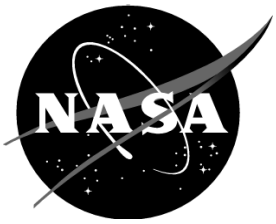
# Process Specification for the Manual Arc Welding of Carbon Steel and Nickel Alloy Hardware

## Engineering Directorate

## Structural Engineering Division

## March 2026




**National Aeronautics and Space Administration**
**Lyndon B. Johnson Space Center**
**Houston, Texas**

# Process Specification for the Manual Arc Welding of Carbon Steel and Nickel Alloy Hardware

**Prepared by:** Junhua Pan (affiliate) Digitally signed by Junhua Pan (affiliate) Date: 2026.03.30 08:43:00 -05'00'

Junhua Pan
Materials and Processes Branch/Amentum

Date

**Reviewed by:** Clinton Denny (affiliate) Digitally signed by Clinton Denny (affiliate) Date: 2026.03.30 10:33:16 -05'00'

Clinton S. Denny
Quality Engineering Branch/NT4

Date

**Approved by:** MARYJANE O'ROURKE Digitally signed by MARYJANE O'ROURKE Date: 2026.06.23 15:56:39 -05'00'

Mary Jane O'Rourke
Materials and Processes Branch/ES4

Date

| REVISIONS | | |
|---|---|---|
| **VERSION** | **CHANGES** | **DATE** |
| Baseline | Original version | 6/1/1995 |
| A | Revised version | 10/29/1997 |
| B | Formatting, changed process owner, rewrite numerous sections for clarification, deleted requirement for WIR, deleted section 8.2 on audits, added section 8.3 on WPQ, deleted mil specs for NDE, added PRCs for NDE. | 07/07/1999 |
| C | Comprehensive technical rewrite and reformat, exclude applicability to pressurized hardware, clarify 3.0, add a "D" class weld in 3.1, expand design requirements, add reference to NASA- SPEC-5004 and delete reference to inspection/NOE PRCs, delete Table II, address use of metal cored filler wires in 6.1.2, clarify 6.1.4, specify requirement' in 6.4, clarify 6.5 to include weld "rework", expand section 7.0 to clarify, combine 7.2 and 7.3, revise 8.0 to clarify compliance with AWS B2.1, revise all acceptance criteria to clarify and simplify. | 9/7/2000 |
| D | Comprehensive rewrite to combine PRC-0005 and PRC-0006 and make editorial changes. PRC-0006 will be cancelled with this change. Include requirements for precision cleaned hardware (ref. JPG 5332.1). Expand Class D definition and requirements. | 01/28/2004 |
| E | Add reference to good workmanship in section 7.1.4. | 03/09/2004 |
| F | Add reference to Class D welding in 3.0 for on-site JSC work authorized by the JSC Engineering Directorate's manufacturing operations. Add additional Class D stipulations in last paragraph of 3.1. Added Reviewer signature block. | 11/21/2007 |
| G | Revised the definitions of flight and non-flight hardware in 2.0; added NAS 410, NASA-STD-5009, PRC-50 0, PRC-6503, PRC-6505, PRC-6506, and PRC-6510 to 4.0; revised 6.5 to allow mechanical repairs; revised 7.0 through 7.3 to add separate inspection requirements for flight hardware and require NAS 410 certification for NDE personnel inspecting flight hardware; and revised Appendix A in its entirety. | 10/12/2019 |
| H | Removed and added text throughout for clarity. Sections 2.0, 5.2, 6.2.3 and 6.5 (c) revised for clarity. Sections 7.1 and 7.3 changed locations. Sections 6.1, 6.2.5 and 9.0 were deleted in their entirety. A definitions Section 10.0 was added. An Appendix B was added. | 12/16/2020 |
| I | Removed para 3.1 alternate weld classification criteria and unnecessary classification text.<br>Added AWS A5.9 to Table IV<br>Added para 8.2 and 8.3 for WPS and PQR requirements | 03/01/2026 |

## 1.0 SCOPE

This process specification provides the minimum requirements that govern the manual arc welding of carbon steel and nickel alloy flight and non-flight hardware. Design, procedural and quality assurance requirements are given. All work instructions and Weld Procedure Specifications (WPS) used during welding shall satisfy the requirements of this process specification.

## 2.0 APPLICABILITY

This process specification applies to manual (and semiautomatic) arc welding of carbon steel and nickel alloy flight and non-flight hardware that is fabricated under the authority of NASA/Johnson Space Center (JSC) by any of the following types of welding processes:

a. Gas tungsten arc welding (GTAW).
b. Gas metal arc welding (GMAW).
c. Flux cored arc welding (FCAW).
d. Shielded metal arc welding (SMAW).

## 3.0 USAGE

This process specification shall be invoked by including a note on the applicable engineering drawing with the following general format which specifies the Process Specification (PRC) and weld class nomenclature:

**WELD AND INSPECT PER NASA/JSC PRC-0005, CLASS X.**

Regarding onsite JSC work for minor facilities repair and manufacture of shop aids that is performed under the work authorization of the JSC Engineering Directorate's manufacturing operations, welds shall be considered Class D, if they conform to the Class D weld criteria and exclusions herein. Execution of these welds shall not require the formality of an engineering drawing, and may be executed by verbal orders.

To minimize fabrication costs by avoiding over-inspection and unnecessary rework/repair, individual welds, or components on a weldment shall be classified separate where possible. This can be accomplished by including a note on the engineering drawing with the general format shown below which specifies only the PRC nomenclature. The weld class shall then be indicated by either: 1) calling out the specific weld class with the welding symbol at the individual weld joints or, 2) by using specific flag notes with the welding symbol at the individual weld joints. Refer to Figure 3.0a and 3.0b below for examples of these methods.

**WELD AND INSPECT PER NASA/JSC PRC-0005. WELD CLASSES SHALL BE AS INDICATED AT WELD LOCATION CALLOUTS.**

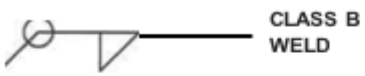



FIGURE 3.0a




FIGURE 3.0b

## 3.1 WELD CLASSIFICATION

Welds made using this specification shall be primarily classified in accordance with the service conditions of the weldment. The "Class" governs the extent to which quality assurance provisions are applied to the weld joint.

Where conditions exist that make it difficult to choose between 2 weld classes, then the more stringent of the 2 classes shall be applied.

Quality assurance provisions for all weld classes are detailed in Section 7.0. Weld classes shall be chosen on the basis of the following definitions:

a. Class A (Flight or non-flight) -. Applies to welds in critical load bearing elements that are not fail-safe. Class A welds are typically used in primary load bearing connections. Failure of a Class A weld in service would be catastrophic and would result in the loss of life, system(s), control, or major components.

b. Class B (Flight or non-flight) - Applies to welds in load bearing elements that are fail-safe. Class B welds are typically used in secondary load bearing (i.e., shared load) connections. Failure of a Class B weld in service would reduce the overall efficiency of the system, but the loss of the system(s) or endangerment to personnel would not be expected.

c. Class C (Flight or non-flight) - Applies to welds that are in minor load bearing elements that are fully contained where failure in service would have minor or no effect on the efficiency of a system and endangerment to personnel would not occur. Class C welds are typically used in secondary or tertiary load bearing (i.e., shared load) connections.

d. Class D (Non-flight hardware only) - Applies to welds that are in noncritical elements and where failure would have no effect on the efficiency of a system and endangerment to personnel would not occur. Class D welds are typically used in connections where any expected load transfer at the weld would be negligible.

In addition to the above definitions, the following requirements shall also apply to weld classifications:

- If any weld intersects or overlaps another weld of a higher classification, then the lower classed weld shall be automatically upgraded to the higher of the 2 weld classes and subjected to the appropriate quality assurance provisions.
- If any weld falls within ½" of any higher classed weld, then it shall be automatically upgraded to the higher of the 2 weld classes and subjected to the appropriate quality assurance provisions.
- Class D welds are only intended for on-site (JSC) fabrication operations. All welds that are specified as Class D on weldments that are subcontracted off-site shall be recognized as Class C and shall be subject to all applicable Class C requirements specified herein. Class D welds shall only apply to welds made on common "structural" low carbon steels or 300 series CRES steels. HSLA, quenched & tempered steels, and "alloy" (e.g., chromium-molybdenum) steels shall not be considered for Class D welding. In addition, welds joining 2 or more dissimilar base metals shall not be allowable under Class D provisions.

## 3.2 WORK INSTRUCTIONS

Work instructions shall be generated for implementing this process specification. The work instructions shall contain sufficient detail to ensure that the manufacturing process produces consistent, repeatable results that comply with this specification. At JSC, these work instructions are approved as Detailed Process Instructions (DPIs) that describe in a detailed, step-by-step format the required procedures, equipment, and materials to be used for conducting a given process. If this manufacturing process is to be performed by an outside vendor, work instruction development shall be the responsibility of the vendor.

## 3.3 DESIGN REQUIREMENTS

a. The design of welded joints (including weld sizes) shall utilize adequate engineering analysis methods (e.g., stress analysis, fracture mechanics/fracture control, etc.) to ensure that the resultant connection strength is capable of successfully transferring the maximum load expected to pass between the interconnecting members and meet the required factors of safety and design margins.

b. All engineering drawings shall depict welded joints using the applicable symbols described in AWS A2.4.

c. The engineering drawing shall specify any additional or alternate testing or inspection requirements. Where spot, intermittent, or other special inspection requirements are specified that deviate from those stated herein, it shall be detailed on the drawing as a note or by using the applicable symbology described in AWS A2.4.

d. Class A welds are expected to be welds requiring full strength of the weld joint therefore, these welds shall be a groove design and· full penetration wherever possible. The ability to successfully perform radiographic examination on these weld joints shall be considered during design.

e. Class A welds which will be subjected to unusual or extreme service conditions (e.g., severe dynamic loading, cyclic, vibration, impact, corrosive, fatigue, extreme temp, etc.), shall be welded using a WPS qualified in accordance with AWS B2.1 "Special Test Weldments." This requirement shall be noted on the engineering drawing.

f. Unless otherwise specified on the engineering drawing or WPS, welded hardware will be delivered in the "as welded" condition. If required, any heat treatment processing

required shall be detailed on the engineering drawing and shall include notation that will reference NASA/JSC PRC-2001 or PRC-2003 as applicable.

g. Intermittent welding (skip welds) shall not be specified for Class A welds.

Intermittent welds shall not be specified for groove welds (square or prepared groove design) unless the unwelded portions of the joint are adequately supported to prevent one member from coming out of plane with the adjoining member.

## 4.0 REFERENCES

The standards listed below shall be considered a part of this specification to the extent specified herein. Unless otherwise indicated, the revision that is in effect on the date of invitation for bids or the date of request for proposals shall apply.

### a. Aerospace Industries Association of America (AIA) National Aerospace Standards (NAS)

| | |
|---|---|
| NAS 410 | *NAS Certification & Qualification of Nondestructive Test Personnel* |

### b. American Society of Nondestructive Testing (ASNT)

| | |
|---|---|
| SNT-TC-1A | *Personnel Qualification and Certification in Nondestructive Testing* |

### *c. American Welding Society (AWS) Standards*

| | |
|---|---|
| ANSI/AWS A2.4 | *Standard Symbols for Welding, Brazing and Nondestructive Testing* |
| ANSI/AWS A3.0 | *Standard Welding Terms and Definitions* |
| ANSI/AWS A5.X-AS.XX | *Specifications for Welding Electrodes, Rods, and Filler Metals (Applicable to Specific Alloy and Process as governed by this PRC)* |
| ANSI/AWS 82.1 | *Standard for Welding Procedure and Performance Qualification* |
| ANSI/AWS D1.1 | *Structural Welding Code – Steel* |
| ANSI/AWS D1.6 | *Structural Welding Code - Stainless Steel* |
| ANSIAWS QC-1 | *Standard for AWS Certification of Welding Inspectors* |

### d. Compressed Gas Association, Inc.

| | |
|---|---|
| G-11.1 | *Argon, Commodity Specification for* |

**e. Federal Documents**

| | |
|---|---|
| BB-C-101 | *Carbon Dioxide (CO2): Technical and U.S.P.* |
| BB-H-1168 | *Helium Federal Specification* |
| BB-O-925 | *Oxygen, Technical, Gas and Liquid* |

**f. Military Documents**

| | |
|---|---|
| MIL-A-18455 | *Argon, Technical* |
| MIL-P-27407 | *Propellant Pressurizing Agent, Helium* |
| MIL-P-27201 | *Military Specification, Propellant, Hydrogen* |

**g. NASA/JSC Documents**

| | |
|---|---|
| JPG 5322.1 | *Contamination Control Requirements Manual* |
| PRC-2001 | *Process Specification for the Heat Treatment of Steel Alloys* |
| PRC-2003 | *Process Specification for the Heat Treatment of Nickel Alloys* |
| PRC-5010 | *Process Specification for Pickling, Etching and Descaling of Metals* |
| PRC-6503 | *Process Specification for Radiographic Inspection* |
| PRC-6505 | *Process Specification for Magnetic Particle Inspection* |
| PRC-6506 | *Process Specification for Liquid Penetrant Inspection* |
| PRC-6510 | *Process Specification for Ultrasonic Inspection of Welds* |
| SOP-004.5 | *Control of Weld and Braze Filler Materials, Electrodes, and Fluxing Materials* |
| SOP-007.1 | *Preparation and Revision of Process Specifications* |

**h. NASA Headquarters**

| | |
|---|---|
| NASA-SPEC-5004 | *Welding of Aerospace Ground Support Equipment and Related Nonconventional Facilities* |
| NASA-STD-5009 | *Nondestructive Evaluation Requirements for Fracture Critical Metallic Components* |

## 5.0 MATERIAL REQUIREMENTS

All materials (base and filler materials as applicable) used in the welding of hardware per this specification, shall meet the requirements of an applicable JSC material specification unless otherwise specified. If a JSC material specification is not available, then an applicable commercial specification or a manufacturer's specification shall be used.

### 5.1 SHIELDING GASES

Allowable shielding gases (including purge gases) are listed in Table I. Gases purchased to alternate specifications shall be allowed provided they meet the minimum requirements of the specifications listed herein. Mixtures of these gases are allowed and the nominal mixture used for the qualification welding shall be that used for production and shall be listed on the WPS. Shielding and purging gas mixtures shall be subject to the qualification variable requirements listed in AWS B2.1. In addition:

a. Hydrogen gas in any concentration, may not be used for welding any alloys known to be susceptible to hydrogen related problems (e.g., alloy steels, Q&T steels, martensitic stainless steels, etc.).

b. Nitrogen shall not be used for shielding or purging in any welding operation governed under this specification.

c. All gases used for shielding or purging shall have a dewpoint of -40°F (minus 40 °C) or better.

### 5.2 FILLER METALS AND ELECTRODES

a) For dissimilar metal welds joining carbon steel to low alloy steel, or between two different low alloy steels, filler metal with strength levels matching the lower strength material shall be used. For dissimilar metal joints involving stainless and corrosion resistant steels, nickel alloys, and/or other materials, filler metal selection shall be based on that stated herein and approved by the responsible M&P Engineering authority prior to use.

b) All filler metals shall be used in accordance with a qualified WPS.

c) Filler metal configurations which cannot be procured to an AWS or other applicable filler metal specification shall meet an applicable NASA/JSC or other industry material specification and shall be approved by the responsible M&P Engineering authority prior to use.

d) Non consumable tungsten and tungsten alloy electrodes for GTAW shall conform to the applicable AWS specification.

e) Filler metals shall be listed on the engineering drawing.

f) For stainless steels, every effort should be made to select an "L" grade filler metal, when available.

**Table I. Allowable Shielding Gasses**

| GAS | DESCRIPTION | SPECIFICATION |
|---|---|---|
| Argon | Gas | MIL-A-18455 |
| Argon | Type 11, Grade B (Liquefied) | CGA G-11.1 |
| Carbon Dioxide | Grade B | BB-C-101 |
| Helium | Type I, Grade A | MIL-P-27407 |
| Hydrogen | Gas | MIL-P-27201 |
| Oxygen | Type I | BB-O-925 |

**Table II. Approved Filler Metals for Welding Carbon and Low Alloy Steel**

| MATERIAL GROUP | SMAW | GTAW/GMAW | FCAW |
|---|---|---|---|
| **M-1** | A5.1: E60XX, E70XX or A5.5: E70XX-A1 (a) | A5.28: E70S-2, E70S-3, ER70S-6 | A5.22: E70T-1, E70T-5 |
| **M-3** | A5.5: E70XX-A1 | A5.28: ER80S / E80C-D2 | (b) |
| **M-4** | A-5.5: E80XX-B2 | AS.28:ER80S,E80C-B2, ER80S / E80C-B2L | (b) |
| **M-5 (3% Cr max)** | AS.5: E90XX-B3 | AS.28:ER90S, E80C-B3, ER90S / E90C-B3L | (b) |

Notes:

(a) A5.5, E70XX-A1 shall be used for materials with maximum specified carbon greater than 0.30%.

(b) Filler metal to be used for joining must be compositionally compatible with base metal. Primary consideration shall be given to mechanical properties, corrosion resistance, and weldability, as applicable for the specific application.

**Table III. Approved Filler Metals for Welding Nickel Alloys**

| BASE METAL | SMAW (AWSA5.11) | GTAW/GMAW (AWS A5.14) |
|---|---|---|
| **Nickel 200**<br>**Nickel 201** | ENi-1 | ERNi-1 |
| **Monet 400** | ENiCu-7 | ERNiCu-7 |
| **Monel K500** | - | ERNiCu-7 |
| **Inconel 600** | ENiCrFe-1,<br>ENiCrFe-3 | ERNiCrFe-5,<br>ERNiCr-3 |
| **Inconel 601** | ENiCrFe-3,<br>ENiCrMo-3 | ERNiCr-3,<br>ERNiCrMo-3 |
| **Inconel 625** | ENiCrMo-3 | ERNiCrMo-3 |
| **Inconel 718**<br>**Inconel X750** | - | ERNiFeCr-2 |
| **Incoloy 800** | ENiCrFe-2,<br>ENiCrCoMo-1 | ERNiCr-3,<br>ERNiCrCoMo-1 |
| **Incoloy 800HT** | ENiCrFe-2 | ERNiCr-3 |
| **Incoloy 825** | - | ERNiFeCr-1 |

**Table IV. Approved Filler Metals for Welding Austenitic Stainless Steel**
**(AWS A5.9)**

| AWS M-8 Base Metal: | 304<br>308 | 304L | 309 | 310 | 316 | 316L | 321<br>347<br>348 |
|---|---|---|---|---|---|---|---|
| 301<br>302<br>304<br>308 | 308<br>308L | 308<br>308L | 308<br>308L<br>309<br>309L | 308<br>308L<br>309<br>309L<br>310 | 308<br>308L<br>316<br>316L | 308<br>308L<br>316<br>316L | 308<br>308L |
| 304L | 308<br>308L | 308L | 308<br>308L<br>309<br>309L | 308<br>308L<br>309<br>309L<br>310 | 308<br>308L<br>316<br>316L | 308L<br>316L<br>309L | 308L<br>347 |
| 309 | | | 309<br>309L | 309<br>309L<br>310 | 309<br>309L<br>316<br>316L | 309<br>309L<br>316<br>316L | 309<br>309L<br>347 |
| 310 | | | | 310 | 316<br>316L<br>310 | 316<br>316L<br>310 | 308<br>308L<br>310 |
| 316 | | | | | 316<br>316L | 316<br>316L | 308<br>308L<br>316<br>316L |
| 316L | | | | | | 309L<br>316L | 309L<br>316L |
| 321<br>347<br>348 | | | | | | | 309L<br>321<br>347 |

### 5.2.1Control and Storage

Welding electrodes shall be stored in a clean, dry, and controlled area that provides protection from contamination, physical damage, and commingling of alloys. Any form of electrodes or weld filler metal which is damaged, dirty, exhibits oxidation/corrosion or has been contaminated with water, oil, grease or any form of hydrocarbons shall not be used and shall be disposed of in accordance with an appropriate disposal procedure.

For JSC operations, welding electrodes and filler materials shall be controlled in accordance with SOP-004.5. Outside vendors shall provide control and storage according to the applicable material specification or manufacturer's recommendation, whichever is more rigid.

## 6.0 PROCESS REQUIREMENTS

All weldments shall be fabricated according to the requirements of this process specification and shall be performed using a WPS that have been qualified in accordance with the requirements of Section 8.0 except for that as detailed below.

Class D welds may be performed without the use of a specific qualified WPS within the following restrictions:

a) all other provisions of this specification are met,

b) the filler metal/electrodes used shall be within the same F-Number group of fillers as those used for the other higher classed welds in the same weldment or as approved by the responsible M&P Engineering organization where the only welds in the weldment design are Class D,

c) the filler metal shall be compositionally compatible with the base metal(s), and

d) welding shall be conducted within the recommendations of the specific filler metal manufacturer.

### 6.1 PROCESS-SPECIFIC REQUIREMENTS

Applicable to all processes, weld joints that are specified for intermittent welding shall have the ends of the parts, or departure from a straight weld line (e.g., square corner, etc.), welded regardless of the interval of the weld.

#### 6.1.1 Gas Tungsten Arc Welding

Additional filler metal shall be used with the GTAW process unless it can be demonstrated by weld qualification that weld cracking and other undesirable metallurgical conditions will not exist in the finished weld made without filler metal (autogenous weld). This method of welding shall be specified on an approved WPS.

#### 6.1.2 Gas Metal Arc Welding

This process shall be recognized to include both solid and metal cored wires.

The GMAW short circuiting transfer mode shall not be used for welding of flight hardware nor to join materials of greater than ¼" thickness unless specifically qualified and documented in a WPS. Thickness limitations for this process mode shall be as specified by AWS B2.1. The process can be used to deposit the root and additional passes in the root region of butt joints exceeding that specifically qualified for, up to a deposited weld metal thickness as allowed by the WPS. The GMAW short circuiting transfer mode shall not be used to make Class A welds.

### 6.1.3 Flux Cored Arc Welding

This process shall be recognized to include both self-shielding and dual shielding filler metals. Dual shielding is when the welding is performed using a flux cored wire and a separate shielding gas.

### 6.1.4 Shielded Metal Arc Welding

Base metals known to be susceptible to hydrogen related problems shall utilize only low hydrogen coated electrodes with this process.

## 6.3 PREHEATING

Preheat shall not exceed the temperature specified in the applicable WPS. In weld joints between different base metal types and/or thicknesses, the higher of the preheat requirements of the joint members shall apply.

### 6.3.1 Interpass Temperature

In weld joints between different base metal types and/or thicknesses, the higher of the interpass temperature requirements of the joint members shall apply. Minimum interpass temperature during welding shall be the same as the preheat temperature specified in the WPS and shall be maintained by the application of concurrent heat as necessary. The maximum interpass temperature for welding quenched & tempered steels shall be at least 50° F below the nominal tempering temperature.

## 6.4 POST-WELD HEAT TREATMENT (PWHT)

Postweld heat treatment, when required by the engineering drawing or WPS, shall be performed after completion of all welding in accordance with NASA/JSC PRC-2001 or PRC-2003, as applicable. Vibratory techniques shall not be used in place of thermal treatments. All postweld inspections shall be applied immediately following all post weld heat treatment activities with the exception of ASTM A514, A517, and A709 Grades 100 and 100W. Inspection of welds made on these alloys shall not occur less than 48 hours after welding.

## 6.5 WELD REPAIRS AND WELDED REPAIRS TO BASE METAL

All weld rework and welded repairs shall be performed using the WPS used for the original weld, a specific qualified WPS for that repair, or as approved by the responsible M&P engineering organization. Rework and repairs shall meet all of the requirements of the original drawing and any additional requirements documented in the WPS. Weld rework and repair does not include the correction of dimensional or other deficiencies of the groove/bevel preparation of weld joints by "buttering" or build up provided the area corrected by welding is fully consumed in the final weld. Also, the following requirements shall apply in the weld repair activity:

a. Mechanical Repairs. Defects shall be repaired by grinding, chipping, sanding, or machining the weld metal to the extent needed to completely remove the defects. For groove welds, the reinforcement shall not be machined past flush to the base metal. For fillet welds, the final machined weld profile shall meet the applicable profile and size requirements. In both cases, the repair shall be blended smoothly into the

unrepaired weld metal. All repairs shall be subjected to the same visual, surface and subsurface inspections as the unrepaired weld. Repairs requiring liquid penetrant inspection shall be etched in accordance with PRC-5010 prior to inspection.

b. Weld Repairs. Defects shall be repaired by grinding, chipping, sanding, thermal gouging or machining the weld metal to the extent needed to completely remove the defects. Except on low carbon steels, thermal gouging and cutting performed with carbon based electrodes shall require the excavated cavity be finished by grinding to sound metal. The final repair cavity shall be of a configuration suitable for welding. Prior to welding, the excavation shall be subjected to the same visual, surface and subsurface inspections as the unrepaired weld. Excavations requiring liquid penetrant inspection shall be etched in accordance with PRC- 5010 prior to inspection. Weld repairs shall be documented by the use of a weldment map or other record with sufficient detail to ensure identification of the weldment, identification of repair location(s), and type of defect. Repair welds shall be subjected to the same visual, surface and subsurface inspections as the unrepaired weld.

No more than two weld attempts shall be made to successfully repair a rejected flaw. If a second attempt is unsuccessful, a discrepancy report requiring review and dispositioning by the responsible Material Review Board (MRB) shall be generated. The level of documentation of repair welds shall, at a minimum, be consistent with that required for the original production weld.

c. Straightening. Welds or adjacent base metal which have been deformed by the welding operation may be straightened. All straightening operations shall take place at temperatures not to exceed the determined critical temperature for that alloy. All straightening operations shall be performed prior to any final inspection. Prior to performing any straightening activities on martenestic stainless steels consult with the responsible M&P Engineering authority

d. Base Metal Repairs. Repairs to base metal anomalies shall be brought to the attention of the responsible M&P Engineering authority for consideration of cause, prior to repair activities.

## 7.0 PROCESS VERIFICATION

Process verification shall consist of the inspections described in sections 7.1 to 7.3. In addition, the manufacturer shall assure that fabrication activities are carried out in a manner that meets the requirements of this process specification.

## 7.1 CERTIFICATION AND QUALIFICATION OF INSPECTION PERSONNEL

### 7.1.1 Visual Inspection

Personnel performing visual inspections of Class A, B and C welds shall be an AWS certified welding inspector (CWI). The CWI certification must be current.

### 7.1.2 Nondestructive Inspection

Personnel performing acceptance inspections of flight hardware (Class I, II, IIIW and GSE - see Appendix B) shall be qualified and certified, at a minimum, to Level 2 in accordance with NAS 410. Personnel performing acceptance inspections requiring Special Non-Destructive Evaluation (NDE) shall also be qualified and certified for Special NDE in accordance with NASA-STD-5009.

Personnel performing acceptance inspections of non-flight hardware (Class III, STE/D, mockup, and facility hardware - see Appendix B) shall be qualified and certified in accordance with either NAS 410 or SNT-TC-1A. Personnel making accept/reject decisions shall, at a minimum, be certified to Level 2. Level 3 personnel making accept/reject decisions shall have successfully completed a hands-on practical examination equivalent to the examination required for Level 2. Level 1 personnel may perform acceptance inspections under the direct supervision of a Level 2 but shall not make accept/reject decisions.

Formal qualification and certification is not required for personnel performing engineering evaluation inspections.

## 7.2 INSPECTION METHODS AND ACCEPTANCE CRITERIA

### 7.2.1 General

Inspections shall be performed in accordance with a written procedure by personnel certified in accordance with section 7.3.

### 7.2.2 Visual

Welds shall be visually inspected for conformance to the drawing requirements and acceptance shall be in accordance with the applicable Class A, B or C acceptance criteria in Appendix A.

### 7.2.3 Liquid Penetrant

a) Non-Flight Hardware: Liquid penetrant inspections shall be performed per PRC-6506. Unless otherwise specified, a fluorescent (Type I) Sensitivity Level 3 or 4 penetrant shall be used for Class A welds and a visible (Type II) penetrant shall be used for Class B welds. Acceptance shall be in accordance with the applicable Class A or B acceptance criteria in Appendix A.

b) Flight Hardware: Liquid penetrant inspections shall be performed per PRC- 6506. Unless otherwise specified, a fluorescent (Type I) Sensitivity Level 3 or 4 penetrant shall be used. Acceptance shall be in accordance with the applicable Class A or B acceptance criteria in Appendix A.

### 7.2.4 Magnetic Particle

a) Non-Flight Hardware: Magnetic particle inspections shall be performed per PRC-6505. Unless otherwise specified, the wet fluorescent continuous method shall be used for Class A welds and the dry continuous method may be used for Class B

welds. Acceptance shall be in accordance with the applicable Class A or B acceptance criteria in Appendix A.

b) Flight Hardware: Magnetic particle inspections shall be performed per PRC- 6505. Unless otherwise specified, the wet fluorescent continuous method shall be used. Acceptance shall be in accordance with the applicable Class A or B acceptance criteria in Appendix A.

### 7.2.5 Radiographic

a) Non-Flight Hardware: Radiographic inspections shall be performed per PRC- 6503. Acceptance shall be in accordance with the applicable Class A acceptance criteria in Appendix A. Gamma radiation sources shall not be used unless approved by the NASA/JSC M&P engineering organization. Approval of gamma radiation sources shall be based on demonstration of radiographic sensitivity equivalent to that obtainable with an X-ray source.

b) Flight Hardware: Radiographic inspections shall be performed per PRC-6503. Acceptance shall be in accordance with the applicable Class A acceptance criteria in Appendix A.

### 7.2.6 Ultrasonic

a) Non-Flight Hardware: Unless otherwise specified, ultrasonic inspections and acceptance shall be performed per PRC-6510, Class A.

b) Flight Hardware: Ultrasonic inspections and acceptance shall be performed per PRC-6510, Class A.

## 7.3 REQUIRED INSPECTIONS

Unless otherwise specified, all welds in a structure shall be subjected to the required inspections for the applicable weld class or classes. Unconsumed temporary or tack welds shall be subjected to the level of inspection required by the highest weld class specified in the design documentation.

### 7.3.1 Class A

Class A welds require visual, surface and subsurface inspections. Surface inspections shall be accomplished using the liquid penetrant method. Subsurface inspections shall be accomplished using the radiographic method. In cases where the weld configuration renders adequate radiographic inspection impractical, an alternate inspection method shall be utilized as approved by the responsible M&P Engineering authority. When ultrasonic inspection is selected and approved as an alternate to radiographic inspection, the ultrasonic inspection shall be performed as specified in section 7.2.5. When liquid penetrant is the only available option for inspection and is selected and approved as an alternate to radiographic inspection, the liquid penetrant inspection shall be performed as specified in section 7.2.3. For multi-pass welds, inspections shall be performed on every pass.

### 7.3.2 Class B

Class B welds require visual and surface inspections. Surface inspections shall be accomplished by using the liquid penetrant or magnetic particle method.

### 7.3.3 Class C

Class C welds only require visual inspection.

### 7.3.4 Class D

Class D welds only require inspection to verify the weld type, nominal size, length and location and to verify that the welds exhibit good workmanship practices. Good workmanship shall be defined as the presence of a uniform appearance and overall clean weld zones absent of spatter, arc strikes, tool marks and other obvious discontinuities. Where a size is not specified, the nominal weld size shall be per best shop practice and at the discretion of the manufacturing organization with the intent to utilize single pass welds wherever possible so as to avoid over-welding. An AWS CWI is not required for this inspection: This level of inspection may serve as a means of "in process" or "self-verification" where design and/or manufacturing protocols permit.

## 8.0 PROCESS DOCUMENTATION REQUIREMENTS

The WPS, PQR, and Welder Performance Qualification (WPQ) shall be prepared and retained as a permanent record and made available upon request to the NASA/JSC M&P organization for review. One copy of the WPS shall be maintained in the vicinity of the welding station and shall be readily accessible by the welding, inspection, supervision, and engineering personnel.

## 8.1 DEVIATIONS AND WAIVERS

Any deviations or waivers regarding the use of this process specification shall be requested in writing. This request shall be directed to the NASA/JSC M&P organization with the appropriate justification and rationale. A written response will be provided upon such a request.

## 8.2 WELDING PROCEDURE SPECIFICATION

A Welding Procedure Specification (WPS) is a qualified written working procedure that must be developed before beginning production for each unique weld type to be produced. Qualification support documentation in the form of a Procedure Qualification Record (PQR) shall be maintained on file to show proof of process/procedure capability using the WPS. The WPS shall be traceable by means of serialized nomenclature and shall show traceability to the applicable PQR(s). The WPS used for production welding shall meet the requirements of AWS B2.1 and shall be certified by the responsible M&P organization at the operating facility, prior to use in production. If a qualified WPS does not exist prior to welding of production parts, one shall be qualified according to AWS B2.1 “Standard Test Weldments” at a minimum. “Prequalified” or “Standard Welding Procedure Specifications” shall not be permitted for production use on Class A or B welds made on flight hardware.

## 8.3 PROCEDURE QUALIFICATION RECORD

A Procedure Qualification Record (PQR) is documentation to support the welding procedure specification to show proof of process/procedure capability. A PQR shall be unique and traceable, by means of serialized nomenclature. The PQR shall be process specific and specific to a unique weld type. Data required in the PQR shall include detailed descriptions of the test coupon configurations and joint designs, all pertinent material specifications, all pertinent essential process variables used, all destructive and nondestructive test results from the qualification sample set, and all required certifications from the approving organization. The PQR shall be approved by the responsible M&P organization at the operating facility.

## 9.0 WELDER QUALIFICATION

Welding shall be performed by a welder qualified and certified in accordance with AWS B2.1. Sufficiently detailed records shall be maintained to demonstrate continuity of performance qualification on a semi-annual (6 month) basis.

## 10.0 DEFINITIONS

**Welding Procedure Specification (WPS)** - A qualified written working procedure that must be developed before beginning production for each unique weld type to be produced. The WPS shall be traceable by means of serialized nomenclature and shall show traceability.

**Procedure Qualification Record (PQR)** - Documentation to support the welding procedure specification to show proof of process/procedure capability. A PQR shall be unique and traceable, by means of serialized nomenclature. The PQR shall be process-specific and specific to a unique weld type. Data required in the PQR shall include detailed descriptions of the test coupon configurations and joint designs, all pertinent material specifications, all pertinent essential process variables used, all destructive and nondestructive test results from the qualification sample set, and all required certifications from the approving organization.

**Welder Performance Qualification (WPQ)** - Documentation that shows that a welder has been tested in accordance with AWS 82.1 and shown competent to produce a sound weld for a specific welding process/base material/filler metal/position combination.

# Appendix A
# WELD ACCEPTANCE CRITERIA

## A1.0 GENERAL

If any of the acceptance criteria given below conflict with the engineering drawing requirements, then the stricter criteria shall apply. The symbol 'T' shall equal the nominal base metal thickness of the thinnest component in the welded connection. The weld length shall be the distance from end to end of the weld deposit or to a sharp change in weld direction where the angle of change in any direction is greater than 30° with a radius of less than 1/2". Unless otherwise stated, the criteria in this Appendix shall apply to all weld classes except Class D. Acceptance criteria for Class D welds are detailed in Section 7.1 of this specification. Alternate and/or additional acceptance criteria, when applicable, shall be specified in the design documentation.

Visual inspection of welds in all steels may begin immediately after the completed welds have cooled to ambient temperature. Acceptance criteria for ASTM A 514, A 517 and A 709 Grade 100 and 100 W steels shall be based on visual inspection performed not less than 48 hours after completion of the weld.

**Table A1.0. Acceptance Criteria**

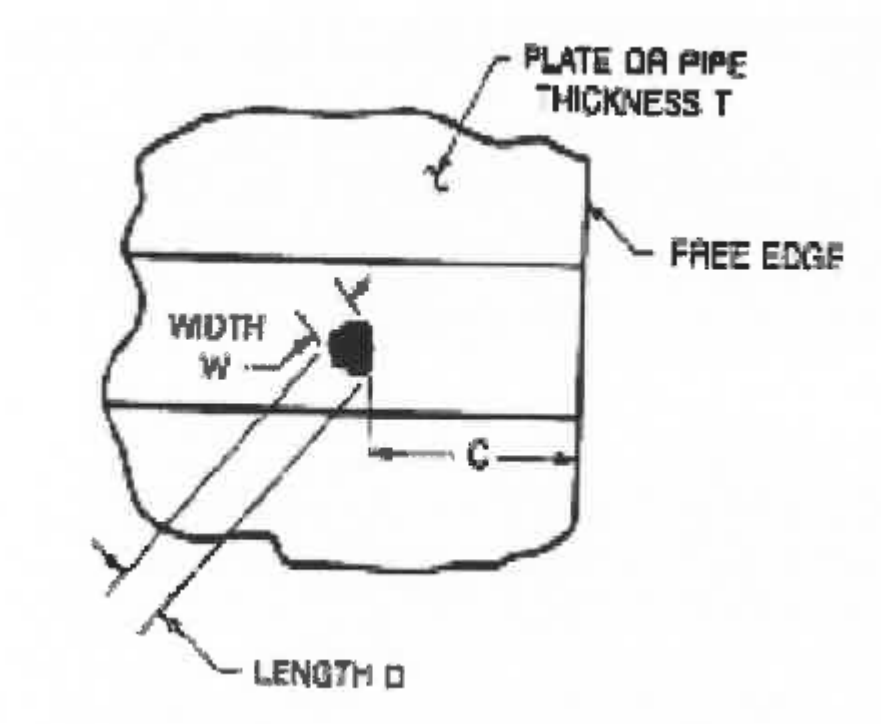
| ITEM | DISCONTINUITY TYPE | Class A | Class B | Class C |
|---|---|---|---|---|
| **1.0** | **CRACKS IN THE WELD OR BASE METAL** | None allowed | None allowed | None allowed |
| **2.0** | **OVERLAP (COLDLAP)** | None allowed | None allowed | None allowed |
| **3.0** | **INCOMPLETE FUSION** | None allowed | None allowed | None allowed |
| **4.0** | **INCOMPLETE PENETRATION(1)** | None allowed | None allowed | None allowed |
| **5.0** | **POROSITY – SURFACE(2)** | | | |
| **5.1** | Maximum Individual Size (3&4) | 0.25T or 0.030" whichever is less | 0.33T or 0.060" whichever is less | 0.50T or 0.090" whichever is less |
| **5.2** | Minimum Spacing | 8x the size of the larger adjacent pore | 4x the size of the larger adjacent pore | 2x the size of the larger adjacent pore |
| **5.3** | Maximum Accumulated Length in any 3" of Weld(5) | 1T or 0.12" whichever is less | 1.33T or 0.24" whichever is less | 2T or 0.36" whichever is less |
| **6.0** | **POROSITY-SUBSURFACE(2)** | | | |
| **6.1** | Maximum Individual Size (3&4) | 0.33T or o.060" whichever is less | 0.50T or 0.090" whichever is less | Not Applicable |
| **6.2** | Minimum Spacing | 4x the size of the larger Adjacent pore | 2x the size of the larger adjacent pore | Not Applicable |

| | | | | |
|---|---|---|---|---|
| **6.3** | Maximum Accumulated Length in any 3" of Weld(5) | 1.33T or 0.24" whichever is less | 2T or 0.36" whichever is less | Not Applicable |
| **7.0** | **INCLUSIONS(2)** | | | |
| **7.1** | Maximum Individual Size(3&4) | 0.33T or 0.060" whichever is less | 0.50T or 0.090" whichever is less | Not Applicable |
| **7.2** | Minimum Spacing | 4x the size of the larger adjacent inclusion | 2x the size of the larger adjacent inclusion | Not Applicable |
| **7.3** | Maximum Accumulated Length in any 3" of Weld(5) | 1.33T or 0.24" whichever is less | 2T or 0.36' whichever is less | Not Applicable |
| **8.0** | **UNDERCUT** | | | |
| **8.1** | Full Length of Weld, Maximum Depth | 0.002" | 0.015T or 0.002", whichever is greater | 0.025T or 0.002", whichever is greater |
| **8.2** | Maximum Individual Defect | 0.07T or 0.03", whichever is less | 0.10T or 0.05", whichever is less | 0.20T or 0.07", whichever is less |
| **8.3** | Maximum Accumulated Length in any 3" of Weld(5) | 0.20" | 0.60" | 1.00" |
| **9.0** | **FACE OR ROOT UNDERFILL-GROOVE WELDS** | | | |
| **9.1** | Full Length of Weld, Maximum Depth | 0.005" | 0.015T or 0.005", whichever is greater | 0.025T or 0.005', whichever is greater |
| **9.2** | Maximum Individual Defect | 0.07T or 0.03", whichever is less | 0.07T or 0.03", whichever is less | 0.07T or 0.03", whichever is less |
| **9.3** | Maximum Accumulated Length in any 3" of Weld(5) | 0.20" | 0.60" | 1.00" |
| **10.0** | **CRATERS** | | | |
| **10.1** | Maximum Depth | 0.20T or 0.03", whichever is less | 0.20T or 0.05",whichever is less | 0.20T or 0.05", whichever is less |
| **10.2** | Maximum Length | 1T | 1T | 2T |
| **11.0** | **ARC STRIKES AND GOUGE MARKS** | Unacceptable | Unacceptable | Unacceptable |
| **12.0** | **WELD REINFORCEMENT-MANUAL WELDS** | | | |
| **12.1** | Material < 0.125" | 1T maximum | No stated requirement | No stated requirement |
| **12.2** | Material 0.125" to 0.510" | 1T or 0.100" maximum, whichever is greater | No stated requirement | No stated requirement |
| **12.3** | Material > 0.510" | 0.170" maximum | No stated requirement | No stated requirement |

| | | | | |
|---|---|---|---|---|
| **13.0** | **PEAKING** | 3 degrees max | 5 degrees max | No stated requirement |
| **14.0** | **MISMATCH BETWEEN MEMBERS AFTER WELDING** | T/10 or 1/8", whichever is less | T/5 or 3/16", whichever is less | No stated requirement |
| **15.0** | FILLET **WELDS** | | | |
| **15.1** | Weld Profiles | See Fig. A2.0 | See Fig. A2.0 | See Fig. A2.0 |
| **15.2** | Weld Size (Size Stated on Drawing) | As shown by welding symbol | As shown by welding symbol | As shown by welding symbol |
| **15.3** | Minimum Weld Size (Size Not Stated on Drawing) - Single Side Fillet | 1.5T | 1.5T | 1.5T |
| **15.4** | Minimum Weld Size (Size Not Stated on Drawing) - Double Side Fillet | 1.0T | 1.0T | 1.0T |
| **15.5** | Maximum Weld Size - Size Stated on Drawing | | | |
| **15.6** | Materials 0.090" | 2.0x | 2.0x | 2.0x |
| **15.7** | Material 0.091" - 0.156" | 1.5x | 1.5x | 1.5x |
| **15.8** | Material 0.157" - 0.750" | 1.25x | 1.25x | 1.25x |
| **15.9** | Material 0.751" | 1.1x | 1.1x | 1.1x |
| **16.0** | **DISCOLORATION** | | | |
| **16.1** | Stainless Steel, Nickel and Cobalt Alloys | | | |
| **16.2** | All oxidation colors except for black | Acceptable | Acceptable | Acceptable |
| **16.3** | Black | Reject | Reject | Reject |
| **16.4** | **STEEL** | | | |
| **16.5** | All oxidation colors except for black | Acceptable | Acceptable | Acceptable |
| **16.6** | Black | Reject | Reject | Reject |
| **17.0** | **LOOSE OXIDATION AND SCALE** | Reject | Reject | Reject |

(1) Applicable to groove welds only.
(2) For all discontinuities approaching a free edge (See Figure A1.0), the closest edge of the discontinuity shall have clearance from the free edge 3X the largest of its dimensions or ≥2X the nominal weld throat, whichever is greater.
(3) Adjacent rounded discontinuities separated by ≤ 1X the length of the longer discontinuity shall be considered a single discontinuity.
(4) Adjacent elongated discontinuities separated by ≤ 3X the diameter of the larger discontinuity, shall be considered a single discontinuity.
(5) For weld lengths less than 3", the total sum of indications shall be an equivalent proportion of the weld length.

## FIGURE A1.0-DISCONTINUITY APPROACHING A FREE EDGE




C= Clearance spacing between closest edge of discontinuity and free edge

## Figure A2.0 -ACCEPTABLE AND UNACCEPTABLE WELD PROFILES

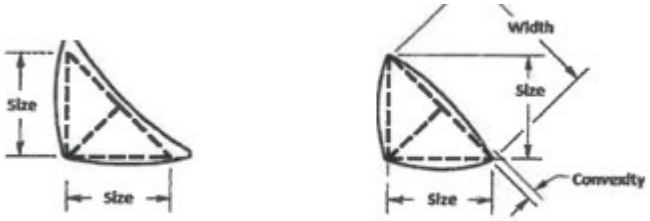



**Figure A2.0.1 Desirable Fillet Welds**

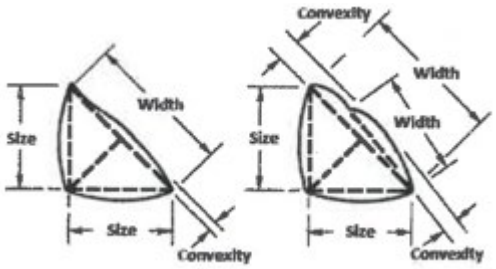



**Figure A2.0.2 Acceptable Fillet Welds**

Note: Convexity of a weld or individual surface bead with dimension width shall not exceed the value of the following table.

| Width of Weld Face or Individual Surface Bead | Maximum Convexity Allowed. |
|---|---|
| Width ≤ 5/16” | 1/16” |
| Width > 5/16” to Width < 1.00” | 1/8” |
| Width ≥ 1.00” | 3/16” |

**Table A2.0.1 Maximum Convexity Allowed**

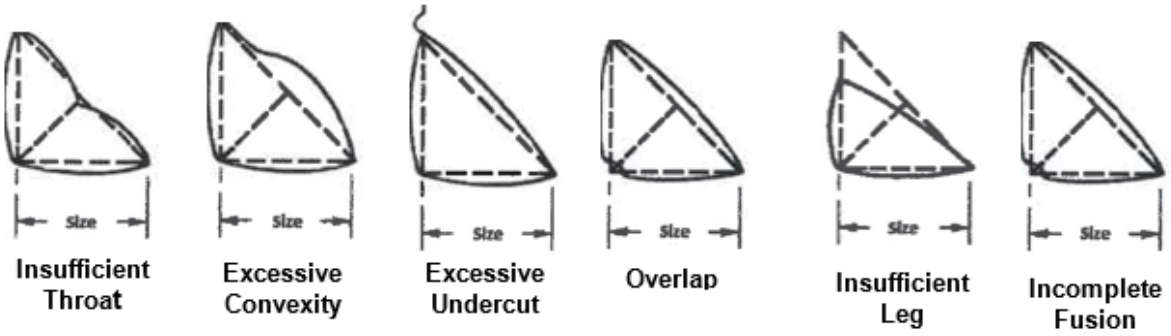



**Figure A2.0.3 Unacceptable Fillet Weld Profile**

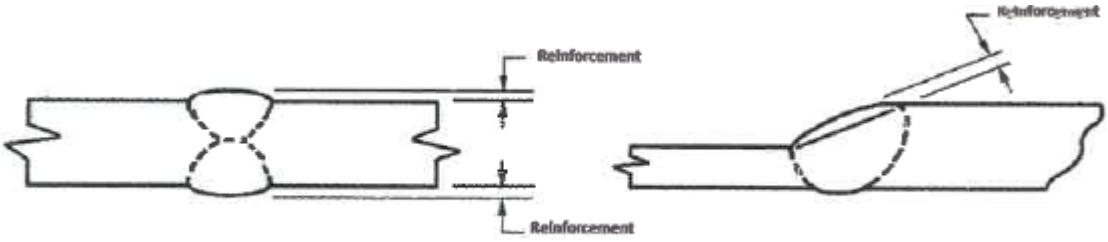



**Figure A.2.4 Acceptable Grove Weld Profiles in Butt Joints**

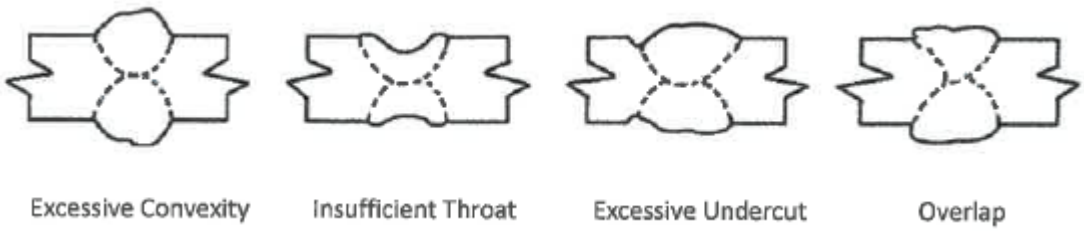



**Figure A.2.5 Unacceptable Grove Weld Profiles in Butt Joints**

## Appendix B Hardware Classification

| Hardware Classification | |
|---|---|
| Class I | Flight hardware - refers to any hardware acceptable for space flight use |
| Class II | Ground tests or training in a hazardous environment |
| Class IIIW | Hardware used in water immersion training |
| GSE | Ground Support Equipment |
| Class III | "Non-Flight hardware" refers to any hardware acceptable for use in non-hazardous training or displays |
| STE/D | Special Test Equipment/Devices used in facilities (buildings and related accessories), mockup mission equipment and engineering prototype and development hardware. |
| 1 E | Any combination of hardware and software that is developed and operated to answer a scientific or engineering question that cannot be addressed in a terrestrial environment. Operating this hardware does not provide mission critical functions, and hazards are eliminated or controlled such that the safety of the crew, the space vehicle, or launch vehicle are not compromised. |