METRIC/INCH-POUND

KSC-DE-512-SM
REVISION L, CHANGE 5

FACILITY SYSTEMS, GROUND SUPPORT SYSTEMS, AND GROUND SUPPORT EQUIPMENT GENERAL DESIGN REQUIREMENTS

CHANGE NOTICE

CHANGED PAGES ARE INDICATED IN PAGE HEADERS.
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FEBRUARY 29, 2012
CHANGED JULY 20, 2016

ENGINEERING DIRECTORATE

National Aeronautics and
Space Administration

John F. Kennedy Space Center

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REVISION L, CHANGE 5

FACILITY SYSTEMS, GROUND SUPPORT SYSTEMS, AND GROUND SUPPORT EQUIPMENT GENERAL DESIGN REQUIREMENTS

Approved by:

Patrick A. Simpkins, D.B.A.
Director, Engineering

This Revision Supersedes All Previous Editions of This Document

FEBRUARY 29, 2012
CHANGED JULY 20, 2016

JOHN F. KENNEDY SPACE CENTER, NASA

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RECORD OF REVISIONS/CHANGES			
REV LTR	**CHANGE 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

RECORD OF REVISIONS/CHANGES			
REV LTR	**CHANGE NO.**	**DESCRIPTION**	**DATE**
	L-3	Permitted the use of cleaning standards that are functionally equivalent to ISO 14952.	July 29, 2014
	L-4	1. Updated KSC Directorate from Center Operations to Spaceport Integration and Services in 1.2.g(2). 2. Updated applicable documents in 2.2 and 2.3. 3. Replaced content of 4.2.3.4 with callout of KNPR 8700.2. 4. Added guidance statement under 4.3.1 to allow use of industry standards for facility-style drawings. 5. Clarified and expanded the exceptions to load testing in 4.6.2.1. 6. Deleted 4.6.2.2 (redundant to 6.4.14) and renumbered subsequent paragraphs. 7. Added allowance for cleaning hydraulic systems to industry standards in 5.2.5. 8. Clarified requirement for structural design of ECS ducting in 5.2.6. 9. Added 5.2.13.3 a. through f. to emphasize requirements for pressure relief devices currently specified in NASA-STD-8719.17. 10. Corrected reference to KNPR 8715.3 section in 5.2.15. 11. Added 5.4.2.1.c and d to clarify welding requirements of superaustenitic stainless-steel tubing. 12. Updated 5.4.4 to allow use of SAE AS fittings. 13. Updated guidance statement in 5.4.21.1.a to clarify use of star washers. 14. Updated 5.6.3 to replace KSC-STD-SF-0004 with MIL-STD-101. 15. Updated 6.3.1.4.2.b to clarify the use of 303 stainless steel. 16. Updated 6.4.14.e to clarify qualification and certification of NDE personnel. 17. Added 6.4.17 for requirement to inspect flex hoses. 18. Updated reference documents in Appendix C.	August 3, 2015

	L-5	1. Deleted NASA-HDBK-1001 from 4.2.4.1 because it has been cancelled, and replaced references to it with NASA-TM-2008-215633 in all other locations. 2. Inserted paragraph 4.3.3 to add the requirement for Modeling and Simulation, and added NASA-STD-7009 to 2.2, Applicable Documents. 3. Moved KSC-STD-G-0003 in 4.5 from requirement to guidance section. 4. Deleted NPD 8730.2 from guidance section in 4.5 and Appendix C, Reference Documents. 5. Moved KSC-STD-G-0003 from 2.2, Applicable Documents, to Appendix C, Reference Documents. 6. Added 5.2.13.3.d for pressure relief device minimum inlet size required by ASME BPVC and renumbered subsequent paragraphs. 7. Updated 5.4.2.1.c to clarify welding of AL6XN tubing. 8. Clarified 5.4.19.3 for printed circuit boards. 9. Deleted NASA-STD-6002 from 5.6.1.b because it has been cancelled and from 2.2, Applicable Documents. 10. Clarified application of PTCFE in 6.1.b. 11. Clarified use of MAPTIS in 6.2.d. 12. Deleted paragraph 6.3.1.4.2.c because it is redundant to 5.4.2.1.a. 13. Simplified requirements for elastomers in 6.3.1.5.1, and moved information to the guidance statement. 14. Moved MIL-HDBK-149 from 2.2, Applicable Documents, to Appendix C, Reference Documents. 15. Simplified requirements for fungus resistance in 6.3.1.5.7 and moved information to the guidance statement. 16. Clarified soldering requirement in 6.4.3.c. 17. Deleted 6.4.7.a and renumbered subsequent paragraphs. 18. Deleted MSFC-SPEC-445 from 6.4.7 and 2.2, Applicable Documents.	July 20, 2016

FOREWORD

KSC-DE-512-SM establishes overall requirements and best design practices to be used at the John F. Kennedy Space Center (KSC) for the development of 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), ground support systems (GSS), and facility ground support systems (F-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 ground systems. 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.

This standards manual supplements NASA-STD-5005 by including KSC-site-specific and local-environment requirements. KSC-DE-512-SM is a single, complete document for design and development of KSC ground systems 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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FACILITY SYSTEMS, GROUND SUPPORT SYSTEMS, AND GROUND SUPPORT EQUIPMENT GENERAL DESIGN REQUIREMENTS

1. SCOPE

1.1 Purpose

KSC-DE-512-SM establishes requirements and guidance for design and fabrication of ground systems (GS) that includes: ground support equipment (GSE), ground support systems (GSS), and facility ground support systems (F-GSS) to provide uniform methods and processes for design and development of robust, safe, reliable, maintainable, supportable, and cost-effective GS in support of space flight and institutional programs and projects. This standard is intended to supplement the minimum requirements of NASA-STD-5005 by applying more stringent, restrictive, or demanding requirements applicable to the specific KSC environment. This standard also provides requirements for GSS and F-GSS because these systems are not covered in NASA-STD-5005.

1.2 Applicability

The applicability of KSC-DE-512-SM relative to other NASA and industry design standards is shown graphically in Figure 1.

a. This standards manual applies to all new GS for programs and projects assigned to KSC.

b. KSC-DE-512-SM establishes minimum design requirements for ground systems, 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, documentation, procurement, fabrication, assembly, test, and installation of ground systems 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 standard are optional for hardware used only at manufacturing, development, or test sites but are required for hardware used at launch, landing, and retrieval sites.

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 and Technology Directorate Technical Authority. See KSC-PLN-5400 and paragraph 1.3.

g. KSC Directorates are responsible to invoke this standards manual for design and development of ground systems. KSC Directorates have responsibilities described as follows:

(1) Engineering and 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.

(2) Spaceport Integration and Services, Protective Services, Authority Having Jurisdiction, has the responsibility and authority to define hazardous areas and approve designs that provide equipment to these areas.

h. This standards manual applies to the following ground systems (see paragraph 3.2):

(1) ground support equipment,

(2) ground support systems,

(3) facility ground support systems,

(4) special test equipment, and

(5) modifications to commercial off-the-shelf (i.e., modified off-the-shelf [MOTS]).

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

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

(1) tools (standard shop),

(2) facilities and utilities (in-house and architect & engineering [A&E] firms), or

(3) commercial off-the-shelf (COTS) equipment.

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

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

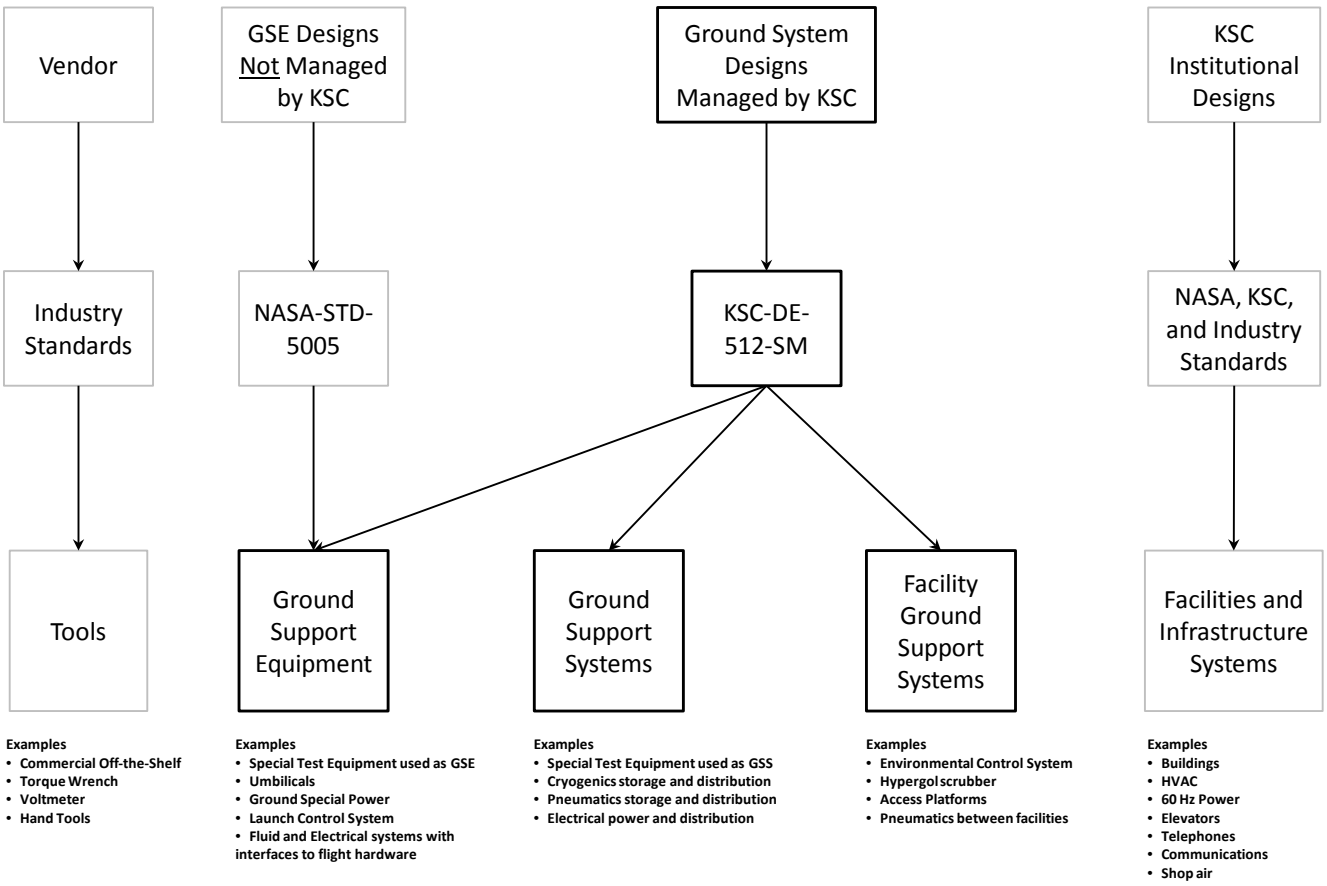

Figure 1. KSC-DE-512-SM Applicability

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 shall be evaluated for use by the KSC Engineering Directorate Technical Authority (see KSC-PLN-5400). Waivers to institutional requirements shall follow the process in KDP-KSC-P-1865.

2. APPLICABLE DOCUMENTS

2.1 General

The latest issuances of documents listed in this section contain provisions that constitute requirements of this standard as cited in the text.

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.

2.2 Government Documents

Department of Defense

AFSPCMAN 91-710	Range Safety User Requirements Manual, Volume 3, Launch Vehicles, Payloads, and Ground Support Systems Requirements
MIL-DTL-16878	Wire, Electrical, Insulated, General Specification 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 and Breech Coupling), Environment Resistant, Removable Crimp and Hermetic Solder Contacts, General Specification for
MIL-HDBK-17-1	Composite Materials Handbook, Volume 1, Polymer Matrix Composites Guidelines for Characterization of Structural Materials
MIL-HDBK-17-2	Composite Materials Handbook, Volume 2, Polymer Matrix Composites Materials Properties
MIL-HDBK-17-3	Composite Materials Handbook, Volume 3, Polymer Matrix Composites Materials Usage, Design, and Analysis

MIL-HDBK-17-4	Composite Materials Handbook, Volume 4, Metal Matrix Composites
MIL-HDBK-17-5	Composite Materials Handbook, Volume 5, Ceramic Matrix Composites
MIL-HDBK-263	Electrostatic Discharge Control Handbook for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices) (Metric)
MIL-HDBK-700	Plastics
MIL-HDBK-6870	Inspection Program Requirements, Nondestructive for Aircraft and Missile Materials and Parts
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-464	Electromagnetic Environmental Effects Requirements for Systems
MIL-STD-810	Environmental Engineering Considerations and Laboratory Tests
MIL-STD-889	Dissimilar Metals
MIL-STD-1686	Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)

Federal (FED)

29 CFR 1910	Occupational Safety and Health Standards
29 CFR 1926	Safety and Health Regulations for Construction
49 CFR 171 through 180	Hazardous Materials Regulations (Department of Transportation)

HF-STD-001	Human Factors Design Standard (Federal Aviation Administration)
DOT/FAA/AR-MMPDS	Metallic Materials Properties Development and Standardization (MMPDS)

NASA

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-6002	Applying Data Matrix Identification Symbols on Aerospace Parts
NASA-STD-7009	Standard for Models and Simulations
NASA-STD-8719.9	Standard for Lifting Devices and Equipment
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 (PV/S)
NASA-STD-8739.1	Workmanship Standard for Polymeric Application on Electronic Assemblies
NASA-STD-8739.2	Workmanship Standard for Surface Mount Technology
NASA-STD-8739.3	Soldered Electrical Connections
NASA-STD-8739.4	Crimping, Interconnecting Cables, Harnesses, and Wiring

NASA-STD-8739.5	Fiber Optic Terminations, Cable Assemblies, and Installation
NASA-TM-2008-215633	Terrestrial Environment (Climatic) Criteria Guidelines for Use in Aerospace Vehicle Development
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 8715.3	NASA General Safety Program Requirements

George C. Marshall Space Flight Center (MSFC), NASA

MSFC-STD-3029	Guidelines for the Selection of Metallic Materials for Stress Corrosion Cracking Resistance in Sodium Chloride Environments

John F. Kennedy Space Center (KSC), NASA

120E3100003	Electrical Cable Fabrication Requirements
79K07491	Installation of Purge Hardware
79K80000 Series	Fluid Component Specification Drawings
KDP-KSC-P-1865	Institutional Requirement Deviation/Waiver Process
KSC-PLN-5400	Technical Authority and Technical Excellence Implementation Plan
KNPR 8700.2	KSC System Safety and Reliability Analysis Methodology Procedural Requirements
KNPR 8715.3	KSC Safety Practices Procedural Requirements
KNPR 8730.1	KSC Metrology and Calibration Procedural Requirements
KNPR 8730.2	Quality Assurance Procedural Requirement

KSC-DD-818-TR	Summary of Measurements of KSC Launch-Induced Environmental Effects (STS-1 through STS-11)
KSC-DF-107	Technical Documentation Style Guide
KSC-E-165	Electrical Ground Support Equipment Fabrication, Specification For
KSC-E-166	Electrical Ground Support Equipment, Installation and Assembly, Specification for
KSC-GP-425	Fluid Fitting Engineering Standards
KSC-GP-435	Engineering Drawing Practices, Vol. 1: 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-5406	Design and Development Electrical, Electronic, and Electromechanical (EEE) Parts Plan
KSC-SPEC-E-0002	Modular Electrical Enclosures, Racks, Consoles, and Accessories, Specification for
KSC-SPEC-P-0012	Refractory Concrete, Specification for
KSC-SPEC-P-0027	Tubing, Steel, Superaustenitic, Corrosion Resistant, UNS N08367 and UNS S31245, Seamed, Bright Annealed, Passivated, Specification for
KSC-SPEC-Z-0007	Tubing, Steel, Corrosion Resistant, Types 304 and 316, Seamless, Annealed, 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-164	Environmental Test Methods for Ground Support Equipment, Standard for
KSC-STD-E-0001	Design of Electrical Control and Monitoring Systems, Equipment (GSE), and Panels, 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-0012	Facility Grounding and Lightning Protection, 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-P-0006	Quick Release Pins and Pin Tethers, Standard for
KSC-STD-Z-0005	Pneumatic Ground-Support Equipment, Design of, Standard for
KSC-STD-Z-0006	Hypergolic Propellants Ground Support Equipment, Design of, Standard for
KSC-STD-Z-0008	Ground Life Support Systems and Equipment, Design of, Standard for
KSC-STD-Z-0009	Cryogenic Ground Support Equipment, Design of, Standard for
MMA-1985-79	Standard Test Method for Evaluating Triboelectric Charge Generation and Decay

2.3 Non-Government Documents

Aerospace Industries Association (AIA)/National Aerospace Standards (NAS)

AIA/NAS 410	NAS Certification and Qualification of Nondestructive Test Personnel

Aluminum Association (AA)

ADM	Aluminum Design Manual

American Institute of Steel Construction (AISC)

AISC 325	Steel Construction Manual

American National Standards Institute (ANSI)

ANSI C18.2M Part 1	American National Standard for Portable Rechargeable Cells and Batteries – General and Specifications
ANSI C18.3M Part 1	American National Standard for Portable Lithium Primary Cells and Batteries – General and Specifications

American Society for Testing and Materials (ASTM)

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 A312	Standard Specification for Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes
ASTM A325	Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength
ASTM A380	Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems
ASTM A490	Standard Specification for Structural Bolts, Alloy Steel, Heat Treated, 150 ksi Minimum Tensile Strength

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 A967	Standard Specification for Chemical Passivation Treatments for Stainless Steel Parts
ASTM B241	Standard Specification for Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube
ASTM D7194	Standard Specification for Aerospace Parts Machined from Polychlorotrifluoroethylene (PCTFE)
ASTM E1417	Standard Practice for Liquid Penetrant Testing
ASTM E1444	Standard Practice for Magnetic Particle Testing
ASTM E1548	Standard Practice for Preparation of Aerospace Contamination Control Plans
ASTM E1742	Standard Practice for Radiographic Examination
ASTM E2217	Standard Practice for Design and Construction of Aerospace Cleanrooms and Contamination Controlled Areas
ASTM E2375	Standard Practice for Ultrasonic Testing of Wrought Products
ASTM MNL 36	Safe Use of Oxygen and Oxygen Systems: Handbook for Design, Operation, and Maintenance

American Society of Civil Engineers (ASCE)

ASCE-7	Minimum Design Loads for Buildings and Other Structures

American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE)

	ASHRAE Handbook—Fundamentals

American Society of Mechanical Engineers (ASME)

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 Y14.100	Engineering Drawing Practices
ASME B30.1	Jacks, Industrial Rollers, Air Casters, and Hydraulic Gantries
ASME B31.3	Process Piping
ASME B31.8	Gas Transmission and Distribution Piping Systems
ASME B31.9	Building Services Piping

American Welding Society (AWS)

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
AWS D17.1/D17.1M	Specification for Fusion Welding of Aerospace Applications

Compressed Gas Association (CGA)

CGA C-7	Guide to the Preparation of Precautionary Labeling and Marking of Compressed Gas Containers

ESD Association

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)

International Electrotechnical Commission

IEC 60807	Rectangular Connectors for Frequencies Below 3 MHz

International Organization for Standardization

ISO 14952	Space systems — Surface cleanliness of fluid systems — Parts 1 through 6

IPC – Association Connecting Electronics Industries

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 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 Printed Boards
IPC-6018	Microwave End Product Board Inspection and Test
IPC J-STD-001	Requirements for Soldered Electrical and Electronic Assemblies, Performance Class 3
IPC J-STD-001(S)	Space Applications Electronic Hardware Addendum to IPC J-STD-001 Requirements for Soldered Electrical and Electronic Assemblies

National Fire Protection Association (NFPA)

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

Sheet Metal and Air Conditioning Contractors' National Association (SMACNA)

SMACNA 1958	HVAC Systems Duct Design

Society of Automotive Engineers (SAE)

SAE AMS-DTL-23053/5	Insulation Sleeving, Electrical, Heat Shrinkable, Polyolefin, Flexible, Crosslinked
SAE AMS 2175	Castings, Classification and Inspection of
SAE AMS 2403	Plating, Nickel, General Purpose
SAE AMS 2404	Plating, Electroless Nickel
SAE AMS 2423	Plating, Nickel Hard Deposit
SAE AMS 2460	Chromium Plating
SAE AMS 2488	Anodic Treatment – Titanium and Titanium Alloys Solution pH 13 or Higher
SAE AMS 2647	Fluorescent Penetrant Inspection Aircraft and Engine Component Maintenance
SAE AMS 2759	Heat Treatment of Steel Parts, General Requirements
SAE AMS 2759/9	Hydrogen Embrittlement Relief (Baking) of Steel Parts
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 2774	Heat Treatment Wrought Nickel Alloy and Cobalt Alloy Parts
SAE AMS-H-6875	Heat Treatment of Steel Raw Materials
SAE AMS-H-81200	Heat Treatment of Titanium and Titanium Alloys

SAE AMS-QQ-P-416	Plating, Cadmium (Electrodeposited)
SAE AMS-STD-2154	Inspection, Ultrasonic, Wrought Metals, Process for
SAE ARP 1247	Aerospace Ground Support Equipment – General Requirements
SAE ARP 1658	Hose Assemblies, Installed, Visual Inspection Guide for
SAE ARP 4402	Eddy Current Inspection of Open Fastener Holes in Aluminum Aircraft Structure
SAE AS 4787	Eddy Current Inspection of Circular Holes in Nonferrous Metallic Aircraft Engine Hardware
SAE AS 5942	Marking of Electrical Insulating Materials
SAE AS 8090	Mobility, Towed Aerospace Ground Equipment, General Requirements 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

2.4 Order of Precedence

This standard establishes requirements and guidance for design and fabrication of KSC ground systems (GSE, GSS, and F-GSS), but does not supersede or waive established Agency requirements found in other documentation. Conflicts between this standard and applicable documents cited herein shall be resolved by the responsible Technical Authorities.

3. ACRONYMS, ABBREVIATIONS, AND DEFINITIONS

3.1 Acronyms and Abbreviations

°C	degrees Celsius
°F	degrees Fahrenheit
A-50	aerozine 50
AA	Aluminum Association
AC	alternating current
ADM	Aluminum Design Manual
AFSPCMAN	Air Force Space Command Manual

AIA	Aerospace Industries Association
AIAA	American Institute of Aeronautics and Astronautics
AISC	American Institute of Steel Construction
AMS	Aerospace Material Specification
ANSI	American National Standards Institute
ARP	Aerospace Recommended Practice
AS	Aerospace Standard
ASCE	American Society of Civil Engineers
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
AWS	American Welding Society
BPVC	Boiler and Pressure Vessel Code
CFR	Code of Federal Regulations
CGA	Compressed Gas Association
CIL	Critical Items List
COPV	Composite Overwrapped Pressure Vessel
COTS	commercial off-the-shelf
DE	design
DOT	Department of Transportation
DTL	detail
ECS	Environmental Control System
ECLSS	Environmental Control and Life Support System
ECA	Electronic Components, Assemblies & Materials Association
ECS	Environmental Control System
EEE	electrical, electronic, and electromechanical
e.g.	for example
EIA	Electronic Industries Association
EMI	electromagnetic interference
EPS	Electrical Power System
ESD	electrostatic discharge
ETFE	ethylene tetrafluoroethylene
FAA	Federal Aviation Administration
FED	Federal
F-GSS	facility ground support system
FMEA	Failure Mode and Effects Analysis
FOD	foreign-object debris
GO_2	gaseous oxygen
GP	general publication (KSC)
GS	ground system
GSE	ground support equipment
GSS	ground support system
HDBK	handbook
HVAC	heating, ventilation, and air conditioning
Hz	hertz

ICD	interface control document
i.e.	that is
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
in	inch
IPC	Association Connecting Electronics Industries
ISO	International Organization for Standardization
IT	information technology
JSC	Lyndon B. Johnson Space Center
kPa	kilopascal
KSC	John F. Kennedy Space Center
ksi	one thousand pounds per square inch
KTI	Kennedy Technical Instruction
LNG	liquefied natural gas
M&P	materials and processes
MAPTIS	Materials and Processes Technical Information System
MHz	megahertz
MIL	military
mm	millimeter
MMA	Malfunction/Materials Analysis
MMH	monomethylhydrazine
MMPDS	Metallic Materials Properties Development and Standardization
MNL	manual
MPa	megapascal
MSFC	George C. Marshall Space Flight Center
N_4H_4	hydrazine
N_2O_4	nitrogen tetroxide
NAS	National Aerospace Standards
NASA	National Aeronautics and Space Administration
NDE	nondestructive evaluation
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NPD	NASA Policy Directive
NPR	NASA Procedural Requirements
NSS	NASA Safety Standard
OSHA	Occupational Safety and Health Administration
PCTFE	polychlorotrifluoroethylene
PFA	plastic film, foam, and adhesive tape
pH	potential of hydrogen
PHE	propellant handler’s ensemble
PPE	personal protective equipment
PQR	procedure qualification record
PRF	performance specification
psi	pound per square inch
psia	pound per square inch absolute
PTFE	polytetrafluoroethylene

PV/S	pressure vessels and pressurized systems
QD	quick disconnect
RF	radio frequency
RH	relative humidity
RP	reference publication
S&MA	Safety and Mission Assurance
SAA	Systems Assurance Analysis
SAE	Society of Automotive Engineers
SCC	stress corrosion cracking
SMACNA	Sheet Metal and Air Conditioning Contractors' National Association
SPEC	specification
SSP	Space Shuttle Program
STD	standard
TM	technical memorandum
TP	technical procedure
UDMH	unsymmetrical dimethylhydrazine
UNS	Unified Numbering System
UTS	ultimate tensile strength
vs.	versus
WPQ	welder/welding operator performance qualification
WPS	welding procedure specification

3.2 Definitions

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 separating the engineering design into the components and disciplines, analyzing, or estimating each component of the operation or failure mechanism separately, and 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.*

catastrophic: a level beyond critical, resulting in loss of life, loss of flight vehicle, or loss of a major ground asset.

commercial off-the-shelf (COTS): equipment, including hardware and associated software/procedures, that is commercially available from the industrial inventory at the time of purchase.

> *Rationale: Commercial items or components should be used when they satisfy the ground systems 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 modified off-the-shelf [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.

corrosive environment: a marine (sea coast) or launch-induced environment that causes degradation of materials due to oxidation or chemical reaction.

> *Rationale: In the corrosive marine (sea coast) 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 ground system: a system whose 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.

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.

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

> *Rationale: Criticality of a ground system (GS) is determined by a Safety and Mission Assurance study analysis of the function and application of the equipment. 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.

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 ground systems. The term *facility* does not include ground support equipment, ground support systems, facility ground support systems, tools, or special test equipment.

facility ground support system (F-GSS): fixed infrastructure and equipment (not including utility systems and collateral equipment) that provides functional or physical support to GSS or

GSE. F-GSS are specialized systems that are designed, built, and tested to more stringent requirements than conventional facilities and their integral facility systems.

Rationale: F-GSS includes fixed environmental control systems (ECS), breathing air systems, long-run piping systems, high-pressure gases, liquid hydrogen (LH_2) and liquid oxygen (LO_2) storage spheres, etc. The requirements for F-GSS and GSS are the same, and the distinction between the two is not always clear. The important distinction is between F-GSS and conventional facility systems. Conventional facility systems are not covered by this standard.

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

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

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: 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 manufacturing equipment is to be used after flight hardware processing begins, 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.

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): ground support equipment, ground support systems, and facility ground support systems.

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 due to 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.

modified off-the-shelf (MOTS): commercially available equipment, including hardware and associated software and procedures, modified in accordance with this document 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.

nonconventional structures: structures that are experimental, specific to a space program, or if any of the following apply:

1. Structural members and connections are predominately atypical to commercial or residential construction.

2. The structure supports or provides direct access to flight hardware (e.g., test stands, launch complexes, access platforms in operational or research facilities, towers, and similar special-purpose facilities).

3. Structures are characterized by unusual or inadequately defined loading conditions (launch acoustics, vibration, rocket exhaust, etc.), a lack of established design precedent, or frequent modifications to support changes in the operational requirements.

Rationale: The transition between conventional and nonconventional is the interface between the structure specifically designed for processing and vehicle access and the generic building structure whose purpose is the physical support of the overall facility. The transition region between conventional and nonconventional structures should be designed to meet the criteria for both types of structure.

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 or uprated, 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 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.

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 and conditions. It includes measurements taken with certified and calibrated tools in accordance with generally accepted scientific or engineering principles.

tools: equipment designed for general use in a variety of applications. Tools are calibrated, when necessary, in accordance with industry standards.

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 includes 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 torquing fasteners, cutting wire, checking electrical continuity, and verifying surface clearances. Examples of tools include torque wrenches, crow's feet, 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.

Rationale: Verification answers the question, "Is it built according to the design?"

4. GENERAL REQUIREMENTS

4.1 General

In order to meet customer requirements, individual system and equipment design projects may need 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 its customers (e.g., users and operators).

Each program/project has the responsibility to define its own policy for the acceptance of commercial-off-the shelf (COTS) equipment in ground systems (GS).

When a program/project approves the use of COTS equipment in GS, the following design requirements apply:

a. COTS equipment shall be evaluated for acceptability from a materials and processes (M&P) standpoint (see 6).

b. Qualification tests and inspections shall be indicated in the engineering documentation.

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

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

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 ground system, and (3) it provides a cost savings that exceeds possible cost increases due to unique maintenance or logistics requirements, modifications, or an increase in the complexity of the interfacing equipment. Vendor or contractor documentation and supporting test data should be incorporated into system control documents.

4.2 Characteristics

4.2.1 Performance Characteristics

4.2.1.1 GS Designed to Meet Flight Hardware Requirements

The GS design shall support the program/project-specific operational requirements of flight hardware.

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.

4.2.1.2 Ground System Degradation and Contamination

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

4.2.1.3 GS Design for Access

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

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

4.2.1.4 Interfaces

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

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

b. Fluid, mechanical, or electrical connections in close proximity shall 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 5.6.1) should indicate function, commodities, pressure, reference designator, etc.

c. GS shall be compatible with all facility interfaces.

An assessment may be required 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; some GS interfaces to GSS or to facility ground support systems (F-GSS).

4.2.2 Physical Characteristics

4.2.2.1 Design Life Duration

a. GS shall 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.

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

4.2.2.2 Limited-Life Items

Items with limited life shall be identified on design drawings 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.

4.2.2.3 Colors

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

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

4.2.3 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 [FMEA]/Critical Items List [CIL] or sneak circuit analysis), will be in accordance with KNPR 8720.2.

4.2.3.1 Redundancy

a. Redundant 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. Redundant systems, subsystems, or components shall be designed such that common-cause failures (e.g., contamination) do not eliminate redundancy.

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

4.2.3.2 Failure Tolerance

a. GS, except primary structure and pressure vessels/piping/tubing in rupture mode, 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 pressure vessels/tubing in rupture mode. Safety of these systems is achieved by application of design requirements contained in this standards manual.

More stringent fault tolerance requirements (e.g., two-fault tolerant 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 shall be addressed in accordance with NPR 8705.2.

4.2.3.3 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.).

4.2.3.4 System Safety and Reliability Analysis

System Safety and Reliability Analyses shall be performed concurrently with GS designs in accordance with KNPR 8700.2.

4.2.4 Environmental Conditions

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

4.2.4.1 Natural Environment

GS used or stored in an uncontrolled 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.

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 of enclosures to protect GS components from the natural environment should be considered essential, in addition to purging of enclosures in hazardous areas as required in 5.4.17.*

4.2.4.2 Launch-Induced Environment

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.

4.2.4.2.1 Launch-Induced Damage

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

4.2.4.3 Controlled Interior Environment

GS designed to function within a controlled interior environment shall be designed to the following temperature and humidity requirements:

a. Temperature: +15 °C (60 °F) to +27 °C (80 °F) and within the extremes of +11 °C (52 °F) to +40 °C (104 °F) for a maximum of 1 hour.

b. Humidity: nominal 55%, within a range of 30% to 70%.

4.2.4.4 Controlled Clean Environment

a. GS shall be designed to meet the program/project contamination control requirements.

b. Clean rooms and associated controlled environments designated as GS shall be designed in accordance with ASTM E2217.

4.2.4.5 Uncontrolled Interior Environment

GS used in an uncontrolled interior environment shall be designed to meet the most severe exterior environmental conditions for humidity and temperature expected at the respective geographical locations, as defined in NASA-TM-2008-215633.

Some uncontrolled interior environments can exceed the most severe exterior environment, e.g., an enclosed trailer in a hot (tropical or desert) exterior environment.

4.2.4.6 Fire/Explosion Hazardproofing

If GS will be 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.

4.2.4.7 Environmental Test Methods

Environmental methods and conditions required for testing and qualification of GS components shall be in accordance with MIL-STD-810 and KSC-STD-164.

4.2.4.8 Seismic Environment

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

4.3 Documentation

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

4.3.1 Drawings and Specifications

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 the application of the United States National CAD Standard from the National Institute for Building Sciences.

4.3.2 Technical Documentation

Technical documentation (e.g., manuals and reports) shall be prepared in accordance with KSC-DF-107.

4.3.3 Modeling and Simulation

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

4.4 Logistics

GS design documentation shall identify spare parts, components, materials, and items necessary to support construction, fabrication, installation, activation, test, verification, and operation.

4.4.1 Limited-Life Item Tracking

a. Limited-life items shall be controlled from the date of their manufacture through their period of operational use, including the time they are in storage.

b. The status of limited-life items shall be documented.

c. GS design documentation shall identify limited-life items and provide instructions for replacement of those parts, components, and materials.

4.5 Qualification

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

KSC-STD-G-0003 should be used for qualification testing.

4.6 Quality Assurance

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

4.6.1 General

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

4.6.1.1 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.

4.6.1.2 Personnel Training

Certification documentation for required training of personnel performing processes during fabrication, assembly, installation, and testing of GS shall be maintained in accordance with KNPR 8730.2.

4.6.2 Testing

a. Testing requirements shall be specified in engineering documentation.

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

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

4.6.2.1 Load Test

a. A load test shall be performed on all structural GSE (access platforms, workstands, etc.) and moveable or articulating GS structures except when **one** of the following conditions is met:

   (1) the load test would create an unsafe condition,

   (2) analysis shows that the load test will result in damage to the structure,

   (3) critical welds have been volumetrically inspected and an independent analysis has been performed and approved by the Technical Authority, or

   (4) one of multiple similar structures or mechanisms will be load-tested, and the Technical Authority waives load testing of all the other similar structures or mechanisms.

Load testing of fixed GS structures may be accomplished 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 non-operational condition.

c. Lifting devices and equipment shall be proofload tested in accordance with NASA-STD-8719.9.

d. In the absence of design analysis, a load test of 8 times the safe working load shall satisfy the factor of safety requirements of this standards manual.

This load test is to eliminate the need for structural analysis. The 8-to-1 load test screens out flaws that could propagate to failure in a structure used at or below the design load. This option should only be used for ductile materials.

4.6.2.2 Metrology and Calibration

Metrology and calibration of all test equipment and tools used in support of fabrication, assembly, installation, and test of GS shall be in accordance with KNPR 8730.1.

4.6.3 Quality Conformance Verification

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

Test, analysis, demonstration, and inspection (including similarity) are recommended methods to verify that each requirement of Sections 4 and 5 of this standard has been satisfied.

4.7 Packaging, Handling, and Transportation

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

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

4.7.1 Shipping and Storage Containers

a. Containers shall be compatible with onsite transportation, handling, and storage methods.

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

c. Containers shall 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.

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

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

4.7.2 Parts Protection

a. Procedures shall 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 shall be packaged in accordance with NPR 6000.1 and program contamination control requirements.

5. DESIGN AND CONSTRUCTION REQUIREMENTS

5.1 Structural Design

5.1.1 GS Structures and Equipment

5.1.1.1 Steel Structures

a. The design of conventional steel structures shall be in accordance with AISC 325.

b. The design of nonconventional steel structures shall be in accordance with established design practices using the factors of safety in 5.1.2.

Nonconventional steel structures may be designed using provisions of AISC 325, provided that the factors of safety are adjusted to be consistent with 5.1.2.

c. High-strength carbon steel fasteners such as ASTM A490 and SAE Grade 8 shall not be used in a corrosive environment.

Galvanizing and other zinc coatings may cause hydrogen embrittlement in high-strength carbon steel fasteners that is difficult to detect. When possible, ASTM A325 or SAE Grade 5 fasteners should be used instead.

5.1.1.2 Aluminum Structures

a. The design of conventional aluminum structures shall be in accordance with ADM.

b. The design of nonconventional aluminum structures shall be in accordance with established design practices using the factors of safety in 5.1.2.

Nonconventional aluminum structures may be designed using provisions of ADM, *provided that the factors of safety are adjusted to be consistent with 5.1.2.*

5.1.2 Factors of Safety

a. The following minimum factor of safety shall be used for support structures (excluding lifting devices, pressure vessels, preload in threaded fasteners, and springs) when not otherwise specified.

(1) GS structures shall be designed to a minimum factor of safety of 2 against deformation or yielding that impairs the function of the part and a minimum factor of safety of 3 against collapsing, buckling, exceeding the ultimate load, or failing to support the design load.

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

(3) For metal castings without an M&P-approved quality plan, the factor of safety shall be 10 against exceeding the UTS.

(4) For metal castings with an M&P-approved quality plan, the factor of safety shall be 5 against exceeding the UTS.

(5) For ductile-matrix composites with no test data, the factor of safety shall be 10 against exceeding the UTS.

(6) For ductile-matrix composites with test data, the factor of safety shall be 5 against exceeding the UTS.

(7) For brittle-matrix composites, the factor of safety shall be 10 against exceeding the UTS.

b. Threaded fasteners shall meet the factors of safety contained in (a) when only the operating load is considered. (This does not include preload, which is covered in 5.2.9.)

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

Due to 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.

d. Structures exposed to cyclic loads shall be designed for a minimum factor of safety of 4 against the design life.

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.

5.1.3 Structural Design Loads

Structural design loads shall be specified in the design documentation.

The design should consider loads created by the assembly, lifting, handling, transportation, operations, wind conditions, launch-induced environments, and seismic events. For torque loads on threaded fasteners, see 5.2.9.

5.2 Mechanical Design

5.2.1 Pneumatics

The design of GS used for pneumatic servicing shall be in accordance with KSC-STD-Z-0005.

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

5.2.1.1 Breathing-Air Systems

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.

5.2.1.2 Vacuum and Compressed-Air Systems

a. Vacuum systems shall be designed in accordance with ASME B31.9.

b. Compressed-air systems having an operating gage pressure up to 1.0 megapascals (MPa) (150 pounds per square inch [psi]) shall be designed in accordance with ASME B31.9.

c. 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.

5.2.2 Cryogenics

a. The design of GS used for cryogenic servicing with liquid hydrogen, liquid oxygen, 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.

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

5.2.3 Hypergols

The design of GS used for hypergolic-fuel or oxidizer servicing with monomethylhydrazine (MMH), unsymmetrical dimethylhydrazine (UDMH), nitrogen tetroxide (N_2O_4), aerozine 50 (A-50), or hydrazine (N_2H_4) shall be in accordance with KSC-STD-Z-0006.

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 (PPE) for operators of GS.

5.2.4 Hydrocarbons

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.

5.2.5 Hydraulics

a. The design of GS used for servicing hydraulic systems shall be in accordance with ASME B31.3 and with KSC-STD-Z-0005.

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

b. Hydraulic systems shall be cleaned in accordance with ASTM D4174 or the precision cleaning requirements of 6.4.8.

ISO 23309 is an acceptable alternative to ASTM D4174.

5.2.6 Environmental Control Systems (ECSs) and Environmental Control and Life Support Systems (ECLSSs)

a. GSE used for an ECS shall be in accordance with ASHRAE Handbook—Fundamentals (Code and Standards), Chapter 39.

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 vented 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.

d. The design of ducting exposed to the launch-induced environment shall be in accordance with the structural requirements of ASME B31.3 or with the structural requirements in 5.1.2.

e. The design of ducting not exposed to the launch-induced environment shall be in accordance with applicable SMACNA ducting standards or with the structural requirements of ASME B31.3 or with the structural requirements in 5.1.2.

Intakes to air distribution systems should be located away from areas where normal toxic vapor venting occurs or where accidental spillage could contaminate breathing-air supplies or vehicle air supplies and 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.

5.2.7 Life Support

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 propellant handler's ensembles (PHEs) should be designed to meet the following criteria:

a. 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.

b. Sufficient clearance should be provided to preclude the operator from brushing against other surfaces.

c. 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.

d. The design should include suitable provisions to prevent discomfort or fatigue for the PHE-suited personnel.

e. Use of expanded metal surfaces and other sharp edges should be avoided.

5.2.8 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.

5.2.9 Threaded Fasteners

a. The design for installation of threaded fastener shall not exceed a preload of 70% of the yield stress on the net cross section of the fastener.

b. The installation criteria for structural bolts, such as those specified in ASTM A325 and ASTM A490, shall be in accordance with AISC 325.

ASTM A490 structural bolts should be avoided in a corrosive environment. Galvanizing and other zinc coatings may cause hydrogen embrittlement that is difficult to detect. When possible, ASTM A325 bolts should be used instead.

c. Installation criteria shall be documented on the fabrication, assembly, or installation drawing.

This section addresses the design of and maximum allowable preload for threaded fasteners. The design application may require a lower preload value due to 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).

5.2.10 Tethering Provisions

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

b. GS intended for use near flight hardware or elevated above personnel or flight hardware shall be designed and constructed with provisions for tethering.

c. Quick-release pins and pin tethers shall be in accordance with KSC-STD-P-0006.

5.2.11 Jacks

The design of jacks shall be in accordance with ASME B30.1.

5.2.12 Transportation Equipment

GS used for transporting flight hardware shall be designed in accordance with SAE ARP 1247.

5.2.12.1 Towed GS

Towed GS shall be designed in accordance with SAE AS 8090.

5.2.12.2 Transportation Equipment Interface Loads

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.

5.2.13 Pressure Systems

All pressurized systems shall comply with NASA-STD-8719.17.

All NASA designs are required to comply with NASA-STD-8719.17, which encompasses many of the specific requirements contained in this document. This standard and the standards cited herein are intended to provide additional requirements.

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.

Shops and welders repairing or altering code vessels require R stamp certification. For noncode vessels, R stamp certification is not required but is good practice.

b. 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 and 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.

5.2.13.1 Code-Stamped Vessel Registration

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

5.2.13.2 Pressure Vessels Used in Transporting Commodities

Pressure vessels used for transporting hazardous commodities shall meet the Department of Transportation requirements in 49 CFR 171 through 180.

5.2.13.3 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, Section VIII, Division 1, including the requirement for the ASME UV or UD stamp.

c. Pressure relief devices for mobile pressure vessels shall meet Department of Transportation (DOT, 49CFR) requirements.

d. The opening through all pipe, fittings, and 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. Relief valves shall be purchased clean to the requirements of 6.4.8 and factory-set to the required system relief pressure.

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

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

5.2.14 Piping Systems

Piping and support systems, except those in remote or “cross country” areas or where personnel traffic is low, shall be in accordance with ASME B31.3 the piping system may be designed to ASME B31.8.

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.

5.2.15 Pressure Vessel/System Certification

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

5.2.16 Ground-to-Flight-Vehicle Umbilical Systems

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

5.3 Electrical/Electronic Design

5.3.1 Electrical Control and Monitor Equipment

The design of GS for electrical control and monitoring shall be in accordance with KSC-STD-E-0001.

AFSPCMAN 91-710 and MIL-HDBK-454 should be consulted for general guidance in electrical/electronic design.

5.3.2 Electrical Design of Pneumatic and Hydraulic Components

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

5.3.3 Pyrotechnic Systems

The design of pyrotechnic GS shall be in accordance with NASA-STD-8719.12.

5.3.4 Electrical Power Systems

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

Incorporation of 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, and *ANSI C18.3M, Part 1*.

5.3.5 Bonding and Grounding

a. For nonfacility ground systems, bonding and grounding shall be in accordance with the requirements of KSC-STD-E-0022 and NFPA 70.

b. For facility systems and earth ground, bonding and grounding shall be in accordance with the requirements of KSC-STD-E-0012 and NFPA 70.

c. Ground systems that directly interface with flight hardware shall be in accordance with NASA-STD-4003 interface requirements.

The designer should be aware whether the system being designed will be operated under a lightning protection system or where induced static electricity is possible. For additional information on lightning protection, refer to International Electrotechnical Commission standard IEC 62305, Parts 1 through 4.

5.3.6 Hazardproofing

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

5.3.7 Software

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

This ensures that KSC-developed software meets the Agency requirements for software engineering practices, software assurance, and software safety. NPR 7150.2 contains provisions applicable to COTS software in NASA-developed systems.

5.3.8 Firmware

Firmware incorporated in the design of GS shall meet the requirements of NPR 7150.2.

5.4 Parts

5.4.1 Electrical, Electronic, and Electromechanical (EEE) Parts

EEE parts shall be selected in accordance with KSC-PLN-5406.

This plan provides detailed requirements and guidelines for selection and utilization of EEE parts in accordance with KNPR 8720.2.

5.4.1.1 Electrostatic-Discharge (ESD)-Sensitive Components and Assemblies

All ESD-sensitive components and assemblies shall be handled using practices in accordance with ESD S20.20, MIL-STD-1686, and MIL-HDBK-263.

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

5.4.2 Stainless-Steel Tubing

a. Austenitic stainless-steel tubing shall be in accordance with KSC-SPEC-Z-0007.

b. Stainless-steel tubing shall be fabricated, tested, and installed in accordance with KSC-SPEC-Z-0008.

5.4.2.1 Superaustenitic Stainless-Steel Tubing

a. When directly exposed to a corrosive environment, tubing shall consist of Unified Numbering System (UNS) N08367 or S31245 superaustenitic stainless steel (trade name AL6XN or 254SMO) in accordance with KSC-SPEC-P-0027.

b. Superaustenitic stainless-steel tubing shall be fabricated, tested, and installed in accordance with KSC-SPEC-Z-0008.

c. Welds performed on superaustenitic stainless-steel tubing shall use either 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.

d. All welds on tubing shall be passivated in accordance with ASTM A380 or A967.

5.4.3 Pipe

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

5.4.3.1 Aluminum Pipe

Aluminum pipe for fluid systems shall be in accordance with ASTM B241.

5.4.3.2 Expansion Joints

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

5.4.4 Metallic Fittings

Flared tubing fittings, tube weld fittings, and pipe fittings shall be selected in accordance with KSC-GP-425 or equivalent SAE AS fittings.

5.4.5 Fluid System Protective Covers

Protective covers shall be provided for all hoses, ports, fittings, and other fluid-fitting connections to GS to protect the threads, protect the sealing surface, and maintain the cleanliness of the system. Prior to installation, protective caps, plugs, and covers shall be maintained clean at the same level or better than the system that they are protecting.

Caution should be used in selecting caps and plugs as covers due to 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.

5.4.6 Fluid System Components

Fluid system components used in the design of liquid or gas systems shall be selected from the 79K80000 series of specifications, unless the required part is not covered by this series.

5.4.6.1 Fluid System Component Acceptance Criteria

If a part is not covered by the 79K80000 series of specifications, it shall be documented with the following minimum information: commodity, environment, performance, installed dimensions, connection interfaces, recommended vendor, materials, compatibility, qualification/acceptance criteria, and recommended maintenance.

5.4.7 Electrical-Power Receptacles and Plugs

a. Alternating-current (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.

5.4.8 Electrical-Power Cable

Power cables shall be in accordance with NFPA 70.

5.4.9 Electrical Cable and Harnesses

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

5.4.10 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.

5.4.11 Electrical Hookup Wire

Electrical hookup wire shall be in accordance with SAE AS 50861, MIL-DTL-16878, or SAE AS 22759.

5.4.12 Connectors

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

MIL-DTL-5015 was replaced with SAE AS 50151.

b. When multiconductor connectors must be used in hazardous locations, they shall be waterproof and used with threaded connectors.

5.4.13 Coaxial Radio Frequency (RF) Connectors

Coaxial RF connectors shall be selected from MIL-PRF-39012.

5.4.14 Protective Covers or Caps for Electrical Connectors

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.*

5.4.15 Optical Covers or Caps

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.

5.4.16 Sensors and Transducers

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

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

5.4.16.1 Sensor and Transducer Acceptance Criteria

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.

5.4.17 Purged Electrical Enclosures

Purged electrical enclosures in hazardous locations shall be in accordance with NFPA 496. Purged electrical enclosures in nonhazardous locations shall be outfitted with purge hardware in accordance with 79K07491.

NFPA 496 contains requirements for the protection of electrical and electronic equipment recognized by NFPA 70 for installations in hazardous locations. Hardware required for purging enclosures (to maintain low relative humidity and positive pressure) should be selected from 79K07491.

5.4.18 Racks, Panels, and Modular Enclosures

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.

5.4.19 Printed Circuit Boards

5.4.19.1 Printed Circuit Board Design

Rigid, flexible, and rigid-flex 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.

5.4.19.2 Printed Circuit Board Fabrication and Acceptance

Rigid, flexible, and rigid-flex 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.

5.4.19.3 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 that will be exposed to vibration or thermal cycling shall be fabricated in accordance with IPC J-STD-001(S), Space Addendum.

5.4.20 Electric Motors and Generators

Motors and generators used in GS shall be selected in accordance with the system requirements for speed, torque, horsepower, and environment. Motors and generators shall meet the applicable National Electrical Manufacturers Association (NEMA) standards and NFPA 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.

5.4.20.1 Motor Starters and Controllers

Motor starters and controllers shall be in accordance with the type of motor, performance ratings, and type of control required. 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, adjustable-frequency AC power drive systems. NFPA 70 provides the size of wiring and conduit required for the starter/controller connections.

5.4.21 GS Fasteners

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

NASA RP-1228 should be used for guidance in selecting and analyzing fasteners.

5.4.21.1 Reuse of Self-Locking Fasteners

a. The reuse of 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 lock washers, also known as toothed lock washers or serrated washers, should be avoided. These washers provide very little resistance to structural vibration and they damage the surfaces they contact. Their application should be limited to lightweight electrical/electronic component mounting within racks and enclosures.

b. 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).

5.4.21.2 Liquid-Locking Compounds

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.

5.5 Electromagnetic Interference (EMI)

a. Electrical and electronic GSE and GSS (nonfacility) shall be designed and tested for electromagnetic compatibility as specified in KSC-STD-E-0022.

b. Facility systems and facility GSS shall be in accordance with the requirements of KSC-STD-E-0012.

The application of MIL-STD-461 to GSE systems should be based on an evaluation of the potential for flight hardware interaction and any existing commercial standards to which the hardware is already certified.

5.6 Identification Markings and Labels

5.6.1 Systems and Equipment

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

5.6.2 Load Test

GS that have been load-tested shall be identified and marked in accordance with KSC-STD-141, and for lifting equipment, NASA-STD-8719.9.

5.6.3 Piping Systems

Ground piping systems shall be identified and color-coded in accordance with MIL-STD-101.

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 not less than 40 feet apart on straight pipe runs inside buildings and 500 feet apart on straight cross-country runs.

a. Working pressures on all piping systems exceeding 60 psig shall be identified adjacent to the commodity on tags and painted titles in the same letter size.

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.

b. 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.

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

(1) The legend on the plate shall provide clear, concise, and positive component identification, including the component's name, find number, media, and pressure.

(2) The purpose of each panel containing components (valves, gages, bulkhead connection points, etc.) shall be identified on the face of the panel.

5.6.4 Compressed-Gas Cylinders

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

5.6.5 Load Capacity

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, NASA-STD-8719.9.

5.6.6 Electrical-Cable and Harness Assemblies

a. Electrical cable and harness assemblies shall be identified at each end of the cable and/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.

b. Labels for cable assemblies shall comply with KSC-E-166.

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

d. Labels for wire harnesses shall comply with KSC-E-166.

e. Labels shall be of heat-shrinkable sleeving that conforms to the requirements of SAE AMS-DTL-23053/5, Class 1.

f. The heat-shrink labels shall be marked in accordance with SAE AS 5942 and shall 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.

5.6.7 Serial Numbers

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

Other unique identifiers include A-numbers and drawing dash numbers for end items.

5.7 Interchangeability

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

5.8 Safety

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

5.8.1 Hazard Analysis

A hazard analysis shall 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 shall be used.

5.8.2 Safety Requirements on KSC Property

GS to be used at KSC shall meet the safety requirements of KNPR 8715.3.

5.8.3 Safety Requirements on Air Force Property

GS to be used on Air Force property shall meet the requirements of AFSPCMAN 91-710, Volume 3.

5.8.4 Safety Requirements on Other NASA Property

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

5.8.5 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 the applicable Occupational Safety and Health Administration (OSHA) lockout/tagout requirements.

5.9 Human Factors

a. HF-STD-001 shall be used to establish human factors criteria for GS design.

b. GS shall comply with 29 CFR 1910.

5.10 Security of Information Technology (IT)

The design of GS shall meet the IT security requirements in NPR 2810.1.

6. MATERIALS AND PROCESSES REQUIREMENTS

M&P used in the design and fabrication of GS shall 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 ESD and contamination.

6.1 Material Properties Design Data

a. The following documents shall be used to establish materials properties for use in system or component design: DOT/FAA/AR-MMPDS, MIL-HDBK-17-2, MIL-HDBK-17-4, MIL-HDBK-17-5, and voluntary-consensus standards or codes (e.g., ASME BPVC-VIII and ASME BPVC-X for pressure vessels, and AISC 325 for structural steel).

The values listed in the codes or standards are minimum material properties. The use of minimum material properties, as stated by the code, is intrinsic to the factor of safety, margin of safety, strength factor, etc., of the design.

b. Parts machined from polychlorotrifluoroethylene (PCTFE) used in oxygen systems or oxygen-enriched systems shall comply with ASTM D7194.

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.

c. When mechanical properties of new or existing structural materials are not available, they shall be determined by the analytical methods described in the following documents: MIL-HDBK-17-1, MIL-HDBK-17-3, MIL-HDBK-17-4, MIL-HDBK-17-5, MIL-HDBK-149, and MIL-HDBK-700.

If the material is not covered by a design code or one of these sources, the Aerospace Structural Metals Database or other published industry sources should be used in accordance with the best practices for design. The properties listed in these documents are typical values, not minimum values; this must be considered when applying the factor of safety appropriate for the design.

6.2 M&P Controls

M&P controls shall be as follows:

a. All materials and processes shall be defined by standards and specifications and be identified directly on the appropriate engineering drawing.

b. The design drawings shall be signed by an M&P engineer authorized by NASA.

c. Composition and properties of all materials and parts shall be certified by the manufacturer or supplier as required by the procuring document.

d. The Materials and Processes Technical Information System (MAPTIS) shall be consulted to obtain material codes and ratings for materials, standard and commercial parts, and components that are exposed to oxygen-enriched fluids, reactive fluids, or ignition sources.

For noncritical GS, the M&P organization's approval on the engineering drawing approves deviations from other M&P requirements of this standard. The use of materials and processes that do not comply with the requirements of this standard may still be acceptable in the actual hardware applications.

6.3 Detailed Requirements

6.3.1 Flammability and Compatibility Requirements

Materials shall be tested in accordance with NASA-STD-6001.

6.3.1.1 Flammability Control

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

Material flammability ratings and tests based on NASA-STD-6001 are available in the MAPTIS database for many materials.

b. The following materials or methods are also acceptable:

(1) Ceramics, metal oxides, and inorganic glasses shall be acceptable without prior testing.

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 M&P organization.

(2) 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 shall be acceptable without further testing, as in the following examples:

(a) Materials used in an environment with an oxygen concentration lower than the test level shall be accepted without further testing (provided that the oxygen partial pressure is not greater than the partial pressure at the test level).

(b) Materials used in an environment where the concentration is greater than the test level shall be retested or considered flammable.

(c) If a material passes the flammability test on a metal substrate, it shall be used on metal substrates of the same thickness or greater.

(d) If the material will be used on a thinner or non-heat-sinking substrate (or on no substrate at all), it shall 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 approval by the M&P organization. Guidelines for assessment and mitigation of hardware flammability characteristics can be found in JSC 29353.

6.3.1.2 Electrical-Wire Insulation Materials

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

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

Arc tracking testing is not required for polytetrafluoroethylene (PTFE), PTFE laminate, ethylene tetrafluoroethlyene (ETFE), or silicone-insulated wires because the resistance of these materials to arc tracking has already been established.

6.3.1.3 Fluid Compatibility

For the purposes of this standard, the definition of "hazardous fluids" includes gaseous oxygen, liquid oxygen, fuels, oxidizers, and other fluids that could cause corrosion, chemically or physically degrade materials in the system, or cause an exothermic reaction.

6.3.1.3.1 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 shall simulate the worst-case use environment that would enhance 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.

6.3.1.3.2 Oxygen Systems

a. Liquid oxygen and gaseous oxygen 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 liquid oxygen and gaseous oxygen applications.

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

c. When the oxygen compatibility assessment shows 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 the M&P organization.

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 oxygen compatibility acceptance testing at maximum design pressure for a minimum of 10 cycles before being placed into service. Components shall be retested 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).

6.3.1.4 Metals

6.3.1.4.1 Carbon and Low-Alloy Steel

Carbon and low-alloy steels heat-treated to strength levels at or above 1,240 MPa (180 ksi) UTS shall be approved by the M&P organization due to sensitivity to SCC.

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.

6.3.1.4.2 Corrosion-Resistant Steel

a. Unstabilized austenitic steels shall not be used under conditions where the temperature is above 371 °C (700 °F).

Welding should be performed only on low-carbon, stabilized grades, or superaustenitic grades (i.e., UNS S30403, UNS S31603, UNS S32100, UNS S34700, UNS N08367, and UNS S31254). Welding higher-carbon, unstabilized austenitic stainless steel can result in sensitization in the weld heat-affected zone. Sensitization occurs when carbon precipitates from the solid solution, mainly at the grain boundaries, depleting the chromium in the adjacent matrix, which results in localized intergranular attack when the material is exposed to corrosive service conditions. Caution should be exercised in using martensitic and ferritic stainless steels because these are susceptible to hydrogen embrittlement, corrosion, and stress corrosion. Austenitic stainless steels are susceptible to pitting corrosion and crevice corrosion in a marine environment; some austenitic stainless steels are susceptible to SCC in a marine environment.

b. The use of free-machining alloys such as UNS S30300 (type 303 SST) and UNS S30323 (type 303Se SST) under high sustained tensile stress in corrosive environments shall require M&P approval.

Standardized testing has shown UNS S30300 and UNS S30323 (303/303Se) stainless steel to be resistant to SCC. Local KSC environment testing has shown a susceptibility to SCC for these free-machining grades. Designers should consult M&P when using these materials.

c. Cleaning, descaling, and passivating of stainless-steel parts, assemblies, equipment, and installed systems shall be in accordance with ASTM A380 and ASTM A967.

d. 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.

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.

6.3.1.4.3 Aluminum

a. Aluminum alloys used in structural applications shall be resistant to general corrosion, pitting, intergranular corrosion, and SCC.

b. Alloys in the 5000-series containing more than 3% magnesium shall not be used in applications where the temperature exceeds 66 °C (150 °F), because grain boundary precipitation above this temperature can create stress-corrosion sensitivity.

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.

6.3.1.4.4 Nickel-Based Alloys

Alloys with high nickel content are susceptible to sulfur embrittlement; therefore, any foreign material that could contain sulfur, such as oils, grease, and cutting lubricants, shall be removed before heat treatment, welding, or high-temperature service.

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.

6.3.1.4.5 Titanium

a. Areas subject to fretting or wear shall be anodized in accordance with SAE AMS 2488 or hard-coated using a wear-resistant material such as a tungsten carbide/cobalt thermal spray.

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 LO_2 or GO_2 at any pressure or with air at oxygen partial pressures above 35 kPa (5 psia).

c. The surfaces of titanium and titanium alloy mill products shall 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.

d. All cleaning fluids and other chemicals used during manufacturing and processing of titanium hardware shall be verified to be compatible with and not detrimental to the material's performance.

The use of titanium in hydrochloric acid, chlorinated solvents, chlorinated cutting fluids, fluorinated hydrocarbons, and anhydrous methyl alcohol should be avoided due to titanium's susceptibility to SCC. Contact of titanium alloys with mercury, cadmium, silver, and gold should

be avoided at certain temperature ranges because of liquid-metal-induced embrittlement and/or solid-metal-induced embrittlement.

6.3.1.4.6 Copper Alloys

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

b. Copper alloys shall not be used in solutions with ammonium ions or in contact with ammonia to prevent SCC.

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. Beryllium copper (UNS C17200) is commonly used for high-strength, nonsparking structural components in applications where it is subject to contact and wear.

6.3.1.4.7 Beryllium and Beryllium Alloys

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.

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.

Refer to the appropriate Material Safety Data Sheet for more detail.

6.3.1.4.8 Tin

a. Tin solder and tin plating shall be alloyed with at least 3% lead to prevent the growth of tin whiskers.

b. For critical GS, lot sampling shall be used to verify the presence of at least 3% lead.

6.3.1.5 Nonmetals

6.3.1.5.1 Elastomers

The use of elastomers in GS shall be evaluated by the M&P organization.

The following criteria should be used for design:

a. Elastomers should be in accordance with MIL-HDBK-149.

b. Elastomers should operate within the parameters of a design service life, including the vendor-specified shelf life.

c. Elastomers should be cure-dated for tracking purposes.

d. 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.

e. 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.

6.3.1.5.2 Composite Materials

a. Composite materials used in GS shall be in accordance with MIL-HDBK-17, Volumes 1 through 5.

b. Defects resulting from manufacturing shall be assessed through NDE techniques to meet the intent of 6.4.15.

6.3.1.5.3 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 KSC-SPEC-P-0012.

6.3.1.5.4 Lubricants

NASA-TM-86556, Parts A and B, should be used in evaluating and selecting solid and liquid lubricants for GS. Guidelines on additional lubricants are contained in NASA/CR–2005-213424. Long-life performance should be considered when selecting lubricants. Use of lubricants near precision-cleaned hardware or electrical connections should be minimized or tightly controlled to prevent cross-contamination.

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

b. Lubricants containing chloro-fluoro compounds shall not be heated above their maximum temperature rating.

The decomposition/reaction products that result from overheating lubricants that contain chloro-fluoro compounds can attack metallic materials and can be toxic.

c. Lubrication of flared tube fittings shall be in accordance with KSC-SPEC-Z-0009.

6.3.1.5.5 Limited-Life Materials

Materials that are not expected to meet the design life requirements but must be used for functional reasons shall be identified as limited-life items in accordance with 4.2.2.2.

Materials should be selected to meet the useful life of the hardware without the need for additional maintenance. Useful life includes storage life, installed life in a nonoperating mode, and operational service life.

6.3.1.5.6 Plastic Film, Foam, and Adhesive Tape (PFA)

Thin plastic films and tape materials used in GS shall be tested in accordance with and meet the requirements of the following for flammability, ESD, and hypergolic ignition/breakthrough characteristics, respectively, as appropriate for the application: NASA-STD-6001 (Test 1 and A.7) and MMA-1985-79.

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.

6.3.1.5.7 Fungus Resistance

Elastomers and polymers used in GS subjected to a humid environment shall be evaluated by the M&P organization.

Materials should meet one of the following criteria or be identified in the design documentation along with any action required such as periodic inspection, maintenance, or replacement of the material:

a. Materials are selected from fungus-inert materials (Group I) identified in MIL-STD-810. Fluorocarbon polymers (including ETFE) and silicones are considered acceptable.

b. Materials are used under one of the following conditions:

(1) Materials are used inside environmentally sealed containers with less than 60% relative humidity (RH) at ambient conditions.

(2) Materials are used inside electrical boxes where the temperature is always greater than or equal to the ambient cabin temperature.

(3) Only the edges of materials are exposed.

c. Materials are tested for fungus resistance in accordance with MIL-STD-810 and receive a rating of 0 or 1.

d. 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.

6.4 Processes

Riveting should be in accordance with MSFC-STD-156. Though MSFC-STD-156 is not current, it does contain the best practices for riveting.

6.4.1 Welding

Fusion welding of GSE shall meet all requirements for nonflight hardware in AWS D17.1, with the exception of pressure systems (see 5.2.13).

Welding of pressure systems is covered by ASME BPVC and ASME B31.3. The selection of parent materials and weld methods for GSE should be based on consideration of the weldments, including adjacent heat-affected zones, as they affect the operational capability of the parts concerned. Welding procedures should be selected to provide a weld of the required quality, use the minimum amount of energy, and protect the heated metal from contamination.

6.4.1.1 Welding Procedure Qualification

a. A welding procedure specification (WPS) that addresses each type of weld shall be prepared and qualified prior to the start of production welding.

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

b. Prior to the start of any production welding, all WPSs and procedure qualification records (PQRs) shall be approved by an M&P engineer authorized by NASA.

6.4.1.2 Welder/Welding Operator Performance Qualification

a. Prior to the start of production welding, each welder and welding operator shall be qualified.

b. Prior to the start of any production welding, all welder/welding operator performance qualification (WPQ) shall be approved by an M&P engineer authorized by NASA.

6.4.1.3 Weld Classification and Inspection

a. Welds whose failure could cause personnel injury, damage to flight hardware, loss of mission, or major damage to a significant ground asset shall be classified and inspected as Class A welds.

b. Welds whose failure could cause loss of function or improper performance shall be classified and inspected as Class B welds.

c. Welds whose failure could not cause improper performance or a hazard to personnel shall be classified and inspected as Class C welds.

6.4.2 Brazing

Brazing should be conducted in accordance with AWS C3.3.

a. Brazing of aluminum alloys shall meet the requirements of AWS C3.7M/C3.7.

b. Torch, induction, and furnace brazing shall meet the requirements of AWS C3.4M/C3.4, AWS C3.5M/C3.5, and AWS C3.6M/C3.6.

c. Subsequent fusion welding operations in the vicinity of brazed joints or other operations involving high temperatures that might affect the brazed joint shall be prohibited unless it can be demonstrated that the fixturing, processes, methods, and/or procedures employed will preclude degradation of the brazed joint.

d. Brazed joints shall be designed for shear loading and, for structural parts, not be relied upon for strength in axial loading.

e. The shear strength of brazed joints shall be evaluated in accordance with AWS C3.2M/C3.2.

f. For furnace brazing of complex configurations, such as heat exchangers and cold plates, destructive testing shall be conducted on preproduction brazed joints to verify that the brazed layer that extends beyond the fillet area is continuous and forms a uniform phase.

g. Brazing of pressure vessels shall be in accordance with ASME BPVC VIII.

6.4.3 Soldering

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

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

c. Tin-Lead (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, unless approved by the Technical Authority.

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

d. For critical GS, lot sampling shall be used to verify the lead content.

e. Soldering shall not be used for structural applications.

6.4.4 Heat Treating and Plating

a. Heat treatment of aluminum alloy parts shall meet the requirements of SAE AMS 2770, SAE AMS 2771, or SAE AMS 2772, as appropriate.

b. Steel parts shall be heat-treated to meet the requirements of SAE AMS-H-6875 or SAE AMS 2759.

c. Heat treatment of titanium and titanium alloy parts shall meet the requirements of SAE AMS-H-81200.

d. Heat treatment of nickel-based and cobalt-based alloy parts shall meet the requirements of SAE AMS 2774.

e. Electrodeposited nickel plating shall be applied according to the requirements of SAE AMS 2403 or SAE AMS 2423.

f. Electroless nickel plate shall be applied in accordance with SAE AMS 2404.

g. The nickel-aluminum interface in nickel-plated aluminum shall be protected from exposure to corrosive environments.

Nickel and aluminum form a strong galvanic cell at the nickel-aluminum interface, and exposure of the aluminum alloy to a corrosive environment can rapidly debond the nickel plate.

h. Galvanized (zinc) coatings shall be applied in accordance with ASTM A123, ASTM A153, and ASTM A653.

i. All repairs to damaged galvanized coatings shall be in accordance with ASTM A780.

j. Chromium plating shall be in accordance with SAE AMS 2460.

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

6.4.5 Forging

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.

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

The information gained from this effort should be used to redesign the forging technique as necessary.

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

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.

6.4.6 Casting

Castings shall meet the requirements in SAE AMS 2175.

6.4.7 Adhesive Bonding

Retesting of adhesives used for production parts is not required if they are within the manufacturer's recommended shelf life.

a. Structural adhesive bonding processes shall be controlled by a documented process to prevent 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.

b. Bonded primary structural joints shall demonstrate cohesive failure modes in shear at ambient temperature.

c. Adhesives shall not have a corrosive effect on other materials when exposed to conditions normally encountered in service.

6.4.8 Fluid System Cleanliness

a. Surface cleanliness of fluid systems shall be in accordance with ISO 14952, Parts 1 through 6.

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.

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

6.4.9 Crimping

Crimping shall be in accordance with NASA-STD-8739.4.

6.4.10 Potting and Molding

Potting and molding of electrical connectors shall be in accordance with KSC-STD-132.

6.4.11 Electrical-Cable Design and Fabrication

Electrical cables shall be designed and fabricated in accordance with KSC-GP-864 as determined by application, criticality, and operational environment.

6.4.12 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.

6.4.13 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 4.2.2.3). Guidelines for corrosion control for facilities, systems, and equipment are given in TM-584.

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

b. Corrosion control of galvanic couples shall be in accordance with MIL-STD-889.

c. All contacts between graphite-based composites and metallic materials shall be treated as dissimilar metal couples and sealed in accordance with NASA-STD-5008.

d. For critical GS, faying surfaces of metal alloys and electrical bonding connections, except for nickel-plated surfaces, shall be sealed in accordance with NASA-STD-5008, except for nickel-plated surfaces.

6.4.13.1 Stress Corrosion Cracking (SCC)

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 M&P authority's signature or electronic approval of the design drawings constitutes approval to use the materials of the design in the intended application.

6.4.14 Nondestructive Evaluation

a. NDE for all components except fracture-critical metallic GS components shall be performed in accordance with MIL-HDBK-6870.

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

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

d. NDE of non-fracture-critical base materials shall be in accordance with ASTM E1417, ASTM E1444, ASTM E1742, ASTM E2375, SAE AMS 2647, SAE AMS-STD-2154, SAE ARP 4402, and SAE AS 4787

Typical NDE methods include 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.

e. Unless otherwise specified by a governing discipline standard (e.g., ASME BPVC, AWS D17.1), qualification and certification of personnel involved in NDE shall comply with AIA/NAS 410.

6.4.15 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.

a. All metallic materials used in hydrogen systems in critical GS shall be approved by the M&P organization.

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 ANSI/AIAA/G-095.

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

c. Corrosion protection shall be in accordance with NASA-STD-5008 to minimize the risk of hydrogen embrittlement due to corrosion.

6.4.16 Contamination Control

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

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

6.4.17 Flex Hose Inspection

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

APPENDIX A. GROUND SYSTEM IDENTIFICATION SYSTEM COLORS

The color chip numbers are from FED-STD-595.

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

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APPENDIX B. DELIVERABLES

B.1 GS Documentation Deliverables

B.1.1 The GS provider is responsible for submitting documentation to verify that the hardware/software has been developed in accordance with this standard.

B.1.2 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, but are not limited to, the following:

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

Intent/Rationale: The using organization requires documentation for safely operating, maintaining, and servicing the GS. To reduce risk to the mission, as well as to 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 C. REFERENCE DOCUMENTS

	United States National CAD Standard
ANSI/AIAA/G-095	Guide to Safety of Hydrogen and Hydrogen Systems
ASME B31.1	Power Piping
ASTM D5363	Standard Specification for Anaerobic Single-Component Adhesives (AN)
ASTM G63	Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service
ASTM G88	Standard Guide for Designing Systems for Oxygen Service
ASTM G93	Standard Practice for Cleaning Methods and Cleanliness Levels for Material and Equipment Used in Oxygen-Enriched Environments
ASTM G94	Standard Guide for Evaluating Metals for Oxygen Service
AWS C3.3	Recommended Practices for Design, Manufacture, and Examination of Critical Brazed Components
ECA EIA/ECA 310-E	Cabinets, Racks, Panels, and Associated Equipment
FED-STD-595	Colors Used in Government Procurement
IEC 62305	Protection Against Lighting, Part 1: General Principles, Part 2: Risk Management, Part 3: Physical Damage and Life Hazards, and Part 4: Electrical and Electronic Systems with 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
JPR 5322.1	Contamination Control Requirements Manual
JSC 29353	Flammability Configuration Analysis for Spacecraft Application
KDP-P-2713	Technical Review Process
KNPR 8720.2	KSC Reliability and Maintainability Procedural Requirements
KSC-C-123	Surface Cleanliness of Ground Support Equipment Fluid Systems, Specification for
KSC-STD-G-0003	Launch Support and Facility Components, Qualifications of, Standard for
KTI-5210	Material Selection List for All Oxygen and Air Services
KTI-5212	Material Selection List for Plastic Films, Foams, and Adhesive Tapes
MIL-HDBK-149	Rubber
MIL-HDBK-454	General Guidelines for Electronic Equipment
MIL-STD-461	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment
MSFC-STD-156	Riveting, Fabrication and Inspection, Standard for
MSFC-SPEC-164	Cleanliness of Components for Use in Oxygen, Fuel, and Pneumatic Systems, Specification for

MSFC-STD-486	Threaded Fasteners, Torque Limits, Standard for
NASA/CR-2005-213424	Lubrication for Space Applications
NASA RP-1228	Fastener Design Manual
NASA/TM-2007-213740	Guide for Oxygen Compatibility Assessments on Oxygen Components and Systems
NASA-TM-86556	Lubrication Handbook for the Space Industry, Part A: Solid Lubricants, Part B: Liquid Lubricants
NASA/TP-2003-212242	EEE-INST-002: Instructions for EEE Parts Selection, Screening, Qualification, and Derating
NEMA C50.41	American National Standard for Polyphase Induction Motors for Power Generating Stations
NEMA ICS 2	Industrial Control and Systems Controllers, Contactors, and Overload Relays Rated 600 Volts
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
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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STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

INSTRUCTIONS

1. The preparing activity must complete blocks 1, 2, 3, and 8. In block 1, both the document number and revision letter should be given.
2. The submitter of this form must complete blocks 4, 5, 6, and 7.
3. The preparing activity must provide a reply within 30 days from receipt of the form.

NOTE: This form may not be used to request copies of documents, nor to request waivers or clarification of requirements on current contracts. Comments submitted on this form do not constitute or imply authorization to waive any portion of the referenced document or to amend contractual requirements.

I RECOMMEND A CHANGE:	1. DOCUMENT NUMBER KSC-DE-512-SM, Revision L, Change 5	2. DOCUMENT DATE July 12, 2016

3. DOCUMENT TITLE
Facility Systems, Ground Support Systems, and Ground Support Equipment General Design Requirements

4. NATURE OF CHANGE *(Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)*

5. REASON FOR RECOMMENDATION

6. SUBMITTER

a. NAME *(Last, First, Middle Initial)*	b. ORGANIZATION	
c. ADDRESS *(Include Zip Code)*	d. TELEPHONE *(Include Area Code)*	7. DATE SUBMITTED

8. PREPARING ACTIVITY

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