INTERIM NASA TECHNICAL STANDARD

NASA-STD-(I)-5005C

National Aeronautics and Space Administration
Washington, DC 20546-0001

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STANDARD FOR THE DESIGN AND FABRICATION OF GROUND SUPPORT EQUIPMENT

MEASUREMENT SYSTEM IDENTIFICATION: METRIC (INCH-POUND)

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This document represents the technical consensus of the developing group but does not yet have final NASA approval.

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
			NPD	ASQC
			SCAPE	NMI
			ISO	

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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 17007.7. 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.

Status	Document Revision	Approval Date	Description
Revision (Continued)	B		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. 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)

FOREWORD

This Interim Technical Standard is published by the National Aeronautics and Space Administration (NASA) to provide uniform engineering and technical requirements for processes, procedures, practices, and methods to meet urgent program and project technical needs. This interim standard has the consensus of the developing Technical Working Group but does not have Agency-wide concurrence required for a NASA Technical Standard.

This interim standard may be cited in contract, program, and other Agency documents as a technical requirement. Mandatory requirements are indicated by the word "shall."

This interim 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 interim 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 Technical Standards System at http://standards.nasa.gov.

Original Signed By

07-20-2007

Christopher J. Scolese
NASA Chief Engineer

Approval Date

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TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

SECTION **PAGE**

TABLE OF CONTENTS

TABLE OF CONTENTS

SECTION **PAGE**

TABLE OF CONTENTS

SECTION **PAGE**

TABLE OF CONTENTS

SECTION **PAGE**

Standard for the Design and Fabrication of Ground Support Equipment

1. SCOPE

1.1 Purpose

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

1.2 Applicability

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. The requirements described here are applicable to all NASA space flight programs that process space flight pedigree hardware using GSE.

This standard may be cited in contracts, program, and other Agency documents as a technical requirement. Mandatory requirements are indicated by the word “shall”; italicized text indicates explanatory or guidance text. These requirements may be tailored for specific programs/projects by documenting the proposed changes/tailoring; tailored requirements shall be approved by the Technical Authority for the program or project. Tailoring also includes using existing or previously developed contractor processes and standards as a submittal of the various required plans.

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 represents an overall cost savings.

Along with identifying this standard for design and development of GSE, Programs, in conjunction with Engineering and S&MA organizations, have the responsibility to provide the following:

a. Determining categories or types (e.g., critical vs. non-critical) of GSE and any additional requirements resulting from these categories or types;

b. Establishing and defining where this standard will be applied when such boundaries require clarification;

c. Establishing program and project-specific requirements; and

d. Establishing minimum configuration management systems to retain the required documentation.

This standard does not apply to the following:

a. Equipment that is used during the manufacturing of flight hardware;

b. Ground support systems (GSS) that interface with GSE; and

c. Facilities.

1.3 Intended Use

This interim standard is intended for use in establishing uniform engineering practices and methods and ensuring that essential requirements are included in the design 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.

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 of sections 4 and 5. The latest issuances of cited documents shall be used unless otherwise approved by the assigned Technical Authority. The applicable documents are accessible via the NASA Technical Standards System at http://standards.nasa.gov, directly from the Standards Developing Organizations, or from other document distributors.

2.2 Government Documents

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-6001	Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments that Support Combustion
NASA-STD-(I)-6008	NASA Fastener Management and Control Practices
NASA-STD-8719.9	Standard for Lifting Devices and Equipment
NASA-STD-8739.1	Workmanship Standard for Staking and Conformal Coating of Printed Wiring Boards and 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 8010.2	Use of the SI (Metric) System of Measurement in NASA Programs
NPD 8730.1B	Metrology and Calibration
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 8715.3	NASA General Safety Program Requirements

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—Materials, Processes and Manufacturing Department Metallic Materials and Processes Group

John F. Kennedy Space Center (KSC), NASA

KDP-KSC-P-1535	Design Review Process
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-E-165	Electrical Ground Support Equipment, Fabrication, Specification for
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/MMA-1985-79	Standard Test Method for Evaluating Triboelectric Charge Generation and Decay

KSC/MTB-175-88	Procedure for Casual Exposure of Materials to Hypergolic Fluids
KNPR 8715.3	KSC Safety Practices Procedural Requirements
KSC-SPEC-F-0006	Heat and Blast Protection Coating Materials
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	Flared Tube Assemblies and Installation of Fittings and Fitting Assemblies, Fabrication and Installation of, Specification for
KSC-SPEC-Z-0009	Lubrication, Thread, Corrosion-Resistant Steel and Aluminum Alloy Tube Fittings, Specification for
KSC-STD-132	Potting and Molding Electrical Cable Assembly Terminations, Standard for
KSC-STD-141	Load Testing Identification and Data Marking, Standard for
KSC-STD-164	Environmental Test Methods for Ground Support Equipment, Standard for
KSC-STD-P-0006	Standard for Quick Release Pins and Pin Tethers
KSC-STD-E-0001	Standard for Design of Electrical Control and Monitor Systems, Equipment and Panels
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-G-0003	Launch Support and Facility Components, Qualification of, Standard for
KSC-STD-SF-0004	Ground Piping Systems Color Coding and Identification, Safety Standard for
KSC-STD-Z-0005	Design of Pneumatic Ground-Support Equipment, Standard for (ITAR Controlled)
KSC-STD-Z-0006	Hypergolic Propellants Ground Support Equipment, Design of, Standard for
KSC-STD-Z-0008	Ground Life Support Systems and Equipment, Standard for, Design of
KSC-STD-Z-0009	Cryogenic Ground Support Equipment, Design of, Standard for
KSC-STD-Z-0010	Environmental Control Systems, Ground Coolant Systems, Coolant Servicing Systems and Ground Support Equipment, Design of, Standard for
79K19600	Electrical Cable Fabrication Requirements
79K80XXX Series	Fluid Component Specification Drawings

Lyndon B. Johnson Space Center (JSC), NASA

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

Military (MIL)

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-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-149	Rubber
MIL-HDBK-454	General Guidelines for Electronic Equipment
MIL-HDBK-695	Rubber Products: Recommended Shelf Life
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	Department of Defense Test Method Standard for Environmental Engineering Considerations and Laboratory Tests
MIL-STD-889	Dissimilar Metals
MIL-STD-1472	Human Engineering

MIL-STD-1576	Electroexplosive Subsystem Safety Requirements and Test Methods for Space Systems

Federal (FED)

29 CFR 1910	Occupational Safety and Health Standards
49 CFR 171 through 181	Department of Transportation: Hazardous Material
FED-STD-595	Colors Used in Government Procurement
MMPDS-02	Metallic Materials Properties Development and Standardization (Federal Aviation Administration)

Technical Manuals and Reports

TM 5-809-10/ NAVFAC P-355/ AFM 88-3, Chapter 13	Seismic Design Guidelines for Upgrading Existing Buildings
AFSPCMAN 91-710, Volume 3	Range Safety User Requirements Manual, Volume 3, Launch Vehicle, Payloads, and Ground Support Equipment Requirements

2.3 Non-Government Documents

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

AIA/NAS 410	NAS Certification and Qualification of Nondestructive Test Personnel
AIA/NAS 412	Foreign Object Damage/Foreign Object Debris (FOD) Prevention

Aluminum Association (AA)

ADM-1	Aluminum Design Manual

American Concrete Institute (ACI)

ACI 318/318R	Structural Concrete, Building Code Requirements for

American Institute of Steel Construction (AISC)

AISC 325	Manual of Steel Construction – Third Edition

American Society of Mechanical Engineers (ASME)

ANSI/ASME Y14.5M-1994	Dimensioning and Tolerancing
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

American Society for Nondestructive Testing (ASNT)

SNT-TC-1A	Recommended Practice No. SNT-TC-1A

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 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 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 Examination of Wrought Products
ASTM SI 10	American National Standard for Use of the International System of Units (SI): The Modern Metric System
ASTM-MANL-36	Manual for Safe Use of Oxygen Systems: Guidelines for Oxygen System Design, Materials Selection, Operations, Storage, and Transportation

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 C3.7	Specification for Aluminum Brazing
AWS D17.1	Specification for Fusion Welding for Aerospace Applications

Compressed Gas Association (CGA)

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

Electronic Industries Association (EIA)

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

International Conference of Building Officials (ICBO)

ICBO-UBC-V1	Uniform Building Code, Volume 1

Institute for Interconnecting and Packaging Electronic Circuits (IPC)

IPC-2221	Generic Standard on Printed Board Design
IPC-HDBK-001 with Amendments 1 and 2	Handbook and Guide to Supplement J-STD-001 (Includes J-STD-001 B-C-D Comparisons)

International Telecommunication Union (ITU)

ITU-T G.120	Transmission Characteristics of National Networks

National Electrical Manufacturers Association (NEMA)

NEMA-ICS2	Industrial Control and Systems: Controllers, Contactors, and Overload Relays, Rated Not More Than 2000 Volts AC or 750 Volts DC; Part 8: Disconnect Devices for Use in Industrial Control Equipment
NEMA-MG1	Motors and Generators

National Fire Protection Association (NFPA)

NFPA 70	National Electrical Code
NFPA 496	Standard for Purged and Pressurized Enclosures for Electrical Equipment

Society of Automotive Engineers (SAE)

AMS 2175	Castings, Classification and Inspection of
AMS 2488	Anodic Treatment – Titanium and Titanium Alloys Solution pH 13 or Higher
AMS 2647	Fluorescent Penetrant Inspection, Aircraft and Engine Component Maintenance
AMS 2759/1	Heat Treatment of Carbon and Low-Alloy Steel Parts Minimum Tensile Strength Below 220 ksi (1517 MPa)
AMS 2759/2	Heat Treatment of Low-Alloy Steel Parts Minimum Tensile Strength 220 ksi (1517 MPa) and Higher
AMS 2759/3	Heat Treatment Precipitation—Hardening Corrosion-Resistant and Maraging Steel Parts
AMS 2759/4	Heat Treatment Austenitic Corrosion-Resistant Steel Parts
AMS 2759/5	Heat Treatment Martensitic Corrosion-Resistant Steel Parts
AMS 2759/6	Gas Nitriding and Heat Treatment of Low-Alloy Steel Parts
AMS 2759/7	Carburizing and Heat Treatment of Carburizing Grade Steel Parts
AMS 2759/8	Ion Nitriding
AMS 2759/9	Hydrogen Embrittlement Relief (Baking) of Steel Parts

AMS 2759/10	Automated Gaseous Nitriding Controlled by Nitriding Potential
AMS 2759/11	Stress Relief of Steel Parts
AMS 2770	Heat Treatment of Wrought Aluminum Alloy Parts
AMS 2771	Heat Treatment of Aluminum Alloy Castings
AMS 2772	Heat Treatment of Aluminum Alloy Raw Materials
AMS 2774	Heat Treatment, Wrought Nickel Alloy and Cobalt Alloy Parts
AMS-H-81200	Heat Treatment of Titanium and Titanium Alloys
AMS-STD-2154	Inspection, Ultrasonic, Wrought Metals, Process for
ARP 1247B	General Requirements for Aerospace Ground Support Equipment, Motorized and Nonmotorized
ARP 4402	Eddy Current Inspection of Open Fastener Holes in Aluminum Aircraft Structure
AS 4787	Eddy Current Inspection of Circular Holes in Non-Ferrous Metallic Aircraft Engine Hardware
AS 50861	Wire, Electric, Polyvinyl Chloride Insulated, Copper or Copper Alloy
AS 8090	Mobility, Towed Aerospace Ground Equipment, General Requirements for
AS 22759	Wire, Electrical, Fluoropolymer-Insulated, PTFE and PTFE-Coated Glass, Silver-Coated Copper Conductor, 600-Volt
SAE J474	Electroplating and Related Finishes

Telcordia Technologies, Inc.

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

When this standard is applied as a requirement or imposed by contract on a program or project, the technical requirements of this standard take precedence, in the case of conflict, over the technical requirements cited in applicable documents or referenced guidance documents.

3. ACRONYMS AND DEFINITIONS

3.1 Acronyms and Abbreviations

Acronyms used in this standard are:

°C	Degrees Celsius
°F	Degrees Fahrenheit
A-50	Aerozine-50
AA	Aluminum Association
ac	Alternating Current
ACI	American Concrete Institute
AFSPC	Air Force Space Command
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
ASME	American Society of Mechanical Engineers
ASNT	American Society for Nondestructive Testing
ASTM	American Society for Testing and Materials
AWS	American Welding Society
CFR	Code of Federal Regulations
CGA	Compressed Gas Association
CIL	Critical Items List
COTS	Commercial Off-the-shelf

dc	Direct Current
ECLSS	Environmental Control and Life Support Systems
ECS	Environmental Control System
EEE	Electrical, Electronic, and Electromechanical
e.g.	For Example
EIA	Electronic Industries Association
EMC	Electromagnetic Control
EMC	Engineering Management Council
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
ET	Eddy Current Testing
ETFE	Ethylene-tetrafluoroethylene
EWR	Eastern and Western Range
FED	Federal
FMEA	Failure Modes and Effects Analysis
FOD	Foreign Object Debris
GOX	Gaseous Oxygen
GP	General Publication (KSC)
GSE	Ground Support Equipment
GSS	Ground Support Systems
HDBK	Handbook
HR	Historical Record
Hz	Hertz
(I)	Interim
ICBO	International Conference of Building Officials
ICD	Interface Control Document
IDD	Interface Definition Document
i.e.	That Is
in	Inch(es)
IPC	Institute for Interconnecting and Packaging Electronic Circuits
ISO	International Standardization Organization
ITU	International Telecommunication Union
JSC	Lyndon B. Johnson Space Center
kPa	Kilopascal
KSC	John F. Kennedy Space Center
ksi	1000 psi
LH_2	Liquid Hydrogen
LHe	Liquid Helium
LO_2	Liquid Oxygen
LOX	Liquid Oxygen
LRU	Line Replaceable Unit

LT	Leak Testing
M&P	Materials and Processes
MANL	Manual
MAPTIS	Materials and Processes Technical Information System
MIL	Military
mm	Millimeter(s)
MMH	Monomethylhydrazine
MPa	Megapascal
MSFC	George C. Marshall Space Flight Center
MT	Magnetic Particle Testing
MUA	Material Usage Agreement
N_2H_4	Hydrazine
N_2O_4	Nitrogen Tetroxide
NAS	National Aerospace Standards
NASA	National Aeronautics and Space Administration
NDE	Nondestructive Evaluation
NDT	Nondestructive Test
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NPD	NASA Policy Directive
NPR	NASA Procedural Requirements
NTSWG	NASA Technical Standards Working Group
PC	Printed Circuit
PCTFE	Polychlorotrifluoroethylene
PFA	Plastic Films, Foams, and Adhesive Tapes
pH	Phosphorus
PHE	Propellant Handlers Ensemble
psi	Pound Per Square Inch
psia	Pound Per Square Inch Absolute
PT	Penetrant Testing
QD	Quick Disconnect
RF	Radio Frequency
RH	Relative Humidity
RT	Radiographic Testing
S&MA	Safety and Mission Assurance
SAE	Society of Automotive Engineers
SCC	Stress Corrosion Cracking
SPEC	Specification
SSP	Space Station Program
STD	Standard
STE	Special Test Equipment
TM	Technical Memorandum
TP	Technical Procedure

UBC	Uniform Building Code
UNS	Unified Numbering System
UT	Ultrasonic Testing
UTS	Ultimate Tensile Strength
VCS	Vapor Control System
vs.	Versus

3.2 Definitions

Definitions used in this standard are:

Commercial Off-the-shelf (COTS): Equipment, including hardware and associated software/procedures, that is commercially available from current industry inventory.

Design Life: The operational life of equipment (to include storage life, installed life in a non-operating mode, and operational service life), after which the equipment will be replaced or recertified. Recertification requirements will be determined by the program/project, and 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): Non-flight equipment, systems, or devices specifically designed and developed for a direct physical or functional interface with flight hardware.

Rationale: GSE 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.

Ground Support Systems (GSS): Infrastructure and equipment (portable or fixed) that provides 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. Failures in the GSS are prevented from propagating to flight hardware by protective features designed into the GSE.

Limited Life: Equipment or components that degrade due to operating time, cycling, or material aging, and that are less 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 ratio of ultimate strength, breaking strength, or yield strength to the maximum material design stress.

Special Test Equipment (STE): Facilities, systems, equipment, or devices that provide a physical or functional interface to GSE but do not provide a functional or physical interface with flight hardware.

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

Rationale: Tools are not designed to specifically interface with flight hardware, nor are they designed to perform a function specific to flight hardware. Their design and general use in industry includes a variety of applications that may be required on flight hardware or GSE. Tools are intended for general use by trained technicians in a shop environment 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

a. The general design criteria and practices specified herein shall be the minimum criteria necessary to meet the needs and expectations of internal NASA customers (e.g., relative to safety, reliability, maintainability, quality, supportability) in a cost-effective manner.

b. *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, criteria that exceed the provisions specified herein shall be determined by the responsible design organization in consultation with its customers (e.g., users and operators).

c. GSE shall follow all environmental regulations and be certified in accordance with certification requirements of the program, project, or installation Center and with Center procedures.

d. Special test equipment (STE) shall be defined and specific policy developed for use of STE on flight hardware by each program/project.

e. The specific sections of this standard that apply to STE shall be established by each program.

f. Specific policy for acceptance of COTS equipment in GSE shall be developed by each program/project.

COTS equipment, parts, items, or components should be used to the maximum extent possible when (1) they satisfy the hardware function, (2) they will not degrade the safety or reliability of the flight or ground system, and (3) they provide a cost savings that will exceed possible cost increases due to unique maintenance or logistics requirements, modifications, or an increase in the complexity of the interfacing equipment.

g. The following areas of acceptance criteria shall be addressed by the policy as follows:

(1) The policy shall include provisions for ensuring that hardware is satisfactory from an overall materials and processes standpoint.

(2) Any additional qualifying tests and inspections shall be indicated in the engineering documentation. *Vendor or contractor documentation and supporting test data should be incorporated into system control documents.*

(3) GSE defined herein shall be subject to the configuration control requirements specified in the approved program/project configuration management plan.

4.2 Functional Designations

All equipment that meets the requirements of this standard and meets the definition outlined in section 3.2 for GSE shall be designated/classified as GSE.

4.3 Characteristics

4.3.1 Performance Characteristics

4.3.1.1 Operability and Maintainability

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

4.3.1.1.1 GSE Designed to Meet Flight Hardware Requirements

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

4.3.1.1.2 GSE Degradation and Contamination

The GSE design shall not degrade or contaminate associated flight or ground systems, subsystems, or experiments during use, checkout servicing, or handling.

4.3.1.1.3 GSE Design for Access

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

4.3.1.2 Interfaces

a. 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.

b. This shall be verified by test or analysis.

4.3.1.2.1 GSE Facility Interface

GSE should meet all facility interface requirements when practical and economically feasible.

4.3.1.2.1.1 Prevention of Incorrect Mating with GSE Interface

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.

4.3.1.3 Producibility

GSE should be designed for ease of production, manufacture, construction, and inspection.

4.3.1.3.1 GSE Design Tolerance

Close manufacturing tolerances should be avoided unless required by design and performance.

4.3.2 Physical Characteristics

4.3.2.1 Limited-life Items

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.

4.3.2.1.1 Limited-life Item Identification

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

4.3.2.2 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.

Initial maintenance and maintenance cycles should be specified by the design engineering organization.

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.

4.3.2.2.1 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, shall be used without additional certification once S&MA has performed the necessary analysis, i.e., Failure Modes and Effects Analysis (FMEA)/Critical Items List (CIL) and historical record (HR), to verify that this equipment brings no new or additional risks to the new program it will be supporting.

4.3.2.3 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:

4.3.2.3.1 Metric System Standard Practice

New flight programs or projects that are required to use the metric system of measurement in accordance with NPD 8010.2, Use of the SI (Metric) System of Measurement in NASA Programs, shall also use the metric system for design of new GSE supporting those programs or projects. Standard practice for the use of the metric system shall be in accordance with ASTM SI 10, American National Standard for Use of the International System of Units (SI): The Modern Metric System.

4.3.3 Reliability

GSE shall be designed to prevent propagation of failures to the flight hardware.

This should include consideration of flight hardware failures that could propagate through the GSE and affect other flight hardware (vent systems, etc.).

4.3.3.1 Redundancy

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.

4.3.3.2 GSE System Failure Reduction

GSE should be designed to minimize the probability of system failure and minimize the severity of the failure effect on the system.

4.3.3.3 GSE Fault Tolerant

At a minimum, all GSE (except primary structure and pressure vessels/tubing in rupture mode) shall be designed to sustain a failure (single-fault tolerant) without causing loss of life, damage to support equipment, or damage to flight hardware.

More stringent fault tolerance requirements (e.g., two-fault tolerant for loss of flight crew) may be applicable depending on program requirements.

4.3.3.4 GSE Failure Analysis

An FMEA shall be performed concurrent with the design.

This is to ensure fault tolerance requirements are satisfied and to minimize the effects and severity of a failure during GSE operations.

4.3.4 Maintainability

GSE should be designed to minimize the complexity and frequency of maintenance.

4.3.5 Environmental Conditions

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

4.3.5.1 Natural Environment

GSE used or stored in an exterior environment shall be designed to function at its respective geographical location after exposure to the natural environment as specified in NASA-HDBK-1001, Terrestrial Environment (Climatic) Criteria Handbook for Use in Aerospace Vehicle

Development, which may be tailored to reflect program-defined risk and exposure times, including operation within the launch commit criteria of the vehicle.

4.3.5.2 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 KSC-GP-1059, Environment and Test Specifications Levels, Ground Support Equipment for Space Shuttle System at Launch Complex 39; KSC-STD-164, Standard for Environmental Test Methods for Ground Support Equipment; KSC-DD-818-TR, Summary of Measurements of KSC Launch Induced Environmental Effects (STS-1 through STS-11); and/or program-induced environmental requirements documents.

4.3.5.2.1 Launch-induced Damage to GSE

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.

4.3.5.3 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) with extremes of an uncontrolled temperature of +11 °C (52 °F) to +40 °C (105 °F) for a maximum of 1 hour.

b. Humidity: nominal 55 percent, with a range of 45 to 70 percent at 21 ±5 °C (70 ±10 °F).

4.3.5.4 Controlled Clean Environment

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

b. GSE shall not present a source of contamination or be considered detrimental to the maintenance of the controlled clean environment.

4.3.5.5 Uncontrolled Interior and Exterior Environment

GSE used in an uncontrolled interior and/or exterior 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.

4.3.5.6 Fire/Explosion Hazard Environment

If GSE will be operated in locations where fire or explosion hazards may 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, Standard for Hazard Proofing of Electrically Energized Equipment.

4.3.5.6.1 Fire/Explosion Hazard-proofing

Purge and pressurization for hazard-proofing shall be in accordance with the requirements of NFPA 496, Standard for Purged and Pressurized Enclosures for Electrical Equipment.

4.3.5.7 Environmental Test Methods

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

4.3.5.8 Seismic Environment

If GSE will be used in a location where seismic activity is likely to occur, it shall be designed to resist the effects of a seismic event using the criteria and guidelines in TM 5-809-10/NAVFAC P-355/AFM 88-3, Seismic Design Guidelines for Upgrading Existing Buildings, Chapter 13 or ICBO-UBC-V1, Uniform Building Code, Volume 1.

4.3.6 Transportability

GSE shall be designed to be transportable by normal methods of transportation such as by ground, air, or sea.

4.3.6.1 Manually Moved GSE

GSE that will be moved by hand shall include the means (e.g., handles, hand holds, or brakes) for individuals to move those items as required to meet operational requirements.

4.3.6.2 GSE that Exceeds Lifting Limits

GSE that exceeds personnel lifting limits specified in MIL-STD-1472, Human Engineering, shall be provided with material handling provisions (e.g., slings, lift points, castors, and skids) necessary to meet the operational requirements for installation/removal, maintenance, and use.

4.4 Documentation

4.4.1 Drawings and Specifications

Drawings and specifications required for the fabrication, construction, installation, modification, test, operation, maintenance, or utilization of GSE shall be prepared in accordance with the program/project-approved drawing practices equal to or more stringent than the engineering drawing and related documentation practices of ANSI/ASME Y14.5M-1994, Dimensioning and Tolerancing.

4.4.2 Technical Documentation

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

Documentation should contain the information of GSE performance that is necessary to validate the readiness of the GSE. This documentation should be prepared in accordance with accepted industrial practices, or in accordance with KSC-DF-107, Technical Documentation Style Guide. Reference Appendix B for a list of deliverables.

4.5 Logistics

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

4.5.1 Limited-life Items

Identified limited-life items shall be controlled from the date of manufacture through operational use, including storage.

4.5.2 Limited-life Items Tracking

Status of limited-life-cycle items shall be maintained.

4.5.3 Limited-life Items Repair and Maintenance

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

4.5.4 Spares Provisioning

The logistics system shall provide the spares provisioning and acquisition of supplies sufficient to support the operational readiness date of the equipment or system as defined by GSE design.

4.5.5 Logistics Supportability

Logistical supportability should be provided by the appropriate operations and maintenance organizations.

4.6 Personnel and Training

GSE design should minimize the required personnel, operator skill sets, and training requirements for the operation and maintenance of hardware and software.

4.6.1 Specialized Training

When GSE is complex enough to warrant it, a software math model should be developed to provide an accurate and realistic simulation environment that will allow for development of procedures (nominal, contingency, emergency) and personnel training and certification.

4.6.2 GSE Personnel Safety Alert Marking

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 OSHA-mandated lockout/tagout.

4.7 Qualification

All GSE shall be qualified in accordance with the provisions of the approved program/project documentation.

4.8 Quality Assurance

4.8.1 General

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

4.8.1.1 Quality-related Requirements

The design should also include special quality-related requirements, such as special processes, special testing, and any other necessary special requirements that produce a quality product.

4.8.1.2 Quality Requirements Definition

Quality requirements shall be defined in program/project quality and technical requirements documents, specifications, contractual requirements, and other specified documentation.

4.8.2 Testing

a. Testing shall be specified by engineering documentation.

b. Testing shall normally be limited to GSE acceptance testing to verify compliance with the applicable specifications and the ability of the GSE to perform required design functions.

4.8.3 Load Test

4.8.3.1 Load Testing

A load test shall be performed on all structural GSE (lifting, handling, and transportation devices).

4.8.3.1.1 Safety Load Test

Whenever there is reason to question whether it is safe to use a lifting device for its intended use, additional load testing shall be performed.

4.8.3.1.2 Test Load Design Factor

The minimum test load shall be 125 percent of the design or working load for non-lifting devices.

4.8.3.1.3 Lifting Device/Equipment

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

4.8.3.2 Nondestructive Test (NDT)

NDT shall be performed in accordance with MIL-HDBK-6870, Inspection Program Requirements Nondestructive for Aircraft and Missile Materials and Parts.

4.8.3.3 Test Reports

Test reports shall be prepared in accordance with the practices of the performing organization.

4.8.3.4 Instrumentation Calibration

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

Also, calibration of measuring instruments should be established and maintained in accordance with NASA-RP-1342, Metrology Calibration and Measurement Processes Guidelines.

4.8.4 Quality Conformance Verification

A verification program shall be specified in the program/project verification plan and in the contract documentation.

Examinations and tests are recommended to verify 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.

4.9 Packaging

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.

4.9.1 Shipping Containers

Shipping containers shall comply with onsite transportation, handling, and storage methods.

4.9.1.1 Shipping Heavy Containers

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

4.9.1.2 Shipping Container Attachment Points

Attachment points shall be provided for crane hoists and tie-downs.

4.9.1.3 Shipping Container Monitoring

Shipping 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.

4.9.2 Weight and Size

The weight and cubic displacement of packaging and packing should be held to a minimum consistent with the method of transportation for the item.

4.9.2.1 Disassembly for Shipment

When required, GSE shall be designed so the configuration (i.e., item) may be disassembled and packaged for shipment.

4.9.3 Parts Protection

Where appropriate, procedures shall be employed to ensure that there is an efficient, reliable, and economical system to protect parts during manufacturing processes and in-plant handling and storage.

4.9.3.1 Part Protection Standardization

There should be standardization of parts protection procedures, methods, materials, and devices (such as carts, boxes, containers, or transportation vehicles) necessary to prevent damage.

4.9.4 Precision-cleaned Parts

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

4.9.5 Marking

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

4.9.6 Environmental Recording Instruments

Shipment of GSE that is sensitive to the environment shall be instrumented to provide a record of the required environmental measurements with respect to time.

4.9.6.1 Environmental Recording Instructions

Instructions detailing the hardware sensitivities and environmental measurements to be recorded shall be included in the shipping requirements of the hardware.

4.9.6.2 Packaging Verification

Proof of adequate packaging shall be demonstrated if the use of a recording instrument is required but is not feasible in a single-item shipment of a small item.

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 AISC 325, Manual of Steel Construction—Third Edition.

5.1.1.2 Aluminum Structures

The design of aluminum structures shall be in accordance with ADM-1, Aluminum Design Manual.

5.1.1.3 Concrete Structures

The design of concrete structures shall be in accordance with ACI 318/318R, Building Code Requirements for Structural Concrete.

5.1.2 Safety Factor

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

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

5.1.2.1 GSE Safety Factor

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 collapse, buckling, or failure to support design loads.

5.1.2.2 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 documented.

Typical load cases such as assembly, transportation, operations, wind loads, lateral stability, and seismic loads should be considered. For torque loads on threaded fasteners, see paragraph 5.2.11.

5.2 Mechanical Design

5.2.1 Pneumatics

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

5.2.1.1 Breathing Air Systems

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

5.2.2 Cryogenics

The design of cryogenic servicing GSE, such as that used for liquid hydrogen (LH_2), liquid oxygen (LO_2), liquid helium (LHe), and liquid methane, shall be in accordance with KSC-STD-Z-0009, Standard for Design of Cryogenic Ground Support Equipment, except that materials used in LO_2 GSE shall comply with ASTM-MANL-36, Manual for Safe Use of Oxygen Systems: Guidelines for Oxygen System Design, Materials Selection, Operations, Storage, and Transportation.

5.2.3 Hypergols

The design of hypergolic fuel or oxidizer servicing GSE, such as that used for monomethylhydrazine (MMH), nitrogen tetroxide (N_2O_4), hydrazine (N_2H_4), Aerozine-50 (A-50) shall be in accordance with KSC-STD-Z-0006, Standard for Design of Hypergolic Propellants Ground Support Equipment.

5.2.4 Hydrocarbons

The design of servicing and storing GSE, such as that used for 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 hydraulic servicing GSE shall be in accordance with ASME B31.3 and with KSC-STD-Z-0005.

It should be supplemented by the latest applicable industry or Government design standard.

5.2.6 Environmental Control System (ECS) and Environmental Control and Life Support Systems (ECLSS)

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

5.2.7 Life Support

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

5.2.8 Lifting Devices

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

5.2.8.1 Lift Certification

Prior to completing the final design, an analysis shall be performed to certify the stability of the lift.

5.2.9 Springs

Springs used in the design of GSE should be in accordance with the Handbook for Spring Design from the Spring Manufacturers Institute.

5.2.10 Umbilical Design

The design of reusable umbilicals should be in accordance with KSC-GP-986, Design Criteria for Reusable Space Vehicle Umbilical Systems, or ISO 15389, Space systems—flight-to-ground umbilicals.

5.2.11 Torque for Threaded Fasteners

5.2.11.1 Fastener Material Stress Loads

The combined stress from all applied loads, including preload, shear, tension, and bending, shall not exceed the yield strength of the fastener material.

5.2.11.1.1 Torque for Threaded Fasteners Less than 32 mm (1-1/4 in)

Torque value for threaded fasteners less than 32 mm (1-1/4 in) in diameter shall be in accordance with MSFC-STD-486, Torque Limits for Standard, Threaded Fasteners, or the alternative value identified.

5.2.11.1.2 Torque for Threaded Fasteners Greater than 32 mm (1-1/4 in)

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

5.2.11.2 Torque Criteria for Bolts

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.

5.2.11.2.1 Torque Criteria Documentation

Torquing criteria shall be documented on the drawing.

5.2.12 Tethering Provisions

5.2.12.1 Tethering of Temporary GSE

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

5.2.12.2 Tethering of GSE Around Flight Hardware

GSE intended for use near flight hardware, or elevated above personnel and/or flight hardware, shall be designed and constructed with provisions for tethering.

5.2.13 Quick Release Pins

Quick release pins and pin tethers shall be in accordance with KSC-STD-P-0006, Standard for Quick Release Pins and Pin Tethers.

5.2.14 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.

5.2.15 Transportation Equipment

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

5.2.15.1 Towed GSE

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

5.2.15.2 Transportation Equipment Interface Loads

Transportation equipment shall be designed so that loads imparted to flight hardware do not exceed 80 percent of the design flight loads.

5.2.16 Pressure Vessels

All 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.

5.2.16.1 Code-stamped Vessel Registration

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

5.1.16.2 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 181, Hazardous Material.

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, Standard for Design of Electrical Control and Monitor Systems, Equipment and Panels.

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

5.3.2 Electrical Design for Pneumatic and Hydraulic Components

The electrical design for pneumatic and hydraulic components shall be in accordance with KSC-STD-E-0004, Standard for Pneumatic and Hydraulic Mechanical Components, Electrical Design.

5.3.3 Pyrotechnic Systems

The design of pyrotechnic GSE shall be in accordance with MIL-STD-1576, Electroexplosive Subsystem Safety Requirements and Test Methods for Space Systems.

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

5.3.4 Electrical Power Systems

The design of GSE used to provide electrical power shall be in accordance with NFPA 70.

5.3.5 Bonding and Grounding

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

Rationale: The designer should be aware if the system being designed will be operated under a lightning protection system.

5.3.6 Hazard Proofing

Hazard proofing of electrically energized equipment 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 should be selected using ANSI/AIAA R-100,Recommended Practice for Parts Management; NASA/TP-2003-212242, (EEE-INST-002), Instructions for EEE Parts Selection, Screening, Qualification, and Derating; or NPD 8730.2, NASA Parts Policy.

Only EEE parts commensurate with the criticality of the application and the life cycle of the GSE shall be used.

5.4.2 Metallic Tubing

Stainless steel tubing shall be selected in accordance with KSC-SPEC-Z-0007, Specification for Tubing, Steel, Corrosion Resistant, Types 304 and 316, Seamless, Annealed, and fabricated and installed in accordance with KSC-SPEC-Z-0008, Specification for the Fabrication and Installation of Flared Tube Assemblies and Installation of Fittings and Fitting Assemblies.

5.4.2.1 Superaustenitic Stainless Steel Tubing

When directly exposed to a marine or launch-induced environment, tubing should consist of superaustenitic stainless steel (trade name AL6XN), such as UNS NO8367 or S31245.

Superaustenitic stainless steel tubing shall be in accordance with ASTM B676, Standard Specification for UNS N08367 Welded Tube, and installed according to KSC-SPEC-Z-0008.

5.4.3 Metallic Fittings

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

5.4.3.1 Compression Fittings

Compression fittings should be selected in accordance with applicable voluntary standards.

5.4.4 Fluid System Protective Caps and Plugs

Protective caps and plugs 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 system cleanliness.

5.4.5 Fluid System Components

Fluid system components used in the design of liquid or gas systems shall be selected from the 79K80XXX series of specifications unless the required part is not covered by this series.

5.4.5.1 Fluid System Component Acceptance Criteria

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

5.4.6 Electrical Power Receptacles and Plugs

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

5.4.7 Electrical Power Cable

Power cables designed for 60 Hz alternating current (ac) shall be in accordance with NFPA 70.

5.4.8 Electrical Cable and Harnesses

Flexible multi-conductor jacketed electrical cable and cable harnesses shall be in accordance with KSC-GP-864, Volume IIA, Electrical Ground Support Equipment Cable Handbook.

5.4.9 Fiber-optics

5.4.9.1 Fiber-optic Protective Caps

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

5.4.9.2 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.

5.4.9.3 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.

5.4.9.4 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.

5.4.9.5 Single-mode Fiber-optic Cable

Single-mode fiber-optic applications shall be in accordance with ITU-T G.120, Transmission Characteristics of National Networks.

5.4.9.6 Multimode Fiber-optic Cable

Multimode fiber-optic applications shall be in accordance with ITU-T G.120.

5.4.10 Electrical Hookup Wire

Electrical hookup wire shall be in accordance with SAE AS50861, Wire, Electric, Polyvinyl Chloride Insulated, Copper or Copper Alloy ; MIL-DTL-16878, General Specification for Wire, Electrical, Insulated; or SAE AS 22759, Wire, Electrical, Fluoropolymer-Insulated, PTFE and PTFE-Coated Glass, Silver-Coated Copper Conductor, 600-Volt.

5.4.11 Connectors

a. Electrical multi-conductor connectors for GSE used for electrical control and monitoring shall be selected from the following: MIL-DTL-5015, General Specification for Connectors, Electrical, Circular Threaded, AN Type; MIL-DTL-22992, General Specification for Connectors, Plugs and Receptacles, Electrical, Waterproof, Quick Disconnect, Heavy Duty Type; MIL-DTL-38999, General Specification for Connectors, Electrical, Circular, Miniature, High Density, Quick Disconnect (Bayonet, Threaded, and Breech Coupling), Environment Resistant, Removable Crimp and Hermetic Solder Contacts; or KSC-GP-864, Volume IIA.

b. When multiconductor connectors must be used in hazardous locations, they shall be “water-proof” and “threaded” type connectors.

c. Operational provisions/controls shall be put in place to avoid the mating or demating of connectors when the connector pins are energized.

5.4.12 Coaxial (RF) Connectors

Coaxial (RF) connectors shall be selected from MIL-PRF-39012, General Specification for Connectors, Coaxial, Radio Frequency.

5.4.13 Electrical Connector Protective Covers or Caps

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

Protective covers or caps should meet the following requirements:

a. Be moisture proof.

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 suitable lanyard, chain, or hinge.

g. Not produce static.

5.4.14 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.

5.4.15 Sensors and Transducers

Sensors and transducers used in the design of GSE systems shall be selected from the Sensors and Transducers list in KSC-DE-512-SM, unless the required part is not covered by this list.

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.

5.4.15.1 Sensor and Transducer Acceptance Criteria

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

5.4.16 Exterior Electrical Enclosures

Electrical enclosures used in exterior applications shall be in accordance with NFPA 496.

5.4.17 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 to ensure fit and interchangeability.

5.4.18 Printed Circuit (PC) Boards

PC boards shall be designed in accordance with IPC-2221, Generic Standard on Printed Board Design.

5.4.18.1 PC Board Fabrication

Fabrication of PC boards shall be in accordance with IPC-HDBK-001, Handbook and Guide to Supplement J-STD-001 (Includes J-STD-001 B-C-D Comparisons), with Amendments 1 and 2.

5.4.19 Electric Motors

Motors used in GSE shall be in accordance with NEMA MG1, Motors and Generators.

5.4.19.1 Motor Starters and Controllers

Starters and controllers shall be in accordance with the NEMA standards for industrial control specified in NEMA-ICS2, Industrial Control and Systems: Controllers, Contactors, and Overload Relays, Rated Not More Than 2000 Volts AC or 750 Volts DC; Part 8: Disconnect Devices for Use in Industrial Control Equipment; and NFPA 70.

5.4.20 Threaded Fasteners

Threaded fasteners shall be in accordance with NASA-STD-(I)-6008, NASA Fastener Management and Control Practices.

For fastener selection and analysis, NASA-RP-1228, Fastener Design Manual should be used as a guide.

5.4.20.1 Critical GSE Fasteners

Critical GSE fasteners, as defined in NASA-STD-(I)-6008, shall have lot traceability from the manufacturer to the buyer.

5.4.20.2 Self-locking Fasteners

Self-locking fasteners, such as nylon locknuts, star lock washers, etc., should be used wherever possible.

5.4.20.3 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.

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.

5.4.20.4 Liquid-locking Compounds

Liquid-locking compounds shall have a validated application process specified on the engineering drawing.

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/EMC requirements in MIL-STD-461, Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment.

Application of the requirements of MIL-STD-461 may require tailoring for use on NASA programs as indicated in MIL-STD-461, paragraphs 1.2, 1.2.1, and 1.2.3.

5.6 Identification Markings and Labels

5.6.1 Systems and Equipment

GSE shall be identified and marked in accordance with MIL-STD-130, Identification Marking of U.S. Military Property.

5.6.2 Load Test

GSE that has been load-tested shall be identified and marked in accordance with KSC-STD-141, Standard for Load Testing Identification and Data Marking 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 identified and color-coded 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 KSC-E-165, Specification for Electrical Ground Support Equipment, Fabrication.

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 in accordance with 29 CFR 1910.

5.8.1 Hazard Analysis

a. A hazard analysis shall be conducted as part of the GSE design process to ensure that hazards are identified and controlled.

b. The analysis shall be conducted in accordance with the program requirements.

5.8.1.1 Hazard Analysis Process

If program requirements do not clearly define a hazard analysis process, the analysis shall be performed in accordance with NPR 8715.3, NASA General Safety Program Requirements.

5.8.2 Safety Requirements on KSC Property

GSE to be used at KSC shall be in accordance with 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 be in accordance with the requirements of AFSPCMAN91-710, Volume 3.

5.9 Human Factors

a. MIL-STD-1472 shall be used to establish human factors criteria for GSE design.

b. GSE shall comply with 29 CFR 1910.

5.9.1 GSE Requiring Propellant Handlers Ensemble (PHE)-Suited Operators

GSE intended for use by PHE-suited operators shall be designed to meet the following requirements:

a. Items (valves, gages, levers, bolts, nuts, and any other items required to be moved, turned, manipulated, or monitored) should be located to optimize access to the item while the PHE-suited operator is in a standing position.

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 surfaces shall be prohibited.

5.10 Security

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

5.11 Materials and Processes (M&P)

5.11.1 General Requirements

Materials and processes 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 electrostatic discharge (ESD) and contamination.

5.11.1.1 Material Properties Design Data

a. To establish materials properties for use in system or component design, MMPDS-02 (for metals), Metallic Materials Properties Development and Standardization (Federal Aviation Administration) or the appropriate vapor control system (VCS) code or standard; e.g., the ASME

Boiler and Pressure Vessel Code, the AISC Steel Construction Manual, and ASTM specifications, shall be used by the design engineer.

b. The use of polychlorotrifluoroethylene (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. For materials not covered by an appropriate design code or standard, MIL-HDBK-17-1, Composite Materials Handbook Volume 1: Polymer Matrix Composites Guidelines for Characterization of Structural Materials, shall be used for composites; MIL-HDBK-149, Rubber, shall be used for elastomers; and MIL-HDBK-700, Plastics, shall be used for plastics.

If the material is not covered by a design code or one of these sources, the Aerospace Structural Metals Handbook 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.

5.11.1.2 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) The design review process shall include M&P assessments in accordance with KDP-KSC-P-1535, Design Review Process.

b. The design drawings and any revisions shall be signed by an authorized M&P engineer from the responsible M&P engineering organization.

The M&P signature approval on an engineering drawing does not constitute materials certification or final materials approval of the hardware.

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

(1) For critical GSE, all certification documentation and processing records shall be retained for the life of the hardware.

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.

(1) New material codes shall be assigned by NASA MSFC.

e. *The use of materials and processes that do not comply with the requirements of this standard may still be acceptable in the actual hardware applications.* 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.

(1) For non-critical GSE, MUAs shall be submitted for M&P that are technically acceptable but do not meet the flammability, compatibility, and stress corrosion cracking requirements of this standard.

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

5.11.2 Detailed Requirements

5.11.2.1 Flammability and Compatibility Requirements

Materials shall be tested in accordance with NASA-STD-6001, Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments that Support Combustion, as described in the following paragraphs.

5.11.2.1.1 Flammability Control

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

For many materials, the MAPTIS database contains material flammability ratings and tests based on NASA-STD-6001. The following are additional acceptable materials or methods:

a. The use of ceramics, metal oxides, and inorganic glasses is accepted without test.

b. When a material is sufficiently chemically and physically similar to a material found to be acceptable by testing in accordance with NASA-STD-6001, the use of this material without testing may be justified on an approved MUA.

c. Materials tested and A-rated under more severe conditions with respect to the use environment are acceptable (considered A-rated) without test, as in the following examples:

(1) Materials used in an environment with an oxygen concentration lower than the test level are accepted without test, whereas materials used in an environment where the concentration is greater than the test level shall be tested or considered flammable by default.

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

(2) If a material passes the flammability test on a metal substrate, it should be used on metal substrates of the same thickness or greater. If the material will be used on a thinner or non-heat-sinking substrate (or on no substrate at all), it shall be retested or considered flammable by default.

Many situations arise in which flammable materials are used in an acceptable manner without test, using mitigation practices and the MUA approval system.

5.11.2.1.2 Fluid Compatibility

5.11.2.1.2.1 Fluids Other than Oxygen

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

NASA-STD-6001, 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 NASA-STD-6001, 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.

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

c. 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.

5.11.2.1.2.2 Oxygen

a. Liquid and gaseous oxygen (LOX/GOX) systems shall use materials that are nonflammable in their worst-case use configuration, as defined by NASA-STD-6001, Test 13 for

[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.

mechanical impact (for LOX or GOX) and Test 17 for upward flammability in GOX (or Test 1 for materials used in oxygen pressures that are less than 350 kPa (50 psia).

For many materials, material flammability ratings and test results based on NASA-STD-6001 are found in the MAPTIS database. KTI-5210, Material Selection List for All Oxygen and Air Service may be referenced for a summary of a mechanical impact test (NASA-STD-6001, Test 13) results for various materials used in LOX and GOX applications.

b. When a material in an oxygen system is determined to be flammable by the above test, an oxygen compatibility assessment shall be conducted and the system safety rationale documented in an MUA.

c. The oxygen compatibility assessment shall clearly state what level of failure tolerance and what level of risk are considered acceptable and thereby do not need mitigation.

The oxygen compatibility assessment should use the evaluation methodology described in NASA/TM-2007-213740, Guide for Oxygen Compatibility Assessments on Oxygen Components and Systems.

d. When a material in an oxygen system fails either test at its maximum use condition and the hazard analysis shows the risk is above an acceptable level, then configurational testing shall be conducted to support the oxygen compatibility assessment.

e. The configurational testing shall exercise the ignition mechanism in question using an accepted test method.

f. The configurational test method and acceptance criteria shall be reviewed and approved as part of the MUA process described in paragraph 5.11.1.2.

g. 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.

h. The need for oxygen compatibility testing and oxygen compatibility assessment shall be addressed on an individual basis for compressed air systems and systems containing enriched oxygen.

Such systems are inherently less hazardous than systems containing pure oxygen; the hazard increases with oxygen concentration, pressure, and temperature. Guidelines on the design of safe oxygen systems are contained in ASTM-MANL-36; ASTM G88-90, Standard Guide for Designing Systems for Oxygen Service; ASTM G63-99, Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service; and ASTM G94-92, Standard Guide for Evaluating Metals for Oxygen Service.

5.11.2.1.2.2.1 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.

This is to ensure that all oxygen system GSE is exposed to oxygen before being connected to flight hardware.

b. Components shall be retested if post-test actions (such as rework, repair, or interfacing with hardware having uncontrolled cleanliness) invalidate the acceptance test.

5.11.2.1.3 Metals

5.11.2.1.3.1 Steel

Carbon and low alloy steels heat-treated to strength levels at or above 180 ksi ultimate tensile strength (UTS) are sensitive to stress corrosion cracking and shall only be used with an approved 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 service temperatures. For some alloys, the transition temperature may be as high as ambient temperature.

5.11.2.1.3.2 Corrosion-resistant Steel

a. Unstabilized, austenitic steels shall not be used 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 stress corrosion cracking (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 directly exposed to the marine and launch-induced environment.

e. Cleaning, descaling, and passivating of new 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.

5.11.2.1.3.3 Aluminum

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

b. The 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 wrought direction, as resistance to SCC is at a minimum in that direction.

5.11.2.1.3.4 Nickel-based Alloys

High nickel content alloys are susceptible to sulfur embrittlement; therefore, any foreign material that could contain sulfur, such as oils, grease, and cutting lubricants, shall be removed by suitable means 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.

5.11.2.1.3.5 Titanium

The use of titanium in hydrochloric acid, chlorinated solvents, chlorinated cutting fluids, fluorinated hydrocarbons, and anhydrous methyl alcohol should be avoided due to its 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.

a. If fretting and/or wear is unavoidable, the subject region 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.

b. Titanium alloys shall not be used with LOX or GOX 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 at elevated temperatures.

This includes contamination as a result of mill processing, heat treating, and forming operations at elevated temperatures.

d. Before use, all cleaning fluids and other chemicals used during manufacturing and processing of titanium hardware shall be verified to be compatible and not detrimental to performance.

5.11.2.1.3.6 Copper Alloys

a. Copper alloys, such as brasses and bronzes, shall be resistant to uniform 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.

Beryllium copper (UNS C17200) is commonly used for high-strength, non-sparking structural components in contact and wear applications.

5.11.2.1.3.7 Beryllium and Beryllium Alloys

Beryllium particles, beryllium oxide, and other beryllium compounds are toxic when inhaled. Care must be exercised during design and fabrication to avoid exposing personnel to these toxins.

Machining, grinding, and finishing operations shall be performed either under liquid coolant with local ventilation or, if dry, with high-velocity, close-capture ventilation. *Refer to the appropriate Material Safety Data Sheet for more detail.*

5.11.2.1.3.8 Tin

a. Tin and tin plating shall not be used in any applications unless the tin is alloyed with at least 3 percent lead to prevent tin whisker growth.

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

5.11.2.1.4 Non-metals

5.11.2.1.4.1 Elastomers

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

b. Elastomeric materials shall be selected to operate within design parameters with a service life that includes storage time, in accordance with vendor-specified shelf life requirements or MIL-HDBK-695, Rubber Products: Recommended 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.

5.11.2.1.4.2 Plastics

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

b. Polychlorotrifluoroethylene (PCTFE) shall comply with ASTM D7194.

5.11.2.1.4.3 Composite Materials

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

b. Defects resulting from the manufacturing process shall be assessed through nondestructive evaluation (NDE) techniques.

5.11.2.1.4.4 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, Specification for Refractory Concrete.

5.11.2.1.4.5 Lubricants

NASA-TM-86556, Lubrication Handbook for 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.

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 rated temperature of the lubricant, because decomposition/reaction products can attack metallic materials.

c. Lubrication of flared tube fittings shall be in accordance with KSC-SPEC-Z-0009, Specification for Lubrication, Thread, Corrosion-Resistant Steel and Aluminum Alloy Tube Fittings.

5.11.2.1.4.6 Limited-life Items

a. All materials shall be selected to meet the useful life (which includes storage life, installed life in a non-operating mode, and operational service life) of the hardware without the need for additional maintenance.

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.

5.11.2.1.4.7 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 NASA-STD-6001; KSC/MMA-1985-79, Standard Test Method for Evaluating Triboelectric Charge Generation and Decay; and KSC/MTB-175-88, Procedure for Casual Exposure of Materials to Hypergolic Fluids, for flammability, ESD, and hypergolic ignition/breakthrough characteristics, respectively, as appropriate for the application.

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.

5.11.2.1.4.8 Fungus Resistance

a. 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 normally stowed in locations where there is no risk of condensation.
(5) Materials are fluorocarbon polymers (including Ethylene-tetrafluoroethylene (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, including 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 be sufficient to leach out the protective agent.

5.11.2.2 Processes

5.11.2.2.1 Welding

a. Welding of critical GSE shall be in accordance with NASA-SPEC-5004, Welding of Aerospace Ground Support Equipment and Related Nonconventional Facilities with the

exception that welding of pressure vessels shall be in accordance with ASME Boiler and Pressure Vessel Code, Section VIII.

b. For non-critical GSE, welding shall be in accordance with either NASA-SPEC-5004 or AWS D17.1, Specification for Fusion Welding for Aerospace Applications, with the exception that welding of pressure vessels shall be in accordance with ASME Boiler and Pressure Vessel Code, Section VIII.

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 operational capability of the parts concerned. Welding procedures should be selected to provide the required weld quality, minimum weld energy input, and protection of the heated metal from contamination.

5.11.2.2.2 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 C3.7, 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 pre-production 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.

5.11.2.2.3 Soldering

a. Soldering of electrical connections shall be in accordance with NASA-STD-8739.3, Soldered Electrical Connections and NASA-STD-8739.2, Workmanship Standard for Surface Mount Technology, in regard to surface mount technology.

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

c. Soldering shall not be used for structural applications.

5.11.2.2.4 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 2759/1-11 (refer to section 2.3 for specific document titles).

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

e. Functional enhancement of metal substrates by electrodeposited coatings (electroplating) shall be performed in accordance with SAE-J474, Electroplating and Related Finishes, which specifies the appropriate references for coating and substrate material combinations.

f. Galvanized (zinc) coatings shall be applied in accordance with ASTM A123, Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products for structural components; with 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; and with ASTM A653, Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process for sheet materials.

g. 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.

5.11.2.2.5 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 re-entrant 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.

5.11.2.2.6 Casting

a. Castings shall meet the requirements in SAE AMS 2175, Classification and Inspection of Castings.

b. The class and grade of casting shall be specified according to the definitions in SAE AMS 2175.

5.11.2.2.7 Adhesive Bonding

a. Structural adhesive bonding shall be in accordance with MSFC-SPEC-445A, Process and Inspection Requirements for Adhesive Bonding.

Retesting of adhesives used for production parts is not required if they are within the manufacturer's recommended shelf life. The sensitivity of structural adhesive bonds to contamination is of particular concern.

b. Structural adhesive bonding processes shall be controlled to prevent contamination that would cause structural failure.

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 expected service species and 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.

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

5.11.2.2.8 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, Specification for Surface Cleanliness of Fluid Systems, 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 de-servicing fluids, could permit flow in a reverse direction.

e. Interfacing GSE shall be cleaned to at least 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.

5.11.2.2.9 Tube Assembly

Fabrication and installation of flared tube assemblies shall be in accordance with KSC-SPEC-Z-0008.

5.11.2.2.10 Riveting

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

5.11.2.2.11 Crimping

Crimping shall be in accordance with NASA-STD-8739.4, Crimping, Interconnecting Cables, Harnesses and Wiring.

5.11.2.2.12 Potting and Molding

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

5.11.2.2.13 Electrical Cable Fabrication

Electrical cable fabrication for control and monitor systems and equipment shall be in accordance with 79K19600.

5.11.2.2.14 Conformal Coating

Conformal coating on PC assemblies shall be in accordance with NASA-STD-8739.1, Workmanship Standard for Staking and Conformal Coating of Printed Wiring Boards and Electronic Assemblies.

5.11.2.2.15 Corrosion Control

Protective coating of hardware should be appropriate to the condition, use, and environment to which the hardware will be exposed during its life cycle. The coating should minimize corrosion, and its color should indicate its use (see paragraph 4.3.2.3). Guidelines for corrosion control for facilities, systems, and equipment are given in TM-584, 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) All electrical bonding connections shall be faying-surface sealed, except for nickel-plated surfaces.

5.11.2.2.15.1 Stress Corrosion Cracking (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.

5.11.2.2.15.2 Environmental Test Methods for Component Qualification

Environmental test methods and conditions required for hardware life cycle testing and qualification shall be in accordance with KSC-STD-G-0003, Standard for Qualification of Launch Support and Facility Components.

5.11.2.2.16 Material Nondestructive Evaluation (NDE)

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

b. NDE of base materials shall be in accordance with the following documents:

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 Examination 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 (PT), magnetic particle (MT), radiographic (RT), ultrasonic (UT) and eddy current (ET) testing. NDE inspection is not limited to the aforementioned methods, and may include additional methods such as leak testing (LT), as well as advanced methods such as shearography and thermography, as required.

c. Qualification and certification of personnel involved in nondestructive testing shall comply with NAS 410, NAS Certification and Qualification of Nondestructive Test Personnel or SNT-TC-1A, Recommended Practice No. SNT-TC-1A.

5.11.2.2.16.1 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 within 4 hours after etching to prevent hydrogen embrittlement.

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

5.11.3 Special Requirements

5.11.3.1 Hydrogen Embrittlement

Hydrogen embrittlement of materials is not very well understood, and there are only limited materials property data generated and reported in MAPTIS.

a. For materials used in hydrogen systems in critical GSE, an MUA shall be submitted rationalizing the selection of metallic materials to preclude cracking and to ensure system reliability and safety.

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

b. Hydrogen embrittlement of metallic materials can also be caused by electrochemical processes or exposure to acids or bases during manufacturing or processing. Such processes shall be controlled to prevent hydrogen embrittlement, or an embrittlement relief treatment shall be performed promptly after processing.

5.11.3.2 Heat and Blast Protection

Coating materials used for heat and blast protection of hardware shall be in accordance with KSC-SPEC-F-0006, Heat and Blast Protection Coating Materials.

5.11.3.3 ESD-sensitive Components and Assemblies

All ESD-sensitive components and assemblies should be handled using practices in accordance with ANSI/ESD S20.20, Development of an Electrostatic Discharge Control Program for: Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices); MIL-STD-1686, Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices); and MIL-HDBK-263, Electrostatic Discharge Control Handbook for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices (Metric).

5.11.3.4 Contamination Control

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

b. The plan shall 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.

c. 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.

d. The FOD prevention program shall 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.

e. The FOD prevention program shall conform to NAS 412, Foreign Object Damage/Foreign Object Debris (FOD) Prevention.

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

5.11.3.4.1 Toxic Materials

The use of toxic materials shall comply with the applicable safety and environmental regulations.

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

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 shall submit documentation to verify that the hardware/software has been developed in accordance with this standard.

B.1.2 All documentation shall be provided 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 shall be completed and submitted in accordance with the criticality assigned to the GSE by the responsible program or project.

APPENDIX C

REFERENCE DOCUMENTS

NASA-RP-1228	Fastener Design Manual
NASA-RP-1342	Metrology Calibration and Measurement Processes Guidelines
NASA/TM-2007-213740	Guide for Oxygen Compatibility Assessments on Oxygen Components and Systems
NASA/TP-2003-212242	EEE-INST-002: Instructions for EEE Parts Selection, Screening, Qualification, and Derating
NPD 8730.2	NASA Parts Policy
KSC-DF-107	Technical Documentation Style Guide
KSC-GP-986	Design Criteria for Reusable Space Vehicle Umbilical Systems
	Support Equipment, Design of, Standard for
KTI-5210	Material Selection List for All Oxygen and Air Service
KTI-5211	Material Selection List for Reactive Fluid Service
KTI-5212	Material Selection List for Plastic Films, Foams, and Adhesive Tapes
TM-584	Corrosion Control and Treatment Manual
JSC 62809	Constellation Spacecraft Pyrotechnic Specification
MIL-HDBK-263	Electrostatic Discharge Control Handbook for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices) (Metric)

Reference Documents (Continued):

MIL-STD-1686	Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)
NASA-TM-86556	Lubrication Handbook for Space Industry, Part A: Solid Lubricants, Part B: Liquid Lubricants
NASA/CR-2005-213424	Lubrication for Space Applications
ANSI/AIAA/G-095-2004	Guide to Safety of Hydrogen and Hydrogen Systems
ANSI/AIAA R-100	Recommended Practice for Parts Management
ANSI/ESD S20.20	Development of an Electrostatic Discharge Control Program for: Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)
ASTM D5363	Standard Specification for Anaerobic Single-Component Adhesives (AN)
ASTM G63	Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service
ASTM G88	Standard Guide for Designing Systems for Oxygen Service
ASTM G94	Standard Guide for Evaluating Metals for Oxygen Service
AWS C3.3	Recommended Practices for Design, Manufacture, and Examination of Critical Brazed Components
ISO 15389	Space systems – Flight-to-ground umbilicals
No number	Handbook for Spring Design