NASA TECHNICAL STANDARD

NASA-STD-5005C

National Aeronautics and Space Administration
Washington, DC 20546-0001

Approved: 03-13-2009
Superseding NASA-STD-5005B and NASA-STD-(I)-5005C

STANDARD FOR THE DESIGN AND FABRICATION OF GROUND SUPPORT EQUIPMENT

MEASUREMENT SYSTEM IDENTIFICATION:
METRIC/SI (ENGLISH)

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DOCUMENT HISTORY LOG

Status	Document Revision	Approval Date	Description	
Baseline		5-10-1996	Baseline Release	
Revision	A	5-15-2001	Incorporates numerous reference updates as listed below:	
			REFERENCES ADDED	REFERENCES DELETED
			NASA-SPEC-5004	MIL-B-7883
			MIL-C-26482	MIL-C-26482
			MIL-DTL-38999	MIL-C-38999
			NSS 1740.16	MIL-H-6088
			NASA-STD-6001	MIL-H-6875
			NASA-STD-5008	MIL-I-6870
			NASA-HDBK-1001	MIL-M-8090
			MIL-HDBK-5961	KSC-STD-C-0001
			MIL-HDBK-6870	MIL-STD-462
			NPD 8010.2	MIL-STD-701
			NPG 1620.1	MIL-STD-975
			NPG 7120.5	NHB 1620.3
			NPG 8715.3	NHB 7120.5
			ANSI/AIAA R-100	NHB 8060.1
			ISO 9001	NASA-TM-4511
			ISO 14625	KSC-CP-986
			ISO 15389	ANSI-ASQC Q9001
			ASTM MNL 36	ASTM E380
			AWS D1.6	ANSI/IEEE 268
			IEEE/ASTM S1 10	
			AMS H-6088	
			AMS H-6875	
			AS 8090	
			DEFINITIONS/ACRONYMS ADDED	DEFINITIONS/ACRONYMS DELETED
			EWR	ASNT
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Status	Document Revision	Approval Date	Description
Revision	B	9-15-2003	Revised as indicated below:

Table of Contents: 5.4.1.5.2 changed from Type J to Reactive fluid service. Foreword, second paragraph, second sentence, changed Engineering Standards Steering Council (ESSC) to "NASA Technical Standards Working Group (NTSWG)."

2.2 Documents deleted: MSFC-SPEC 522, MSFC-PROC-186, MSFC-PROC-380, MSFC-SPEC-222, MSFC-SPEC-379, MSFC-SPEC-515, NSTS-DN-C-0005, MIL-C-5015, MIL-C-26482, MIL-C-39012, MIL-H-81200, MIL-W-16878, NSS/GO 1740.9, KSC, KHB 1700.7. Documents added: NASA-STD-8719.9, MIL-DTL-5015, MIL-DTL-16878, MIL-PRF-39012, Title of MIL-STD-810 changed to: "Department of Defense Test Method Standard for Environmental Engineering, Considerations and Laboratory Tests". Revision "H" was added to MIL-HDBK-5. MIL-HDBK-17 changed to MIL-HDBK-17/1, "Composite Materials Handbook Volume 1, Polymer Matrix Components Guidelines for Characterization of Structural Materials". MIL-HDBK-6870, title changed to: "Inspection Program Requirements Nondestructive for Aircraft and Missile Materials and Parts". NSS1740.16, title changed to "Guidelines for Hydrogen System Design, Materials, Selection, Operations, Storage and Transportation".

2.3 SAS 30 and SAS 33 were deleted; ADM-1 Aluminum Design Manual was added; AISI SG 673 title changed to "Cold Formed Steel Design Manual"; MO 16 was changed to AISC 316-89, "Manual of Steel Construction – Vol. 1 (Reference 316-1989) Allowable Stress Design"; MO 15L was changed to AISC 325-11 LFRD "Manual of Steel Construction Third Edition. ISO 9001 Quality-Management Systems Requirements; IEEE/ASTM S1 10 Added "American National Standard for Use of the International System of Units (SI), MG-1 changed to "Information Guide for General Purpose Industrial AC Small and Medium Squirrel-Cage Induction Motor Standards"; CGA C-4 Replaced by CGA-C-7; AMS H-6875, Title changed to Heat Treatment of Steel, Process For"; AMS-H-6088 superseded by AMS-2770, -2771, -2772; AMS-H-81200, "Heat Treatment of Titanium and Titanium Alloys" was added. Added "Steel" to NASA-STD-6001 title. Changed title of TM 5-809-10/NAVFAC to "Seismic Design Guidelines for Upgrading Existing Buildings, P-355/AFM 88-3, Chapter 13." Changed title of EWR 127-1 to "Eastern and Western Range Safety Policies and Processes, Range Safety Requirements." Added ASTM A36, Standard Specification for Carbon Structural Steel; ASTM A325, Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength; and ASTM A490, Standard Specification for Structural Bolts, Alloy Steel, Heat Treated, 150 ksi Minimum Tensile Strength.

3.1: Abbreviations/Acronyms added A-50, AMS, ICBO, NTSWG, SDO, and YA. Deleted NAS and NHB.

4.3.5.4: Changed NSTS-SN-C-0005 to JSC-SN-C-0005.

4.8.3.1: Lifting devices NSS-GO-1749 replaced by NASA-STD-8719.9.

5.1.1 AISC MO15L replaced by AISC M015L,…AA SAS 30 replaced by AA SAS 33. Changed MO16 to 316-89; changed AA SAS 30 to ADM-1.

5.2.2: Changed ASTM MNL 36 to ASTM MANL 36.

5.2.8 NSS/GO 1740.9 replaced by NASA-STD-8719.9….

5.2.11 MO 15L or MO 16 as appropriate replaced by AISC 318-89 and added ASTM before A490.

5.2.15: Change Division I, II, or III to 1, 2, or 3.

5.4.1.1 MIL-S-16216 Replaced by T9074-BD-G1B-010/300

5.4.1.2 MSFC-SPEC-522 replaced by NASA-STD-6004.

Status	Document Revision	Approval Date	Description
Revision (Continued)	B		
5.1.4.5.2 "Type J" replaced by "Reactive" throughout section 5.4.2.2: Added ANSI/ before AIAA R-100. 5.4.2.9 MIL-W-16878 replaced by MIL-DTL-16878. 5.4.2.10 MIL-C-5015 replaced by MIL-DTL-5015, … 5.4.2.10.1 MIL-C-39012 replaced by MIL-PRF-39012. 5.4.2.15: Changed ICS 2 to NEMA-ICS2. 5.4.3.1 MIL-H-81200 replaced by AMS-H-81200. 5.4.3.13 AMS2770, AMS2771, and AMS2772 replaces AMS-H-6088. Changed AMS I-6875 to AMS-H-6875. 5.6.8 word "end "added before items 5.9 KHB 1700.7 added			
Interim	C	07-20-2007	Interim Revision (General Revision—Document Completely Rewritten)
Revision	C	03-13-2009	General Revision—Document Completely Rewritten Transitioned Interim NASA Technical Standard NASA-STD-(I)-5005C to NASA Technical Standard NASA-STD-5005C.

FOREWORD

This Standard is published by the National Aeronautics and Space Administration (NASA) to provide uniform engineering and technical requirements for processes, procedures, practices, and methods that have been endorsed as standard for NASA programs and projects, including requirements for selection, application, and design criteria of an item.

This Standard is approved for use by NASA Headquarters and NASA Centers, including Component Facilities and Technical and Service Support Centers.

This Standard establishes minimum requirements and engineering best practices for design and development of ground systems and equipment intended for use in preparing space flight systems for flight after acceptance by the Government. This Standard does not apply to facilities or equipment used in the manufacturing of space flight systems.

Individual provisions of this Standard should be and are intended to be tailored (i.e., modified or deleted) by contract or program specifications to meet specific program, project, and Center needs and constraints based on a criticality review by Safety and Mission Assurance (S&MA) according to program and Center procedures.

Requests for information, corrections, or additions to this Standard should be submitted via "Feedback" in the NASA Standards and Technical Assistance Resource Tool at http://standards.nasa.gov.

Original Signed By ______________________ **03/13/2009** ______________________

Michael G. Ryschkewitsch
NASA Chief Engineer

Approval Date

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APPENDICES

STANDARD FOR THE DESIGN AND FABRICATION OF GROUND SUPPORT EQUIPMENT

1. SCOPE

1.1 Purpose

This Standard establishes top-level requirements and guidance for design and fabrication of ground support equipment (GSE) to assist National Aeronautics and Space Administration (NASA) space flight programs/projects in providing robust, safe, reliable, maintainable, supportable, and cost-effective GSE.

1.2 Applicability

a. The application of this Standard to NASA space flight programs is at the discretion of the program. This Standard recommends a set of GSE design requirements for NASA programs and projects. This Standard is intended for use in establishing uniform engineering practices and methods and ensuring that essential requirements are included in the design, procurement, and fabrication of GSE used to support the operations of receiving, transportation, handling, assembly, inspection, test, checkout, service, launch, and recovery of space vehicles and payloads at NASA's launch, landing, or retrieval locations.

b. This Standard is approved for use by NASA Headquarters and NASA Centers, including Component Facilities and Technical and Service Support Centers, and may be cited in contract, program, and other Agency documents as a technical requirement. This Standard may also apply to the Jet Propulsion Laboratory or to contractors, grant recipients, or parties to agreements only to the extent specified or referenced in their contracts, grants, or agreements.

c. Requirements are numbered and indicated by the word "shall." Explanatory or guidance text is indicated in italics beginning in section 4.

d. Programs, projects, and elements are responsible for flowing requirements down to contractors, subcontractors, and suppliers of components at the lowest level. Program contractors may elect to manufacture deliverable GSE to flight hardware requirements if using flight hardware requirements (1) does not increase risk, (2) represents an overall cost savings, and (3) does not violate local, State, or federal laws.

e. Along with identifying this Standard for design and development of GSE, programs, in conjunction with Engineering and Safety and Mission Assurance (S&MA) organizations, have the responsibility to:

(1) Determine categories or types of GSE (e.g., critical vs. noncritical) and any additional requirements resulting from these categories or types.

(2) Establish and define where this Standard will be applied and when such boundaries require clarification.

(3) Establish program- and project-specific requirements.

(4) Establish minimum configuration management systems to retain the required documentation.

f. This Standard does not apply to the following:

(1) Equipment that is used solely during the manufacturing of flight hardware.
(2) Ground support systems (GSSs) that interface with GSE.
(3) Facilities.
(4) Tools.

1.3 Tailoring

Tailoring of this Standard for application to a specific program or project shall be formally documented as part of program or project requirements and approved by the Technical Authority.

2. APPLICABLE DOCUMENTS

2.1 General

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

2.1.1 The latest issuances of cited documents shall apply unless specific versions are designated.

2.1.2 Non-use of specific versions as designated shall be approved by the responsible Technical Authority.

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

2.2 Government Documents

Department of Defense

AFSPCMAN 91-710, Volume 3	Range Safety User Requirements Manual Volume 3 - Launch Vehicles, Payloads, and Ground Support Systems Requirements
MIL-DTL-5015	Connectors, Electrical, Circular Threaded, AN Type, General Specification for
MIL-DTL-16878	Wire, Electrical, Insulated, General Specification for
MIL-DTL-22992	Connectors, Plugs and Receptacles, Electrical, Waterproof, Quick Disconnect, Heavy Duty Type, General Specification for
MIL-DTL-24308	Connectors, Electric, Rectangular, Nonenvironmental, Miniature, Polarized Shell, Rack and Panel, General Specification for
MIL-DTL-38999	Connectors, Electrical, Circular, Miniature, High Density, Quick Disconnect (Bayonet, Threaded and Breech Coupling), Environment Resistant, Removable Crimp and Hermetic Solder Contacts, General Specification for
MIL-HDBK-17-1	Composite Materials Handbook Volume 1. Polymer Matrix Composites Guidelines for Characterization of Structural Materials
MIL-HDBK-17-2	Composite Materials Handbook Volume 2. Polymer Matrix Composites Materials Properties
MIL-HDBK-17-3	Composite Materials Handbook Volume 3. Polymer Matrix Composites Materials Usage, Design, and Analysis
MIL-HDBK-17-4	Composite Materials Handbook Volume 4. Metal Matrix Composites
MIL-HDBK-17-5	Composite Materials Handbook Volume 5. Ceramic Matrix Composites
MIL-HDBK-149	Rubber

MIL-HDBK-263	Electrostatic Discharge Control Handbook for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices) (Metric)
MIL-HDBK-454	General Guidelines for Electronic Equipment
MIL-HDBK-700	Plastics
MIL-HDBK-6870	Inspection Program Requirements, Nondestructive for Aircraft and Missile Materials and Parts
MIL-PRF-39012	Connectors, Coaxial, Radio Frequency, General Specification for
MIL-STD-130	Identification Marking of U.S. Military Property
MIL-STD-461	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment
MIL-STD-810	Environmental Engineering Considerations and Laboratory Tests
MIL-STD-889	Dissimilar Metals
MIL-STD-1686	Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)

Federal (FED)

29 CFR 1910	Occupational Safety and Health Standards
49 CFR 171 through 180	Hazardous Materials Regulations (Department of Transportation)
FED-STD-595	Colors Used in Government Procurement
HF-STD-001	Human Factors Design Standard (Federal Aviation Administration)
MMPDS	Metallic Materials Properties Development and Standardization (Federal Aviation Administration)

NASA

NASA-HDBK-1001	Terrestrial Environment (Climatic) Criteria Handbook for Use in Aerospace Vehicle Development
NASA-SPEC-5004	Welding of Aerospace Ground Support Equipment and Related Nonconventional Facilities
NASA-STD-4003	Electrical Bonding for NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment
NASA-STD-5008	Protective Coating of Carbon Steel, Stainless Steel, and Aluminum on Launch Structures, Facilities, and Ground Support Equipment
NASA-STD-5009	Nondestructive Evaluation Requirements for Fracture-Critical Metallic Components
NASA-STD-6001 (latest version, including the interim (I) version)	Flammability, Offgassing, and Compatibility Requirements and Test Procedures
NASA-STD-6002	Applying Data Matrix Identification Symbols on Aerospace Parts
NASA-STD-8719.9	Standard for Lifting Devices and Equipment
NASA-STD-8739.1	Workmanship Standard for Polymeric Application on Electronic Assemblies
NASA-STD-8739.2	Workmanship Standard for Surface Mount Technology
NASA-STD-8739.3	Soldered Electrical Connections
NASA-STD-8739.4	Crimping, Interconnecting Cables, Harnesses, and Wiring
NASA-STD-8739.5	Fiber Optic Terminations, Cable Assemblies, and Installation
NASA-STD-8739.8	Software Assurance Standard
NPD 8730.1	Metrology and Calibration
NPD 8730.2	NASA Parts Policy

NPR 1600.1	NASA Security Program Procedural Requirements
NPR 6000.1	Requirements for Packaging, Handling, and Transportation for Aeronautical and Space Systems, Equipment, and Associated Components
NPR 7150.2	NASA Software Engineering Requirements
NPR 8705.2	Human-Rating Requirements for Space Systems
NPR 8715.3	NASA General Safety Program Requirements
NSS 1740.12	Safety Standard for Explosives, Propellants, and Pyrotechnics

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

MSFC-SPEC-445A	Adhesive Bonding, Process and Inspection, Requirements for
MSFC-STD-156	Riveting, Fabrication and Inspection, Standard for
MSFC-STD-486	Standard, Threaded Fasteners, Torque Limits for,
MSFC-STD-3029	Guidelines for the Selection of Metallic Materials for Stress Corrosion Cracking Resistance in Sodium Chloride Environments

John F. Kennedy Space Center (KSC), NASA

79K80XXX Series	Fluid Component Specification Drawings
KNPR 8715.3	KSC Safety Practices Procedural Requirements
KSC-C-123	Surface Cleanliness of Fluid Systems, Specification for
KSC-DD-818-TR	Summary of Measurements of KSC Launch Induced Environmental Effects (STS-1 through STS-11)
KSC-DE-512-SM	Facility, System, and Equipment General Design Requirements
KSC-GP-425	Fluid Fitting Engineering Standards
KSC-GP-864	Volume IIA, Electrical Ground Support Equipment Cable Handbook

KSC-GP-1059	Environment and Test Specifications Levels, Ground Support Equipment for Space Shuttle System at Launch Complex 39
KSC-NE-9187	Sensors, Transducers and Signal Conditioning Systems Selection Guidelines
KSC-SPEC-P-0012	Refractory Concrete, Specification for
KSC-SPEC-Z-0007	Tubing, Steel, Corrosion Resistant, Types 304 and 316, Seamless, Annealed, Specification for
KSC-SPEC-Z-0008	Fabrication and Installation of Flared Tube Assemblies and Installation of Fittings and Fitting Assemblies, Specification for
KSC-STD-132	Potting and Molding Electrical Cable Assembly Terminations, Standard for
KSC-STD-141	Load Test Identification and Data Marking, Standard for
KSC-STD-164	Environmental Test Methods for Ground Support Equipment, Standard for
KSC-STD-E-0001	Design of Electrical Control and Monitoring Systems, Equipment (GSE) and Panels, Standard for
KSC-STD-E-0002	Hazard Proofing of Electrically Energized Equipment, Standard for
KSC-STD-E-0004	Pneumatic and Hydraulic Mechanical Components, Electrical Design, Standard for
KSC-STD-E-0011	Electrical Power Receptacles and Plugs, Standard for
KSC-STD-E-0012	Facility Grounding and Lightning Protection, Standard for
KSC-STD-P-0006	Quick Release Pins and Pin Tethers, Standard for
KSC-STD-SF-0004	Safety Standard for Ground Piping Systems Color Coding and Identification
KSC-STD-Z-0005	Design of Pneumatic Ground-Support Equipment, Standard for

KSC-STD-Z-0006	Hypergolic Propellants Ground Support Equipment, Design of, Standard for
KSC-STD-Z-0008	Design of Ground Life Support Systems and Equipment, Standard for
KSC-STD-Z-0009	Design of Cryogenic Ground Support Equipment, Standard for
KSC-STD-Z-0010	Design of Environmental Control Systems, Ground Coolant Systems, Coolant Servicing Systems, and Ground Support Equipment, Standard for
MMA-1985-79	Standard Test Method for Evaluating Triboelectric Charge Generation and Decay

Lyndon B. Johnson Space Center (JSC), NASA

SSP 50004	Ground Support Equipment Design Requirements: International Space Station
SW-E-0002	Ground Support Equipment General Design Requirements: Space Shuttle

2.3 Non-Government Documents

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

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

Aluminum Association (AA)

ADM-105-516166	Aluminum Design Manual

American Institute of Steel Construction (AISC)

AISC 325	Steel Construction Manual

American National Standards Institute (ANSI)

EOS/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)

SMACNA1958	HVAC Systems - Duct Design

American Society for Testing and Materials (ASTM)

ASTM A123	Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products
ASTM A153	Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware
ASTM A312	Standard Specification for Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes
ASTM A325	Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength
ASTM A380	Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems
ASTM A490	Standard Specification for Structural Bolts, Alloy Steel, Heat Treated, 150 ksi Minimum Tensile Strength
ASTM A653	Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process
ASTM A780	Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings
ASTM B241	Standard Specification for Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube
ASTM B676	Standard Specification for UNS N08367 Welded Tube
ASTM D7194	Standard Specification for Aerospace Parts Machined from Polychlorotrifluoroethylene (PCTFE)
ASTM E1417	Standard Practice for Liquid Penetrant Testing
ASTM E1444	Standard Practice for Magnetic Particle Testing
ASTM E1548	Standard Practice for Preparation of Aerospace Contamination Control Plans

ASTM E1742	Standard Practice for Radiographic Examination
ASTM E2375	Standard Practice for Ultrasonic Testing of Wrought Products

American Society of Civil Engineers (ASCE)

ASCE-7	Minimum Design Loads for Buildings and Other Structures

American Society of Mechanical Engineers (ASME)

ASME Y14.100	Engineering Drawing Practices
ASME B30.1	Jacks – Safety Standard for Cableways, Cranes, Derricks, Hoists, Hooks, Jacks, and Slings
ASME B31.3	Process Piping
ASME Boiler and Pressure Vessel Code, Section VIII, Divisions 1, 2, and 3	Rules for Construction of Pressure Vessels
ASME Boiler and Pressure Vessel Code, Section X	Fiber-Reinforced Plastic Pressure Vessels

American Welding Society (AWS)

AWS C3.2M/C3.2	Standard Method for Evaluating the Strength of Brazed Joints
AWS C3.4	Specification for Torch Brazing
AWS C3.5	Specification for Induction Brazing
AWS C3.6	Specification for Furnace Brazing
AWS C3.7M/C3.7	Specification for Aluminum Brazing

Compressed Gas Association (CGA)

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

Electronic Industries Association (EIA)

ECA EIA/ECA 310-E	Cabinets, Racks, Panels, and Associated Equipment

International Electrotechnical Commission

IEC 60807	Rectangular Connectors for Frequencies Below 3 MHz

International Organization for Standardization (ISO)

ISO 14644	Cleanrooms and Associated Controlled Environments, Parts 1 through 4

International Telecommunication Union (ITU)

ITU-T G.651	Characteristics of a 50/125 Micrometer Multimode Graded Index Optical Fibre Cable
ITU-T G.652	Characteristics of a Single-Mode Optical Fibre and Cable

IPC – Association Connecting Electronics Industries

IPC-2221	Generic Standard on Printed Board Design
IPC-2222	Sectional Design Standard for Rigid Organic Printed Boards
IPC-2223	Sectional Design Standard for Flexible Printed Boards
IPC-2252	Design Guide for RF/Microwave Circuit Boards
IPC-6011	Generic Performance Specification for Printed Boards, Performance Class 3
IPC-6012	Qualification and Performance Specification for Rigid Printed Boards, Performance Class 3/A (Space and Military Avionics)
IPC-6013	Qualification and Performance Specification for Flexible Printed Boards, Performance Class 3
IPC-6018	Microwave End Product Board Inspection and Test, Performance Class 3
IPC J-STD-001	Requirements for Soldered Electrical and Electronic Assemblies, Performance Class 3

IPC J-STD-001DS	Requirements for Soldered Electrical and Electronic Assemblies, Space Applications Hardware Addendum to J-STD-001D.
IPC-WHMA-A-620	Requirements and Acceptance for Cable and Wire Harness Assemblies, Performance Class 3

National Electrical Manufacturers Association (NEMA)

NEMA ICS 2 (R2005)	Industrial Control and Systems: Controllers, Contactors, and Overload Relays Rated 600 Volts
NEMA MG 1	Motors and Generators

National Fire Protection Association (NFPA)

NFPA 59A	Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)
NFPA 70	National Electrical Code
NFPA 70E	Standard for Electrical Safety in the Workplace
NFPA 496	Standard for Purged and Pressurized Enclosures for Electrical Equipment

Society of Automotive Engineers (SAE)

SAE AIR 4071	Lubricants for Oxygen Use
SAE AMS 2175	Castings, Classification and Inspection of
SAE AMS 2403L	Plating, Nickel General Purpose
SAE AMS 2404E	Plating, Electroless Nickel
SAE AMS 2423D	Plating, Nickel Hard Deposit
SAE AMS 2488	Anodic Treatment – Titanium and Titanium Alloys Solution pH 13 or Higher
SAE AMS 2647	Fluorescent Penetrant Inspection Aircraft and Engine Component Maintenance
SAE AMS 2759D	Heat Treatment of Steel Parts, General Requirements
SAE AMS 2759/9	Hydrogen Embrittlement Relief (Baking) of Steel Parts

SAE AMS 2770	Heat Treatment of Wrought Aluminum Alloy Parts
SAE AMS 2771	Heat Treatment of Aluminum Alloy Castings
SAE AMS 2772	Heat Treatment of Aluminum Alloy Raw Materials
SAE AMS 2774	Heat Treatment Wrought Nickel Alloy and Cobalt Alloy Parts
SAE AMS-H-6875A	Heat Treatment of Steel Raw Materials
SAE AMS-H-81200	Heat Treatment of Titanium and Titanium Alloys
SAE AMS-STD-2154	Inspection, Ultrasonic, Wrought Metals, Process for
SAE ARP 1247B	General Requirements for Aerospace Ground Support Equipment Motorized and Nonmotorized
SAE ARP 4402	Eddy Current Inspection of Open Fastener Holes in Aluminum Aircraft Structure
SAE AS 4787	Eddy Current Inspection of Circular Holes in Non-Ferrous Metallic Aircraft Engine Hardware
SAE AS 8090	Mobility, Towed Aerospace Ground Equipment, General Requirements for
SAE AS 22759	Wire, Electrical, Fluoropolymer-Insulated, Copper or Copper Alloy
SAE AS 50861	Wire, Electric, Polyvinyl Chloride Insulated, Copper or Copper Alloy

Telcordia

GR-20	Generic Requirements for Optical Fiber and Optical Fiber Cable
GR-409	Generic Requirements for Premises Fiber Optic Cable

2.4 Order of Precedence

This Standard establishes top-level requirements and guidance for design and fabrication of GSE to assist NASA space flight programs/projects in providing robust, safe, reliable, maintainable, supportable, and cost-effective GSE but does not supersede nor waive established Agency requirements found in other documentation.

2.4.1 Conflicts between this Standard and other requirements documents shall be resolved by the responsible Technical Authorities.

3. ACRONYMS AND DEFINITIONS

3.1 Acronyms and Abbreviations

°C	degrees Celsius
°F	degrees Fahrenheit
AA	Aluminum Association
ADM	Aluminum Design Manual
AFSPC	Air Force Space Command
AFSPCMAN	Air Force Space Command Manual
AIA	Aerospace Industries Association
AIAA	American Institute of Aeronautics and Astronautics
AISC	American Institute of Steel Construction
AMS	Aerospace Material Specification
ANSI	American National Standards Institute
ARP	Aerospace Recommended Practice
AS	Aerospace Standard
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
AWS	American Welding Society
C	cleanliness
CFR	Code of Federal Regulations
CGA	Compressed Gas Association
COPV	Composite Overwound Pressure Vessels
COTS	commercial off-the-shelf
DE	design
DTL	detail
E	electrical
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
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EOS	electrical overstress
EPS	Electrical Power System
ESD	electrostatic discharge

ETFE	ethylene tetrafluoroethylene
FED	Federal
FOD	foreign-object debris
GO_2	gaseous oxygen
GP	general publication (KSC)
GR	generic requirement
GSE	ground support equipment
GSS	ground support system
HDBK	handbook
(I)	interim
ICD	interface control document
IDD	interface definition document
i.e.	that is
IEEE	Institute of Electrical and Electronic Engineers
in	inch
ISO	International Standardization Organization for Standardization
ITU	International Telecommunication Union
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
LH_2	liquid hydrogen
LHe	liquid helium
LN_2	liquid nitrogen
LNG	liquefied natural gas
LO_2	liquid oxygen
LRU	line replaceable unit
M&P	materials and processes
	Materials and Processes organization
MAPTIS	Materials and Processes Technical Information System
MHz	megahertz
MIL	military
mm	millimeter
MMA	Malfunction/Materials Analysis
MMH	monomethylhydrazine
MMPDS	Metallic Materials Properties Development and Standardization
MNL	manual
MPa	megapascal
MSFC	George C. Marshall Space Flight Center
MUA	Material Usage Agreement
NAFPI	National Aerospace FOD Prevention Inc.
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
PC	printed circuit
PCA	printed circuit assembly
PCB	printed circuit board
PCTFE	polychlorotrifluoroethylene
PFA	plastic films, foams, and adhesive tapes
pH	potential of hydrogen
PHE	propellant handler's ensemble
PRF	performance specification
psia	pound per square inch absolute
PTFE	polytetrafluoroethylene
QD	quick disconnect
RF	radio frequency
RH	relative humidity
RP	reference publication
S&MA	Safety and Mission Assurance
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
UNS	Unified Numbering System
UTS	ultimate tensile strength
vs.	versus

3.2 Definitions

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.

Critical GSE: GSE whose failure could result in a critical or catastrophic hazard or event.

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.

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

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 Systems (GSS): Infrastructure and equipment (portable or fixed) that provide functional and/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, be identical to the design standards for GSE. Protective features designed into the GSE prevent failures from propagating to flight hardware.

Limited Life: Equipment or components that degrade due to operating time, cycling, or material aging and that have a life time shorter than the system's design life. Limited-life items require periodic replacement or refurbishment, which must be defined in design and maintenance documents.

Safe Working Load: An assigned weight that is the maximum 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."

Safety Factor: 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 safety factor 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 Standard specifies the minimum safety factor for GSE 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.

Tools: Equipment designed for general use in a variety of applications. Tools are calibrated, when necessary, in accordance with industrial 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.

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 GSE.

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

a. COTS equipment shall be evaluated for acceptability from a materials and processes (M&P) standpoint (see section 5.11).

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 document have been met.

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 GSE Designed to Meet Flight Hardware Requirements

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

In addition to operational requirements, GSE should be designed for ease of production, manufacture, construction, and inspection. GSE 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 GSE Degradation and Contamination

The GSE shall not degrade or contaminate associated flight or ground systems, subsystems, or experiments while it is being used, checked out, serviced, or otherwise handled.

4.2.1.3 GSE Design for Access

GSE design shall include provisions for access for handling, servicing, calibration, maintenance, and replacement of line-replaceable units (LRUs) and limited-life items.

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

4.2.1.4 Interfaces

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

Interfaces should be verified by test and/or analysis. GSE should be designed to reduce or eliminate the potential for a mating device (fluid, mechanical, or electrical) to be connected to the wrong interface with flight hardware.

4.2.1.4.1 GSE Facility Interface

GSE shall be compatible with all facility interfaces.

An assessment may be required to determine if it is more cost-effective to modify the facility interface or design the GSE to meet the existing facility interface.

4.2.2 Physical Characteristics

4.2.2.1 Design Life Duration

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

b. During this period, normal preventive maintenance, repair, or calibration shall be accomplished to maintain specified performance.

The design engineering organization should specify policies for initial maintenance, maintenance cycles, and fair wear-and-tear.

Integrated processors or smart electrical GSE typically have a shorter design life due to technology advancements and obsolescence. The design life of mechanical GSE is typically based on the program's direction for the life cycle.

4.2.2.1.1 Existing or Legacy GSE Design Life

Existing or legacy GSE that has remaining useful life and was previously certified to the requirements of documents such as SW-E-0002, Ground Support Equipment General Design Requirements: Space Shuttle; KSC-DE-512-SM, Facility, System, and Equipment General Design Requirements; SSP 50004, Ground Support Equipment Design Requirements: International Space Station; or a previous version of this Standard, NASA-STD-5005, Standard for the Design and Fabrication of Ground Support Equipment, shall comply with S&MA requirements, including but not limited to reliability and failure tolerance requirements, applicable to the program or project using the GSE.

4.2.2.2 Limited-Life Items

Items with limited life shall be identified on design drawings and annotated with the specified period for replacement/refurbishment.

Use of items with a projected lifetime that is less than the design life of the GSE 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 non-operating mode should also be tracked.

4.2.2.3 Colors

a. The following colors shall be used for the type of GSE indicated:

Color	Color Chip Number	GSE Type
Gray	26440 or 26251	Electrical/electronic, hydro/pneumatic consoles, racks, and cabinets
Gray	16187 or 16473	Structural steel/aluminum
Red	11105 or 21105	Remove-before-flight items, safety equipment, and protective equipment
White	17875 or 27875	White room or clean room equipment
Black	37038	Panel lettering
Yellow or White	13538, 17875, or 27875	Handling and transportation equipment
Yellow w/Brown Band	13655 (yellow), 10080 (brown)	Equipment for hypergolic fuel servicing
Green w/Brown Band	14110 (green), 10080 (brown)	Equipment for hypergolic oxidizer servicing
Blue	25102	Control racks and consoles

b. Colors shall be in accordance with FED-STD-595, Colors Used in Government Procurement.

4.2.3 Reliability

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 (i.e., contamination, etc.) do not invalidate the assumption of failure independence.

4.2.3.2 Failure Tolerance

a. GSE shall be designed such that no single failure/inadvertent operator action results in ground/flight equipment or facility loss/damage or personal injury/occupational illness; and

b. GSE shall be designed such that no single failure/inadvertent operator action results in ground/flight equipment or facility loss/damage or loss of life provided that failure modes/inadvertent operator actions are controlled using a systematic application of approved standards and design margins; and

c. GSE shall be designed such that no combination of two failures and/or inadvertent operator actions results in ground/flight equipment or facility loss/damage or loss of life if the failure modes/inadvertent operator actions are not controlled using a systematic application of approved standards and design margins.

To comply with this requirement, GSE 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" by the GSE design community.

d. The failure of primary structure, pressure vessel wall structure, and pressurized fluid lines shall be excepted from the failure tolerance requirements of 4.2.3.2.a, b., and c., provided that any failure that could lead to loss of life is controlled through a systematic application of approved standards and design margins that overcome the absence of failure tolerance.

e. GSE failure modes/inadvertent operator actions with the potential for loss of flight crew shall be addressed in accordance with NPR 8705.2, Human-Rating Requirements for Space Systems.

4.2.3.3 Failure Propagation

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

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

4.2.4 Environmental Conditions

GSE shall be designed to withstand the natural and induced environments to which it will be subjected during its life cycle.

4.2.4.1 Natural Environment

GSE 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, Terrestrial Environment (Climatic) Criteria Handbook for Use in Aerospace Vehicle Development.

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.

4.2.4.2 Launch-Induced Environment

GSE required to function during or after exposure to the launch-induced environment shall be designed to withstand the environment defined in the following documents in this order of precedence: program-specific documents with requirements for the launch-induced environment; KSC-DD-818-TR, Summary of Measurements of KSC Launch Induced Environmental Effects (STS-1 through STS-11); or KSC-GP-1059, Environment and Test Specifications Levels, Ground Support Equipment for Space Shuttle System at Launch Complex 39.

These requirements should be applied in accordance with KSC-STD-164, Environmental Test Methods for Ground Support Equipment, Standard for.

4.2.4.2.1 Launch-Induced Damage

GSE not designed to function after exposure to the launch-induced environment shall not cause damage to the flight hardware, facilities, or other GSE or degrade to a condition that poses a hazard to personnel or the environment.

4.2.4.3 Controlled Interior Environment

GSE 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) or, if within an uncontrolled environment, within the extremes of +11 °C (52 °F) to +40 °C (105 °F) for a maximum of 1 hour.

b. Humidity: nominal 55 percent, within a range of 30 percent to 70 percent at 21 (±5) °C (70 (±10) °F).

4.2.4.4 Controlled Clean Environment

a. GSE shall be designed to meet the program’s/project’s contamination control requirements.

b. Clean rooms and associated controlled environments designated as GSE shall be designed in accordance with ISO 14644, Cleanrooms and Associated Controlled Environments, Parts 1 through 4.

4.2.4.5 Uncontrolled Interior Environment

GSE used in an uncontrolled interior environment shall be designed to meet the most severe exterior environmental conditions for humidity and temperature anticipated at the respective geographical locations, as defined in NASA-HDBK-1001.

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

4.2.4.6 Fire/Explosion Hazard Proofing

If GSE will be operated in locations where fire or explosion hazards exist, as defined by NFPA 70, National Electrical Code, Article 500, it shall be hazard proofed in accordance with the requirements in KSC-STD-E-0002, Hazard Proofing of Electrically Energized Equipment, Standard for.

4.2.4.7 Environmental Test Methods

Environmental methods and conditions required for testing and qualification of GSE components shall be in accordance with MIL-STD-810, Environmental Engineering Considerations and Laboratory Tests, and KSC-STD-164.

4.2.4.8 Seismic Environment

GSE 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, Minimum Design Loads for Buildings and Other Structures, Chapter 15, Seismic Design Requirements for Non-Building Structures.

4.3 Documentation

4.3.1 Drawings and Specifications

Drawings and specifications required for the fabrication, construction, installation, modification, test, operation, maintenance, sustaining, and use of GSE shall be prepared in accordance with drawing practices equal to or more stringent than the engineering drawing practices of ASME Y14.100, Engineering Drawing Practices.

4.3.2 Technical Documentation

Technical documentation (e.g., manuals and reports) shall be prepared and delivered to the user of the GSE.

Documentation should include applicable deliverables contained in Appendix B.

4.4 Logistics

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

4.4.1 Limited-Life Item Tracking

a. Identified 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 maintained.

c. GSE design documentation shall provide for the repair and maintenance of parts, components, and materials.

4.4.2 Safety and Warning Indications

The GSE design shall provide safety and warning indications to alert personnel of impending or existing hazards.

GSE should be designed to allow efficient implementation of the applicable Occupational Safety and Health Administration- (OSHA-) mandated lockout/tagout requirements.

4.5 Qualification

All components used in GSE shall undergo qualification testing to verify performance in their intended environment.

4.6 Quality Assurance

4.6.1 General

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

4.6.1.1 Quality Requirements Definition

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 also include special quality-related requirements, such as any special processes or special testing that should be conducted, and any other special requirements that are necessary to produce a quality product.

4.6.2 Testing

a. Testing shall be specified by engineering documentation.

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

4.6.2.1 Load Test

a. A load test shall be performed on all structural GSE (access platforms, workstands, etc.).

b. The minimum test load shall be 125 percent of the design or working load for devices that are not used for lifting.

c. Lifting devices and equipment shall be load-tested in accordance with NASA-STD-8719.9, Standard for Lifting Devices and Equipment.

4.6.2.2 Nondestructive Evaluation (NDE)

a. NDE for all components except fracture-critical metallic GSE components shall be performed in accordance with MIL-HDBK-6870, Inspection Program Requirements, Nondestructive for Aircraft and Missile Materials and Parts.

b. NDE for all fracture-critical metallic GSE components shall be performed in accordance with NASA-STD-5009, Nondestructive Evaluation Requirements for Planning for Fracture-Critical Metallic Components.

4.6.2.3 Instrumentation Calibration

Calibration records for measuring instruments shall be established and maintained in accordance with NPD 8730.1, Metrology and Calibration.

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 (reference Appendix B).

Examinations and tests are recommended to verify that all requirements of sections 4 and 5 of this Standard have been achieved. This quality conformance verification program may include:

a. Tests and analyses of the performance and reliability requirements.
b. Measurement or comparison of specified physical characteristics.
c. Verification, with specific criteria, of workmanship.
d. Test and inspection methods for ensuring compliance, including environmental; and
e. Conditions for performance.

4.7 Packaging, Handling, and Transportation

Requirements for packaging, transporting, shipping, and handling shall be in accordance with NPR 6000.1, Requirements for Packaging, Handling, and Transportation for Aeronautical and Space Systems, Equipment, and Associated Components.

GSE should be designed so that it can be transported by ground, air, or sea using standard, readily available vehicles.

4.7.1 Shipping and Storage Containers

a. Containers shall comply 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 processes 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 GSE Structures and Equipment

5.1.1.1 Steel Structures

The design of steel structures shall be in accordance with the AISC 325, Steel Construction Manual, Allowable Stress Design Method.

5.1.1.2 Aluminum Structures

The design of aluminum structures shall be in accordance with ADM-105-516166, Aluminum Design Manual.

5.1.2 Safety Factor

a. The safety factor shall **not** be used to justify exceeding the safe working load.

b. The following minimum safety factors shall be used for support structures (excluding lifting devices, pressure vessels, threaded fasteners, and springs) when **not** otherwise specified.

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

(2) For brittle materials and fiber-reinforced polymers, the factor of safety shall be 5 against exceeding the ultimate tensile strength (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.

5.1.2.1 Safety Factor for Cyclic Loading

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

5.1.3 Structural Design Loads

Structural design loads shall be specified in the design documentation.

The design should consider typical load cases such as the loads created by the assembly, transportation, and operations processes; wind conditions; the structure's lateral stability; and seismic events. For torque loads on threaded fasteners, see paragraph 5.2.9.

5.2 Mechanical Design

5.2.1 Pneumatics

The design of GSE used for pneumatic servicing shall be in accordance with KSC-STD-Z-0005, Design of Pneumatic Ground-Support Equipment, Standard for.

5.2.1.1 Breathing Air Systems

Breathing air systems shall conform to 29 CFR 1910, Occupational Safety and Health Standards.

5.2.2 Cryogenics

a. The design of GSE used for cryogenic servicing with liquid hydrogen (LH_2), liquid oxygen (LO_2), and liquid nitrogen (LN_2) shall be in accordance with KSC-STD-Z-0009, Design of Cryogenic Ground Support Equipment, Standard for.

b. The design of GSE used for cryogenic servicing with liquid methane shall be in accordance with NFPA 59A, Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG), Standard for.

The design of GSE used for cryogenic servicing with liquid helium (LHe) and cold fluids should use KSC-STD-Z-0009 as a guide. The design of reusable umbilicals should be in accordance with KSC-GP-986-40, KSC Design Criteria for Reusable Space Vehicle Umbilical Systems, or ISO 15389, Space systems—Flight-to-ground umbilicals.

5.2.3 Hypergols

The design of GSE used for hypergolic fuel or oxidizer servicing with monomethylhydrazine (MMH), nitrogen tetroxide, and hydrazine shall be in accordance with KSC-STD-Z-0006, Hypergolic Propellants Ground Support Equipment, Design of, Standard for.

5.2.4 Hydrocarbons

The design of GSE 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, Process Piping.

5.2.5 Hydraulics

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

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

a. The design of GSE used for an ECS or ECLSS shall be in accordance with KSC-STD-Z-0010, Design of Environmental Control Systems, Ground Coolant Systems, Coolant Servicing Systems, and Ground Support Equipment, Standard for.

b. The design of ducting shall be in accordance with ASME B31.3 or SMACNA 1958, HVAC Systems - Duct Design.

5.2.7 Life Support

The design of GSE used for life support systems shall be in accordance with KSC-STD-Z-0008, Design of Ground Life Support Systems and Equipment, Standard for.

GSE 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. GSE 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 causing discomfort to and fatiguing the PHE-suited personnel.

e. Use of expanded metal surfaces should be prohibited.

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 Torque for Threaded Fasteners

a. The combined stress from all applied loads (plus an uncertainty factor), including the preload, shear, tension, and bending stress, shall not exceed the yield strength of the fastener material.

b. The torque limit for threaded fasteners that are less than or equal to 32 millimeters (mm) (1-1/4 inches (in)) in diameter shall be in accordance with MSFC-STD-486, Standard, Threaded Fasteners, Torque Limits for, or the alternative limit identified on the drawing.

c. Threaded fasteners greater than 32 mm (1-1/4 in) in diameter shall be designed for a maximum torque that results in a preload of 70 percent of the yield stress on the net cross section.

d. The torquing criteria for structural bolts, such as specified in ASTM A325, Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength, and ASTM A490, Standard Specification for Structural Bolts, Alloy Steel, Heat Treated, 150 ksi Minimum Tensile Strength, shall be in accordance with AISC 325.

e. Torquing criteria shall be documented on the fabrication, assembly, or installation drawing.

5.2.10 Tethering Provisions

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

b. GSE intended for use near flight hardware or elevated above personnel and/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, Quick Release Pins and Pin Tethers, Standard for.

5.2.11 Jacks

The design of jacks shall be in accordance with ASME B30.1, Jacks—Safety Standard for Cableways, Cranes, Derricks, Hoists, Hooks, Jacks, and Slings.

5.2.12 Transportation Equipment

GSE used for transporting flight hardware shall be designed in accordance with SAE ARP 1247B, General Requirements for Aerospace Ground Support Equipment Motorized and Nonmotorized.

5.2.12.1 Towed GSE

Towed GSE shall be designed in accordance with SAE AS 8090, Mobility, Towed Aerospace Ground Equipment, General Requirements for.

5.2.12.2 Transportation Equipment Interface Loads

Transportation equipment shall be designed so that loads imparted to flight hardware do not exceed 80 percent 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 Vessels

a. Metallic pressure vessels for use in GSE shall be designed, constructed, tested, and stamped in accordance with ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, 2, or 3, Rules for Construction of Pressure Vessels.

b. Composite Overwound Pressure Vessels (COPVs) for use in GSE shall be designed, constructed, tested, and marked in accordance with ASME Boiler and Pressure Vessel Code, Section X, Fiber-Reinforced Plastic Pressure Vessels.

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, Hazardous Materials Regulations.

5.3 Electrical/Electronic Design

5.3.1 Electrical Control and Monitor Equipment

a. The design of GSE for electrical control and monitoring shall be in accordance with KSC-STD-E-0001, Design of Electrical Control and Monitoring Systems, Equipment (GSE) and Panels, Standard for.

b. If hardware will be used on Air Force Space Command (AFSPC) ranges, it shall comply with AFSPCMAN 91-710, Range Safety User Requirements Manual Volume 3 - Launch Vehicles, Payloads, and Ground Support Systems Requirements.

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, Pneumatic and Hydraulic Mechanical Components, Electrical Design, Standard for.

5.3.3 Pyrotechnic Systems

The design of pyrotechnic GSE shall be in accordance with NSS 1740.12, Safety Standard for Explosives, Propellants, and Pyrotechnics.

Pyrotechnic GSE should also be designed in accordance with JSC 62809, Constellation Spacecraft Pyrotechnic Specification.

5.3.4 Electrical Power Systems

The design of Electrical Power System (EPS) GSE covered by NFPA 70 shall be in accordance with NFPA 70 and NFPA 70E, Standard for Electrical Safety in the Workplace.

Incorporation of batteries in the design of GSE should follow the recommended practices in the following documents:

a. IEEE 484, IEEE Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications.

b. IEEE 1106, IEEE Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications.

c. IEEE 1187, IEEE Recommended Practice for Installation Design and Installation of Valve-Regulated Lead-Acid Storage Batteries for Stationary Applications.

d. IEEE 446, IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications.

5.3.5 Bonding and Grounding

a. Bonding and grounding shall be provided in accordance with NFPA 70 and NASA-STD-4003, Electrical Bonding for NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment.

b. GSE intended for use at KSC shall be designed in accordance with KSC-STD-E-0012, Facility Grounding and Lightning Protection, Standard for.

The designer should be aware whether the system being designed will be operated under a lightning protection system and/or in an environment where induced static electricity is possible.

5.3.6 Hazard Proofing

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 in the design of GSE shall meet the requirements of NPR 7150.2, NASA Software Engineering Requirements, and NASA-STD-8739.8, Software Assurance Standard.

5.3.8 Firmware

Firmware incorporated in the design of GSE 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 NPD 8730.2, NASA Parts Policy.

EEE parts may be selected using AIAA R-100, Recommended Practice for Parts Management, or NASA/TP-2003-212242, EEE-INST-002, Instructions for EEE Parts Selection, Screening, Qualification, and Derating.

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:

a. EOS/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).

b. MIL-STD-1686, Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices).

c. MIL-HDBK-263, Electrostatic Discharge Control Handbook for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices) (Metric).

Insulator materials should never be used near ESD-sensitive components and assemblies.

5.4.2 Metallic Tubing

a. Stainless steel tubing shall be selected in accordance with KSC-SPEC-Z-0007, Tubing, Steel, Corrosion Resistant, Types 304 and 316, Seamless, Annealed, Specification for.

b. Stainless steel tubing shall be fabricated and installed in accordance with KSC-SPEC-Z-0008, Fabrication and Installation of Flared Tube Assemblies and Installation of Fittings and Fitting Assemblies, Specification for.

5.4.2.1 Superaustenitic Stainless Steel Tubing

a. When directly exposed to a marine or launch-induced environment, tubing shall consist of superaustenitic stainless steel (trade name AL6XN), such as UNS N08367 or S31245.

b. Superaustenitic stainless steel tubing shall be in accordance with ASTM B676, Standard Specification for UNS N08367 Welded Tube.

c. Superaustenitic stainless steel tubing shall be installed according to KSC-SPEC-Z-0008.

5.4.3 Pipe

Stainless steel pipe for fluid systems shall be in accordance with ASTM A312, Standard Specification for Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes, Types UNS S30400, S30403, S31600, or S31603 (304, 304L, 316, or 316L).

5.4.3.1 Aluminum Pipe

Aluminum pipe shall be in accordance with ASTM B241, Standard Specification for Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube.

5.4.3.2 Convoluted Expansion Joints

When expansion joints are used in fluid systems in highly corrosive environments, the convoluted bellows shall be made from UNS N06022 (Hastelloy C22) material.

5.4.4 Metallic Fittings

Flared tubing fittings and tube weld fittings shall be selected in accordance with KSC-GP-425, Fluid Fitting Engineering Standards.

5.4.5 Fluid System Protective Covers

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

Caution should be used in selecting caps and plugs as covers due to the potential for generating debris during installation and 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 79K80XXX series of specifications, Fluid Component Specification Drawings, 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 79K80XXX series of specifications, it shall be documented with the following minimum information included: 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

Electrical power receptacles and plugs for GSE shall be in accordance with KSC-STD-E-0011, Electrical Power Receptacles and Plugs, Standard for.

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, Volume IIA, Electrical Ground Support Equipment Cable Handbook.

5.4.10 Fiber Optics

5.4.10.1 Fiber-Optic Protective Caps

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

5.4.10.2 Fiber-Optic Cable Assemblies

Fiber-optic cable assemblies, installations, and terminations shall be in accordance with NASA-STD-8739.5, Fiber Optic Terminations, Cable Assemblies, and Installation.

5.4.10.3 Underground Fiber-Optic Cable

Fiber-optic cable for underground cable ducts or direct bury applications shall be in accordance with Telcordia GR-20, Generic Requirements for Optical Fiber and Optical Fiber Cable.

5.4.10.4 Intra-Building Fiber-Optic Cable

Fiber-optic cable for intra-building premise applications shall be in accordance with Telcordia GR-409, Generic Requirements for Premises Fiber Optic Cable.

5.4.10.5 Single-Mode Fiber-Optic Cable

Single-mode fiber-optic applications shall be in accordance with ITU-T G.652, Characteristics of a Single-Mode Optical Fibre and Cable.

5.4.10.6 Multimode Fiber-Optic Cable

Multimode fiber-optic applications shall be in accordance with ITU-T G.651, Characteristics of a 50/125 Micrometer Multimode Graded Index Optical Fibre Cable.

5.4.11 Electrical Hookup Wire

Electrical hookup wire shall be in accordance with SAE AS 50861, Wire, Electric, Polyvinyl Chloride Insulated, Copper or Copper Alloy; MIL-DTL-16878, Wire, Electrical, Insulated, General Specification for; or SAE AS 22759, Wire, Electrical, Fluoropolymer-Insulated, Copper or Copper Alloy.

5.4.12 Connectors

a. Electrical multiconductor connectors for GSE used for electrical control and monitoring shall be selected from the following:

(1) MIL-DTL-5015, Connectors, Electrical, Circular Threaded, AN Type, General Specification for.

(2) MIL-DTL-22992, Connectors, Plugs and Receptacles, Electrical, Waterproof, Quick Disconnect, Heavy Duty Type, General Specification for.

(3) MIL-DTL-24308, Connectors, Electric, Rectangular, Nonenvironmental, Miniature, Polarized Shell, Rack and Panel, General Specification for.

(4) 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.

(5) IEC 60807, Rectangular Connectors for Frequencies Below 3 MHz.

(6) KSC-GP-864, Volume IIA.

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, Connectors, Coaxial, Radio Frequency, General Specification for.

5.4.14 Electrical Connector Protective Covers or Caps

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

Protective covers or caps should meet the following requirements:

a. Protect against moisture intrusion.

b. Protect sealing surfaces, threads, and pins against damage.

c. Resist abrasion, chipping, or flaking.

d. *Comply with cleanliness requirements for the plugs and receptacles on which they are used.*

e. *Consist of material that is compatible with the connector materials.*

f. *Connect to the cable with a suitable lanyard, chain, or hinge.*

g. *Not produce static.*

5.4.15 Optical Covers or Caps

a. Where applicable, optical covers/caps shall be provided to protect optics such as collimators and other external stimuli.

b. Optical covers/caps shall be installed to provide protection as follows:

(1) Protect the internal optics of the GSE from damage and contamination during the handling of the GSE, as well as during the handling and installation of supporting equipment.

(2) Protect the internal optics of the GSE from damage and contamination during shipment.

(3) Protect the flight optical system from contamination and damage during installation and handling of the GSE.

Optical covers/caps should be easily removable for use, as well as easily installable during handling and shipment. When possible, 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 GSE systems shall be selected using KSC-NE-9187, Sensors, Transducers and Signal Conditioning Systems Selection Guidelines.

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:

a. Commodity.
b. Environment.
c. Performance.
d. Recommended vendor.
e. Materials.
f. Compatibility.
g. Qualification/acceptance criteria.

5.4.17 Purged Electrical Enclosures

Purged electrical enclosures shall be in accordance with NFPA 496, Standard for Purged and Pressurized Enclosures for Electrical Equipment.

5.4.18 Racks, Panels, and Modular Enclosures

Electronic racks, panels, and modular enclosures shall conform to the configuration and dimensional requirements of EIA 310-E, Cabinets, Racks, Panels, and Associated Equipment.

5.4.19 Printed Circuit (PC) Boards (PCBs)

5.4.19.1 PCB Design

Rigid, flexible, and rigid-flex PCBs (single, double, metal-core, or multilayer structures) shall meet the design specifications of the following standards, as applicable:

a. IPC-2221, Generic Standard on Printed Board Design

b. IPC-2222, Sectional Design Standard for Rigid Organic Printed Boards

c. IPC-2223, Sectional Design Standard for Flexible Printed Boards

d. IPC-2252, Design Guide for RF/Microwave Circuit Boards

All board types within the IPC-2221 series standard documents are acceptable provided that performance classification 3 is specified.

5.4.19.2 PCB Fabrication and Acceptance

Rigid, flexible, and rigid-flex PCBs (single, double, metal-core, or multilayer structures) shall meet the qualification and performance specifications of the following standards, as applicable:

a. IPC-6011, Generic Performance Specification for Printed Boards, Performance Class 3.

b. IPC-6012, Qualification and Performance Specification for Rigid Printed Boards, Performance Class 3/A (Space and Military Avionics).

c. IPC-6013, Qualification and Performance Specification for Flexible Printed Boards, Performance Class 3.

d. IPC-6018, Microwave End Product Board Inspection and Test, Performance Class 3.

5.4.19.3 Printed Circuit Assembly (PCA) Fabrication and Acceptance

a. PCAs that will not be exposed to vibration or thermal cycling environments at space flight levels shall be fabricated in accordance with IPC J-STD-001, Requirements for Soldered Electrical and Electronic Assemblies, Performance Class 3.

NASA-STD-8739.2, Workmanship Standard for Surface Mount Technology, and NASA-STD-8739.3, Soldered Electrical Connections, may be used in lieu of the IPC J-STD-001 standard.

b. PCAs that will be exposed to vibration or thermal cycling environments at space flight levels shall be fabricated in accordance with IPC J-STD-001DS, Requirements for Soldered Electrical and Electronic Assemblies, Space Applications Hardware Addendum to J-STD-001D.

NASA-STD-8739.2 and NASA-STD-8739.3 may be used in lieu of the IPC J-STD-001DS standard.

5.4.20 Electric Motors

Motors used in GSE shall be in accordance with NEMA MG 1, Motors and Generators.

5.4.20.1 Motor Starters and Controllers

Starters and controllers shall be in accordance with the NEMA standards for industrial control as specified in NEMA ICS 2 (R2005), Industrial Control and Systems: Controllers, Contactors, and Overload Relays, Rated 600 Volts; Part 8: Disconnect Devices for Use in Industrial Control Equipment; and NFPA 70.

5.4.21 Critical GSE Fasteners

Critical GSE fasteners shall have lot traceability from the manufacturer to the buyer.

NASA RP-1228, Fastener Design Manual, should be used for guidance in selecting and performing analysis of 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 breakaway torque.

Self-locking fasteners should be used wherever possible. The use of star lock washers should be avoided.

b. Wet installation of fasteners (using a corrosion-resistant sealant and installing the fastener while the sealant is still wet) shall be required in aqueous corrosive environments and applications where condensation can occur.

5.4.21.2 Liquid-Locking Compounds

Engineering drawings for liquid-locking compounds shall specify a validated application process.

Liquid-locking compounds should be selected in accordance with ASTM D5363, Standard Specification for Anaerobic Single-Component Adhesives (AN).

5.5 Electromagnetic Interference (EMI)

Electrical and electronic systems shall be designed to meet the EMI/electromagnetic compatibility (EMC) requirements in MIL-STD-461, Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment.

The requirements of MIL-STD-461 may be tailored for use on NASA programs as indicated in MIL-STD-461, paragraphs 1.2, 1.2.1, and 1.2.3. The application of MIL-STD-461 to GSE 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. GSE shall be identified and marked in accordance with MIL-STD-130, Identification Marking of U.S. Military Property.

b. When data matrix identification symbols are used to identify GSE, they shall be applied in accordance with NASA-STD-6002, Applying Data Matrix Identification Symbols on Aerospace Parts.

5.6.2 Load Test

GSE that has been load-tested shall be identified and marked in accordance with KSC-STD-141, Load Test Identification and Data Marking, Standard for, and 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, Safety Standard for Ground Piping Systems Color Coding and Identification.

5.6.4 Compressed Gas Cylinders

Compressed gas cylinders shall be labeled in accordance with CGA C-7, Guide to the Preparation of Precautionary Labeling and Marking of Compressed Gas Containers.

5.6.5 Load Capacity

GSE used for hoisting, transportation, handling, and personnel access shall be conspicuously marked, in accordance with NASA-STD-8719.9, to indicate the maximum safe working load.

5.6.6 Electrical Cable and Harness Assemblies

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 NASA-STD-8739.4, Crimping, Interconnecting Cables, Harnesses, and Wiring.

5.6.7 Serial Numbers

Serial numbers shall be required on those end items, items, components, or assemblies that contain limited-life parts (e.g., valves or regulators) or that require periodic inspection, checkout, repair, maintenance, servicing, or calibration (e.g., pressure transducers, gages, switches, or torque wrenches).

5.7 Interchangeability

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

5.8 Safety

All GSE shall be designed to meet the requirements in 29 CFR 1910, NPR 8715.3, NASA General Safety Program Requirements, and those listed in sections 5.8.1 through 5.8.4 below.

5.8.1 Hazard Analysis

A hazard analysis shall be conducted as part of the GSE design process to identify, mitigate, and control hazards.

5.8.2 Safety Requirements on KSC Property

GSE to be used at KSC shall meet the safety requirements of KNPR 8715.3, KSC Safety Practices Procedural Requirements.

5.8.3 Safety Requirements on Air Force Property

GSE 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

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

5.9 Human Factors

a. HF-STD-001, Human Factors Design Standard, shall be used to establish human factors criteria for GSE design.

b. GSE shall comply with 29 CFR 1910.

5.10 Security

Security requirements for GSE shall be in accordance with NPR 1600.1, NASA Security Program Procedural Requirements.

5.11 M&P Requirements

M&P used in the design and fabrication of facilities and GSE 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 include: operational temperature limits, loads, contamination, life expectancy, exposure to moisture or other fluids, and vehicle-related induced and natural environments. Properties that should be considered in material selection include: mechanical properties, fracture toughness, flammability and offgassing characteristics, corrosion, stress corrosion, thermal and mechanical fatigue properties, glass-transition temperature, coefficient of thermal expansion mismatch, vacuum outgassing, fluids compatibility, microbial resistance, moisture resistance, fretting, galling, and susceptibility to ESD and contamination.

5.11.1 Material Properties Design Data

a. Metallic Materials Properties Development and Standardization (MMPDS) (for metals); MIL-HDBK-17-2, Composite Materials Handbook, Volume 2. Polymer Matrix Composites Materials Properties; MIL-HDBK-17-4, Composite Materials Handbook, Volume 4. Metal Matrix Composites; MIL-HDBK-17-5, Composite Materials Handbook, Volume 5. Ceramic Matrix Composites; or voluntary consensus standard code or standard (e.g., the ASME

Boiler and Pressure Vessel Code for pressure vessels and AISC 325 for structural steel) shall be used to establish materials properties for use in system or component design.

b. The use of PCTFE shall comply with ASTM D7194, Standard Specification for Aerospace Parts Machined from Polychlorotrifluoroethylene (PCTFE).

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.

c. When mechanical properties of new or existing structural materials are not available, they shall be determined by the analytical methods described in:

(1) MIL-HDBK-17-1, Composite Materials Handbook, Volume 1. Polymer Matrix Composites Guidelines for Characterization of Structural Materials, and MIL-HDBK-17-3, Composite Materials Handbook, Volume 3. Polymer Matrix Composites Materials Usage, Design, and Analysis (for polymers).

(2) MIL-HDBK-17-4 for metal matrix composites.

(3) MIL-HDBK-17-5 for ceramic matrix composites.

(4) MIL-HDBK-149, Rubber (for elastomers).

(5) MIL-HDBK-700, Plastics (for plastics).

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.

5.11.2 M&P Controls

M&P controls shall be as follows:

a. All M&P shall be defined by standards and specifications and be identified directly on the appropriate engineering drawing.

(1) Engineering drawings shall be reviewed for compliance with all applicable M&P requirements.

(2) An M&P assessment shall be done concurrently with the design.

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

c. All parts or materials shall be certified as to composition, properties, and requirements as identified 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.

e. New material codes shall be assigned by NASA MSFC.

f. For critical GSE, Material Usage Agreements (MUAs) shall be submitted for all M&P that are technically acceptable but do not meet the M&P requirements of this Standard.

An example of a typical MUA form is given in Appendix A.

g. For noncritical GSE, MUAs shall be submitted for M&P that are technically acceptable but do not meet the requirements of this Standard in regard to flammability, compatibility, and stress corrosion cracking (SCC).

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

5.11.3 Detailed Requirements

5.11.3.1 Flammability and Compatibility Requirements

Materials shall be tested in accordance with the latest version of NASA-STD-6001, including the (I) version, Flammability, Offgassing, and Compatibility Requirements and Test Procedures, as described in the following paragraphs.

5.11.3.1.1 Flammability Control

a. Materials that are nonflammable or self-extinguishing in their use configuration as defined by the latest version of NASA-STD-6001, including the (I) version, Test 1 or Test 10, shall be used for flammability control.

Material flammability ratings and tests based on the latest version of NASA-STD-6001, including the (I) version, may be found in the MAPTIS database for many materials.

b. The following materials or methods are also acceptable:

(1) It shall be acceptable to use ceramics, metal oxides, and inorganic glasses without prior testing.

When a material is sufficiently chemically and physically similar to a material found to be acceptable by testing in accordance with the latest version of NASA-STD-6001, including the (I) version, this material may be used without additional testing if its use is justified on an approved MUA.

(2) Materials whose flammability and self-extinguishing properties have been tested, in accordance with the latest version of NASA-STD-6001, including the (I) version, 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 testing (provided that the oxygen partial pressure is not substantially 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 tested or considered flammable by default.

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 by default.

Materials that are considered flammable by default may still be accepted through the MUA approval process.

Many situations arise in which flammable materials are used in an acceptable manner without testing, using mitigation practices and the MUA approval system. Guidelines for assessment and mitigation of hardware flammability characteristics can be found in JSC 29353, Flammability Configuration Analysis for Spacecraft Applications.

5.11.3.1.2 Electrical Wire Insulation Materials

a. Electrical wire insulation materials shall be evaluated for flammability in accordance with the latest version of NASA-STD-6001, including the (I) version, Test 4.

b. Arc tracking shall be evaluated in accordance with the latest version of NASA-STD-6001, including the (I) version, Test 18.

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

5.11.3.1.3 Fluid Compatibility

5.11.3.1.3.1 Fluids Other than Oxygen

a. Materials exposed to hazardous fluids[1] other than oxygen shall be evaluated or tested for compatibility.

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[1] For the purpose 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.

The latest version of NASA-STD-6001, including the (I) version, Test 15, is a screening test for short-term exposure to fuels and oxidizers. For many materials, material compatibility ratings and test results based on the latest version of NASA-STD-6001, including the (I) version, Test 15, are available in the MAPTIS database. KTI-5211, Material Selection List for Reactive Fluid Service, may be referenced for a summary of reactive fluid compatibility test results for various materials.

b. Appropriate compatibility tests shall be conducted for materials that are subjected to long-term exposure to fuels, oxidizers, and other hazardous fluids.

c. The test conditions shall simulate the worst-case use environment that would enhance reactions or degradation of the material or fluid.

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

5.11.3.1.3.2 Oxygen

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

Material flammability ratings and test results based on the latest version of NASA-STD-6001, including the (I) version, are found in the MAPTIS database for many materials. KTI-5210, Material Selection List for All Oxygen and Air Services, may be referenced for a summary of results of a mechanical impact test (see the latest version of NASA-STD-6001, including the (I) version, Test 13) for various materials used in LO_2 and GO_2 applications.

b. When a material in an oxygen system is determined to be flammable by Test 17, an oxygen compatibility assessment shall be conducted in accordance with the latest version of NASA-STD-6001, including the (I) version, and the system safety rationale documented in an MUA.

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 mechanism in question using an accepted test method.

e. The configurational test method and acceptance criteria shall be reviewed and approved as part of the MUA process described in paragraph 5.11.2.

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 pressurized systems containing enriched oxygen, the need for an oxygen compatibility assessment shall be addressed on a case-by-case basis.

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

Guidelines on the design of safe oxygen systems are contained in ASTM MNL 36, Safe Use of Oxygen and Oxygen Systems: Handbook for Design, Operation, and Maintenance; ASTM G88-90, Standard Guide for Designing Systems for Oxygen Service; ASTM G63-99, Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service; ASTM G94-92, Standard Guide for Evaluating Metals for Oxygen Service; and NASA/TM-2007-213740, Guide for Oxygen Compatibility Assessments on Oxygen Components and Systems.

5.11.3.1.3.2.1 Oxygen Component Acceptance Test

a. Oxygen and enriched 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 to ensure that all oxygen system GSE is exposed to oxygen before being connected to flight hardware.

b. 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).

5.11.3.1.4 Metals

5.11.3.1.4.1 Steel

Carbon and low alloy steels heat-treated to strength levels at or above 180 ksi UTS are sensitive to SCC and shall require an MUA.

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.

5.11.3.1.4.2 Corrosion-Resistant Steel

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

b. Welding shall 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).

Caution should be exercised in using 400 series stainless steels to minimize hydrogen embrittlement, corrosion, and stress corrosion. Austenitic stainless steels are susceptible to pitting corrosion and crevice corrosion in a chloride-rich (marine) environment; some austenitic stainless steels are susceptible to SCC in a chloride-rich (marine) environment.

c. Service-related corrosion issues are common for free-machining alloys such as UNS S30300 and UNS S30323; and they shall not be used in applications where they can get wet, such as natural or launch-induced environments.

d. UNS N08367 or UNS S31254 shall be used in pressure piping and tubing in lieu of 300-series stainless steel when the piping on tubing is directly exposed to the marine and launch-induced environment.

e. Cleaning, descaling, and passivating of stainless steel parts, assemblies, equipment, and installed systems shall be in accordance with ASTM A380, Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems.

f. When acid cleaning baths are used for steel parts, the parts shall be baked in accordance with SAE AMS 2759/9, Hydrogen Embrittlement Relief (Baking) of Steel Parts, to alleviate potential hydrogen embrittlement problems.

Hardware should be designed to avoid fretting and/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 with each other through a sliding movement, and gall-resistant alloys such as Nitronic® should be considered as alternatives.

5.11.3.1.4.3 Aluminum

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

b. 5000-series alloys containing more than 3 percent 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, as resistance to SCC is at a minimum in that direction.

5.11.3.1.4.4 Nickel-Based Alloys

Alloys with a 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 prior to 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.

5.11.3.1.4.5 Titanium

a. Areas subject to fretting and/or wear shall be anodized in accordance with SAE AMS 2488, Anodic Treatment—Titanium and Titanium Alloys Solution pH 13 or Higher, 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 that occurs at interfaces with titanium and its alloys has often caused cracks to occur, especially due to fatigue. The preferred policy is to implement a design that precludes the fretting and/or wear that occurs with titanium and its alloys.

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

c. The surfaces of titanium and titanium alloy mill products shall be 100-percent machined, chemically milled, or pickled to a sufficient depth to remove all contaminated zones and layers formed while the material was exposed to elevated temperatures.

Contaminated zones and layers may be formed as a result of mill processing, heat treating, and forming operations at elevated temperatures.

d. Before they are used, 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. Hardware should be designed to avoid fretting and/or wear of titanium alloys.

5.11.3.1.4.6 Copper Alloys

a. Copper alloys, such as brasses and bronzes, shall be resistant to corrosion, pitting, and SCC.

b. To prevent SCC, copper-based alloys such as brass shall not be used in solutions with ammonium ions or in contact with ammonia.

GSE 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.

5.11.3.1.4.7 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.

5.11.3.1.4.8 Tin

a. Tin and tin plating shall not be used in an application unless the tin is alloyed with at least 3 percent lead to prevent the growth of tin whiskers.

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

5.11.3.1.5 Nonmetals

5.11.3.1.5.1 Elastomers

a. Elastomers used in GSE shall be in accordance with MIL-HDBK-700.

b. Elastomeric materials shall be selected to operate within the parameters of a design service life, including the vendor-specified shelf life.

c. Elastomeric materials 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.

5.11.3.1.5.2 Composite Materials

a. Composite materials used in GSE shall be developed and qualified in accordance with MIL-HDBK-17, Volumes 1 through 5.

b. Defects resulting from the manufacturing process shall be assessed through NDE techniques to meet the intent of paragraph 4.6.2.2 of this Standard.

5.11.3.1.5.3 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, Refractory Concrete, Specification for.

5.11.3.1.5.4 Lubricants

NASA-TM-86556, Lubrication Handbook for the Space Industry, Part A: Solid Lubricants and Part B, Liquid Lubricants, should be used in evaluating and selecting lubricants for GSE. Lubricants are not restricted to those listed in NASA-TM-86556; guidelines on additional lubricants are contained in NASA/CR-2005-213424, Lubrication for Space Applications. Long-life performance should be considered when selecting lubricants. Use of lubricants in close proximity to precision-cleaned hardware or electrical connections should be minimized or tightly controlled to prevent cross-contamination.

a. Lubricants containing chloro-fluoro components shall not be used with aluminum or magnesium if shear stresses can be imposed.

b. Hardware with lubricants containing chloro-fluoro components shall not be heated above the maximum temperature for which the lubricant is rated.

Decomposition/reaction products from over-heating lubricants with chloro-fluoro components can attack metallic materials and can be toxic to personnel.

c. Lubrication of flared tube fittings shall be in accordance with SAE AIR 4071, Lubricants for Oxygen Use.

5.11.3.1.5.5 Limited-Life Materials

a. All materials shall 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 non-operating mode, and operational service life.

b. 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 requiring maintainability.

5.11.3.1.5.6 Plastic Films, Foams, and Adhesive Tapes (PFA)

Thin plastic films and tape materials used in GSE 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:

a. The latest version of NASA-STD-6001, including the (I) version.

b. MMA-1985-79, Standard Test Method for Evaluating Triboelectric Charge Generation and Decay.

c. The latest version of NASA-STD-6001, including the (I) version, A.7 Reactivity and Penetration of Materials due to Incidental Exposure to Hydrazine, Monomethylhydrazine, Unsymmetrical Dimethylhydrazine, Aerozine 50, Nitrogen Tetroxide, and Ammonia.

Material flammability ratings and ESD and hypergol compatibility test results for many PFAs are found in the MAPTIS database. KTI-5212, Material Selection List for Plastic Films, Foams, and Adhesive Tapes, may be referenced for a summary of flammability, ESD, and hypergol compatibility test results for various PFAs.

5.11.3.1.5.7 Fungus Resistance

a. For GSE used in a marine environment, materials that do not provide nutrients to fungi shall be used, as identified in MIL-HDBK-454, General Guidelines for Electronic Equipment, Table 4-I, Group I, except when one of the following criteria is met:

(1) Materials are used inside environmentally sealed containers with an internal container humidity of less than 60 percent 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.

(4) Materials are fluorocarbon polymers (including ETFE) or silicones.

b. Alternate materials shall be tested for fungus resistance in accordance with MIL-STD-810.

c. When materials that do provide nutrients to fungi are used, they shall be treated to prevent fungus growth.

d. Materials not meeting this requirement shall be identified, as well as any action required, such as periodic inspection, maintenance, or replacement of the material.

e. Treatment for fungus growth shall not adversely affect the unit's performance or service life or constitute a health hazard to higher order life.

f. Materials so treated shall be protected from environments that would leach out the protective agent.

5.11.4 Processes

5.11.4.1 Welding

Welding of GSE shall be in accordance with NASA-SPEC-5004, Welding of Aerospace Ground Support Equipment and Related Nonconventional Facilities, with the exception of pressure vessels (refer to paragraph 5.2.13 in this Standard).

The selection of parent materials and weld methods for a design 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.

5.11.4.2 Brazing

Brazing should be conducted in accordance with AWS C3.3, Recommended Practices for Design, Manufacture, and Examination of Critical Brazed Components.

a. Brazing of aluminum alloys shall meet the requirements of AWS C3.7M/C3.7, Specification for Aluminum Brazing.

b. Torch, induction, and furnace brazing shall meet the requirements of AWS C3.4, Specification for Torch Brazing; AWS C3.5, Specification for Induction Brazing; and AWS C3.6, Specification for Furnace Brazing, respectively.

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, Standard Method for Evaluating the Strength of Brazed Joints.

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 Boiler and Pressure Vessel Code, Section VIII.

5.11.4.3 Soldering

a. Soldering of electrical connections that will not be exposed to vibration or thermal cycling environments at space flight levels shall be fabricated in accordance with IPC J-STD-001. NASA-STD-8739.2 and NASA-STD-8739.3 may be used in lieu of the IPC J-STD-001 standard.

b. Soldering of electrical connections that will be exposed to vibration or thermal cycling environments at space flight levels shall be fabricated in accordance with IPC J-STD-001DS. NASA-STD-8739.2 and NASA-STD-8739.3 may be used in lieu of the IPC J-STD-001DS standard.

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

(1) For critical GSE, lot sampling shall be used to verify the presence of at least 3 percent lead.

d. Soldering shall not be used for structural applications.

5.11.4.4 Heat Treating and Plating

a. Heat treatment of aluminum alloy parts shall meet the requirements of SAE AMS 2772, Heat Treatment of Aluminum Alloy Raw Materials; SAE AMS 2770, Heat Treatment of Wrought Aluminum Alloy Parts; or SAE AMS 2771, Heat Treatment of Aluminum Alloy Castings, as appropriate.

b. Steel parts shall be heat-treated to meet the requirements of SAE AMS-H-6875A, Heat Treatment of Steel Raw Materials, or SAE AMS 2759D, Heat Treatment of Steel Parts General Requirements.

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

d. Heat treatment of nickel-based and cobalt-based alloy parts shall meet the requirements of SAE AMS 2774, Heat Treatment Wrought Nickel Alloy and Cobalt Alloy Parts.

e. Electrodeposited nickel plating shall be applied according to the requirements of SAE AMS 2403L, Plating, Nickel General Purpose, or SAE AMS 2423D, Plating, Nickel Hard Deposit.

f. Electroless nickel plate shall be applied in accordance with SAE AMS 2404E, Plating, Electroless Nickel.

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 produce rapid debonding of the nickel plate.

h. Galvanized (zinc) coatings shall be applied in accordance with:

(1) ASTM A123, Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products, for structural components.

(2) ASTM A153, Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware, for associated iron and steel hardware such as nuts, bolts, and washers that are coated by immersing them in molten zinc.

(3) ASTM A653, Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process, for sheet materials.

i. All repairs to damaged galvanized coatings shall be in accordance with ASTM A780, Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings.

5.11.4.5 Forging

Because mechanical properties are optimum in the direction of material flow during forging, forging techniques should be used that produce an internal grain-flow pattern such that the direction of flow is parallel to the principal stresses. The forging pattern should be free from reentrant and sharply folded flow lines.

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

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

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

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

5.11.4.6 Casting

a. Fracture-critical castings shall meet the requirements in NASA-STD-5009.

b. Non-fracture-critical castings shall meet the requirements in SAE AMS 2175, Castings, Classification and Inspection of.

5.11.4.7 Adhesive Bonding

a. Structural adhesive bonding shall be in accordance with MSFC-SPEC-445A, Adhesive Bonding, Process and Inspection, Requirements for, 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 in-process cleanliness inspections should be conducted as 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.

5.11.4.8 Fluid System Cleanliness

a. Surface cleanliness levels, test methods, cleaning and packaging requirements, and protection and inspection procedures for piping, tubing, fittings, and other fluid system components shall be in accordance with KSC-C-123, Surface Cleanliness of Fluid Systems, Specification for, or as specified in the program contamination control requirements or fluid procurement and use control specification.

b. The cleanliness level and test method shall be specified based upon the application.

c. For GSE interfaces with precision-cleaned flight fluid systems, 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 servicing or deservicing fluids, could permit flow in a reverse direction.

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

f. GSE fluid hardware (such as hoses and servicing units) shall be handled with the same cleanliness procedures used for flight hardware.

5.11.4.9 Riveting

Riveting shall be in accordance with MSFC-STD-156, Riveting, Fabrication and Inspection, Standard for.

5.11.4.10 Crimping

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

5.11.4.11 Potting and Molding

Potting and molding of electrical connectors shall be in accordance with KSC-STD-132, Potting and Molding Electrical Cable Assembly Terminations, Standard for.

5.11.4.12 Electrical Cable Design and Fabrication

5.11.4.12.1 Electrical Cable Design

Electrical cables for control and monitor systems and equipment shall be designed in accordance with NASA-STD-8739.4 or KSC-GP-864, Volume IIA, as determined by application, criticality, and operational environment.

5.11.4.12.2 Electrical Cable Fabrication

5.11.4.12.2.1 Electrical Cable Fabrication for Noncritical Applications

Electrical cables fabricated for noncritical applications in benign environments shall be fabricated in accordance with IPC-WHMA-A-620, Requirements and Acceptance for Cable and Wire Harness Assemblies, Performance Class 3.

NASA-STD-8739.4 may be used in lieu of IPC-WHMA-A-620.

5.11.4.12.2.2 Electrical Cable Fabrication for Critical Applications

Electrical cables fabricated for critical applications shall be fabricated in accordance with NASA-STD-8739.4 or KSC-GP-864, Volume IIA.

Cables used in critical applications are subject to vibration or thermal cycling testing.

5.11.4.13 Conformal Coating

Conformal coating on PC assemblies shall be in accordance with NASA-STD-8739.1, Workmanship Standard for Polymeric Application on Electronic Assemblies.

5.11.4.14 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 indicates its use (see paragraph 4.2.2.3). Guidelines for corrosion control for facilities, systems, and equipment are given in TM-584C, Corrosion Control and Treatment Manual..

a. Protective coating of hardware shall be in accordance with NASA-STD-5008, Protective Coating of Carbon Steel, Stainless Steel, and Aluminum on Launch Structures, Facilities, and Ground Support Equipment.

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

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 GSE, the following additional requirements shall also be implemented:

(1) Faying surfaces of metal alloys shall be sealed in accordance with NASA-STD-5008.

(2) The faying surfaces of all electrical bonding connections shall be sealed, except for nickel-plated surfaces.

5.11.4.14.1 SCC

Materials shall be selected from alloys that are highly resistant to SCC as specified in MSFC-STD-3029, Guidelines for the Selection of Metallic Materials for Stress Corrosion Cracking Resistance in Sodium Chloride Environments.

5.11.4.15 Material NDE

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

b. Fracture-critical areas shall be inspected in accordance with NASA-STD-5009.

c. NDE of non-fracture-critical base materials shall be in accordance with:

ASTM E1417	Standard Practice for Liquid Penetrant Testing
ASTM E1444	Standard Practice for Magnetic Particle Testing
ASTM E1742	Standard Practice for Radiographic Examination
ASTM E2375	Standard Practice for Ultrasonic Testing of Wrought Products
SAE AMS 2647	Fluorescent Penetrant Inspection Aircraft and Engine Component Maintenance
SAE AMS-STD-2154	Inspection, Ultrasonic, Wrought Metals, Process for
SAE ARP 4402	Eddy Current Inspection of Open Fastener Holes in Aluminum Aircraft Structure
SAE AS 4787	Eddy Current Inspection of Circular Holes in Nonferrous Metallic Aircraft Engine Hardware

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, as well as advanced methods such as shearography and thermography, as required.

c. Qualification and certification of personnel involved in NDE shall comply with AIA/NAS 410, NAS Certification & Qualification of Nondestructive Test Personnel.

5.11.4.15.1 Chemical Etching

a. Metals with surfaces that have been smeared/flowed by processing shall require chemical etching before penetrant inspection.

Processes causing smearing include, but are not limited to, machining, grinding, grit blasting, wire brushing, peening, and polishing.

b. High-strength steels etched to remove smeared metal shall be baked after etching to prevent hydrogen embrittlement in accordance with SAE AMS-2759/9.

c. Threads and holes shall be masked or plugged before etching.

5.11.4.16 Hydrogen Embrittlement

Hydrogen embrittlement of metals is not very well understood, and only a limited amount of materials property data has been generated and reported in MAPTIS.

a. An MUA shall be submitted for all metallic materials used in hydrogen systems in critical GSE.

Test data may have to be generated in a simulated environment to support the rationale. Guidelines for designing safe hydrogen systems are contained in ANSI/AIAA G-095-2004, Guide to Safety of Hydrogen and Hydrogen Systems.

b. Metallic materials that are electrochemically treated or exposed to acids or bases during manufacturing or processing shall be processed in a manner to prevent hydrogen embrittlement, or be treated for hydrogen embrittlement relief in accordance with SAE AMS-2759/9.

5.11.4.17 Contamination Control

a. A contamination control plan shall be generated in accordance with ASTM E1548, Standard Practice for Preparation of Aerospace Contamination Control Plans.

The contamination control plan should include controls on contamination-sensitive manufacturing processes, such as adhesive bonding; controls on packaging for shipment and storage; cleanliness level acceptance limits and verification methods for fluid systems; and a foreign-object-debris (FOD) prevention program. The FOD prevention program should be established for all mechanical and electrical GSE, including the design, development, manufacturing, assembly, repair, processing, testing, maintenance, operation, and checkout of the equipment to ensure the highest practical level of cleanliness. The FOD prevention program should follow the National Aerospace FOD Prevention Inc. (NAFPI) Guideline, FOD Prevention Guideline. The FOD prevention program should also conform to AIA/NAS 412, Foreign Object Damage/Foreign Object Debris (FOD) Prevention.

b. Definitions shall be established for cleanliness-level acceptance limits and verification methods for GSE fluid systems and for GSE internal and external surfaces that interface with flight hardware.

c. Engineering drawings shall identify cleanliness levels for all GSE.

APPENDIX A
SAMPLE MATERIAL USAGE AGREEMENT (KSC FORM 21-475)

Material Usage Agreement

1. MUA No.	2. System/Subsystem	
3. Prepared By: Name	Organization	Date
4. System Dwg. No. and Title		
5. Component Specification	Vendor	P/N
6. Material and Specification	7. Material Manufacturer	

8. Use Environment

☐ Controlled Interior ☐ Indoor ☐ Outdoor ☐ Outdoor Launch

Pressure ____________ Temperature ____________ Media ____________

9. Application and Deviation

SAMPLE

10. Acceptance Rationale

11. System Engineer/Lead Designer

Name	Organization	Signature	Date

12. NASA Safety Representative ☐ Approve ☐ Disapprove

Name	Organization	Signature	Date

13. Contractor Safety Representative ☐ Approve ☐ Disapprove

Name	Organization	Signature	Date

14. Center Materials Representative ☐ Approve ☐ Disapprove

Name	Organization	Signature	Date

KSC FORM 21-475 NS (REV. 9/00) PREVIOUS EDITIONS ARE OBSOLETE

APPENDIX A
SAMPLE MATERIAL USAGE AGREEMENT (KSC FORM 21-475) (Continued)

INSTRUCTIONS FOR COMPLETION OF MATERIAL USAGE AGREEMENT (KSC FORM 21- 475)

Complete each block of KSC Form 21-475 as follows. If a block is not applicable, or if the information is not available, enter "N/A".

Block No.	Block Title	Instructions
1	MUA No.	Assigned by the CMR.
2	System/Subsystem	Enter the system or subsystem where the material is used.
3	Prepared by	Enter the name and organization of the person technically responsible for the preparation of the MUA. Enter the date.
4	System Dwg. No. & Title	Enter the applicable system drawing number and title.
5	Component Specification, Vendor, and P/N	Enter the NASA component specification number, the vendor name, and the part number.
6	Material and Specification	Enter the name and the specification of the material that is the subject of the MUA.
7	Material Manufacturer	Enter the name of the material manufacturer.
8	Use Environment	Check the appropriate box (for stress corrosion cracking issues) or enter the pressure, temperature, and media characteristics of the environment in which the material will be used (for compatibility issues).
9	Application and Deviation	Enter the description of the material application and the deviation from requirements.
10	Acceptance Rationale	Enter the proposed rationale for acceptance of the material usage.
11	System Engineer/Lead Designer	The responsible system engineer/lead designer shall affix his/her signature, typed or printed name, organization, and date of signature.
12	NASA Safety Representative	To indicate approval/disapproval, the cognizant NASA Safety Representative shall check the appropriate box and affix his/her signature, typed or printed name, organization, and date of signature.
13	Contractor Safety Representative	To indicate approval/disapproval, the cognizant Contractor Safety Representative shall check the appropriate box and affix his/her signature, typed or printed name, organization, and date of signature.
14	Center Materials Representative	To indicate approval/disapproval, the CMR shall check the appropriate box and affix his/her signature, typed or printed name, organization, and date of signature.

APPENDIX B

DELIVERABLES

B.1 GSE Documentation Deliverables

B.1.1 The GSE provider has the responsibility to submit documentation to verify that the hardware/software has been developed in accordance with this Standard.

B.1.2 The GSE provider has the responsibility to provide all the necessary documentation to the using organization when the GSE is delivered for use, regardless of who "owns" the GSE at the time of delivery.

Examples of this documentation include, but are not limited to, the following:

a. Certification Approval Request (indicates how the GSE was certified as complying with this Standard).

b. Master Verification Matrix (indicates which GSE requirements were met and how).

c. Material Inspection and Receiving Report.

d. Validation and verification compliance records.

e. Drawings with parts list or bills of material.

f. Maintenance manuals/procedures.

g. Material certifications and lot traceability.

h. Operating manuals/procedures.

i. Software Version Description document.

j. Firmware Version Description document.

k. Facility and Flight Vehicle Interface requirements.

l. Hazard Analyses or Ground Safety Data pack.

m. Failure Modes, Effects, and Criticality Analysis.

n. Critical Items List.

Intent/Rationale: The using organization requires documentation for safely operating, maintaining, and servicing the GSE. To reduce risk to the mission, as well as to ground personnel and flight crews, a failure mode and effects analysis should be completed and submitted in accordance with the criticality assigned to the GSE by the responsible program or project.

APPENDIX C

REFERENCE DOCUMENTS AND DATABASE

C.1 Reference Documents

	FOD Prevention Guideline
	Handbook for Spring Design
AIA/NAS 412	Foreign Object Damage/Foreign Object Debris (FOD) Prevention
AIAA R-100	Recommended Practice for Parts Management
ANSI/AIAA/G-095-2004	Guide to Safety of Hydrogen and Hydrogen Systems
ASTM D5363	Standard Specification for Anaerobic Single-Component Adhesives (AN)
ASTM G63-99	Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service
ASTM G88-90	Standard Guide for Designing Systems for Oxygen Service
ASTM G94-92	Standard Guide for Evaluating Metals for Oxygen Service
ASTM MNL 36	Safe Use of Oxygen and Oxygen Systems: Handbook for Design, Operation, and Maintenance
AWS C3.3	Recommended Practices for Design, Manufacture, and Examination of Critical Brazed Components
IEEE 446	IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications
IEEE 484	IEEE Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications
IEEE 1106	IEEE Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications
IEEE 1187	IEEE Recommended Practice for Installation Design and

	Installation of Valve-Regulated Lead-Acid Storage Batteries for Stationary Applications
ISO 15389	Space systems – Flight-to-ground umbilicals
JSC 29353	Flammability Configuration Analysis for Spacecraft Applications
JSC 62809	Constellation Spacecraft Pyrotechnic Specification
KSC-E-165	Electrical Ground Support Equipment Fabrication, Specification for
KSC-GP-986-40	KSC Design Criteria for Reusable Space Vehicle Umbilical Systems
TM-584C	Corrosion Control and Treatment Manual
KTI-5210	Material Selection List for All Oxygen and Air Services
KTI-5211	Material Selection List for Reactive Fluid Service
KTI-5212	Material Selection List for Plastic Films, Foams, and Adhesive Tapes
NASA/CR-2005-213424	Lubrication for Space Applications
NASA RP-1228	Fastener Design Manual
NASA/TM-2007-213740	Guide for Oxygen Compatibility Assessments on Oxygen Components and Systems
NASA-TM-86556	Lubrication Handbook for the Space Industry, Part A: Solid Lubricants, Part B: Liquid Lubricants
NASA/TP-2003-212242	EEE-INST-002: Instructions for EEE Parts Selection, Screening, Qualification, and Derating

C.2 Reference Database

Aerospace Structural Metals Database