurements for control and monitoring of GSE.

4.18.6 Quality Conformance Verification

Documentation shall be provided by the design organization (see Appendix C) to verify compliance with this standards manual in accordance with the program/project verification plan.

Test, analysis, demonstration, and inspection (including similarity) are recommended methods to verify that each requirement of Sections 4 through 10 has been satisfied.

4.19 Packaging, Handling, Storage, and Transportation

a. Requirements for packaging, transporting, shipping, and handling will be in accordance with NPR 6000.1.

GS should be designed to be transported by ground, air, or sea, using commercially available methods.

b. Transportation of pressurized GS shall be limited to GS with containers, vessels, and tanks designed, fabricated, and tested in accordance with 49 CFR.

4.19.1 Transportation Loads

a. Transportation equipment shall be designed so that loads imparted to flight hardware do not exceed 80% of the flight limit loads.

Transportation loads should be evaluated early in the design cycle since they may be the governing design load case.

b. In the absence of a Program document specifying transportation loads, transportation loads in Table 1 shall be used based on the mode of transportation.

Table 1. Transportation Loads

Transportation Method		Direction		
		Forward (g)	**Lateral (g)**	**Vertical (g)**
Transportation Method	**Boat/Barge**	±0.75	±1.0	+2.5/–0.5
	Air (nominal)	±3.0	±1.5	+3.0/–1.0
	Air (Crash)	+9.0/–1.5	±1.5	+4.5/–2.0
	Truck	±2.0	±2.0	+3.0/–1.0
	Rail, Humping	±30.0	±5.0	±15.0
	Rail, Normal Operation	±3.0	±1.5	+3.0/–1.0
	Dolly/Airbearing	±1.0	±1.0	±1.0
	Specialized multi-wheel, low speed transport vehicle (i.e. Kamag)	+1.0 braking -0.5acceleration	±0.25	+1.25/–0.25
	Forklift	±1.0	±0.5	+2.0/–0.0
	Crane/Hoist	±0.1	±0.1	±1.33

Note 1 – Vertical (+) acceleration is up, vertical (–) acceleration is down. (+) acceleration means the force (barge deck, truck bed, etc.) is pushing up on the GSE and flight hardware. To properly apply these (+) loads in an analysis tool or free-body diagram, the GSE/flight hardware is constrained at the barge/truck/train interface, and a load equal to the (+) vertical load factor is applied down in the direction of gravity.

Note 2 – All (+) loads or all (–) loads for a transportation method occur simultaneously in each of the three directions.

Note 3 – Loads are to be applied at logical center-of-gravity (CG) locations, including all mass in the load path, depending on what is being analyzed. The following is an example: An engine is being shipped in a container on a truck, and the engine is supported within the container by a support structure. Load factors are applied at the engine and support structure CG when analyzing the support-structure–to–container interfaces. Load factors are applied to the engine/support structure/container CG when analyzing the container-to-truck interfaces.

Note 4 – All vertical loads include 1.0g for gravity.

4.19.2 Shipping and Storage Containers

a. Containers designed to protect or transport flight hardware or critical GSE will be compatible with onsite transportation, handling, and storage methods.

b. Container attachment points will be provided for crane hoists and tie-downs.

c. Containers will be marked in accordance with NPR 6000.1 so that contents can be identified without opening the container.

Containers should be designed so that indicators that require monitoring (e.g., desiccants, humidity monitors, shock meters, and tilt meters) can be monitored without opening the shipping container.

Containers having a gross weight of more than 65 kilograms (144 lb.) should be provided with integral skids or pallets for shipment.

4.19.3 Parts Protection

a. Procedures will be employed to protect parts during manufacturing and in-plant handling and storage.

Any procedures, methods, materials, and devices (such as carts, boxes, containers, or transportation vehicles) that are used to protect parts should be standardized to prevent damage to hardware.

b. Precision-cleaned parts will be packaged in accordance with NPR 6000.1 and program contamination control requirements.

4.19.4 Pyrotechnic Devices

a. The handling and storage of pyrotechnic devices will be in accordance with NASA-STD-8719.12 and KNPR 8715.3-1.

b. Design and installation of pyrotechnic firing circuits and devices shall be in accordance with MSFC-SPEC-3635.

5. MATERIALS AND PROCESSES

Approval by the responsible M&P authority of the engineering drawing authorizes deviations from M&P requirements of this standards manual. A Material Usage Agreement (MUA) approved by the responsible M&P authority may be used to document a material or process requirement deviation when the update to the engineering drawing is not imminent. A Material Usage Permit (MUP) is used for approving non-flight materials and equipment that are not covered by an existing cross-program document specifying materials and equipment used in and around flight hardware.

a. The design drawings shall be approved by responsible M&P authority.

b. M&P used in the design and fabrication of GS will be selected by considering the worst-case operational requirements for the particular application and the design engineering properties of the candidate materials.

For example, the operational requirements should consider operational temperature limits, loads, contamination, life expectancy, exposure to moisture or other fluids, corrosive environments, and launch-induced and natural environments. Properties that should be considered in material selection include mechanical properties, fracture toughness, flammability and offgassing characteristics, corrosion and stress corrosion resistance, thermal- and mechanical-fatigue properties, glass-transition temperature, mismatches between coefficients of thermal expansion, vacuum outgassing, fluid compatibility, microbial resistance, moisture resistance, fretting, galling, and susceptibility to electrostatic discharge and contamination.

c. All materials and processes will be defined by standards and specifications and be identified directly on the appropriate engineering documentation.

d. Composition and properties of all materials and parts will be certified by the manufacturer or supplier as required by the design drawing or the procuring document.

e. The Materials and Processes Technical Information System (MAPTIS) will be consulted to obtain material codes and ratings for materials, standard and commercial parts, and components that are used in hypergolic propellant or oxygen-enriched systems or that are exposed to ignition sources. M&P approval of the engineering drawing authorizes final use.

5.1 Flammability Control

Materials used for flammability control shall be nonflammable or self-extinguishing in their use configuration as defined by NASA-STD-6001, Test 1, Test 4, or Test 10.

Flammability control is the principle of material selection to specifically prevent the initiation or spread of combustion. Material flammability ratings and tests based on NASA-STD-6001 are available in the MAPTIS database for many materials.

The following materials or methods are also acceptable for flammability control:

- *Ceramics, metal oxides, and inorganic glasses are acceptable without prior testing due to their chemically inert nature.*
- *When a material is sufficiently similar (chemically and physically) to a material found to be acceptable by testing in accordance with NASA-STD-6001, this material may be used without additional testing if its use is approved by the responsible M&P authority.*
- *Materials whose flammability and self-extinguishing properties have been tested in accordance with NASA-STD-6001 under conditions more severe than those encountered in the use environment are acceptable without further testing, as in the following examples:*

- *Materials used in an environment with an oxygen concentration lower than the test level are acceptable without further testing (provided that the oxygen partial pressure is not greater than the partial pressure at the test level).*
- *Materials used in an environment where the oxygen concentration is greater than the test level should be retested or considered flammable.*
- *If a material passes the flammability test on a metal substrate, it should be used on metal substrates of the same thickness or greater.*
- *If the material will be used on a thinner or non-heat-sinking substrate (or on no substrate at all), it should be retested or considered flammable.*

Many situations arise in which flammable materials are used in an acceptable manner without testing, but such uses require mitigation practices and should be approved by the M&P authority. Guidelines for assessment and mitigation of hardware flammability characteristics can be found in JSC 29353.

5.2 Fungus Resistance

The use of elastomers and polymers in GS subjected to a humid environment (relative humidity equal to or greater than 60%) will be approved by the responsible M&P authority in accordance with the elastomeric material section of this document.

For GS used in a humid environment, material selection should meet one the following criteria:

- *Materials are selected from fungus-inert materials (Group I) identified in MIL-STD-810. Fluorocarbon polymers, ethylene tetrafluoroethylene (ETFE), and silicones are considered acceptable.*
- *Materials are used inside environmentally sealed containers with less than 60% relative humidity at ambient conditions, or materials are used inside electrical boxes where the temperature is always equal to or greater than the ambient cabin temperature, or only the edges of materials are exposed.*
- *Materials are tested for fungus resistance in accordance with MIL-STD-810 and receive a rating of 0 or 1.*
- *Materials are treated to prevent fungus growth in a manner that does not adversely affect the unit's performance or service life and are protected from environments that would leach out the protective agent.*

Materials not meeting one of these criteria should be identified in the design documentation along with any action required, such as periodic inspection, maintenance, or replacement of the material.

5.3 Nondestructive Evaluation

Typical nondestructive evaluation (NDE) methods include dye penetrant, magnetic particle, radiographic, ultrasonic, and eddy current testing. NDE inspection is not limited to these methods and may include additional methods such as leak testing, and advanced methods such as shearography and thermography, as required.

a. All NDE of welds shall be performed in accordance with the applicable welding specification.

b. Unless otherwise specified by a governing discipline standard (e.g., the ASME Boiler and Pressure Vessel Code or a standard of the American Institute of Steel Construction), qualification and certification of personnel involved in NDE shall comply with AWS D17.1.

c. NDE of nonfracture-critical base materials shall be in accordance with the ASTM test method appropriate for the product form.

d. NDE for fracture-critical metallic GS components shall be performed in accordance with NASA-STD-5009.

5.4 Metals

5.4.1 Carbon and Low-Alloy Steel

The ductile-to-brittle transition temperature exhibited in steels should be considered when using carbon and low-alloy steels in hardware operating in or exposed to low temperatures while in service. For some alloys; the transition temperature may be as high as the ambient temperature.

a. Because of their sensitivity to stress corrosion cracking (SCC), carbon and low-alloy steels heat-treated to strength levels at or above 1240 MPa (180 ksi) ultimate tensile strength (UTS) shall be approved by the responsible M&P authority.

b. Steel parts shall be heat-treated to meet the requirements of SAE AMS-H-6875 or SAE AMS 2759 or a process approved by the responsible M&P authority.

c. When acid cleaning baths are used for steel parts, the parts shall be baked in accordance with SAE AMS 2759/9 to alleviate potential hydrogen embrittlement problems.

5.4.2 Corrosion-Resistant Steel

a. Free-machining alloys such as Unified Numbering System (UNS) S30300 (type 303 stainless steel) and UNS S30323 (type 303Se stainless steel) used in corrosive environments shall be approved by the responsible M&P authority.

Standardized testing has shown 303/303Se stainless steel to be resistant to SCC. Local KSC environment testing has shown a susceptibility to SCC for these free-machining grades.

b. Cleaning, descaling, and passivating of stainless-steel parts, assemblies, equipment, and installed systems shall be in accordance with ASTM A967.

Note that ASTM A967 requires ASTM A380 for cleaning and descaling.

Unstabilized austenitic steels should not be used under conditions where the temperature is above 370 °C (700 °F) due to sensitization.

Welding should be performed only on low-carbon, stabilized grades or superaustenitic grades. Welding higher-carbon, unstabilized austenitic stainless steel can result in sensitization in the weld heat-affected zone. Exercise caution in using martensitic and ferritic stainless steels because these are susceptible to hydrogen embrittlement, corrosion, and stress corrosion. Austenitic stainless steels may be susceptible to pitting corrosion and crevice corrosion in a marine environment.

Hardware should be designed to avoid fretting or wear of stainless-steel alloys. Lubricants and lubricated coatings should be considered for use with stainless-steel materials in applications where they come into contact through a sliding movement.

Stainless-steel alloys (such as Nitronic 60) that resist galling should be considered as alternatives.

5.4.3 Aluminum

Hardware made with aluminum alloys should not be loaded through the short transverse grain direction because resistance to SCC is at a minimum in that direction.

a. Aluminum alloys used in structural applications shall be resistant to general corrosion, pitting, intergranular corrosion, and SCC.
b. Heat treatment processes specified for aluminum alloy parts will meet the requirements of a voluntary consensus standard approved by M&P for the specific application.

Common standards used for the heat treatment of aluminum alloys include SAE AMS 2770, SAE AMS 2771, and SAE AMS 2772.

5.4.4 Nickel-Based Alloys

a. Alloys with high nickel content are susceptible to sulfur embrittlement; therefore, any foreign material that could contain sulfur, such as oils, greases, and cutting lubricants, shall be removed before heat treatment, welding, or high-temperature service.
b. Heat treatment of nickel-based alloy parts will meet the requirements of SAE AMS 2774.

Some of the precipitation-hardening superalloys are susceptible to depletion of the alloying element at the surface in a high-temperature, oxidizing environment. This effect should be carefully evaluated when a thin sheet is used, since a slight depletion could involve a considerable proportion of the cross section of the material.

5.4.5 Titanium

a. Areas subject to fretting or wear shall be anodized or hard-coated using a wear-resistant material such as a tungsten carbide/cobalt thermal spray.

Titanium anodization should be in accordance with SAE AMS 2488. Titanium and its alloys exhibit very poor resistance to wear. Fretting may cause cracking, potentially leading to fatigue failure. The design should avoid fretting or wear in titanium and its alloys.

b. Titanium alloys shall not be used with liquid oxygen (LO_2) or gaseous oxygen (GO_2) at any pressure or with air at oxygen partial pressures above 35 kPa (5 psia).

c. Heat treatment processes specified for titanium and titanium alloy parts will use a process approved by M&P Engineering for the specific application.

The surfaces of titanium and titanium alloy mill products should be 100% machined, chemically milled, or pickled to a sufficient depth to remove all oxygen-contaminated layers (alpha case) formed as a result of mill processing, heat treating, and forming operations at elevated temperatures.

Heat treatment of titanium should use SAE AMS-H-81200. The use of titanium in hydrochloric acid, chlorinated solvents, chlorinated cutting fluids, fluorinated hydrocarbons, and anhydrous methyl alcohol should be avoided because of titanium's susceptibility to SCC. Contact of titanium alloys with mercury, cadmium, silver, or gold should be avoided at certain temperature ranges because of liquid-metal-induced embrittlement, solid-metal-induced embrittlement, or both.

5.4.6 Copper Alloys

a. Copper alloys, brasses, and bronzes used in GS shall be resistant to general corrosion and pitting, and highly resistant to SCC in accordance with MSFC-STD-3029.

b. To prevent SCC, copper alloys shall not be used in contact with ammonia.

GS should be designed so that copper is not exposed to hydrazine environments. Copper has the potential for SCC when exposed to ammonia, which is a product of hydrazine decomposition.

5.4.7 Beryllium and Beryllium Alloys

Machining, grinding, and finishing operations on beryllium and beryllium alloys shall be performed either wet, using a liquid coolant with local ventilation, or dry, using high-velocity, close-capture ventilation.

Beryllium copper (UNS C17200) is commonly used for high-strength, nonsparking structural components in applications where it is subject to contact and wear. Beryllium particles, beryllium oxide, and other beryllium compounds are toxic when inhaled. Extreme caution must be exercised during fabrication to avoid exposing personnel to beryllium or beryllium compounds. Refer to the appropriate Safety Data Sheet (formerly known as Material Safety Data Sheet) for more detail.

5.4.8 Tin

Tin (Sn) solder and Sn plating should be alloyed with at least 3% lead (Pb) to prevent the growth of Sn whiskers. Requirements for Pb content for electrical or electronic applications are contained in the electrical soldering section.

5.4.9 Plating

a. Galvanized coatings and other metallic plating shall be applied in accordance with a voluntary consensus standard approved by M&P for the specific application.

b. Cadmium platting shall not be used in new design.

Galvanized coatings should be in accordance with ASTM A123, ASTM A153, and ASTM A653. Repairs to galvanized coatings should be in accordance with ASTM A780.

Chromium plating should be in accordance with SAE AMS 2460.

Cadmium plating should be in accordance with SAE AMS-QQ-P-416.

5.4.10 Corrosion Control

Protective coating of hardware should be appropriate to the condition, use, and environment to which the hardware will be exposed during its life cycle. The coating should minimize corrosion and its color should indicate its use (see Appendix B). Guidelines for corrosion control for facilities, systems, and equipment are given in TM-584.

a. Protective coating and sealing of hardware shall be in accordance with NASA-STD-5008.

Stainless steel tubing in a launch environment must be coated per NASA-STD-5008.

b. The principles contained in MIL-STD-889 will be used for corrosion control of galvanic couples in corrosive environments.

NASA-STD-5008 covers sealing for critical GS, faying surfaces of metal alloys and electrical bonding connections, except for nickel-plated surfaces.

5.4.11 Stress Corrosion Cracking

In critical applications, metals exposed to the KSC environment shall be selected from alloys that are highly resistant to SCC as specified in MSFC-STD-3029.

In noncritical applications, the designer should select from alloys that are highly resistant to SCC as specified in MSFC-STD-3029. When COTS items are selected, the designer should attempt to identify the materials used and determine if an SCC failure would be critical. Materials protected from the environment, such as lubricated roller bearings and gears within a sealed gearbox, are exempt from the above requirement. The responsible M&P authority's signature or electronic approval of the design drawings constitutes authorization to use the materials of the design in the intended application.

5.4.12 Hydrogen Embrittlement

The embrittlement of a metal or alloy by hydrogen involves the diffusion of atomic hydrogen into a component subject to a manufacturing process or environmental event. The entrained hydrogen reduces the ductility of the metal and load-bearing capacity, resulting in brittle fracture at stresses below the yield stress of susceptible materials.

Hydrogen can be introduced by processes such as electroplating, phosphating, pickling, passivation, and welding. Hydrogen can also be introduced as a by-product of a corrosion reaction in which some of the hydrogen enters the metal in atomic form.

All metallic materials used in hydrogen systems in GS shall be approved by the responsible M&P authority.

Test data may have to be generated in a simulated environment to support the approval rationale. Guidelines for designing safe hydrogen systems are contained in AIAA G-095.

After electroplating, phosphating, pickling, passivation, or other processes that can introduce hydrogen, materials that are susceptible to hydrogen embrittlement should undergo a final baking heat treatment in accordance with SAE AMS 2759/9.

5.5 Nonmetals

5.5.1 Elastomers

The use of elastomers in GS shall be approved by the responsible M&P authority.

Elastomers should operate within the parameters of a design service life, including the vendor-specified shelf life. Elastomers should be cure-dated for tracking purposes. Elastomers should not have a corrosive effect on other materials when exposed to conditions normally encountered in service (examples include one-part silicones that liberate acetic acid when they are cured). When rubbers or elastomers are used at low temperatures, the ability of these materials to maintain the required elastomeric properties should be verified by testing them at or below use temperature. Application data for elastomers is available in MAPTIS.

5.5.2 Composite Materials

a. Composite materials used in GS shall be in accordance with SAE CMH-17 and with MIL-HDBK-17, Volumes 4 and 5.

b. Defects resulting from manufacturing will be assessed through NDE techniques to meet the intent of 5.3.

5.5.3 Refractory Concrete

Refractory concrete used for heat and blast protection of flame deflectors and other areas of the launch pad shall be in accordance with a detailed procurement specification including compressive strength, erosion rate testing in a representative environment (i.e., 3,300 Btu/square foot-second), fineness, etc.

Refractory concrete should have a modulus of rupture greater than 500 psi, compressive strength greater than 4,500 psi, a fineness modulus of 2.75 to 3.75, and survive a heat flux of 3,300 Btu/ft^2-s for ten seconds with less than 0.125 in. of thickness loss.

5.5.4 Lubricants

a. Lubricants shall be selected for the specific application considering contact pressure, temperature, wear, life, contamination, and material compatibility and approved by M&P.

b. Lubricants containing chloro-fluoro compounds shall not be used with aluminum or magnesium.

The decomposition/reaction products that result from overheating lubricants that contain chloro-fluoro compounds can attack metallic materials and can be toxic. Examples of chloro-fluoro compound lubricants include many vacuum oils, chlorotrifluoroethylene-based grease and oil, halocarbon lubricants, and chlorofluorocarbon-based lubricants.

c. Lubrication of flared tube fittings is covered in Section 8 and will be in accordance with KSC-SPEC-Z-0009 which is required in KSC-SPEC-Z-0008.

Use of lubricants near precision-cleaned hardware or electrical connections should be minimized or tightly controlled to prevent cross-contamination. Lubricants such as used in flared tube assemblies can migrate downstream into flight hardware causing contamination or damaging catalyst beds.

5.5.5 Plastic Film, Foam, and Adhesive Tape

a. Thin plastic film, foam, and adhesive tape (PFA) materials used in GS that could be exposed to hypergols shall be tested in accordance with and meet the requirements of NASA-STD-6001, Test 15, Appendix 7.

b. Thin PFA materials used in GS in close proximity to ESD-sensitive components shall be tested for ESD in accordance with ASTM D4470 or an M&P-approved test method.

MMA-1985-79 is an M&P-approved alternative ESD test method. Material flammability ratings and hypergol compatibility test results for many PFAs are found in the MAPTIS database. KTI-5212 may be consulted for a summary of flammability, ESD, and hypergol compatibility test results for various PFAs.

Thin PFA materials used in GS for flammability control require testing to meet the requirements of 5.1.

5.6 Contamination Control

a. Engineering documentation shall specify internal and external surface cleanliness levels for all GS.

b. When required by the program, a contamination control plan will be generated in accordance with ASTM E1548.

Clean rooms and associated controlled environments should be designed in accordance with ASTM E2217.

6. STRUCTURAL REQUIREMENTS

6.1 Material Properties

a. Material properties for design shall be based on the material composition, physical properties, and mechanical properties from the voluntary consensus standard used in the procurement of the material.

For example, if stainless-steel plate is procured to a particular ASTM specification, the mechanical properties used for analysis are taken from that particular ASTM specification.

When specifying materials, ensure not only the voluntary consensus standard and grade, but also the supplementary requirements and tests which control properties such as finish, corrosion resistance, grain structure, etc. which may be crucial to the performance of the GS.

b. When lot testing indicates mechanical properties greater than the specification minimum values, the values used for design and analysis shall be less than the specification value plus one half of the increase above the specification value and the design documentation is annotated with the new design minimum value.

$$\sigma_{\text{yield design}} = (\sigma_{\text{yield spec}} + \sigma_{\text{yield measured}}) / 2.0$$

c. If mechanical properties of new or existing structural materials are not available, the properties will be determined by analytical methods approved by the responsible M&P authority to satisfy the intent of 6.1.a.

6.2 Threaded Fasteners

This section addresses the design of and maximum allowable preload for threaded fasteners. The design application may require a lower preload value because of actual applied loads, gaskets, seals, etc. Other sources for installation/torque criteria include MSFC-STD-486 and KSC-SPEC-Z-0008. For nonstructural applications where a specific clamping force is not required, the designer may specify that fasteners be installed snug tight (tighten the fastener with *standard tools, using ordinary force, until the assembly layers come into firm contact, determined visually and by feel).*

a. Fastener preload stress shall be less than 70% of the yield stress on the net cross section.
b. The installation criteria for structural bolts in conventional steel structures, such as those specified in ASTM F3125, shall be in accordance with AISC 325.
c. ASTM F3148 or A490 structural bolts or bolts of similar material composition and tensile strength (e.g., SAE Grade 8 or ISO Class 12.9) shall not be used in a corrosive environment without specific M&P approval.

Galvanizing and some zinc coatings may cause hydrogen embrittlement in high-strength carbon steel fasteners that is difficult to detect. When possible, A325 or SAE Grade 5 fasteners should be used instead. When Grade 8 or A490 fasteners are required, consider ASTM F1136, Grade 3 for a protective coating system (with M&P approval). When using F3148 bolts, they should be Type 1 with ASTM B695, F2833, F3019, or A1059 coating, or F1136 Grade 3 coating specified (with M&P approval).

d. Fastener installation criteria (e.g., torque value, lubrication, etc.) shall be documented on the fabrication, assembly, or installation drawing.

6.3 Welding

Welding of structural GS shall meet all requirements for nonflight hardware in AWS D17.1 with the exception of pressure systems, which are addressed in Section 8.

Welding of pressure systems is covered by ASME BPVC and ASME B31.3 and not covered by this section.

6.3.1 Weld Classification and Inspection

a. Class A: Welds whose failure would be catastrophic in effect or weld joints that are highly loaded and characterized as a single point failure with no redundancy for the redistribution of stress into another member shall be designated Class A.
b. Class B: Welds whose failure would reduce the overall efficiency or safety margin of the system, but loss of system function, hazard to personnel or damage to flight hardware, would not be experienced shall be designated Class B.
c. Class C: Welds whose failure would not affect the efficiency or safety margin of the system, endanger personnel, or damage flight hardware shall be designated Class C.

Weld classification can be relaxed by the NASA Technical Authority based on an assessment of joint criticality, use of automatic/machine welding processes, or alternate weld inspection methods. Fabrication of collateral equipment (handrails, stairs, elevator landings, etc.) is typically Class C (visual inspection only). Pipe supports and cable trays can be designated Class C consistent with National Electric Code, ASME piping codes, and OSHA.

6.3.2 Welder/Welding Operator Performance Qualification

a. Welders and welding operators shall be qualified prior to production welding.

This includes providing Welder Continuity Records as applicable.

b. Welder/welding operator performance qualifications shall be approved by M&P prior to production welding.

6.3.3 Welding Procedure Qualification

a. Welding procedure specifications (WPS) shall be prepared and qualified for each weld prior to production welding.

A WPS is always required, even if the procedure is considered to be prequalified by an applicable American Welding Society standard. WPS for stainless steels and nickel alloys must always be qualified by testing.

b. WPS and procedure qualification records shall be approved by M&P prior to production welding.

6.4 Structural Brazing

Structural brazing shall be conducted in accordance with AWS C3.3 with a process for the specific application approved by M&P.

The following should be used as guidance for creating the process:

- *Follow AWS C3.7M/C3.7 for brazing of aluminum alloys.*
- *Follow AWS C3.4M/C3.4, C3.5M/C3.5, and C3.6M/3.6 for torch, induction, and furnace brazing.*
- *Subsequent welding operations in the vicinity of brazed joints or other operations involving high temperatures that might affect the brazed joint should be prohibited unless it can be demonstrated that the fixturing, processes, methods, or procedures employed will preclude degradation of the brazed joint.*
- *Brazed joints will be designed for shear loading and, for structural parts, not be relied upon for strength in axial loading.*
- *Follow AWS C3.2M/C3.2 to establish the shear strength of brazed joints.*
- *ASME BPVC-VIII covers requirements for brazing of pressure vessels.*

6.5 Forging

a. For critical GS, after the forging technique (including degree of working) is established, the first production forging shall be sectioned to show the grain-flow patterns and to verify mechanical properties.

b. The procedure shall be repeated after any change in the forging technique.

c. The resulting data shall be retained and made available for review by the procuring activity.

The information gained from this effort should be used to redesign the forging technique as necessary. Forging techniques should produce an internal grain-flow pattern parallel to the principal stresses, because mechanical properties are optimum in the direction of material flow during forging. The forging pattern should be free from reentrant and sharply folded flow lines.

6.6 Casting

Casting processes specified in GS designs shall be in accordance with a voluntary consensus standard approved by M&P.

Casting processes and inspection should be in accordance with SAE AMS 2175.

6.7 Adhesive Bonding

Structural adhesive bonding shall be in accordance with a process approved by M&P for the specific application.

The following should be used as guidance for creating the process:

- *Structural adhesive bonding should be in accordance with MSFC-SPEC-445.*
- *Retesting adhesives used for production parts is not required if they are within the manufacturer's recommended shelf life.*
- *The documented process addresses prevention of contamination.*
- *The sensitivity of structural adhesive bonds to contamination is of particular concern. In the absence of relevant performance data, bond sensitivity studies should be conducted to verify that the required adhesive properties are maintained after exposure to the expected materials at the expected concentrations, including ozone, ambient humidity, cleaning fluids, and lubricants. Adequate cleanliness inspections should be conducted during the fabrication part of the bonding process.*
- *In testing, bonded primary structural joints should demonstrate cohesive failure modes in shear at ambient temperature.*
- *The corrosive effect of adhesives on other materials when exposed to conditions normally encountered in service is considered.*

6.8 Conventional Structures

6.8.1 Steel Conventional Structures

The design of conventional steel structures for GS or that interface with GS shall be in accordance with AISC 325, Allowable Strength Design method or in accordance with 6.9.1, *Steel Nonconventional Structures*.

AISC Load and Resistance Factor Design (LRFD) is not compatible with GS design methods and load combinations. LRFD may be used for access structures that are not GSE and do not structurally interface with GSE.

It is permissible to design conventional structures as nonconventional structures.

Note that OSHA has requirements for certain conventional steel structures in addition to AISC, such as a 5:1 factor of safety for mobile stairs and specific loads ratings for guardrails.

6.8.2 Aluminum Conventional Structures

The design of conventional aluminum structures shall be in accordance with the ADM or in accordance with 6.9.2.

Nonconventional aluminum structures may be designed using provisions of the ADM, provided that the factors of safety are adjusted to be consistent with 6.9.

It is permissible to design conventional structures as nonconventional structures.

6.8.3 Composite Conventional Structures

The design of conventional fiber-reinforced polymer composite structures shall be in accordance with one of the following:

- ASCE Standard for Load & Resistance Factor Design (LRFD) of Pultruded Fiber Reinforced Polymer (FRP) Structures, or
- ASD Factor of safety of 2.5 for tension and flexure and a factor of safety of 3.0 for compression and shear, or
- Section 6.9.3.

Composite material strength should be characterized to a statistically-based value representing the 80% lower confidence bound on the 5th-percentile value of a specified population, determined in accordance with ASTM D7290.

6.8.4 Loads for Conventional Structures

a. Structural design loads shall be specified in the design documentation.

b. Wind loading for structural designs shall be in accordance with ASCE-7 or a Program specified wind load document.

c. Floor loading for access-controlled areas, workstands, and other specialized platforms shall be based on actual predicted loads in any credible arrangement at 100 lb/ft^2 load pressure.

d. Flooring systems shall be designed or commercial flooring selected for a minimum load pressure of 100 lb/ft^2.

e. When a concentrated load is specified, a load of 2000 lb shall be applied to 6.25 ft^2 (a 2.5 ft square).

f. Floor loading for standard, building-type structures will be based on ASCE-7.

The design should consider loads created by the assembly, lifting, handling, transportation, operations, wind conditions, launch-induced environments, and seismic events.

6.9 Nonconventional Structures (includes structural aspects of mechanisms)

The following minimum factors of safety are used for structures and load-bearing components (excluding lifting devices, pressure vessels, preload in threaded fasteners, and springs) when not otherwise specified (see Table 2).

a. GS structures and load-bearing components shall be designed to a minimum factor of safety of 2.0 against deformation or yielding that impairs the function of the part; and a minimum factor of safety of 3.0 against collapsing, buckling, exceeding the ultimate load, or failing to support the design load.

b. For brittle metals (less than 5% elongation-to-failure), the factor of safety shall be 5.0 against exceeding the UTS.

c. For additive manufacturing of metallic materials, the factor of safety shall be 5.0 against exceeding the UTS.

d. For ductile metal castings, the factor of safety shall be 4.0 against exceeding the UTS.

e. For lifting provisions on GS, hoist rings, lifting lugs on GS structures, etc., the factor of safety shall be 5.0 against exceeding the UTS.

Lifting equipment (hoists, shackles, wire rope, cranes, etc.) is covered by NASA-STD-8719.9.

Required factors of safety are expressed with the appropriate number of significant figures/digits. For example, a calculated design factor of 2.98 would round to 3.0 for comparison with the minimum required factor of safety.

The required factor of safety for buckling is the same as UTS. It is good practice to double the safety factor for Euler/Eigen buckling solutions due to the inherent unconservatism in that method.

Table 2. Summary Table of Factors of Safety

Material or application	Factors of Safety on Yield Strength	Factors of Safety on Ultimate Strength
Ductile metal; virgin polymers	2.0	3.0
Brittle metal	N/A	5.0
Additive manufacturing	N/A	5.0
3D printed/recycled polymers	N/A	8.0
Ductile metal castings	N/A	4.0
Composites	N/A	4.5
Lifting lugs and hoist rings	N/A	5.0

6.9.1 Steel Nonconventional Structures

Nonconventional steel structures shall be designed in accordance with the factors of safety for nonconventional structures either by direct calculation or by using the AISC methods, substituting the factors of safety for nonconventional structures for the Code values.

6.9.2 Aluminum Nonconventional Structures

a. Nonconventional aluminum structures shall be designed in accordance with the factors of safety for nonconventional structures either by direct calculation or by using the Aluminum Association methods, substituting the factors of safety for nonconventional structures for the Code values.

b. Aluminum fillet welds and threads shall have a 0.85 reduction (knockdown factor) applied to the material shear strength.

The knockdown factor on aluminum threads is because most aluminum threads do not redistribute loads as readily as other metallic materials. Aluminum threads can have a cascading failure where the first engaged thread fails before the lowest thread takes any load. The knockdown for fillet welds is due to the fact that aluminum welds have substantially lower ductility than the base metal. This prevents the normal redistribution of load that blunts the inherent stress concentration and geometric effects in a fillet weld. Steels and stainless steels have similar or higher ductility in the heat affected zone and weld filler material.

6.9.3 Polymer and Composite Nonconventional Structures

The following minimum factors of safety shall be used for structures and load-bearing components (excluding lifting devices, pressure vessels, preload in threaded fasteners, and springs) when not otherwise specified.

- For polymeric materials produced directly from the petrochemical feed-stock: 3.0 against exceeding the UTS.

- For polymeric materials produced by additive manufacturing, 3D printing, or from recycled feedstock: 8.0 against exceeding the UTS.
- For fiber-reinforced polymer composites: 4.5 against exceeding the UTS.

6.9.4 Fasteners for Nonconventional Structures

a. Threaded fasteners used in nonconventional structures shall meet the factors of safety for nonconventional structures when only the operating load is considered. (This does not include preload, which is covered separately in 6.2.)

b. GS fasteners used in critical applications shall have lot traceability from the manufacturer to final installation.

Traceability applies to any single fastener if its failure will have catastrophic effects. Redundant fasteners do not require traceability even in a critical system. NASA-RP-1228 should be used for guidance in selecting and analyzing fasteners.

c. Critical fasteners shall be identified in the design documentation with the procurement requirement for traceability.

d. Fasteners shall be selected from ASME standards, National Aerospace Standards, Military Standards, or other standards that define material, strength, testing, and coating requirements.

e. Reusing self-locking fasteners shall be permitted when the running torque before clamp-up remains between the maximum self-locking torque and the minimum break-away torque.

Self-locking fasteners should be used wherever possible. The use of star (toothed or serrated) lock washers or helical (split or spring) washers should be avoided. These washers provide very little resistance to structural vibration and damage the surfaces they contact. Their application should be limited to lightweight electrical/electronic component mounting within racks and enclosures.

f. Fasteners used in corrosive environments and applications where condensation can occur shall be installed using a corrosion-resistant sealant while the sealant is still wet (wet installation).

g. When liquid-locking compounds are used for fastener installation, engineering drawings shall specify a validated process for application.

Liquid-locking compounds should be selected in accordance with ASTM D5363. A validated process for application may be the COTS vendor's application instructions.

h. When calculating thread shear, the calculation shall not consider a length of engaged threads beyond the major diameter of the threaded fastener.

6.9.5 Loads for Nonconventional Structures

a. The minimum dynamic amplification factor applied to a dynamic load shall be 2.0.

A load is only dynamic if its full application occurs faster than half the period of the first natural frequency of the structure. The dynamic amplification factor is a multiple of the static load to obtain an equivalent static load from a dynamic load when a true dynamic analysis is not performed. The factor of 2.0 equates to a suddenly applied load. Impact loads will be higher.

b. Design loads shall be based on a conservative estimation of the maximum loading condition over the design life of the structure.

The traditional basis for "conservative" loads is a 2.5 standard deviation (sigma) chance of exceedance. The 2.5 sigma basis for structural loads has been used for GSE design for several programs, including the Shuttle Program. The exceedance for 2.5 sigma is approximately 1/167.

6.9.6 Springs

Springs shall be designed to a minimum factor of safety of 1.4 against exceeding the UTS.

Because of the nature of their design, springs do not meet the factors of safety specified for other engineering applications and should be designed in accordance with the Handbook of Spring Design from the Spring Manufacturers Institute.

6.10 Load Test

a. A load test shall be performed on all structural GSE and moveable or articulating GSS nonconventional structures (access platforms, workstands, etc.), except when an independent analysis is performed and the load test exemption is approved by the Technical Authority

Typical reason the Technical Authority may approve a load test exemption include:

- *the load test would create an unsafe condition,*
- *the simplicity of the load path makes the load test ineffectual,*
- *the primary load path is a COTS structure,*
- *the load test would be impractical due to the structure's size,*
- *analysis shows that the load test will result in damage to the structure,*
- *one of multiple similar structures or mechanisms is load tested, or*
- *a partial load-test is performed using a representative section of the structure.*

b. GS, other than lifting equipment, shall be load tested to 125% of the design or working load, not including vehicle blast loads, hurricane wind loads, or other non-failure-critical loads when the structure/mechanism is in a nonoperational condition.

c. Lifting devices and equipment will be load tested in accordance with NASA-STD-8719.9.

d. GS, other than lifting equipment, that have been load tested shall be identified and marked in accordance with KSC-STD-141.

e. Lifting equipment shall be identified and marked in accordance with KSC-STD-141 and NASA-STD-8719.9.

NASA-STD-8719.9 contains requirements for both initial load testing (proof load) and periodic load testing for lifting equipment. Stationary conventional structures would not typically be subjected to a load test.

6.11 Fatigue and Design Life

Structures exposed to cyclic loads shall be designed for a minimum factor of safety of 4 against the design life, using 150% of the alternating stress.

The ratio of fatigue life to design life is 4 as a minimum. The designer/analyst has the responsibility to determine when cyclic loads are significant in the design. The relationship between stress/strength and fatigue life is highly nonlinear. Applying the factor of safety to life is the established engineering method to handle this nonlinearity. The structure is designed to withstand four times the number of load cycles expected during the design life. The factor of safety applied to life is sometimes called the Service Life Factor.

7. MECHANISM REQUIREMENTS

7.1 Mechanical Margins

a. A static force/torque margin of 1.0 or greater shall be required to initiate motion.

b. A static force/torque margin of 1.0 or greater shall be required for all holding/braking configurations.

c. A dynamic force/torque margin of 0.25 or greater shall be required at all points of travel.

The force/torque margins address uncertainties in friction, damping, or other factors that could impede motion. Force/torque margin is equal to the available driving force/torque divided by the resisting torque, minus 1. A margin of 1.0 means that there is 200% of the required force to initiate motion.

7.2 Cranes, Hoists, and Other Lifting Devices

The design and certification of lifting devices (cranes, crane girders, hoists, lifting slings, jacks, etc.) shall be in accordance with NASA-STD-8719.9.

7.3 Transportation Equipment

Moving/rolling GS shall have a stability analysis performed using either 0.2 g acceleration or a sudden stop at the maximum operational speed, with the wheels, slides, skids, etc. in the least advantageous position for the purpose of the analysis.

7.4 Umbilical Design

Reusable umbilicals shall be designed in accordance with KSC-GP-986.

7.5 Bearings

Journal (sleeve) bearings and rolling-element bearings shall be selected and used in accordance with the manufacturers' rated load limits without the application of additional safety factors.

7.6 Tethering Provisions

a. GS and GS components used near flight hardware or above personnel or flight hardware that require temporary removal/installation during operations, such as quick-release pins and quick-disconnect caps, shall be tethered to (or otherwise held captive by) the equipment for which they are used.

b. The tether shall be swaged to the handle of the quick release pin.

Split ring connections typical of commercial quick release pins are not acceptable. Split ring connections have been the source of many failures creating FOD and scrubbing at least one NASA launch. Quick-release pins and pin tethers should be in accordance with KSC-STD-P-0006.

7.7 Redundancy in Mechanisms

Mechanisms shall not be considered redundant if the failure of either the primary or secondary would be undetectable before its critical operation is required.

A single-point failure mode within a redundant device of a system is typically not a single-point failure mode of that system. If it is, the devices are not completely redundant. Where two or more mechanisms are used to execute a single critical function, the deployment/operation of one must be independent of the successful deployment/operation of the other. A mechanically redundant device should be provided such that its failure could not prevent successful deployment of the other device.

8. FLUID SYSTEM REQUIREMENTS

All NASA designs, PVS used on NASA installations, and PVS designed or fabricated on NASA contract are required to comply with NASA-STD-8719.17, which encompasses many of the specific requirements contained in this standards manual. This standards manual and the standards cited herein are intended to provide additional requirements. Nothing contained herein can be construed as providing relief from any requirement in NASA-STD-8719.17.

a. All pressurized systems will comply with NASA-STD-8719.17.

b. The design of pressure systems, including pressure vessels, transmission lines, and GS, will comply with KNPR 8715.3-1, Chapter 7, which complies with NASA-STD-8719.17.

c. The design and analysis of PVS will be reviewed and approved prior to start of PVS construction in accordance with NPR 8715.1.

d. Fluid systems other than breathing air shall not use 3/8 in. quick disconnect fittings to avoid the possibility of cross-connection.

e. The design of fluid systems shall contain provisions to mitigate damage to other systems, particularly electronics, in the event of a leak.

Mitigating provisions may include, but are not limited to, subsystems physical separation, limiting leak points, sealing all potential points of fluid entry into electrical enclosures, etc.

8.1 Fluid System Cleanliness

a. Surface cleanliness of fluid systems shall be in accordance with ASTM G93.

The following standards are considered functionally equivalent to ASTM G93: KSC-C-123, IEST-STD-CC1246, ISO 14952, JPR 5322.1, MSFC-SPEC-164, and SAE ARP 1176. Other precision-cleaning standards may be used with approval from M&P.

b. The cleanliness level and test method shall be specified in the design documentation.

c. For GS interfaces with precision-cleaned fluid systems for flight, the supply interface/final filters shall be located as close to the flight hardware interface as possible.

d. Interface filters shall be used on outlet lines if it is determined that any operations, such as the servicing or deservicing of fluids, could permit flow in a reverse direction.

e. Interfacing fluid system GS shall be cleaned to meet or exceed the cleanliness level of the flight hardware.

f. Port cleaning of relief valves shall not be performed for oxygen enriched or reactive fluid service.

Port cleaning of relief valves (as opposed to full disassembly, cleaning, and resetting) is permitted for inert fluid service only.

g. Protective covers shall be provided for all hoses, ports, fittings, and other fluid-fitting connections to GS to protect the threads and sealing surface and maintain the cleanliness of the system.

Use caution in selecting caps and plugs as covers because of the potential for generating debris during installation or removal, especially in oxygen systems. When possible, the protective cover should be connected with a lanyard or the equipment should have a designated storage provision.

8.2 Fluid Compatibility

For the purposes of this standards manual, the definition of "hazardous fluids" includes GO_2, LO_2, fuels, oxidizers, ammonia, and other fluids that could cause corrosion, chemically or physically degrade materials in the system, or cause an exothermic reaction.

8.2.1 Hazardous Fluids Other than Oxygen

a. Materials exposed to hazardous fluids other than oxygen shall be evaluated or tested for compatibility.

NASA-STD-6001, Test 15, tests materials for short-term exposure to fuels and oxidizers. NASA-STD-6001, Test A.7, tests materials for incidental exposure, such as a splash, to fuels and oxidizers. For many materials, material compatibility ratings and test results based on NASA-STD-6001, Test 15, are available in the MAPTIS database.

b. Appropriate compatibility tests shall be conducted for materials that are subjected to long-term exposure to fuels, oxidizers, or other hazardous fluids. The test conditions are customer-specified and simulate the worst-case use environment that would intensify reactions or degradation of the material or fluid.

c. Material degradation in long-term tests shall be characterized by posttest analyses of the material and fluid to determine the extent of changes in chemical and physical characteristics, including mechanical properties.

8.2.2 Oxygen Systems

a. LO_2 and GO_2 systems shall use materials that are nonflammable in their worst-case use configuration, as defined by NASA-STD-6001, Test 17, for upward flammability in GO_2, or Test 1 for materials used in oxygen pressures that are less than 350 kPa (50 psia).

Material flammability ratings and test results based on NASA-STD-6001 are available in the MAPTIS database for many materials. KTI-5210 may be consulted for a summary of oxygen compatibility test results for various materials used in LO_2 and GO_2 applications.

b. When a material in an oxygen system is determined to be flammable by NASA-STD-6001, Test 17, an oxygen compatibility assessment shall be conducted in accordance with NASA-STD-6001 and the system safety rationale documented and approved by M&P.

The results of the oxygen compatibility assessment may require configurational testing.

c. When the oxygen compatibility assessment shows that the risk is above an acceptable level, configurational testing shall be conducted to support the oxygen compatibility assessment.

d. Configurational testing shall exercise the ignition mechanisms identified by the oxygen compatibility assessment, using test methods described in ASTM MNL 36.

e. The configurational test method and acceptance criteria shall be reviewed and approved by M&P.

f. The as-built configuration shall be verified against the oxygen compatibility assessment to ensure that mitigation methods identified in the report were incorporated into the design and construction of the hardware.

g. For compressed-air systems and oxygen-enriched systems, the need for an oxygen compatibility assessment shall be addressed on a case-by-case basis.

Compressed-air systems and oxygen-enriched systems are inherently less hazardous than systems containing pure oxygen; the hazard increases with oxygen concentration and pressure.

Guidelines on the design of safe oxygen systems are contained in ASTM MNL 36, ASTM G88, ASTM G63, ASTM G94, and NASA/TM-2007-213740.

h. Oxygen, oxygen-enriched, and compressed-air system components that operate at pressures above 1.83 MPa (265 psia) shall undergo verification or validation testing at maximum design pressure for a minimum of 10 cycles before being placed into service.

This testing is normally performed as part of verification testing. Retesting is required if the results are invalidated by actions occurring after the test (such as rework, repair, or interfacing with hardware for which the cleanliness level is unknown or uncontrolled). For critical systems and systems directly interfacing with flight hardware, the acceptance testing should be performed for 10 cycles.

i. Parts machined from polychlorotrifluoroethylene (PCTFE) shall comply with ASTM D7194, Type II, when used in oxygen systems at any pressure or when used in compressed-air or breathing air systems over 3000 psia. ASTM D7194 requires dimensional stability for parts machined from PCTFE. Dimensional stability minimizes the occurrence of flow friction in oxygen and oxygen-enriched system components with PCTFE soft goods. PCTFE used in inert fluid systems or PCTFE which is not directly in the oxygen flow stream (e.g., secondary seals) does not require compliance to ASTM D7194. Approval for the use of PCTFE in oxygen systems without compliance to ASTM D7194 or for the use of PCTFE in compressed air or breathing air systems above 3000 psi without compliance to ASTM D7194 requires approval by an M&P engineer approved by NASA.

ASTM D7194 requires an annealing process for parts machined from PCTFE. Annealing results in dimensional stability, which minimizes the occurrence of flow friction in oxygen system components with PCTFE soft goods. PCTFE used in inert fluid systems does not require annealing. PCTFE, which is not directly in the oxygen flow stream (e.g., secondary seals), do not require annealing. Approval for the use of PCTFE in oxygen-enriched systems without annealing requires approval by M&P.

8.3 Oxygen System Cleanliness

LO_2, GO_2, and oxygen enriched systems shall be cleaned to level 300A or cleaner in accordance with ASTM G93.

The following standards are considered functionally equivalent to ASTM G93: KSC-C-123, IEST-STD-CC1246, ISO 14952, JPR 5322.1, MSFC-SPEC-164, and SAE ARP 1176. Other precision-cleaning standards may be used with approval from M&P.

8.4 Fluid System Margins

Design margins for fluid systems should be listed in analysis documents. Typical margins on flow rate requirements are 150% (an additional design margin of 50%) at concept design review and 125% at the final design review. Margins for heat transfer should be based on temperature difference (delta T). Margins in cryogenic systems may be expressed in amount of subcooling (for zero quality) or in additional vapor phase for non-zero quality.

8.5 Pressure Vessels and Pressurized Systems

8.5.1 Stationary Pressure Vessels

a. Metallic pressure vessels for use in GS shall be designed, constructed, tested, and stamped in accordance with ASME BPVC-VIII, Division 1, 2, or 3.

b. ASME Code Vessels shall only be modified by shops and welders with National Board Inspection Code (NBIC) R stamp certification per NB-23. Non-code PVS should be altered or repaired in accordance with the requirements of the most applicable voluntary consensus standard.

c. New custom-designed and fabricated metallic pressure vessels using unlisted materials as defined by ASME BPVC-VIII part UG-10 shall have a minimum factor of safety against burst of 4.

Shops and welders repairing or altering code vessels require R-stamp certification. Non-code PVS should be altered or repaired in accordance with the requirements of the most applicable voluntary consensus standard.

d. Composite Overwrapped Pressure Vessels (COPVs) for use in GS shall be designed, constructed, tested, and marked in accordance with ASME BPVC-X.

COPVs should be used only when necessary because of weight constraints. Special training and certification are required for personnel handling or repairing COPVs. Damage to COPVs can be difficult to detect because reliable NDE methods have not been developed. COPV failure modes can be catastrophic, requiring special safety clears during pressurization.

e. All new ASME code-stamped vessels shall be registered with the National Board of Boiler and Pressure Vessel Inspectors.

8.5.2 Mobile Pressure Vessels

a. Compressed-gas cylinders shall be labeled in accordance with CGA C-7.

b. Pressure vessels used for transporting hazardous commodities will meet the Department of Transportation's (DOT's) requirements in 49 CFR or ASME BPVC-XII.

Note: Pressure vessels from international sources designed and built to the requirements of EU 97/23/EC are not acceptable for use in GS.

8.6 Design of Piping Systems

a. Piping, tubing, fittings, and support systems in remote or cross-country areas or where personnel traffic is low shall be in accordance with ASME B31.8 or ASME B31.3.

b. Piping, tubing, fittings, and support systems for refrigeration or heat transfer systems shall be in accordance with ASME B31.5 or ASME B31.3.

c. All other piping, tubing, fittings, and support systems shall be in accordance with ASME B31.3.

d. The completed system will be pressure-tested in accordance with ASME B31.3.

e. When less than 100% volumetric inspection is performed, the allowable stress of welded pipe, tubing, fittings, and joints will be 80% of the material allowable stress (one-third of ultimate strength or two-thirds of yield strength at temperature).

f. If a specific piping system layout is required to meet specific performance (pressure drop, flow rate, temperature change, etc.), system flexibility per ASME B31.3, or other design consideration, then field routing by the fabricator shall not be allowed.

Guidance: Field routing by the fabricator is not allowed when the routing affects subsystem compliance to performance requirements (pressure drop, flow rate, temperature change, etc.) or Code requirements. Field routing can generate not only high pressure drops or flow restrictions but also mechanical loads into fluid panel and, components from external loads or thermal strain.

Examples include piping between facilities in low-traffic areas, buried pipelines, and long-run piping between remote facilities. Where ASME B31.3 piping connects to ASME B31.8 piping (e.g., at facility interfaces), the design should consider the differences in internal diameters and how the piping will be cleaned (via pipeline cleaning pigs). ASME B31.1 meets or exceeds the requirements of ASME B31.3 and may be used as an alternative.

8.6.1 Unlisted Piping Components

Piping, tubing, and fittings shall be considered compliant with ASME B31.3, Section 304.7.2, if they meet **all** of the following requirements:

- Stress under the maximum pressure does not exceed one-third of the minimum tensile strength in the design temperature range.
- Stress under the maximum pressure does not exceed two-thirds of the minimum yield strength in the design temperature range.
- The material is ductile.

8.6.2 Identification, Color-Coding, and Labeling of Piping

a. GS piping and tubing shall be identified and color-coded in accordance with MIL-STD-101.

b. Working pressures on all piping systems exceeding 60 psig shall be identified adjacent to the commodity in the same letter size.

c. Where conventional markings are likely to be damaged by extreme temperatures or hidden by a covering of frost, a stainless-steel identification tag shall be securely fastened at the same locations given for color bands in MIL-STD-101.

d. Each panel-mounted component shall be identified on the face of the panel adjacent to the component (beneath the component if practicable).

Color bands may be made of pressure-sensitive tape (only if recommended by the manufacturer for specified temperature range) or painted on, and should be applied no less than 40 ft apart on straight pipe runs inside buildings and 500 ft apart on straight cross-country runs.

Fire protection and related potable-water piping systems could be pressurized at varying ranges, and additional labeling is not considered justified. Steam, flammable gases, and other hazardous materials should be labeled at all pressures.

The component identification should include the component's name, find number, media, and pressure. The media and pressure may be listed on the panel face. The purpose of each panel should be identified on the face of the panel.

8.6.3 Welding of Piping and Tubing

a. Welding process and weld acceptance criteria for pressurized piping and tubing shall be in accordance with ASME B31.3.

b. All welds on piping and tubing shall be cleaned and passivated in accordance with ASTM A967.

Note that ASTM A967 requires ASTM A380 for cleaning and descaling.

c. Welds in tubing systems shall be installed, tested, and rated in accordance with KSC-SPEC-Z-0008.

Welds performed on superaustenitic stainless-steel tubing exposed to a corrosive environment should use fittings, consumable weld inserts, or weld filler material of Inconel 625 or Hastelloy C-22 (UNS N60625 or N06022).

d. Welds in pneumatic systems over 150 psig shall be subjected to 100% radiographic testing in accordance with ASME B31.3 for normal fluid service.

e. Manual welds in GSE piping and tubing over 150 psig shall have 100% visual inspection and 100% radiographic or ultrasound inspection in accordance with ASME standards.

f. Automatic welds in GSE piping and tubing over 150 psig shall have 100% visual inspection and 10% radiographic or ultrasound inspection in accordance with ASME standards.

Meeting the AWS D17.1 requirement for in process examination of automatic gas tungsten arc welding may be substituted for the required 100% radiographic testing.

g. Per ASME B31.3, piping and tubing welds in GSE and GSS pneumatic systems under 150 psig will have 100% visual inspection in accordance with ASME standards.

h. Per ASME B31.3, piping and tubing welds in GSS over 150 psig will have 100% visual inspection and 5% random inspection using radiography or ultrasound in accordance with ASME standards.

i. Per ASME B31.3, all welds in Category M fluid service systems will have 100% visual inspection, 100% radiographic inspection, and 100% penetrant or magnetic particle testing in accordance with ASME standards.

Weld inspection requirements are increased from the minimum ASME B31.3 in conjunction with AWS D17.1 and this document. The NDE inspection methods are performed and evaluated in accordance with ASME requirements.

8.6.4 Flexible Hoses

Designs using convoluted, unlined bellows or flexible metal hoses should include analysis in accordance with MSFC-SPEC-3746 to preclude premature failure due to flow-induced vibration. Acoustic coupling that can intensify the stresses caused by flow-induced vibration should be avoided by ensuring that normal fluid flow requirements do not exceed a velocity of Mach 0.2.

a. Flexible hoses shall be used below one-fourth of the manufacturer's specified burst pressure.

The increased burst pressure factor of safety for flexible hoses above what is required for process piping (4.0 vs. 3.0) is based on the ASME knockdown factor for weld inspection because the welds cannot be properly inspected after forming convolutes. Also, the in-service condition of a flexible hose (including convoluted, polymeric braided, or elastomeric hoses) is more difficult to assess than pipe, tubing, or components.

b. In-service inspection of flexible hoses shall be in accordance with SAE ARP 1658.

c. Convoluted metal flexible hoses without a history of successful use at KSC or at a NASA facility shall have a minimum of 20% longitudinal weld inspection in accordance with ASME B31.3, Appendix X inspection criteria.

Several manufacturers and hose designs covered by component specification control drawings have extensive service history and are considered acceptable for use without additional weld inspection.

8.6.5 Pipe Specifications

a. Stainless-steel pipe for fluid systems shall be in accordance with ASTM A312.

b. Pipe fittings shall conform to ASME B16 standards, KSC-GP-425, or SAE J518.

ASME B16 standards include B16.5, B16.9, B16.11, and B16.25.

c. Expansion joints used in fluid systems in marine or launch-induced environments shall be made from UNS N06022 (Hastelloy C22) material.

8.6.6 Tubing Specifications

a. Austenitic stainless-steel tubing shall be purchased per ASTM A269 or ASTM A213.

b. Austenitic stainless-steel tubing shall be seamless or seam-welded with 100% weld inspection of the longitudinal welds per ASME B31.3.

c. Austenitic stainless-steel tubing shall be UNS S30400 or S31600 in accordance with ASTM A269 or ASTM A213.

d. Austenitic stainless-steel tubing shall have a wall thickness tolerance of −0/+10%.

e. Austenitic stainless-steel tubing shall be tested in accordance with practice D in ASTM A967.

f. Austenitic stainless-steel tubing shall be tested for intergranular corrosion in accordance with ASTM A269 or ASTM A213, supplementary requirement S4.

g. Austenitic stainless-steel tubing shall be Eddy Current tested for defects in accordance with ASTM E426.

h. Austenitic stainless-steel mechanical properties shall be verified by tensile testing per ASME B31.3.

i. Austenitic stainless-steel tubing shall be marked with the ASTM standard "A269" or "A213", the specific alloy (304 or 316), and the required wall thickness tolerance, −0%/+10%.

The reduced tolerance on tubing wall thickness is necessary to match the pressure ratings of 37-degree for flared-tube fittings.

j. When directly exposed to a corrosive environment, tubing shall consist of UNS N08367 or S31254 superaustenitic stainless steel (trade name AL6XN or 254SMO) in accordance with ASTM A249 or ASTM A269 or consist of UNS S31600/S31603 (316/316L) dual-certified stainless steel in accordance with ASTM A269 or ASTM A213 and the requirements of this section.

KSC-SPEC-P-0027 covers the procurement of seam-welded AL6XN tubing similar to ASTM A249. Low-carbon (316L) tubing is preferred for welded applications whereas the standard carbon 316 tubing has higher mechanical strength. Dual-certified tubing provides the mechanical strength of 316 with the welding/corrosion advantage of 316L.

k. UNS N08637 and UNS S31254 tubing shall be subjected to pitting and crevice corrosion testing in accordance with ASTM G48, Methods A and B.

l. Tubing shall be passivated in accordance with ASTM A967, with verification by Practice D.

m. *Each tube length shall be tested for discontinuities via nondestructive electromagnetic (eddy current) test in accordance with ASTM E426, using a calibrated defect prepared in accordance with ASTM E213 as a standard for acceptance or rejection of each tube length.*

8.6.7 Tubing Fabrication and Installation

a. Tubing shall be fabricated, tested, and installed in accordance with KSC-SPEC-Z-0008.

b. Tube welds shall be inspected in accordance with ASME B31.3.

Welds performed on superaustenitic stainless-steel tubing should use fittings, consumable weld inserts, or weld filler material of Inconel 625 or Hastelloy C 22 (UNS N60625 or N06022) in applications where the full corrosion resistance of superaustenitic stainless steel is required.

8.6.8 Fluid Fittings

Flared-tubing fittings, tube weld fittings, and pipe fittings shall be selected in accordance with KSC-GP-425 (or equivalent SAE AS fittings) unless approval is obtained from the Technical Authority for a specific application.

KSC-GP-425 fittings are preferred for all fluid systems for improved standardization, compliance with PVS codes, ease of maintenance, and superior sealing qualities. AN fittings, other 37-degree flared-tube fittings, or alternative industry standard fittings may be approved for a specific application by the Technical Authority.

8.6.9 Unlisted Components

Components other than pressure relief devices shall be considered compliant with ASME B31.3, Section 304.7.2, if they meet **all** of the following requirements:

"Successful history" is NASA or NASA contractor experience without structural failures for the service life of a fluid system or the length of the program supported by the system. Alternatively, "successful history" is successful experience used in support of NASA programs by commercial entities.

- The component is COTS manufactured by a manufacturer selected from those with successful history of providing the identical or similar components to KSC, NASA, or NASA contractors.
- The component has a 3:1 ratio of manufacturer's rated burst pressure to system design pressure (MAWP). If the component is rated for a burst pressure ratio less than 3, the component is derated to a new design pressure of one-third of the manufacturer's burst pressure rating. Brittle materials or cast iron covered by ASME BPVC-VIII, Division 1, Part UCI, require a factor of 10:1 against rated burst pressure.
- The pressure boundary of the component is made from materials listed in ASME B31.3 or ASME BPVC-II.

- The component is used only under conditions of pressure, temperature, humidity, vibration, etc., that meet the manufacturer's ratings or that have been tested by KSC, NASA, or a NASA contractor for the same or similarly proportioned components of the same or like material.
- Flexible hoses are used below one-fourth of the manufacturer's rated burst pressure.

8.6.10 Unlisted Components Other Than COTS

Components that do not satisfy 8.6.9 or components that are custom designed shall meet **all** of the following requirements:

- The component has a minimum 4:1 ratio of burst pressure to design pressure (MAWP).
- Brittle materials or cast iron covered by ASME BPVC-VIII, Division 1, Part UCI, have a minimum 10:1 ratio of burst pressure to design pressure.
- The pressure boundary of the component is made from materials listed in ASME B31.3 or ASME BPVC-II.
- The component has either a design analysis package or a test report to document the minimum burst pressure requirement.

8.6.11 Pressure Relief Devices

a. Pressure relief devices for piping systems shall meet ASME B31.3.

b. Pressure relief devices for stationary pressure vessels shall meet ASME BPVC-VIII, Division 1, including the requirement for the ASME UV or UD stamp, or CGA S1.3.

c. Pressure relief devices for mobile pressure vessels shall meet DOT's requirements in 49 CFR and CGA S1.1 or CGA S1.2.

d. The opening through all pipe, fittings, and components between a pressure source (vessel, regulator, etc.) and its pressure relief valve shall have at least the area of the pressure relief valve inlet.

e. Pressure relief devices on vessels shall be designed for the effects of a fire if any of the following apply:

   - The vessel contains flammable materials or oxidizer (N_2O_4, oxygen, nitrogen dioxide, etc.).
   - Flammable materials are stored within 10 ft of the PVS.
   - Pressurized flammable fluids stored **below** 15 psig are stored within 50 ft of the PVS.
   - Pressurized flammable fluids stored **above** 15 psig are stored within 100 ft of the PVS.

- The vessel is within in a building constructed with or containing flammable materials (e.g., partition walls or carpeting).

f. Relief valves shall be purchased clean to the requirements of 8.1 and factory-set to the required system relief pressure.

g. Changes to the set pressure of the relief valves shall be performed only by the manufacturer or an NBIC VR-certified vendor.

h. For existing or heritage systems used as GS, pressure relief devices shall be in full compliance with ASME B31.3 or ASME BPVC-VIII, before the system is placed in service.

8.6.12 Qualification of Components by Pressure Test

Components shall be considered compliant with ASME B31.3, Section 304.7.2, if they meet either of the following conditions:

- The component is rated at one-fourth of the test pressure if the materials of manufacture are known and are ductile (over 5% elongation at failure).
- The component is rated at one-tenth of the test pressure if the materials of manufacture are unknown or are brittle (less than 5% elongation at failure).

8.7 Vacuum and Compressed-Air Systems

Compressed air systems in this section includes shop air, but not breathing air or Environmental Control System (ECS).

a. Vacuum systems shall be designed in accordance with the allowable stresses in ASME B31.3.

b. New vacuum vessels excluded by the NASA-STD-8719.17 and not covered by another requirement shall be designed with the safety factors in 6.9.

c. Compressed-air systems having an operating gage pressure up to 1.0 MPa (150 psi) shall be designed in accordance with a voluntary consensus standard such as one from ASME or the Compressed Gas Association (CGA).

d. Compressed-air systems above 1.0 MPa (150 psi) shall be designed in accordance with ASME B31.3 and KSC-STD-Z-0005.

ASME B31.1 meets or exceeds the requirements of ASME B31.3 and may be used as an alternative.

e. Compressed-air systems shall be cleaned to a level of Generally Clean or the precision cleaning requirements of 8.1.

Generally Clean is defined in ISO 14952, KSC-C-123, and other cleaning standards.

8.8 Breathing Air

a. Breathing-air respirator systems shall conform to 29 CFR 1910.
b. Breathing-air storage and distribution systems shall be designed in accordance with KSC-STD-Z-0008.
c. The design of GS used for life support systems shall be in accordance with KSC-STD-Z-0008.

GS intended for use by operators wearing PHEs should be designed to meet the following criteria:

- *Items (valves, gages, levers, bolts, nuts, and any other items required to be moved, turned, manipulated, or monitored) should be located in a position that will make it easier for a PHE-suited operator to access the item while standing.*
- *Sufficient clearance should be provided to preclude the operator from brushing against other surfaces.*
- *GS should be designed to avoid requirements for PHE-suited operators to reach into tight areas; stoop to avoid low overhead obstructions; mount supplementary ladders or stairs; touch rough surfaces; or sit, kneel, or lie on the floors or decks.*
- *The design should include suitable provisions to prevent discomfort or fatigue for the PHE-suited personnel.*
- *Use of expanded metal surfaces and other sharp edges should be avoided.*

8.9 Pneumatics

a. The design of pneumatic GS shall be in accordance with KSC-STD-Z-0005.
b. Pneumatic cylinders and pneumatic actuators shall be designed to meet a voluntary consensus standard approved by the Technical Authority or to have a minimum factor of safety of 4 against burst.

Media includes, but is not limited to, nitrogen, helium, hydrogen, oxygen, methane, breathing air, and special mixtures of these gases.

8.10 Hydraulics

8.10.1 Hydraulic Design

The design of GS hydraulic systems over 150 psig shall be in accordance with ASME B31.3 or NFPA T2.6.1, and with KSC-STD-Z-0005.

8.10.2 Hydraulic Components and Assemblies

COTS hydraulic systems, subsystems, assemblies, or components shall meet one of the following:

- ASME B31.3, NFPA T2.6.1, ISO/TR 10771-2, or another voluntary consensus standard approved by the Technical Authority.
- Components without certification to a specific design standard may be used at a pressure less than one-fourth of the manufacturer's rated burst pressure or one-fourth of the pressure obtained from a pressure test conducted in accordance with ASME B31.3, Section 304.7.2.

8.10.3 Hydraulic Cylinders and Actuators

Hydraulic cylinders and actuators shall be designed to meet a voluntary consensus standard approved by the Technical Authority or to have a minimum factor of safety of 4 against burst.

8.10.4 Hydraulic Accumulators, Vessels, and Reservoirs

a. Hydraulic accumulators charged with a pneumatic pressure shall meet ASME BPVC-VIII, Division 1 or 2.
b. Hydraulic storage vessels shall meet API STD 620 or ASME BPVC.
c. Unpressurized hydraulic reservoirs shall meet the structural requirements of this standards manual or API STD 620 or ASME BPVC.

8.10.5 Hydraulic System Cleaning

Hydraulic systems shall be cleaned in accordance with ASTM D4174 or the precision cleaning requirements of 8.1.

ISO 23309 is an acceptable alternative to ASTM D4174.

8.10.6 COTS Hydraulic Systems

Prepackaged hydraulic power systems and oil lubrication systems shall be considered COTS if the following conditions are met:

- the systems are used within manufacturer's rated capacity,
- the systems are protected against overpressure,
- the systems are maintained in accordance with the manufacturer's instructions, and
- no modifications or interconnecting piping/tubing has been added to the original manufacturer's COTS design.

8.10.7 Oil Lubrication and Grease Lubrication Systems

a. Oil lubrication systems that operate under 150 psig and all grease lubrication systems shall be designed to the appropriate voluntary consensus standard.

b. Overpressure protection shall be provided for oil and grease lubrication systems utilizing positive displacement pumps.

8.11 Hydrocarbon Fuel

The design of GS used for servicing with hydrocarbon fuels (JP-4, JP-5, RP-1, and ASTM jet fuels A and B) shall be in accordance with ASME B31.3.

ASME B31.1 meets or exceeds the requirements of ASME B31.3 and may be used as an alternative.

8.12 Environmental Control Systems

a. GSE used for an ECS shall be in accordance with the ASHRAE Fundamentals IP Handbook, Chapter 40, Codes and Standards.

Components purchased to standards of the Air-Conditioning, Heating, and Refrigeration Institute may be used as an alternative.

b. Gaseous nitrogen shall be isolated from the ECS air ducting system by using two valves in series in the gaseous nitrogen supply line and venting to exterior atmosphere between the valves.

c. If the gaseous nitrogen supply is connected to the ECS duct system, ECS shall include the capability of monitoring the oxygen content in the ducting or in the room serviced by the ECS.

d. The design of ducting exposed to the launch-induced environment shall be in accordance with ASME B31.3 or with the structural requirements in 6.9.

Although, systems under 15 psig are excluded from the official scope of ASME B31.3, the combination of internal pressure and induced environments (acoustic, vibration, and plume) the design requirements of ASME B31.3 category D fluid service may be used for the ECS system piping design.

e. The design of ducting not exposed to the launch-induced environment shall be in accordance with applicable SMACNA ducting standards, ASME B31.3, or with the structural requirements in 6.9.

Intakes to air distribution systems should be located away from areas where toxic vapors are normally vented or where accidental spillage could contaminate breathing-air supplies or vehicle air supplies. Intakes should protect equipment from the accumulation of toxic vapors. Prefilters should be used in fresh-air intakes and be located upstream of primary filters to prevent excessive loading of the primary filter. Filters should be located immediately upstream of all interfaces where control of particulate matter is required for system performance.

8.13 Cryogenic Systems

Cryogenic flanges should be re-torqued 30 hours after the initial torque application to seat the gasket material in the serrations and accommodate the associated torque relaxation.

a. The design of GS used for cryogenic servicing with liquid hydrogen, LO_2, and liquid nitrogen shall be in accordance with KSC-STD-Z-0009.

b. The design of GS used for cryogenic servicing with liquid methane shall be in accordance with NFPA 59A.

c. Cryogenic systems shall be designed for severe cyclic conditions in accordance with ASME B31.3.

The design of GS used for cryogenic servicing with liquid helium and cryogenic fluids should use KSC-STD-Z-0009 as a guide.

The design of cryogenic GS used in occupied facilities should be in accordance with NFPA 55.

8.14 Hypergolic Fluid Systems

Hypergolic propellants are fuels and oxidizers or fuels and catalysts that, when combined, produce a violent, explosive, high-energy, exothermic reaction without any other ignition source. Hypergolic propellants are highly toxic, are very sensitive to material selection for containment or sealing, and require the use of personal protective equipment for GS operators.

a. The design of GS used for hypergolic-fuel or oxidizer servicing with monomethylhydrazine, unsymmetrical dimethylhydrazine, N_2O_4, aerozine 50, or hydrazine shall be in accordance with KSC-STD-Z-0006.

b. Fluid fittings in hypergolic-fuel systems that are intended to be connected or disconnected as a part of normal operations (not maintenance or testing) shall use only left-hand threads. Alternative: 5/8 in. or 1-3/4 in. fittings in accordance with KSC-GP-425.

c. Fluid fittings in hypergolic oxidizer systems that are intended to be connected or disconnected as a part of normal operations (not maintenance or testing) shall use only right-hand threads. Alternative: 5/8 in. or 1-3/4 in. fittings in accordance with KSC-GP-425.

d. Hypergolic fluid systems shall be designed in accordance with ASME B31.3 as Category M toxic fluid service.

e. Leak testing shall utilize the sensitive leak test method from ASME B31.3 performed at the system maximum expected operating pressure (MEOP).

ASME B31.3 specifies that the leak test be performed at the lower of 25% of MEOP or 15 psi. Performing the leak test at MEOP will increase the sensitivity for leak detection.

f. Pipe threads (national pipe thread or other tapered pipe threads) shall not be used except for conversion fittings from pipe-thread components to straight thread.

Components using pipe threads should not be selected. The connections from pipe thread to straight thread should occur as close as possible to the pipe-thread component.

8.15 Ammonia

a. Ammonia systems shall be designed in accordance with ASME B31.3 as Category M toxic fluid service.

b. Leak testing shall be per ASME B31.3, including additional sensitive leak test method from ASME B31.3 performed at the system MEOP.

ASME B31.3 specifies that the leak test be performed at the lower of 25% of MEOP or 15 psi. Performing the leak test at MEOP will increase the sensitivity for leak detection.

If ammonia is used as a refrigerant see 8.16.

c. Ammonia systems will follow OSHA 1910.111 for storage and handling.

8.16 Refrigeration Systems

Refrigeration systems using nontoxic fluids below 500 psi (3.45 MPa) built from commercially available components shall be in accordance with ASHRAE Fundamentals IP Handbook, UL 207, or ASME B31 standards.

COTS refrigeration systems and facility HVAC systems are not covered by this standards manual.

9. ELECTRICAL AND ELECTRONICS REQUIREMENTS

Electrical and electronic equipment should be capable of a minimum of 10% expansion or modification without major redesign.

9.1 Electrical Design for Pneumatic and Hydraulic Components

The electrical design for pneumatic and hydraulic components shall be in accordance with KSC-STD-E-0004.

9.2 Electrical Power Systems

The design of electrical power systems covered by NFPA 70 shall be in accordance with NFPA 70 and NFPA 70E.

Incorporating batteries in the design of GS should follow the recommended practices in the following documents: IEEE 484; IEEE 1106; IEEE 1187; IEEE 446; ANSI C18.2M, Part 1; ANSI C18.3M, Part 1; and ANSI C18.5M, Part 1.

9.2.1 Electrical GSE Power

Electrical GSE shall operate from the following nominal alternating-current (AC) and direct-current (DC) voltages as applicable:

- AC 60 Hz root mean square voltages (VAC) of 120/240 VAC, 120/208 VAC, 240/480 VAC, or 277/480 VAC.
- DC voltages: 28 volts direct current (VDC), 56VDC, or 120VDC.

400 Hz power may be specified in GS design with prior approval from the responsible Technical Authority.

9.2.2 Emergency Power

When loss of power will cause hazardous conditions, those power systems shall be backed up by batteries connected in a manner that ensures uninterrupted power for safing of GSE systems.

9.3 Bonding, Grounding, Shielding, and Protection from Electromagnetic Interference, Lightning, and Transient Voltages

a. GS shall be bonded, grounded, shielded, and protected from electromagnetic interference, lightning, and transient voltages in accordance with KSC-STD-E-0022 and NFPA 70.

b. GS that directly interface with flight hardware which provide bonding, grounding, or shielding to the flight hardware shall be in accordance with NASA-STD-4003.

KSC-STD-E-0022 works in conjunction with KSC-STD-E-0012, which provides requirements for facility grounding, bonding, and lightning designs. For additional information on lightning protection, refer to IEC 62305, Parts 1 through 4. EMC requirements apply to COTS equipment utilized in GS. The NASA Technical Authority for electrical and electronic design has the authority to approve tailored tests plans, requirements and specific test parameters to meet the requirements of KSC-STD-E-0022.

9.4 Hazardproofing

The design of electronic equipment and wiring for all voltages in hazardous locations shall be in accordance with NFPA 70, Article 500; with NFPA 497; and with KSC-STD-E-0002.

9.5 Electrical, Electronic, and Electromechanical Parts

a. Electrical, electronic, and electromechanical (EEE) parts shall be in accordance with KSC-PLN-5406.

b. Derating of EEE parts shall be in accordance with KSC-PLN-5406 and NFPA 70.

KSC-PLN-5406 addresses EEE part selection, derating, obsolescence, screening, procurement, counterfeit prevention, etc. See NASA-HDBK-4008 for design and development guidance of programmable logic devices.

9.6 ESD-Sensitive Components and Assemblies

ESD practices and processes shall be in accordance with ESD S20.20.

To prevent ESD, the moisture should be a minimum of 14 grains/pound of air. This value is from the ESD Association. This equates to the following relative humidity:

Temperature (F)	*20*	*30*	*45*	*55*	*65*	*75*	*95*	*100*
% Relative Humidity	*88*	*58*	*32*	*22*	*16*	*11*	*6*	*5*

Insulator materials should not be used near ESD-sensitive components or assemblies.

9.7 Electrical Power Receptacles and Plugs

a. AC electrical power receptacles and plugs that supply power to GS shall be in accordance with KSC-STD-E-0011.

b. Electrical power receptacles and plugs within GS shall be in accordance with KSC-GP-864.

9.8 Cable, Wiring, and Harnesses

a. Cable, wiring, and harnesses shall be in accordance with NFPA 70.

b. Electrical hookup wire shall be in accordance with SAE AS 50861, SAE AS 22759 or NEMA HP 7.

c. Flexible, multiconductor, jacketed electrical cable, and cable harnesses shall be designed and fabricated in accordance with KSC-GP-864.

d. Crimping shall be in accordance with NASA-STD-8739.4 or IPC/WHMA-A-620 and IPC/WHMA-A-620-S.

Reference NASA-STD-8739.6 for implementation and exceptions of IPC/WHMA-A-620.

e. Electrical-wire insulation materials shall be evaluated for flammability in accordance with NASA-STD-6001, Test 4.

Testing of UL listed COTS cable assemblies is not required.

f. Arc tracking shall be evaluated in accordance with NASA-STD-6001, Test 18.

g. Kapton insulation shall not be used in GS wiring.

Arc tracking testing is not required for chlorinated polyethylene, polytetrafluoroethylene (PTFE), PTFE laminate, ETFE, or silicone-insulated wires because the resistance of these materials to arc tracking has already been established. Arc tracking testing is intended for other insulation materials, such as polyimide, which has a service history of arc tracking problems.

h. Electrical cable and harness assemblies shall be identified at each end of the cable or harness and labeled to show the assembly part number, cable or harness reference designation number, and cable or harness end marking in accordance with the requirements provided on the cable assembly drawing and described in 120E3100003.

i. Cable assemblies and wire harnesses shall be marked in accordance with KSC-E-166.

j. Labels shall meet the requirements of KSC-STD-E-0015.

k. Heat-shrinkable sleeving labels shall conform to the requirements of SAE AMS-DTL-23053/5, Class 1.

Heat shrinkable flexible polyolefin sleeving is used for light duty harness jackets, individual conductors, or wire color coding marking and identification.

l. The heat-shrink labels shall be marked in accordance with SAE AS 5942 and meet the testing requirements of MIL-STD-202, Method 215.

MIL-DTL-23053/5 was replaced by SAE AMS-DTL-23053/5. MIL-M-81531 was replaced by SAE AS 5942.

9.9 Glands and Cable Termination Fittings

a. Glands and fittings shall be selected based on cable type, environmental conditions, EMI/EMC requirements, and material compatibility.

b. Glands and fittings shall be installed in accordance with the manufacturer's specifications.

Glands and cable termination fittings are an acceptable alternative to typical connector terminations. Glands and cable termination fittings provide a means for passing armored, metal-clad, and jacketed cable through a bulkhead or enclosure.

9.10 Soldering

a. Soldering of electrical connections shall be in accordance with IPC J-STD-001.

b. Soldering of critical electrical connections exposed to launch-induced vibration or thermal cycling shall be performed in accordance with IPC J-STD-001(S).

c. Unless otherwise approved by the Technical Authority, Sn-Pb based solders and Sn-Pb part surface finishes (minimum 3% Pb by weight) shall be used for the assembly of electronics hardware intended for critical GSE.

The use of Pb-free solders or Pb-free Sn-based part surface finishes may be allowed when justified by technical need and approved by the Technical Authority. COTS equipment that complies with the Restriction of Hazardous Substances (RoHS) must be evaluated for its intended application, environment, and life cycle. To mitigate the effect of Sn whiskers in RoHS-compliant equipment used in critical applications, redundancy should be considered.

d. For critical GS, the Pb content of solder shall be verified by material certification or by lot sampling.

9.11 Fiber Optics

a. Fiber-optic cable assemblies, installations, and terminations shall be in accordance with NASA-STD-8739.5 and KSC-GP-864.

b. Protective caps shall be provided for all fiber-optic connections to GS so that the mating surface is protected.

9.12 Connectors

a. Electrical multiconductor connectors for GS shall be selected from the following documents: SAE AS 50151, MIL-DTL-22992, MIL-DTL-24308, MIL-DTL-38999, IEC 60807-1, or KSC-GP-864.

Mil Spec style commercial connectors (non-Department of Defense Qualified Parts List) are acceptable if they are qualified for their natural and induced operational environment.

b. Bayonet style connectors shall not be used in new designs except when required to interface with heritage equipment.

c. All electrical connectors in outdoor and hazardous locations shall be threaded and provide provisions for potting and molding (using KSC specified mold adapters or commercial adapters).

d. Coaxial radio frequency (RF) connectors shall be selected from MIL-PRF-39012.

e. Potting and molding of electrical connectors shall be in accordance with KSC-STD-132 or an equivalent standard approved by the responsible Technical Authority.

f. Protective covers or caps shall be specified for use with electrical-connector plugs and receptacles in accordance with KSC-GP-864 when they are not connected.

Metallic protection caps should be used during transportation or other potentially damaging handling situations.

Protective covers or caps should:

- *protect against moisture intrusion;*
- *protect sealing surfaces, threads, and pins against damage;*
- *resist abrasion, chipping, and flaking;*
- *comply with cleanliness requirements for the plugs and receptacles on which they are used;*
- *consist of material that is compatible with the connector materials;*
- *connect to the cable with a suitable lanyard, chain, or hinge; and*
- *not produce static.*

g. Covers/caps shall be provided to protect optics.

Optical covers/caps should be easy to install and remove. The covers/caps should be connected with a lanyard or the equipment should have a designated storage provision.

9.13 Sensors and Transducers

a. Sensors and transducers used in the design of GS shall be selected using KSC-NE-9187.

Measurement applications that provide visibility only and are not relied upon to control a condition that could damage flight hardware or could create a safety hazard may use COTS components.

b. If a part is not covered by KSC-NE-9187, it shall be documented with the following minimum information included: commodity, environment, performance, recommended vendor, materials, compatibility, and qualification/acceptance criteria.

9.14 Racks, Panels, Purged Rooms, and Modular Enclosures

a. Electronic racks, panels, and enclosures shall be in accordance with KSC-SPEC-E-0002.

Electronic racks, panels, and modular enclosures should conform to the configuration and dimensional requirements of ECA EIA/ECA 310-E.

b. Purged electrical enclosures in hazardous locations shall be in accordance with NFPA 496 and pressurized to 56 millimeter (2.2 in.) of water pressure (0.08 psi).

NFPA 496 contains requirements for the protection of electrical and electronic equipment for installations in hazardous locations recognized by NFPA 70. The required minimum pressure of 2.2 in. of water column is to account for leakage, degradation of seals over time, and corrosion. Electrical enclosures should be designed to withstand a minimum of 4 in. of water column internal pressure without permanent deformation.

c. Purged electrical enclosures shall be outfitted with purge hardware in accordance with 79K07491 or other hardware that meets all requirements of NFPA 496.

79K07491 shows the inlet and outlet hardware required for hazardproofing purges and environmental purges to maintain low relative humidity and positive pressure.

d. Purged rooms or large volumes in hazardous areas (other than electrical enclosures and boxes) shall be pressurized to a minimum of 75 Pa (0.3 in. of water).

Hazardproofing purges and environmental purges to maintain low relative humidity and positive pressure for large volumes, such as electrical rooms, have a lower required pressure for practical reasons associated with their size.

9.15 Electromagnetic Relays

a. Electromagnetic relays shall be hermetically sealed units with continuous duty-rated coils.

b. Relays shall be selected on the basis of application with regard to operate/release time, pickup/dropout voltage, and coil resistance.

Transient suppression across the relay coil should be considered in order to minimize electromagnetic-interference surges caused by coil inductances.

9.16 Switches

9.16.1 Low Current Switches

Low-current switches (under 1 ampere [A]) shall have a wiping-type operation and gold-plated or silver-plated contacts.

Where units are miniature, sealing is preferred prior to soldering in order to prevent flux contamination.

9.16.2 High Current Switches

High-current switches (over 1 A) shall be industrial-rated, be approved/recognized by Underwriters Laboratory (UL) or another independent test laboratory, or military grade.

Arc suppression capacitors, or other transient suppression devices, typically 0.1 µF at 200% of working AC voltage, are recommended across contacts. Contacts should be silver-plated.

9.16.3 Heavy-Duty Pushbutton or Key Switches

Heavy-duty, high-cycle switches, such as crane pendants and emergency stops, shall be industrial-control type, National Electrical Manufacturer's Association (NEMA) 1-, 12-, or 13-rated.

9.16.4 Rotary Switches

High-current rotary switches shall be of power tap construction with silver-plated contacts.

Rotary switches should be of enclosed construction. Nonshorting types are recommended.

9.16.5 Corrosive or Outdoor Environments

For corrosive or outdoor environments, switches shall be hermetically sealed or provided with other means to ensure a stable, dry environment.

Switches may be MIL-STD qualified or MIL-PRF qualified, of the sealed type, or purged with dry air or GN_2*. Wiping contacts also serves to eliminate corrosive buildup.*

9.17 Fuses

a. Fuses shall be approved or recognized by UL.

Slow-blow fuses are preferred where two times the fuse rating has to be used for inductive or higher-current circuits.

b. Wiring shall be capable of momentary surge currents at the selected fuse capacity.

c. Fuse rating shall be marked near the fuse holder or blocks and on schematics.

The effects of blown fusing on critical circuit operation are important considerations.

d. Fuses shall be rated for no more than the equipment short circuit current.

9.18 Circuit Breakers

a. Circuit breakers shall be used in all electrical power lines carrying over 5 A.

Circuit breakers must be able to interrupt the short-circuit capacity of the circuit to which they are connected; each application must be examined for all its probable uses.

b. Power circuits shall be protected by companion-trip or common-trip magnetic circuit breakers.

c. Circuit breakers shall be trip-free.

d. Circuit breakers shall be protected from environmental conditions that may affect their operation.

e. Circuit breaker selection and rating shall be in accordance with NFPA 70.

Molded-case breakers are typically used in GSE and GSS applications.

Refer to NFPA 70E for Incident Energy and Flash Protection Boundary Calculations and Considerations.

9.19 Bus Bars

Bus bars shall be made of copper conforming to ASTM B152.

9.20 Printed Circuit Boards

9.20.1 Printed Circuit Board Design

Rigid, flexible, and rigid-flexible printed circuit boards (single, double, metal-core, or multilayer structures) shall meet the design specifications of the following standards, as applicable: IPC 2221 (for critical applications, performance classification 3 shall be used), IPC 2222, IPC 2223, and IPC 2252.

All board types within the IPC 2221 series standard documents are acceptable.

9.20.2 Printed Circuit Board Fabrication and Acceptance

Rigid, flexible, and rigid-flexible printed circuit boards (single, double, metal-core, or multilayer structures) shall meet the qualification and performance specifications of the following standards, as applicable: IPC 6011 (for critical applications, performance classification 3 shall be used), IPC 6012 (for critical applications, performance classification 3 shall be used), IPC 6013, and IPC 6018.

9.20.3 Printed Circuit Assembly Fabrication and Acceptance

a. Printed circuit assemblies shall be fabricated in accordance with IPC J-STD-001.

b. Critical printed circuit assemblies exposed to launch-induced vibration or thermal cycling shall be fabricated in accordance with IPC J-STD-001(S).

9.20.4 Conformal Coating

Where electronic circuitry can be damaged or degraded by moisture, dust, chemicals, temperature extremes, mechanical stress, or vibration, conformal coating shall be required in accordance with NASA-STD-8739.1.

When established, requirements for conformal coating should be stated in the design documentation.

9.21 Electric Motors and Generators

a. Motors and generators used in GS shall be selected in accordance with the system requirements for speed, torque, horsepower, and environment.

b. Motors and generators shall meet the NEMA standards and National Fire Protection Association requirements that govern the classification and general application of motors and generators.

NEMA MG 1 is a comprehensive document that includes the classification, general standards, manufacturing, and test of motors and generators. This document should be used as a guide for specification and selection of GS motors and generators. Another reference and guide is NEMA C50.41. NFPA 70 provides the size of wiring and conduit required for the motor connections.

9.22 Motor Starters and Controllers

a. Motor starters and controllers shall be in accordance with the type of motor, performance ratings, and type of control required.

b. Enclosures for motor starters and controllers shall meet the environmental requirements for their locations.

NEMA ICS 2, Parts 1 through 9, is a comprehensive document that provides practical information concerning ratings, construction, test, performance, and manufacture of industrial control equipment. NEMA ICS 61800-2 specifies ratings for low-voltage, variable frequency AC power drive systems. NFPA 70 provides the size of wiring and conduit required for the starter/controller connections. NEMA ICS 7 provides general standards for drive converters, drives, and drive systems.

9.23 Electrical Fabrication, Assembly and Installation

a. Fabrication of electrical GS shall be in accordance with KSC-E-165.

b. Assembly and installation of electrical GS shall be in accordance with KSC-E-166 and NFPA 70.

10. CONTROL AND SOFTWARE REQUIREMENTS

10.1 Programmable Logic Controllers

a. Programmable logic controllers (PLCs) used in GSE shall be in accordance with IEC 61131-2 and IEC 61131-3.

b. The operation of PLC software and hardware shall allow for various levels of health monitoring and permit configuration of failure modes.

c. The processor executive shall recognize nonfatal faults and perform predefined tasks to alert the operator.

d. The hardware shall recognize fatal errors and respond by placing outputs in the predefined failed-safe mode.

e. The processor executive shall recognize faults with system components and perform defined tasks to safe the failed component and alert operators.

10.2 Software

Software incorporated into the design of GS will meet the requirements of NPR 7150.2.

Software (including COTS software) includes firmware and embedded software (e.g., the software in PLCs and motor controllers). NPR 7150.2 contains provisions applicable to COTS software in NASA-developed systems.

10.3 Security of Information Technology

The design of GS will meet the information technology security requirements specified in NPR 2810.1 and NPR 7150.2.

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APPENDIX A. REFERENCE DOCUMENTS

	Handbook of Spring Design from the Spring Manufacturers Institute
29 CFR 1910.147	Control of Hazardous Energy (Lockout/Tagout) – Inspection Procedures and Interpretive Guidance
AIAA G-095	Guide to Safety of Hydrogen and Hydrogen Systems
ANSI C18.2M, Part 1	American National Standard for Portable Rechargeable Cells and Batteries – General and Specifications
ANSI C18.3M, Part 1	Portable Lithium Primary Cells and Batteries – General and Specifications
ANSI C18.5M, Part 1	Portable Lithium Rechargeable Cells and Batteries – General and Specifications
ASME B16 series	Standards for Pipes and Fittings
ASME B31.1	Power Piping
ASME Y14.44	Reference Designations for Electrical and Electronics Parts and Equipment
ASTM A123	Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products
ASTM A153	Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware
ASTM A380	Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems
ASTM A653	Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process
ASTM A780	Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings
ASTM A1059	Standard Specification for Zinc Alloy Thermo-Diffusion Coatings (TDC) on Steel Fasteners, Hardware, and Other Products
ASTM B695	Standard Specification for Coatings of Zinc Mechanically Deposited on Iron and Steel

ASTM D5363	Standard Specification for Anaerobic Single-Component Adhesives (AN)
ASTM D7290	Standard Practice for Evaluating Material Property Characteristic Values for Polymeric Composites for Civil Engineering Structural Applications
ASTM E2217	Standard Practice for Design and Construction of Aerospace Cleanrooms and Contamination Controlled Areas
ASTM F1136	Standard Specification for Zinc/Aluminum Corrosion Protective Coatings for Fasteners
ASTM F2833	Standard Specification for Corrosion Protective Fastener Coatings with Zinc Rich Base Coat and Aluminum Organic/Inorganic Type
ASTM F3019	Standard Specification for Chromium Free Zinc-Flake Composite, with or without Integral Lubricant, Corrosion Protective Coatings for Fasteners
ASTM G63	Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service
ASTM G88	Standard Guide for Designing Systems for Oxygen Service
ASTM G94	Standard Guide for Evaluating Metals for Oxygen Service
AWS C3.2M/C3.2	Standard Method for Evaluating the Strength of Brazed Joints
AWS C3.4M/C3.4	Specification for Torch Brazing
AWS C3.5M/C3.5	Specification for Induction Brazing
AWS C3.6M/C3.6	Specification for Furnace Brazing
AWS C3.7M/C3.7	Specification for Aluminum Brazing
ECA EIA/ECA 310-E	Cabinets, Racks, Panels, and Associated Equipment
GP-863	General Criteria for Design of New Equipment and Facilities
ICC-ES AC156	Acceptance Criteria for Seismic Certification by Shake-Table Testing of Nonstructural Components.
IEC 62305	Protection Against Lightning, Part 1: General principles, Part 2: Risk management, Part 3: Physical damage to structures and life hazard, and Part 4: Electrical and electronic systems within structures

IEEE 446	Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications
IEEE 484	Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications
IEEE 1106	Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications
IEEE 1187	Recommended Practice for Installation Design and Installation of Valve-Regulated Lead-Acid Storage Batteries for Stationary Applications
IEST-STD-CC1246	Product Cleanliness Levels–Applications, Requirements, and Determination
ISO 14952	Space systems — Surface cleanliness of fluid systems
ISO 23309	Hydraulic fluid power systems - Assembled systems - Methods of cleaning lines by flushing
JPR 5322.1	Contamination Control Requirements Manual
JSC 29353	Flammability Configuration Analysis for Spacecraft Applications
KDP-P-2713	Technical Review Process
KSC-C-123	Surface Cleanliness of Ground Support Equipment Fluid Systems, Specification for
KSC-STD-E-0012	Facility Grounding and Lightning Protection, Standard for
KSC-STD-G-0003	Launch Support and Facility Components, Qualification of, Standard for
KSC-STD-P-0006	Quick Release Pins and Pin Tethers, Standard for
KSC-SPEC-Z-0007	Tubing, Steel, Corrosion Resistant, Types 304 and 316, Seamless, Annealed, Specification for
KTI-5210	Material Selection List for Oxygen Service
KTI-5212	Material Selection List for Plastic Films, Foams, and Adhesive Tapes
MMA-1985-79	Standard Test Method for Evaluating Triboelectric Charge Generation and Decay

MSFC-SPEC-164	MSFC Technical Standard: Cleanliness of Components for Use in Oxygen, Fuel, and Pneumatic Systems, Specification For
MSFC-SPEC-445	Adhesive Bonding, Process and Inspection, Requirements for
MSFC-SPEC-3746	Flow-Induced Vibration Assessment Requirements for Metal Bellows and Flexhoses
MSFC-STD-486	Standard, Threaded Fasteners, Torque Limits for
NASA-HDBK-4008	Programmable Logic Devices (PLD) Handbook
NASA-RP-1228	Fastener Design Manual
NASA/TM-2007-213740	Guide for Oxygen Compatibility Assessments on Oxygen Components and Systems
NASA TM-2014-281335	VAB Temperature and Humidity Study
NEMA C50.41	Polyphase Induction Motors for Power Generating Stations
NEMA ICS 2	Industrial Control and Systems Controllers, Contactors and Overload Relays Rated 600 Volts
NEMA ICS 7	Industrial Control and Systems: Adjustable-Speed Drives
NEMA ICS 61800-2	Adjustable Speed Electrical Power Drive Systems, Part 2: General requirements – Rating specifications for low voltage adjustable frequency a.c. power drive systems
NEMA MG 1	Motors and Generators
NFPA 55	Compressed Gases and Cryogenic Fluids Code
SAE AMS 2175	Castings, Classification and Inspection of
SAE AMS 2460	Chromium Plating
SAE AMS 2488	Anodic Treatment – Titanium and Titanium Alloys Solution pH 13 or Higher
SAE AMS 2770	Heat Treatment of Wrought Aluminum Alloy Parts
SAE AMS 2771	Heat Treatment of Aluminum Alloy Castings
SAE AMS 2772	Heat Treatment of Aluminum Alloy Raw Materials
SAE AMS-H-81200	Heat Treatment of Titanium and Titanium Alloys

SAE AMS-QQ-P-416	Plating, Cadmium (Electrodeposited)
SAE AMS-STD-595	Colors Used in Government Procurement
SAE ARP 1176	Oxygen System and Component Cleaning
SSP 50004	Ground Support Equipment Design Requirements: International Space Station
SW-E-0002	Ground Support Equipment General Design Requirements: Space Shuttle
TM-584	Corrosion Control and Treatment Manual

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APPENDIX B. GROUND SYSTEM IDENTIFICATION SYSTEM COLORS

The listed color chip numbers are from SAE AMS-STD-595. Actual colors used for GS may be the commercially available color closest to the listed color chip number.

Application	Color	Color Chip Number
Electrical/electronic, hydraulic, and pneumatic consoles, racks, and cabinets	Gray	26440 or 26251
Structural steel/aluminum	Gray	16187 or 16473
Remove-before-flight items, safety equipment, and protective equipment	Red	11105 or 21105
White room or clean room equipment, storage vessels when solar heat transfer is a concern	White	17875 or 27875
Panel lettering	Black	37038
Handling and transportation equipment	Yellow or White	13538 (yellow) 17875 or 27875 (white)
Control racks and consoles	Blue	25102
Connections and interfaces for hypergolic fuel servicing (see MIL-STD-101 for color coding of piping systems)	Yellow Brown Band (optional)	13655 (yellow) 10080 (brown)
Connections and interfaces for hypergolic oxidizer servicing (see MIL-STD-101 for color coding of piping systems)	Green Brown Band (optional)	14110 (green) 10080 (brown)

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APPENDIX C. GS DOCUMENTATION DELIVERABLES

C.1 The GS provider is responsible for submitting documentation to verify that the hardware/software has been developed in accordance with this standard.

C.2 The GS provider is responsible for providing all the necessary documentation to the using organization when the GS is delivered for use, regardless of who “owns” the GS at the time of delivery. Examples of this documentation include the following:

- Certification Approval Request (indicates how the GS was certified as complying with this standard)
- Design Verification Matrix (indicates which GS requirements were met and how)
- Material Inspection and Receiving Report
- Software Version Description Document
- Validation and verification compliance records
- Facility and flight vehicle interface requirements
- Drawings with parts list or bill of materials
- Firmware Version Description Document
- Maintenance manuals/procedures
- Material certifications and lot traceability
- Hazard Analyses or Ground Safety Data Pack
- Failure Modes, Effects, and Criticality Analysis
- Operating manuals/procedures
- Critical Items List

Intent/rationale: The using organization requires documentation for safely operating, maintaining, and servicing the GS. To reduce risk to the mission, ground personnel, and flight crews, a Failure Modes and Effects Analysis should be completed and submitted in accordance with the criticality assigned to the GS by the responsible program or project. KDP-P-2713 lists typical documentation requirements.

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APPENDIX D. PRESSURE VESSELS AND SYSTEMS

In cases where NASA-STD-8719.17 does not specify a voluntary consensus standard, PVS is considered qualified for service if it meets the following engineering requirements and is certified by the Pressure Systems Manager in accordance with NASA-STD-8719.17.

D.1 Pressure Vessels

Pressure vessels shall meet either ASME BPVC-VIII; Division 1, 2, or 3; or DOT's requirements in 49 CFR for mobile vessels.

D.2 Pipe, Tubing, and Associated fittings

Components shall meet **all** of the following requirements:

- Stress under the maximum pressure does not exceed one-third of the minimum tensile strength in the design temperature range.
- Stress under the maximum pressure does not exceed two-thirds of the minimum yield strength in the design temperature range.
- Welds have 5% random inspection, using radiography or ultrasound, and are inspected in accordance with ASME standards.
- The allowable stress of welded pipe, tubing, fittings, and joints do not exceed 80% of the material allowable stress (one-third of ultimate strength or two-thirds of yield strength at temperature).

This requirement is consistent with ASME B31.3, allowable stress with a joint efficiency factor of 0.8 (80%).

- Stress analysis includes all interior and exterior loads such as pressure, wind, thermal expansion, pipe flexibility analysis, vibration, plume effects, etc.

D.3 Components

Components other than relief valves or burst discs shall meet **all** of the following:

- The component is COTS and manufactured by a reputable manufacturer.
- The manufacturer has a successful history of providing the identical or similar components; in identical or similar service; to KSC, NASA, or NASA contractors.

"Successful history" is NASA or NASA contractor experience without structural failures for the service life of a fluid system or the length of the program supported by the system. Alternatively, "successful history" is successful experience used in support of NASA programs by commercial entities.

- The component has a 4:1 ratio of manufacturer's rated burst pressure to system design pressure (MAWP for ASME BPVC-VIII).
- If the component is rated for a burst pressure ratio less than 4, the component is derated to a new design pressure of one-fourth the manufacturer's burst pressure rating.
- Brittle materials or cast iron covered by ASME BPVC-VIII, Division 1, Part UCI require a factor of 10:1 against rated burst pressure.
- The pressure boundary of the component is made from materials listed in ASME B31.3 or ASME BPVC-II.
- The component is used only under conditions of pressure, temperature, humidity, vibration, etc., that meet the manufacturer's ratings or that have been tested by KSC, NASA, or NASA contractor for the same or similarly proportioned components of the same or like material.
- Flexible hoses are used below one-fourth of the manufacturer's rated burst pressure.

D.4 Relief Valves and Burst Discs

D.4.1 Relief Valves and Burst Discs for Pressure Vessels

Relief valves and burst discs used to protect pressure vessels shall meet ASME BPVC-VIII, Division 1, including the required UV stamp.

D.4.2 Relief Valves and Burst Discs for Systems

Relief valves and burst discs used to protect piping systems and components shall meet **one** of the following:

- ASME B31.1
- ASME B31.3
- ISO 4126

D.5 Testing

Completed systems shall either be hydrostatically tested to 150% of MAWP or be pneumatically tested to 110% of MAWP.

D.6 Qualification of Components by Pressure Test

Components may be qualified for use by a pressure test under the following conditions:

- If the materials of manufacture are known and are ductile (over 5% elongation at failure), then the component may be used at one-fourth of the test pressure.
- If the materials of manufacture are unknown or are brittle (less than 5% elongation at failure), then the component may be used at one-tenth of the test pressure.