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Facility Systems, Ground Support Systems, and Ground Support Equipment General Design Requirements

Eric A. Thaxton
NASA/Kennedy Space Center
Kennedy Space Center, FL

National Aeronautics and Space Administration

Kennedy Space Center
Kennedy Space Center, FL 32899

June 2014
FACILITY SYSTEMS, GROUND SUPPORT SYSTEMS,
AND GROUND SUPPORT EQUIPMENT
GENERAL DESIGN REQUIREMENTS

FEBRUARY 29, 2012
CHANGED JUNE 23, 2014

ENGINEERING AND TECHNOLOGY DIRECTORATE

National Aeronautics and
Space Administration

John F. Kennedy Space Center

KSC FORM 16-12 (REV. 6/95) PREVIOUS EDITIONS ARE OBSOLETE (CG 11/95)

APPROVED FOR PUBLIC RELEASE – DISTRIBUTION IS UNLIMITED
FACILITY SYSTEMS, GROUND SUPPORT SYSTEMS, AND GROUND SUPPORT EQUIPMENT
GENERAL DESIGN REQUIREMENTS

Approved by:

P.E. Phillips
Director, Engineering and Technology Directorate

This Revision Supersedes All Previous Editions of This Document

FEBRUARY 29, 2012
CHANGED JUNE 23, 2014

JOHN F. KENNEDY SPACE CENTER, NASA

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<td>February 20, 1987</td>
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<td>August 5, 1994</td>
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<td>December 15, 1994</td>
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<td>June 1, 1995</td>
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<td>September 14, 2000</td>
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<td>May 30, 2002</td>
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<td>2. Clarified applicability of NASA-STD-5005 in 1.2.i.</td>
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<td>3. Corrected references in 1.2.k.</td>
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<td>5. Added ASHRAE Handbook—Fundamentals to applicable documents in 2.3.</td>
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<td>6. Updated list of acronyms and abbreviations in 3.1 to add ASHRAE (American Society of Heating, Refrigeration, and Air-Conditioning Engineers), GHz (gigahertz), m (meter), and V (volt) and delete EMC (electromagnetic compatibility) and MUA (Material Usage Agreement).</td>
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<td>7. Changed term from safety factor to factor of safety in 3.2, 5.1.1.1.b, 5.1.1.2.b, and 5.1.2.d.</td>
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<td>8. Moved the table of colors from 4.2.2.3 to Appendix A and clarified the existing requirement and guidance in 4.2.2.3.</td>
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<td>9. Split 4.2.3.4.d into 3 paragraphs (d, e, and f) to limit each paragraph to a single requirement. Renumbered subsequent paragraphs in 4.2.3.4.</td>
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<td>10. Corrected typographical error in guidance paragraph for 4.2.3.4.j.</td>
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<td>12. Corrected paragraph reference in 4.6.2.2.</td>
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<td>13. Changed the title of 5.1.2 from Safety Factors to Factors of Safety and clarified requirements.</td>
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<td>14. Rewrote 5.2.6 to delete references to KSC-STD-Z-0010, which has been cancelled.</td>
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<td>15. Deleted “Torque for” from title of 5.2.9 and clarified requirements.</td>
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<td>16. Added NASA-STD-8719.17 to paragraph 5.2.13 as required by NPD 8710.5 and changed title to Pressure Systems.</td>
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<td>17. Deleted guidance statements from 5.4.19.3.</td>
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<td>18. Updated 5.5 to add EMI levels for design.</td>
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<td>19.</td>
<td>Replaced all references to “MUA” with “approval by the M&amp;P organization” (see 6.2, 6.3, and 6.4.15.a).</td>
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<td>20.</td>
<td>Updated 6.4.3 to account for the cancellation of NASA-STD-8739.2 and NASA-STD-8739.3.</td>
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<td>21.</td>
<td>Moved guidance statement about riveting from 6.4.9 to 6.4, deleted 6.4.9 (Riveting), and renumbered the remaining paragraphs (6.4.9 through 6.4.16).</td>
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<td>23.</td>
<td>Rewrote requirement in 6.4.16 as a “shall” statement.</td>
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<td>24.</td>
<td>Deleted the Material Usage Agreement (MUA) form from Appendix A.</td>
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<td>Updated 2.2, 2.3, and Appendix C to accurately reflect all current applicable and reference documents.</td>
<td>June 23, 2014</td>
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<td>2.</td>
<td>Updated abbreviations in 3.1.</td>
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<td>4.</td>
<td>Updated 5.4.1 to include KSC-PLN-5406 for EEE Parts.</td>
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<td>5.</td>
<td>Deleted reference to KSC-C-123 in guidance statement in 5.4.5.</td>
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<td>6.</td>
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<td>7.</td>
<td>Updated 6.4.1 to replace NASA-SPEC-5004 (cancelled) with AWS D17.1.</td>
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<td></td>
<td>8.</td>
<td>Updated 6.4.8 to replace KSC-C-123 with ISO 14952, Parts 2 and 6.</td>
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<td></td>
<td>9.</td>
<td>Removed 6.4.15.d, which was redundant to 6.4.1.</td>
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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) Center Operations, Protective Services Branch, 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.
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](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


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

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KSC-STD-P-0006   Quick Release Pins and Pin Tethers, Standard for
KSC-STD-SF-0004   Ground Piping Systems Color Coding and Identification, Safety 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-0009   Cryogenic Ground Support Equipment, Design of, Standard for

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
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**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-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
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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**

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<td>°C</td>
<td>degrees Celsius</td>
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<td>°F</td>
<td>degrees Fahrenheit</td>
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<td>A-50</td>
<td>aerozine 50</td>
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<tr>
<td>AA</td>
<td>Aluminum Association</td>
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<tr>
<td>AC</td>
<td>alternating current</td>
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<tr>
<td>ADM</td>
<td>Aluminum Design Manual</td>
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<tr>
<td>AFSPCMAN</td>
<td>Air Force Space Command Manual</td>
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<td>AIA</td>
<td>Aerospace Industries Association</td>
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<td>AIAA</td>
<td>American Institute of Aeronautics and Astronautics</td>
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<tr>
<td>AISC</td>
<td>American Institute of Steel Construction</td>
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<tr>
<td>AMS</td>
<td>Aerospace Material Specification</td>
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<td>ANSI</td>
<td>American National Standards Institute</td>
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<tr>
<td>ARP</td>
<td>Aerospace Recommended Practice</td>
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<td>AS</td>
<td>Aerospace Standard</td>
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<td>ASCE</td>
<td>American Society of Civil Engineers</td>
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<td>American Society of Heating, Refrigeration, and Air-Conditioning Engineers</td>
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<td>American Society of Mechanical Engineers</td>
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<td>ASTM</td>
<td>American Society for Testing and Materials</td>
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<td>American Welding Society</td>
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<td>BPVC</td>
<td>Boiler and Pressure Vessel Code</td>
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<td>CFR</td>
<td>Code of Federal Regulations</td>
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<td>CGA</td>
<td>Compressed Gas Association</td>
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<td>CIL</td>
<td>Critical Items List</td>
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<td>COPV</td>
<td>Composite Overwrapped Pressure Vessel</td>
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<td>COTS</td>
<td>commercial off-the-shelf</td>
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<tr>
<td>DE</td>
<td>design</td>
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<td>DOT</td>
<td>Department of Transportation</td>
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<td>DTL</td>
<td>detail</td>
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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
GO2 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
MAF 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
N4H4  hydrazine
N2O4  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
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 (LH₂) and liquid oxygen (LO₂) 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

a. A criticality assessment shall be performed early in the design phase to determine the need for performing a reliability and/or safety analysis.

The criticality of a system failure mode will be assigned on the basis of worst-case credible failure effect, assuming the loss of all redundancy (where applicable). This will include possible catastrophic or critical effects of system failure, including the effects of loss of hardware functions.

b. System inputs (including dependencies such as electrical power and pneumatic purges) and outputs (including all control and monitoring functions) that could fail with potentially catastrophic or critical consequences shall be identified as reliability critical (FMEA is required).

System inputs and outputs can be obtained from a system requirements document if available.

c. Systems with hazards to personnel or equipment during normal or credible use scenarios shall be identified as critical (Hazard Analysis is required).

In addition, information obtained from criticality assessments is often used in determining how a system will be designed, documented, fabricated, assembled, installed, and tested.
Table 1. Criticality Categories

<table>
<thead>
<tr>
<th>Criticality</th>
<th>Criticality Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Single failure that could result in loss of life or vehicle.</td>
</tr>
<tr>
<td>1R</td>
<td>Redundant hardware item, which if all failed, could cause loss of life or vehicle.</td>
</tr>
<tr>
<td>1S</td>
<td>Single failure in a safety or hazard monitoring system that could cause the system to fail to detect, combat, or operate when needed during the existence of a hazardous condition and could result in loss of life or vehicle.</td>
</tr>
<tr>
<td>2</td>
<td>Single failure that could result in loss of mission, damage to a vehicle system, or major damage to a significant ground asset.</td>
</tr>
<tr>
<td>2R</td>
<td>Redundant hardware item, which if all failed, could cause a loss of mission, damage to a vehicle system, or major damage to a significant ground asset.</td>
</tr>
<tr>
<td>3</td>
<td>All other failures.</td>
</tr>
</tbody>
</table>

Guidelines in Determining Criticality

- **In determining the criticality of a subsystem, emergency systems or contingency and emergency operations (e.g., fire suppression, crew escape, and abort) will not be considered as a level of redundancy.**

- **The criticality assignment for an item whose failure affects the loading or pressure on primary structure, thermal protection, or pressure vessels will be based on the worst-case potential effect of exceeding the maximum load that the structure can withstand without deformation, rupture, or collapse.**

- **In determining the classification of criticality categories, it will be assumed that personnel actions will be performed to activate standby redundant items, as long as requirements for detectability and time to effect are met. Manual standby redundancy must be activated by a trained operator in accordance with a preapproved written procedure.**

  d. An FMEA shall be performed in accordance with program-defined methodology on those systems and subsystems identified by the criticality analysis as having the potential to cause a criticality 1, 1S, 1R, or 2 condition.

  e. Based on the results of the FMEA, components having failure modes that could cause an undesirable event (other than criticality 3) shall be identified, categorized, and approved in accordance with the applicable agency, program, or KSC requirements.

  f. In the absence of a program requirement, the methodology of **KNPR 8700.2** shall be used.
All components other than criticality 3 are included in a CIL report, where they are reviewed for criteria such as qualification, failure history, tests, and verifications that will justify the design.

g. The criticality categories shown in Table 1 shall be used when the program does not identify categories.

h. Static components, such as pressure vessels, pressure lines, cables, connectors, and wiring, shall be considered only if failure can be attributed to an active component failure.

Analysis ground rules and exceptions to program methodology or related to the scope of analysis should be clearly stated with justification.

i. A Hazard Analysis shall be performed on those systems and subsystems determined by the criticality assessment to be a potential threat to flight systems, ground systems, or safety.

j. Based on the results of the Hazard Analysis, those hazards that could not be eliminated by design or mitigated to an acceptable level shall require a Hazard Report.

The Hazard Report summarizes all controls and verifications that would be used to mitigate the hazard. As with the FMEA, Hazard Analyses are performed and Hazard Reports are written in accordance with the applicable program requirements. In the absence of a program requirement, the methodology of KNPR 8700.2 applies.

k. FMEA and/or Hazard Analysis including the results of the analysis shall be combined into a Systems Assurance Analysis (SAA) to summarize the risks resulting from each system/subsystem analysis.

l. CIL and Hazard Reports shall be approved and maintained as part of the design documentation.

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-HDBK-1001.

Specifications in NASA-HDBK-1001 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-HDBK-1001.

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 Zones 3 or 4 as defined in NASA-HDBK-1001 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.

4.3.2 Technical Documentation

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

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 in accordance with KSC-STD-G-0003.

Qualification of components is guided by NPD 8730.2.

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 the load test creates an unsafe condition or when analysis shows the load test will result in damage to the structure.

*Load testing of fixed GS structures may be accomplished using a representative section of the structure.*

b. The minimum test load shall be 125% of the design or working load for GS not used for lifting.

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 Nondestructive Evaluation (NDE)

NDE for components and materials shall be in accordance with 6.4.14.

4.6.2.3 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 paragraph 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


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 (N₂O₄), aerozine 50 (A-50), or hydrazine (N₂H₄) 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

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.

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 shall be in accordance with ASME B31.3 or SMACNA 1958.

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
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.

5.2.14 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 13, 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.
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.

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 that will not be exposed to vibration or thermal cycling at space flight levels shall be fabricated in accordance with IPC J-STD-001.

b. Printed circuit assemblies that will be exposed to vibration or thermal cycling at space flight levels shall be fabricated in accordance with IPC J-STD-001ES.

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 should be avoided.*

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

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

b. When data matrix identification symbols are used to identify GS, they shall be applied in accordance with NASA-STD-6002.

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 KSC-STD-SF-0004.

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) 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.

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 tetrafluoroethylene (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 GO₂ (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.*


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. Free-machining alloys such as UNS S30300 (type 303 SST) and UNS S30323 (type 303Se SST) shall not be used in corrosive environments.

c. UNS N08367 (trade name AL-6XN) or UNS S31254 (trade name 254 SMO) shall be used in pressure piping and tubing in lieu of 300-series stainless steel when the piping or tubing is directly exposed to a corrosive environment.

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

e. 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 LO₂ or GO₂ 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

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

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

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

d. Elastomers shall 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 shall 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

For GS used in a humid environment, materials shall 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 not exposed to vibration or thermal cycling shall be in accordance with IPC J-STD-001.

b. Soldering of electrical connections exposed to vibration or thermal cycling shall be performed in accordance with IPC J-STD-001ES.

c. All solder and solderable platings or protective finishes based on tin shall contain a minimum lead content of 3% by weight.

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.
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

a. Structural adhesive bonding shall be in accordance with MSFC-SPEC-445, with the exception of retesting.

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

b. 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.

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

d. 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.

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. 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.
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APPENDIX A. GROUND SYSTEM IDENTIFICATION SYSTEM COLORS

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

<table>
<thead>
<tr>
<th>Color</th>
<th>Color Chip Number</th>
<th>Ground System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray</td>
<td>26440 or 26251</td>
<td>Electrical/electronic, hydro/pneumatic consoles, racks, and cabinets</td>
</tr>
<tr>
<td>Gray</td>
<td>16187 or 16473</td>
<td>Structural steel/aluminum</td>
</tr>
<tr>
<td>Red</td>
<td>11105 or 21105</td>
<td>Remove-before-flight items, safety equipment, and protective equipment</td>
</tr>
<tr>
<td>White</td>
<td>17875 or 27875</td>
<td>White room or clean room equipment</td>
</tr>
<tr>
<td>Black</td>
<td>37038</td>
<td>Panel lettering</td>
</tr>
<tr>
<td>Yellow or White</td>
<td>13538, 17875, or 27875</td>
<td>Handling and transportation equipment</td>
</tr>
<tr>
<td>Blue</td>
<td>25102</td>
<td>Control racks and consoles</td>
</tr>
<tr>
<td>Yellow Brown Band (optional)</td>
<td>13655 (yellow) 10080 (brown)</td>
<td>Connections and interfaces for hypergolic fuel servicing (see KSC-STD-SF-0004 for color coding of piping systems)</td>
</tr>
<tr>
<td>Green Brown Band (optional)</td>
<td>14110 (green) 10080 (brown)</td>
<td>Connections and interfaces for hypergolic oxidizer servicing (see KSC-STD-SF-0004 for color coding of piping systems)</td>
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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.
### APPENDIX C. REFERENCE DOCUMENTS

<table>
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<th>Description</th>
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<tbody>
<tr>
<td>ASME B31.1</td>
<td>Power Piping</td>
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<tr>
<td>ASTM D5363</td>
<td>Standard Specification for Anaerobic Single-Component Adhesives (AN)</td>
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<td>ASTM G88</td>
<td>Standard Guide for Designing Systems for Oxygen Service</td>
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<td>AWS C3.3</td>
<td>Recommended Practices for Design, Manufacture, and Examination of Critical Brazed Components</td>
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<tr>
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<td>Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications</td>
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<tr>
<td>IEEE 1106</td>
<td>Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications</td>
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<td>KSC Reliability and Maintainability Procedural Requirements</td>
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<td>Material Selection List for All Oxygen and Air Services</td>
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<td>Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment</td>
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<td>MSFC-STD-156</td>
<td>Riveting, Fabrication and Inspection, Standard for</td>
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<td>NASA/CR-2005-213424</td>
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<td>NASA RP-1228</td>
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<td>NEMA C50.41</td>
<td>American National Standard for Polyphase Induction Motors for Power Generating Stations</td>
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<td>NEMA ICS 2</td>
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<td>TM-584</td>
<td>Corrosion Control and Treatment Manual</td>
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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.

<table>
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<th>I RECOMMEND A CHANGE:</th>
<th>1. DOCUMENT NUMBER</th>
<th>2. DOCUMENT DATE</th>
</tr>
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</table>

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
a. NAME  
   Engineering and Technology Directorate, (NE)  
b. TELEPHONE (Include Area Code)  
   (321) 867-7770

c. ADDRESS (Include Zip Code)  
   John F. Kennedy Space Center  
   Kennedy Space Center, Florida 32899