Space Station Program Robotic Systems Integration Standards

Volume 1: Robotic Accommodation Requirements

International Space Station Program

Revision C

September 1998

National Aeronautics and Space Administration
International Space Station Program
Johnson Space Center
Houston, Texas

REVISION AND HISTORY PAGE

REV.	DESCRIPTION	PUB. DATE
--	BASELINE ISSUE (REFERENCE SSCBD BB003023 EFF. 05-03-91)	05-91
A	REVISION A (REFERENCE SSCBD BB003543 EFF. 11-23-93)	10-93
B	REVISION B (REFERENCE SSCD: 000002, EFF. 2/07/94) 9/12/94	
C	REVISION C (REFERENCE SSCN: 00843, EFF. 10/15/98) 04/20/99	

INTERNATIONAL SPACE STATION PROGRAM

SPACE STATION PROGRAM ROBOTIC SYSTEMS INTEGRATION STANDARDS
VOLUME 1: ROBOTIC ACCOMMODATION REQUIREMENTS

September, 1998

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PREFACE

The Robotic Systems Integration Standards (RSIS) provides robotic systems integration design requirements, considerations, and approved standards for the International Space Station Program (ISSP). It contains contractually binding design requirements for the accommodation of robotic systems in the extravehicular environment of Space Station. The appendices provide an abbreviation and acronym list, and a glossary.

The contents of this document are intended to be consistent with the tasks and products to be prepared by NASA Product Groups and ISSP participants as defined in SSP 41000, System Specification for the International Space Station. The Space Station Program Robotic Systems Integration Standards, Volume 1: Robotic Accommodation Requirements, shall be implemented on all new ISSP contractual and internal activities and shall be included in any existing contracts through contract changes. This document is under the control of the Space Station Control Board, and any changes or revisions will be approved by the authorized representatives of the ISSP participants.

NASA/CSA

INTERNATIONAL SPACE STATION PROGRAM

SPACE STATION PROGRAM ROBOTIC SYSTEMS INTEGRATION STANDARDS VOLUME 1: ROBOTIC ACCOMMODATION REQUIREMENTS

SEPTEMBER 1998

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For NASA	DATE

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For CSA (Approval with condition as stated in CSA letter CMNASA 0397 dated December 1, 1998)	DATE

INTERNATIONAL SPACE STATION PROGRAM

SPACE STATION PROGRAM ROBOTIC SYSTEMS INTEGRATION STANDARDS VOLUME 1: ROBOTIC ACCOMMODATION REQUIREMENTS

LIST OF CHANGES

September, 1998

All changes to paragraphs, tables, and figures in this document are shown below:

SSCBD	ENTRY DATE	CHANGE	PARAGRAPHS
BB003543	10-93	REVISION A	ALL
ISSP Sync-up	3-94	REVISION B	ALL
ISSP Sync-up & Verification Addition	9-98	REVISION C	ALL

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APPENDICES

TABLES

1.0 INTRODUCTION

1.1 PURPOSE

SSP 30550, Volume 1, Robotic Systems Integration Standards; Robotic Accommodation Requirements, levies design requirements on Space Station equipment to provide for the accommodation of dexterous robotic systems. These design requirements are intended for use by external equipment designers to ensure proper integration between their equipment and the various robotic systems. The overall objective of these requirements is to ensure safe, simple, and consistent robotic accommodations are incorporated into applicable equipment design.

1.2 SCOPE

This document establishes performance, design, development, and integration requirements for dexterous robotic system interfaces and the tools associated with those interfaces. The requirements specified herein are applicable to all hardware and equipment designated to interface with the Space Station dexterous robotic systems, including worksite mounting locations and support equipment.

The requirements contained in SSP 30550, Volume 1, relate generically to all Space Station dexterous robotic systems except where explicitly noted. Detailed accommodation requirements specific to a particular robotic system can be found in the Interface Control Document (ICD) associated with that system. In addition, requirements and information pertaining to the characteristics and interfaces of a particular Space Station robotic system can be found in the System Requirement Document (SRD) and/or the Robotic System User's Guide (RSUG) for that system.

A number of requirements in SSP 30550, Volume 1, refer the reader to other program and non-program documents and standards. These references are for information only. The applicability of these documents to the International Space Station Program (ISSP) is governed by SSP 41000 and the Segment Specifications.

Within this document, the term "robotic system" refers to the dexterous robotic systems used on the Space Station. In the context of teleoperations, the human operator is included as an integral part of the robotic system.

1.3 PRECEDENCE

This document is considered an applicable document to SSP 41000, System Specification - International Space Station (ISS). In case of conflict between this document and SSP 41000, with respect to robotic system accommodation requirements for the ISSP, SSP 41000 will take precedence.

1.4 DELEGATION OF AUTHORITY

SSP 30550, Volume 1 is the responsibility of the Space Station Program Office (SSPO) and is subject to Space Station Control Board (SSCB) change control.

1.5 WAIVER/DEVIATION

Deviations and waivers from the requirements in SSP 30550 Volume 1 may be requested on a case by case basis. The process for obtaining deviations and waivers will begin with a formal presentation of the proposed deviation/waiver, in the form of a change request, to the Mobile Servicing System (MSS) Integration Panel (MIP). The MIP will provide a recommended disposition of the deviation/waiver from the panel membership and refer the deviation/waiver to the appropriate ISSP control board for final disposition.

1.6 HOW TO USE THE DOCUMENT

SSP 30550, Volume 1, is comprised of a main body and two Appendices. The main body of the document contains design requirements applicable to external equipment designated to interface with dexterous robotic systems (including worksite mounting locations, and support equipment). The two Appendices provide an abbreviations / acronyms list and a glossary.

Within the document, an undetermined requirement or value within a requirement is shown as “ To Be Determined” (TBD); However, when text for a requirement or a value within a requirement has been proposed, it is shown as “To Be Resolved” (TBR). The number in parenthesis following the TBR [e.g.. TBR (14) is based on existing information and is considered to be contractually binding.

For simplicity, throughout SSP 30550, Volume 1, the term “tool” is used when the subject refers to robotic tools and common tools. In the case where both tool categories are not applicable, specific tool category names (e.g. common tool) will be used. Refer to the Glossary (Appendix B) for the differentiation between robotic and common tools.

2.0 APPLICABLE DOCUMENTS

The following documents of the date and issue shown include specifications, models, standards, guidelines, handbooks, and other special publications. “Current Issue” is shown in parenthesis in place of the specific date and issue when the document is under SSCB control. The status of documents identified by “Current Issue” may be determined from the Space Station Program Baseline Activity Index and Status Report.

The documents in this paragraph are applicable to the extent specified herein. Inclusion of applicable documents herein does not in any way supersede the order of precedence specified in Paragraph 1.3.

SSP 30240	Space Station Grounding Requirements (Current Issue)
SSP 30243	Space Station System Requirements for Electro Magnetic Capability (Current Issue)
SSP 30245	Space Station Electrical Bonding Requirements (Current Issue)
SSP 30559	Structural Design and Verification Requirements (Current Issue)
SSP 42003	MSS to Space Station ICD, Part 1 (Current Issue)
SSP 42004	MSS to User ICD, Part 1 (Current Issue)
SSP 50005	ISS Flight Crew Integration Standard (Current Issue)

3.0 REQUIREMENTS

This section defines requirements to be incorporated into ORUs, hardware, and worksites that are to be compatible with dexterous robotics.

3.1 INTRODUCTION

This section is divided into three main categories, ORU/Manipulated Hardware (OMH) Design, Worksite Design, and Feature Integration and Design. In addition to these three categories, Hazards to Robotic Systems are also addressed. It is important to note that the requirements included in this document are only those which are unique to dexterous robotics. The first two sections, OMH Design Requirements and Worksite Design Requirements provide for the robotic design in each distinct area. The Feature Integration and Design Requirements section identifies robotic integration and design requirements for each feature typically occurring on an OMH item or worksite.

In this document, the term OMH applies to any item that is handled (or is physically contacted) by the Dexterous Robot. It applies equally to ORUs, tools, covers, latches, and non-ORU equipment that is operated or handled by the robot. Table 3.1-1 lists the ISS ORUs, hardware items and tools that are to be manipulated by dexterous robots. The list is partitioned by ISS segment, OMH provider, and OMH integrator. These items and the associated worksites are to be designed to allow the dexterous robot to accomplish the complete on-orbit maintenance task. This includes accessing and removing the replacement ORU from the carrier on which it is launched, temporarily stowing the replacement and/or failed ORU during the maintenance activities, accessing the failed ORU, removing and replacing the ORU and, finally restowing the failed ORU on the carrier for return from orbit. It includes the operation of any enclosures, fasteners, valves and tooling required to accomplish the activity.

The external ISS OMH which is required to be compatible with dexterous robots is identified in Table 3.1-1.

The addition of dexterous robot compatible or maintainable ORUs, and equipment deployment functions into the ISS program is predicated on including such OMH or equipment in table 3.1-1. The inclusion of ORUs or equipment deployment functions in Table 3.1-1 requires proof, to the MIP, of intent to comply with all applicable requirements in this RSIS Volume 1 at the revision level assigned at the time of inclusion.

TABLE 3.1-1 INTERNATIONAL SPACE STATION (ISS) EXTERIOR HARDWARE DESIGNATED FOR DEXTEROUS ROBOTIC MANIPULATION

Segment	External OMH		
MSS	Dexterous Robotic Compatible OMH		
	Arm Computer Unit		
	Camera Light and Pan Tilt Assembly (CLPA)		
	Canadian Remote Power Controller Module (CRPCM)		
	Video Distribution Unit (VDU)		
	7/16 Inch Socket Extension Tool		
USOS	Dexterous Robotic Compatible OMH	OMH Provider (Product Group)	OMH Integrator (Product Group)
	ACS Baseband Signal Processor (S1/P1 only)	1	1
	ACS TDRSS Transponder (S1/P1 only)	1	1
	Battery Charge Discharge Unit (BCDU)	2	2
	Battery Subassembly	2	2
	Beta Gimbal Electronic Control Unit (ECU)	2	2
	Charged Particle Directional Spectrometer (CPDS) - EVCPDS	GFE	1
	DC Switch Unit (DCSU)	2	2
	DC to DC Converter Unit (DDCU) - except DDCU-HP	2	1&2
	Main Bus Switching Unit (MBSU)	2	1
	MDM - all types except on MT & PMA-1	1	1&2
	MDM - Enhanced Space Station	1	1
	Pump Flow Control Subassembly (PFCS)	2	2
	Remote Power Controller Module (RPCM) - all external types not on Mobile Transporter	2	1&2
	Rotary Joint Motor Controller (RJMC) - TRRJ only	1	1
	Robotic Micro Conical Tool (RMCT)	GFE	GFE
	Robotic Offset Tool	2	2
	Sequential Shunt Unit (SSU)	2	2
	Video Switch	1	1
	Photovoltaic Control Unit (PVCU)	2	2
	External Television Camera Group (ETVCG) with external Video Luminaire (S1/P1/S3/P3 only)	1	1
	Dexterous Robotic Tasks		
	Mast Canister Roll for ECU changeout	2	2
	S0 Bay 3 SPDA Doors	1	1
	Mobile Transporter Stop	1	1
	Tether Shuttle Stop	1	1

External Robotic Payloads	Dexterous Robotic Compatible OMH		
	EXPRESS Pallet Adapters		

3.2 ORU/MANIPULATED HARDWARE DESIGN REQUIREMENTS

This section defines the robotic requirements to be incorporated into the design of ORU/Manipulated Hardware (OMH). Where applicable section 3.4 Feature Integration and Design should also be invoked.

3.2.1 OMH General Requirements

The following general requirements are provided to ensure that Space Station external equipment is compatible with robotic systems. The requirements in this section relate to the highest level considerations for: Simplicity, Standardization, Human/Machine Compatibility, and Maintainability.

3.2.1.1 Installation/Attachment Configuration Standardization DELETED

3.2.1.2 Standard Tools

OMH designs SHALL be compatible with the standard robotic end effector or tool set defined in SSP 42004 Sections G, J, L, and M.

3.2.1.3 Standard Interfaces and Hardware

External equipment designated for operation, maintenance, and integration with robotic systems SHALL employ interfaces and hardware and associated access envelopes as defined in SSP 42004 Sections C, D, E, F, G, H, J, and K.

3.2.1.4 Lockwire and Staking DELETED

3.2.1.5 Single End Effector Operations

OMH SHALL be designed such that insertion, removal, and actuation can be accomplished by a single robot end effector. A second end effector may be used to stabilize the manipulator, provide alternative camera viewing, or to temporarily hold OMH during portions of an operation for which manipulator stabilization is not required.

3.2.1.6 Soldering, Welding, and Brazing DELETED

3.2.1.7 Interchangeability

OMH of the same or similar form but having different functional properties SHALL not be physically interchangeable.

3.2.1.8 Keying
OMH SHALL be keyed so that it will be physically impossible to install them incorrectly.

3.2.1.9 Thermal Interfaces
All OMH SHALL be transportable while exposed to the on-orbit space station environment for up to TBD hours without an active thermal interface to the robotic system.

3.2.1.10 Hazards DELETED

3.2.1.11 Straight Line Motion DELETED

3.2.1.12 End-to-End Robot Compatibility DELETED

3.2.1.13 OMH Color Selection
OMH colors SHALL be white or black as specified in SSP 50005 paragraph 9.5.3.2.i.8.a.

3.2.2 OMH Forces and Loads

3.2.2.1 Maximum OMH Size
The maximum external dimensions of OMH which are to be inserted, removed, stowed, and transported on the dexterous robotic system SHALL be in accordance with line 1 of Table 3.2.2.1-1.

3.2.2.1.1 Maximum Support Equipment Size
The maximum external dimensions of support equipment required to stow and transport OMH with the dexterous robot system SHALL be in accordance with line 2 of Table 3.2.2.1-1.

3.2.2.1.2 Maximum Size Stowed and Translated Equipment
The maximum external dimensions of the combination of OMH and associated support equipment which is to be stowed and transported by the dexterous robot system SHALL be in accordance with line 3 of Table 3.2.2.1-1.

TABLE 3.2.2.1-1 MAXIMUM EQUIPMENT SIZE

ITEM	LENGTH	WIDTH	HEIGHT
1. OMH	5.25 ft (1.6 m)	5.25 ft (1.6 m)	5.25 ft (1.6 m)
2. Support Equipment	5.25 ft (1.6 m)	5.25 ft (1.6 m)	5.25 ft (1.6 m)
3. OMH and Support Equipment Summation	5.25 ft (1.6 m)	5.25 ft (1.6 m)	5.25 ft (1.6 m)

3.2.2.2 Maximum OMH Mass and Moment Of Inertia

Equipment designated to be manipulated by a dexterous robotic system SHALL have a maximum mass of 1320 lbm (600 kg) and have a mass moment of inertia no larger than 202 slug-ft^2 (275 kg-m^2) measured from a Micro, Modified Micro, or a H-handle grasp fixture. Equipment having a Micro Conical or Modified Micro Conical grasp fitting SHALL have a maximum mass of 1320 lbm (600 kg) and have a mass moment of inertia no larger than 148 slug-ft^2 (200 kg-m^2) measured from the fitting.

3.2.2.3 Standard Grasp Area Maximum Loads

When the OMH is hard-docked, standard grasp areas and their associated load paths SHALL have the strength to withstand combined loads as follows: H-handle grasp fixture 250 ft-lbs (339 N-m) torque, 50 lbf (222 N); Micro and Modified Micro grasp fixtures 125 ft-lbs (169.5 N-m) torque, 50 lbf (222 N); Micro Conical and Modified Micro Conical grasp fittings 125 ft-lbs (169.5 N-m) torque, 50 lbf (222 N).

When a standard grasp area on OMH will be used by a dexterous robotic system, load paths through OMH components SHALL have strength to withstand:

i) inertia loads induced by the dexterous robotic system consistent with the maximum loads stated above when the OMH is attached only by the end effector or tool.
ii) constrained loads induced by the dexterous robotic system consistent with the maximum loads stated above when the OMH is attached to both the end effector or tool and at the corresponding worksite through the OMH.

3.2.2.4 Maximum Force

The force required for insertion, removal, and actuation of the OMH by the dexterous robot SHALL not exceed 20 lbf (89 N).

3.2.2.5 Maximum Size Translated Equipment <u>DELETED</u>

3.2.2.6 Maximum Size Movable Equipment <u>DELETED</u>

3.3 WORKSITE DESIGN REQUIREMENTS

This section defines the robotic requirements to be incorporated into the design of robotic worksites. The requirements contained in this section must be utilized in conjunction with Sections 3.2 and 3.4 where applicable.

3.3.1 Worksite General Requirements

3.3.1.1 Straight Line Motion

Worksites for OMH which is to be inserted, removed, or actuated SHALL be designed so that insertion, removal, or actuation of the manipulated hardware is possible by moving the OMH through sequential single Cartesian degree-of-freedom motions. The sequential single Cartesian degree-of-freedom motions for ORU insertion begins at the point where the ORU back plane enters the receptacle volume (3 inches (76 mm) from coarse alignment guides).

3.3.1.2 Color Selection <u>**DELETED**</u>

3.3.1.3 Worksite Color Selection

The worksite colors SHALL be white or black as specified in SSP 50005 paragraph 9.5.3.2.i.8.a.

3.3.1.4 Controls and Displays

Robotic controls and displays SHALL not be placed at robotic system worksites.

3.3.1.5 Worksite Interfaces

OMH of the same size, shape, and function within a segment-level major component or within multiple segment-level major components provided by the same developer SHALL incorporate the same common ORU-to-worksite interface hardware.

3.3.2 Worksite Identification and Labeling <u>**DELETED**</u>

3.3.2.1 Consistent Vertical Orientation (Local Vertical) <u>**DELETED**</u>

3.3.2.2 Unique Identification <u>**DELETED**</u>

3.3.3 Worksite Accessibility and Clearance

3.3.3.1 Unobstructed Remote Visual Access

Remote visual access SHALL be provided such that the OMH can be inserted and removed without visual obstruction by adjacent hardware and structure when camera positions and fields of view are in accordance with the February 17, 1995 release of the SPDM model.

3.3.3.2 OMH Translation Clearance <u>**DELETED**</u>

3.3.3.3 Manipulator Clearance

A minimum of 3 inches (76 mm) of clearance SHALL be provided between the manipulator (excluding the end effector, associated tooling, and OMH) and adjacent equipment for translation paths and worksite structure when using the February 17, 1995 release of the SPDM model.

3.3.3.4 End Effector/Tool Clearance

Clearances for the dexterous end effectors and tools SHALL be in accordance with the access envelopes defined in SSP 42004 Section C paragraph C3.2.2.1; Section D paragraph D3.2.2.1; Section E paragraph E3.2.1.1; Section G paragraph G3.2.2.1; Section H paragraph H3.2.2.1; and Section K paragraph K3.2.2.1.

3.3.3.5 OMH Clearance

Element equipment within 3 inches (76 mm) of the OMH when translating along the OMH insertion and removal design corridor SHALL be designed to withstand a force of 35 lbf [156 N].

3.3.3.6 Accessibility DELETED

3.3.3.7 Equipment Spacing DELETED

3.3.3.8 Rear Access DELETED

3.3.3.9 Thermal Blankets DELETED

3.3.4 Maintenance Support Facility Requirements

3.3.4.1 Service Points for Fluid Systems DELETED

3.4 FEATURE INTEGRATION AND DESIGN REQUIREMENTS

This section defines the integration and design requirements associated with each feature in the OMH and worksite design. The requirements contained in this section must be utilized in conjunction with sections 3.2 and 3.3 where applicable.

3.4.1 Grasp Interface Integration and Design Requirements

3.4.1.1 Grasp Interface Integration to OMH and Worksites

3.4.1.1.1 Standardization

Dexterous robotic grasp interfaces for OMH of the same size, shape and function SHALL be the same with respect to type and position of the grasp interface.

3.4.1.1.2 Interface Quantity

OMH SHALL be physically inserted, removed, manipulated, and actuated using one dexterous robotic grasp interface except when multiple fasteners require actuation, in which case more than one grasp interface can be used for actuation.

3.4.1.1.3 Location

Dexterous robotic grasp interfaces on OMH SHALL be placed such that the X axis of the grasp interface is parallel to the OMH insertion and removal path where the coordinate system is as defined in SSP 42004 Sections C for H-handle and Micro Fixtures: Section D for Micro Conical Fittings: Section H for Modified Micro Fixtures: and Section K for Modified Micro Conical Fittings.

3.4.1.1.4 Local Torque Reaction DELETED

3.4.1.1.5 Standard Grasp Area

OMH with a maximum mass moment of inertia less than 73 slug-ft^2 (98.9 kg-m^2) (measured from the grasp area) SHALL incorporate a H-handle fixture, Micro fixture, Modified Micro fixture, Micro Conical fitting, or a Modified Micro Conical fitting for handling.

3.4.1.1.6 Reinforced Grasp Area

OMH with a maximum mass moment of inertia between 73 slug-ft^2 (98.9 kg-m^2) and 202 slug-ft^2 (275 kg-m^2) (measured from the grasp area) SHALL incorporate an H-handle fixture for handling.

3.4.1.1.7 Load Path Strength DELETED

3.4.1.1.8 Interference DELETED

3.4.1.1.9 Clearance DELETED

3.4.1.1.10 Relocatable Grasp Interfaces

Relocatable dexterous robotic grasp fixtures and fittings SHALL be capable of being removed, stowed and installed using one manipulator arm.

3.4.1.2 Grasp Interface Design

Grasp interfaces and associated clearance envelopes SHALL be in accordance with SSP 42004, Section C for H-handle and Micro Fixtures, Section D for Micro Conical Fittings, Section H for Modified Micro Fixtures, Section J for Modified Micro Fixtures which are to be actuated by the Robotic Offset Tool, Section K for Modified Micro Conical Fittings, and Section L for robotic tool to dexterous robot end effector grasp interfaces.

3.4.1.2.1 Shape DELETED

3.4.1.2.2 Surface DELETED

3.4.1.2.3 Alignment DELETED

3.4.1.2.4 Status Indicators DELETED

3.4.2 Fastener Integration And Design Requirements

3.4.2.1 Fastener Integration To OMH and Worksites

3.4.2.1.1 Easily Distinguishable DELETED

3.4.2.1.2 Direct Access

Fasteners that are not collocated with a grasp fixture SHALL provide the clearance and target viewing envelopes specified in SSP 42004 paragraph G3.2.2.1.

3.4.2.1.3 Fastener Clearance DELETED

3.4.2.1.4 Fastener Engagement

The OMH which has a dexterous robot actuated fastener SHALL provide indication of fastener to structure engagement. This may be accomplished by providing a hardware status indicator or by specification of the number of fastener turns and associated fastener final torque value.

3.4.2.1.5 Fastener Alignment Provisions

Alignment aids shall be provided to assist in mating the tool with the fastener head and positioning the fastener into its proper location.

3.4.2.1.6 Safety DELETED

3.4.2.2 Fastener Design

3.4.2.2.1 General Fastener Requirements

3.4.2.2.1.1 Latches/Handles/Operating Mechanism

All robot operated latches, handles, and fasteners, an operating mechanisms shall be designed to be latched/unlatched and opened/closed with one manipulator.

3.4.2.2.1.2 Fastener Actuation

The actuation of a fastener shall not require force or torque to be applied in more than one degree of freedom. Each actuation requires no more than one DOF force and one DOF torque.

3.4.2.2.1.3 Captive Fasteners

All fasteners actuated by the dexterous robot SHALL be captive.

3.4.2.2.1.4 Captive Fasteners DELETED

3.4.2.2.1.5 Fastener Actuation Load Limits

3.4.2.2.1.5.1 Fastener Actuation Load Limits DELETED

3.4.2.2.1.5.2 Minimum Installation Torque - All Fasteners

The minimum torque required to be applied to a fastener head to tighten a single threaded fastener SHALL be 3.9 ft-lbf (5.3 N-m).

3.4.2.2.1.5.3 Tightening and Loosening Torque Accuracies DELETED

3.4.2.2.1.5.4 Minimum Removal Torque - All Fasteners DELETED

3.4.2.2.1.5.5 Maximum Installation Torque - Collocated Fasteners

The maximum torque required to be applied to a fastener head to install a single fastener which is collocated with a grasp interface SHALL be 42.5 ft-lbf (58 N-m).

3.4.2.2.1.5.6 Maximum Removal Torque - Collocated Fasteners

The maximum torque required to be applied to a fastener head to remove a single fastener which is collocated with a grasp interface SHALL be 42.5 ft-lbf (58 N-m).

3.4.2.2.1.5.7 Maximum Installation Torque - Non-Collocated Fasteners

The maximum torque required to be applied to a fastener head to install a single fastener which is not collocated with a grasp interface SHALL be 25 ft-lbf (33.89 N-m).

3.4.2.2.1.5.8 Maximum Removal Torque - Non-Collocated Fasteners

The maximum torque required to be applied to a fastener head to remove a single fastener which is not collocated with a grasp interface SHALL be 25 ft-lbf (33.89 N-m).

3.4.2.2.1.5.9 Maximum Actuation Force - All Fasteners

Acquisition and actuation of fastener mechanisms and any associated fastener locking mechanisms SHALL require no more than 5 lbf (22.2 N) of axial force from the torque driver.

3.4.2.2.1.5.10 Maximum Survivable Actuation Force - All Fasteners

Fastener mechanisms SHALL be designed to sustain loads induced by an axial force from the torque driver of 20 lbf (89 N).

3.4.2.2.1.6 Push Force DELETED

3.4.2.2.1.7 Ruggedness DELETED

3.4.2.2.1.8 Head Configuration

Fastener heads SHALL be configured in accordance with SSP 42004 Section C paragraph C3.2.2.2.1 for fasteners collocated with H-handle and Micro Fixtures; Section D paragraph D3.2.2.2.1 for fasteners collocated with Micro Conical Fittings; Section G paragraph G3.2.2.2 for non-collocated fasteners; Section H paragraph H3.2.2.2.1 for fasteners collocated with Modified Micro Fixtures; or Section K paragraph K3.2.2.2.1 for fasteners collocated with Modified Micro Conical Fittings.

3.4.2.2.1.9 Fastener Knobs/Handles DELETED

3.4.2.2.1.10 Self-Tapping Fasteners

Self-tapping fasteners SHALL not be used.

3.4.2.2.1.11 Non-Actuation Loads on Fasteners DELETED

3.4.2.2.1.11.1 Non-Actuation Forces DELETED

3.4.2.2.1.11.2 Non-Actuation Torques - All Fasteners DELETED

3.4.2.2.2 Threaded Fastener Requirements

3.4.2.2.2.1 Thread Type DELETED

3.4.2.2.2.2 Maximum Installation Torque See 3.4.2.2.1.5.5 & 3.4.2.2.1.5.7

3.4.2.2.2.3 Maximum Removal Torque See 3.4.2.2.1.5.6 & 3.4.2.2.1.5.8

3.4.2.2.2.4 Locking DELETED See 3.4.2.2.1.5.9

3.4.2.2.2.5 Left-Handed Threads DELETED

3.4.2.2.2.6 Thread Fastening Direction

Fasteners and fastening mechanisms designed to secure OMH and associated support equipment to robotic worksites or the robotic system itself SHALL fasten with clockwise application of torque from the dexterous robot and unfasten with counter clockwise application of torque from the dexterous robot.

3.4.2.2.2.7 Positive Disengagement DELETED

3.4.2.2.3 Non-Threaded Fastener Requirements DELETED

3.4.2.2.3.1 Fastener Force/Torque DELETED

3.4.2.2.3.2 Minimum Fastener Size DELETED

3.4.2.2.4 Quick Release Fastener Requirements

3.4.2.2.4.1 Connect/Disconnect

Quick-release fasteners SHALL require a maximum of a 45 degree turn or a single linear motion to operate to soft dock or hard dock.

3.4.2.2.4.2 Positive Lock

Quick-release fasteners SHALL be positive locking in open and closed positions.

3.4.2.2.5 Pin Fastener Requirements

3.4.2.2.5.1 Locking Devices

Dexterous robot compatible locking devices used in conjunction with dexterous compatible pin fasteners SHALL be made accessible and visible to the teleoperator when using camera positions and fields of view in accordance with the February 17, 1995 release of the SPDM model.

3.4.2.2.5.2 Guides

Dexterous robot compatible pin fasteners SHALL have guide mechanisms for insertion.

3.4.3 Mechanical Alignment System Integration and Design Requirements

3.4.3.1 Mechanical Alignment System Integration to OMH and Worksites

3.4.3.1.1 Alignment Guides

Coarse and fine alignment guides SHALL be provided for inserting and removing OMH.

3.4.3.1.2 Coarse Alignment

Coarse alignment mechanisms SHALL guide equipment to within the capture envelope of its fine alignment mechanisms.

3.4.3.1.3 Fine Alignment <u>DELETED</u>

3.4.3.1.4 Fine Alignment

Mating of equipment SHALL be achieved relying only upon the fine alignment mechanism, which is independent of the positioning accuracies of the dexterous robotic system.

3.4.3.1.5 Coarse/Fine Alignment Transition <u>DELETED</u>

3.4.3.2 Mechanical Alignment System Design

3.4.3.2.1 Coarse Alignment Guide Capture Envelope

At a minimum, equipment coarse alignment guides SHALL accommodate simultaneous misalignments (measured at the tip of the end effector) of up to +/- 0.25 inches (6.4 mm) in each translational axis and +/- 0.5 degrees in each rotational axis.

3.4.3.2.2 Misalignments <u>DELETED</u>

3.4.3.2.3 Worst Case Operational Loads

The alignment guide system SHALL be designed to withstand an insertion/removal force of 35 lbf [156 N] and a moment of 125 lbf-ft [169.5 N-m].

3.4.3.2.4 Thermal Deformation DELETED

3.4.3.2.5 Connectors

Connectors (i.e. power, data, fluids, etc.) SHALL not be used as alignment guides for OMH.

3.4.4 Visual Cue Integration and Design Requirements

3.4.4.1 Visual Cue Integration to OMH and Worksites

3.4.4.1.1 Robotic System-To-Equipment Visual Cues - Targets

Targets SHALL be provided for all robotically compatible grasp interfaces and fasteners in accordance with SSP 42004 Section C paragraph C3.2.1.1 for the H-handle and Micro Fixture; Section D paragraph D3.2.1.1 for the Micro Conical Fitting; Section G paragraph G3.2.2.2 for the non-collocated fastener head; Section H paragraph H3.2.1.1 for the Modified Micro Fixture; and Section K paragraph K3.2.1.1 for the Modified Micro Conical Fitting.

3.4.4.1.2 Grasp Area Identification DELETED

3.4.4.1.3 Visual Cue Usage DELETED

3.4.4.1.4 Robotic System-To-Equipment Visual Cue-Target Accuracy

Targets SHALL allow the IVA operator to position and orient the dexterous robot end effector or tool from free space to within the grasp interface or fastener capture envelope specified in Table 3.4.4.1.4-1 without violating the associated approach envelope for the grasp interface or fastener defined in SSP 42004 Section C paragraph C3.2.2.1 for the H-handle and Micro Fixture; Section D paragraph D3.2.2.1 for the Micro Conical Fitting; Section G paragraph G3.2.2.1 for the non-collocated fastener head; Section H paragraph H3.2.2.1 for the Modified Micro Fixture; and Section K paragraph K3.2.2.1 for the Modified Micro Conical Fitting.

TABLE 3.4.4.1.4-1 CAPTURE ENVELOPES FOR GRASP/FASTENER INTERFACES

SDGF INTERFACE	TRANSLATION ENVELOPES	ROTATION ENVELOPES
H-handle grasp fixture	+/- .25 inches in X +/- .25 inches in Y +/- .25 inches in Z	+/- 3° in roll +/- 3° in pitch +/- 3° in yaw
Micro and Modified Micro grasp fixture	+/- .25 inches in X +/- .25 inches in Y +/- .25 inches in Z	+/- 3° in roll +/- 3° in pitch +/- 3° in yaw
Micro Conical and Modified Micro Conical grasp fitting	NA in X +/- .25 inches in Y +/- .25 inches in Z	+/- 3° in roll +/- 3° in pitch +/- 3° in yaw

Non-collocated fastener head	NA in X +/- .25 inches in Y +/- .25 inches in Z	NA in roll +/- 3° in pitch +/- 3° in yaw

3.4.4.1.5 Equipment-to-Worksite Visual Cues

Multiple marking Visual Cues consisting of parallel and/or perpendicular features or single unit leave behind Targets used with the OTCM camera to berth OMH or a combination of both types of cues SHALL be provided on the OMH and worksite.

3.4.4.1.6 Equipment-to-Worksite Visual Cue Accuracy

Alignment markings or leave behind targets or a combination of both types of cues SHALL allow the IVA operator to orient and position OMH from free space to within the coarse alignment guide capture envelope prior to insertion within the coarse alignment guides.

3.4.4.1.6.1 Targets DELETED See 3.4.4.1.4

3.4.4.2 Visual Cue Design

3.4.4.2.1 Visual Cue Accuracy (2) DELETED

3.4.4.2.2 Visual Cue Color_ DELETED

3.4.4.2.3 Visual Orientation Cue DELETED

3.4.4.2.4 Alignment Markings for Visual Cues DELETED See 3.4.4.1.6

3.4.4.2.5 Targets for SDGFs DELETED

3.4.4.2.5.1 Targets for Fasteners DELETED

3.4.4.2.5.2 Targets for Berthing Visual Cues DELETED

3.4.4.2.6 Visual Cue Contrast

3.4.4.2.6.1 Alignment Markings

Alignment markings SHALL be lusterless white on dark-colored hardware and lusterless black on light-colored hardware with colors as specified in SSP 50005 paragraph 9.5.3.2.i.8.a.

3.4.4.2.6.2 Targets

Target design SHALL be implemented using lusterless black and white or clear features with colors as specified in SSP 50005 paragraph 9.5.3.2.i.8.a.

3.4.5 Soft Capture Integration and Design Requirements DELETED

3.4.5.1 Soft Capture Integration to OMH and Worksites DELETED

3.4.5.1.1 Soft Capture (Inadvertent Release) Integration DELETED

3.4.5.2 Soft Capture Design DELETED.

3.4.6 Status Indicator Integration and Design Requirements

3.4.6.1 Status Indicator Integration to OMH and Worksites DELETED

3.4.6.2 Status Indicator Design

3.4.6.2.1 Use

Status indicators SHALL display the following states:

a. Ready-to-Latch, Ready-to-Mate, Ready-to-Install, or Ready-to-Attach (completion of coarse alignment)
b. Soft Dock (when required to complete robotic task)
c. Latched, Mated, Locked, Installed or Attached (completion of fine alignment)
d. Unlatched, Unmated, Unlocked, Removed, or Detached.

3.4.6.2.2 Standardization

The appearance of status indicators designed to be viewed by the dexterous robot cameras for OMH of the same size, shape, and function within a segment-level major component or within multiple segment-level major components provided by the same developer SHALL be common.

3.4.6.2.3 Compatibility

Status indicators SHALL provide information that is within the field of view of the robot end effector camera as defined in Section H3.2.2.2 of SSP 42004 or by providing a force indication upon completion of coarse alignment and a repeatable indication of fastener turns count when fine alignment is completed.

3.4.6.2.4 Indicator State Restriction

Status indicators SHALL be restricted to not more than four states.

3.4.6.2.5 Failed Condition Indication DELETED

3.4.7 Utility Connector Integration and Design Requirements

3.4.7.1 Utility Connector Integration to OMH and Worksites

3.4.7.1.1 Warning Labels And Recessed Connectors DELETED

3.4.7.1.2 Maintenance

Electrical connectors SHALL permit disconnection and reconnection without loss of wiring or connectors functionality.

3.4.7.1.3 Structural Loads <u>DELETED</u>

3.4.7.1.4 Connector Access <u>DELETED</u>

3.4.7.1.5 Fluid Connectors

Remote visual access to fluid connectors SHALL be provided for dexterous robot actuated fluid connectors when camera positions and fields of view are in accordance with the February 17, 1995 release of the SPDM model except for blind-mate connectors.

3.4.7.2 Utility Connector Design

3.4.7.2.1 Blind Mate

The connectors for dexterous robot manipulated OMH which is to be inserted and removed SHALL be designed such that they are connected when the OMH is inserted and disconnected when the OMH is removed.

3.4.7.2.2 Mate/Demate Force

Connectors SHALL require a maximum of 20 lbf (89 N) axial force or 10 lbf (45 N) lateral force or 10 ft-lbf (13.6 N-m) torque for mating and demating, unless connectors are integrated into OMH.

3.4.7.2.3 Single Manipulator Operation <u>DELETED</u> See 3.2.1.5

3.4.7.2.4 Accessibility

Individual connectors requiring dexterous robot support for mating and demating SHALL mate and demate without requiring the mating or demating of another connector or OMH.

3.4.7.2.5 Ease of Disconnect

Connectors SHALL require no more than one rotary turn by the dexterous robot arm to mate or demate (a 45 deg turn is preferred) unless a dexterous robotic tool is used to perform the operation.

3.4.7.2.6 Connector Guides <u>DELETED</u> See 3.4.3

3.4.7.2.7 Soft Dock <u>DELETED</u> See 3.4.5.1

3.4.7.2.8 Positive Lock

All connectors SHALL have a positive lock function unless the connector is incorporated into a piece of OMH which is positively locked.

3.4.7.2.9 Status Indicators DELETED See 3.4.6

3.4.7.2.10 Protective Caps

Protective caps on dexterous robotically mated connectors SHALL be passively activated by the mating operation of the connectors.

3.4.7.2.11 Compatibility DELETED

3.4.7.2.12 Stowage/Retention

An interim attachment at the OMH worksite SHALL be provided for demated connectors requiring manipulation by the dexterous robot.

3.4.7.2.13 Power/Data Interface DELETED

3.4.7.2.14 End Effector Actuation DELETED

3.4.8 Label and Marking Integration and Design Requirements

3.4.8.1 Labeling and Marking Integration to OMH and Worksites.

3.4.8.1.1 Label and Marking General Requirements

3.4.8.1.1.1 Label and Marking DELETED

3.4.8.1.1.2 Association Errors DELETED

3.4.8.1.1.3 Robotic Vision System Compatibility

Labels and markings required to complete robotic operations SHALL be placed in a location that is visually accessible.

3.4.8.1.2 Label and Markings Requirements

3.4.8.1.2.1 Orientation DELETED

3.4.8.1.2.2 Identification Labels / Markings DELETED

3.4.8.1.3 Marking Requirements

Labels and markings SHALL conform to SSP 50005 paragraph 9.5.3.

3.4.8.1.3.1 Identification <u>DELETED</u>

3.4.8.1.3.2 Identification <u>DELETED</u>

3.4.8.1.3.3 Location

Caution and warning markings or labels SHALL be provided within the global worksite for all robot hazards identified within that worksite in accordance with SSP 50005 paragraph 9.5.3.1.13.

3.4.8.1.4 Coding Requirements <u>DELETED</u>

3.4.8.1.4.1 Location Code <u>DELETED</u>

3.4.8.1.4.2 Location Code <u>DELETED</u>

3.4.8.1.4.3 Brightness Coding <u>DELETED</u>

3.4.8.1.4.4 Color Coding <u>DELETED</u>

3.4.8.1.4.5 Flash Coding <u>DELETED</u>

3.4.8.1.4.6 Pattern Coding <u>DELETED</u>

3.4.8.1.4.7 Shape Coding Usage <u>DELETED</u>

3.4.8.1.4.8 Position and Orientation Independence <u>DELETED</u>

3.4.8.2 Labeling and Marking Design

3.4.8.2.1 Engraved Lettering/Numerals

Engraved lettering/numerals SHALL only be used for robotic system applications if the engraved letters/numerals are colored a contrasting color in accordance with SSP 50005 paragraph 9.5.3.2.i.8.a.

3.4.8.2.2 Zone Markings

On indicators where zone markings are used to indicate various operating conditions, the colors SHALL be in accordance with SSP 50005 paragraph 9.5.3.2.i.7.

3.4.8.2.3 Label Quantity

When any label or marking is required for both EVA and robotic system operations, a single label or marking SHALL be provided.

3.4.9 Access Closure Integration and Design Requirements

3.4.9.1 Access Closure Integration to OMH and Worksites DELETED

3.4.9.2 Access Closure Design

3.4.9.2.1 Cover Compatibility

Access closures that permit access to robot compatible equipment shall also be robot compatible.

3.4.9.2.2 Loads DELETED

3.4.9.2.3 Thermal Blankets DELETED

3.4.9.2.4 Protective Covers DELETED

3.4.9.2.5 Single Manipulator

Access closures SHALL open and close along a single degree-of-freedom path (one translation or one rotation) using one manipulator arm.

3.4.9.2.6 Captured/Self-Supporting Closures

All access closures SHALL be captured and self-supporting in the open position.

3.4.9.2.7 Grasp Interface DELETED See 3.4.1

3.4.9.2.8 Pinching Latches

Pinching latches or other similar devices SHALL not be used.

3.4.9.2.9 Positive Lock DELETED

3.4.9.2.10 Flexible Materials DELETED

3.4.10 Mobility/Stability Aid and Reinforced Grasp Area Integration and Design Requirements

3.4.10.1 Mobility/Stability Aid and Reinforced Grasp Area Integration to and Worksites

3.4.10.1.1 ORU/Manipulated Hardware DELETED

3.4.10.1.2 Required Usage

Mobility/stability aids SHALL be provided at worksites that require a dexterous robotic system to operate from a robotic positioning system.

3.4.10.1.3 Equipment Accessibility

Mobility/stability aids SHALL be positioned such that they do not interfere with the operation or maintenance of adjacent equipment.

3.4.10.1.4 Spacing

The separation distance between the mobility/stability aid and the OMH grasp interface used for dexterous manipulation SHALL be no greater than 10.5 ft (3.20m) and no less than 3 ft (0.91m). Separation distances outside this envelope will require the performance of the robot system to be substantiated for use in a specified task by kinematic or dynamic analysis.

3.4.10.1.5 Spacing <u>DELETED</u>

3.4.10.2 Mobility/Stability Aid and Reinforced Grasp Area Design

3.4.10.2.1 Status Indication

Portable mobility/stability aids SHALL provide a positive status indication of when they are in the locked position.

3.4.10.2.2 Removal and Relocation

Portable mobility/stability aids SHALL be installed, removed, and relocated by dexterous robotic means.

3.4.10.2.3 Reinforced Grasp Area Interface Strength

All reinforced grasp areas associated with fixed and portable robotic system mobility/stability aid structural interfaces SHALL be designed to sustain combined loads of 50 lbf (222.5 N) and 250 ft-lbf (339 N-m) torque (applied in any direction).

3.4.10.2.3.1 Mobility/Stability Aid Mounting Plane Strength <u>DELETED</u>

3.4.10.2.3.2 Mobility/Stability Aid Mounting Plane Stiffness

The mobility/stability aid mounting plane SHALL have a stiffness of 5000 ft-lbf/rad (6780 N-m/rad) around any axis and 1000 lbf/in (175127 N/m) along any axis.

3.4.10.2.4 Alignment <u>DELETED</u> See 3.4.4.1.1

3.4.10.2.5 Identification

Reinforced grasp areas SHALL be distinguishable from standard grasp areas.

3.4.10.2.6 Equipment Restraints <u>DELETED</u> See 3.4.10.1.2

3.4.10.2.7 Surface Quality <u>DELETED</u>

3.4.10.2.8 Standardization

Mobility/stability aids SHALL be standardized in accordance with SSP 42004, Section C.

3.4.10.2.9 Securing Pins DELETED See 3.4.2.2.5

3.4.11 Berthing Point Integration and Design Requirements DELETED

3.4.11.1 Berthing Point Integration to OMH and Worksites DELETED

3.4.11.1.1 Required Usage DELETED

3.4.11.1.2 Location DELETED

3.4.11.1.3 Access DELETED

3.4.11.1.4 Orientation Requirements DELETED

3.4.11.1.5 Hazard Protection DELETED

3.4.11.1.6 Utilities DELETED

3.4.11.1.7 Berthing Point Rigidity DELETED

3.4.11.2 Berthing Point Design DELETED

3.4.12 Stowage and Restraint Integration and Design Requirements

3.4.12.1 Stowage and Restraint Integration To OMH and Worksites DELETED

3.4.12.1.1 Captive Equipment and Fasteners DELETED

3.4.12.1.2 Access DELETED

3.4.12.1.3 Placement DELETED

3.4.12.1.4 Straps DELETED

3.4.12.1.5 Adhesive Equipment Restraints DELETED

3.4.12.2 Stowage and Restraint Design

3.4.12.2.1 Removal

OMH items mounted on pallets and carriers SHALL be individually restrained, removed and replaced.

3.4.12.2.2 Retainer Operation DELETED

3.4.12.2.3 Container Labeling DELETED

3.4.12.2.4 Single Manipulator Operation DELETED

3.4.12.2.5 Adjustability DELETED

3.4.12.2.6 Preferred Location Of Restrained Items DELETED

3.4.12.2.7 Minimum Load DELETED

3.4.12.2.8 Maximum Load (1) DELETED

3.4.12.2.9 Maximum Load (2) DELETED

3.4.12.2.10 Commonality DELETED

3.4.12.2.11 Attachment DELETED

3.4.12.2.12 Obstructions DELETED

3.4.12.2.13 Tethers DELETED

3.4.12.2.14 Stowage DELETED

3.4.13 Cable and Umbilical Integration and Design Requirements

3.4.13.1 Cable and Umbilical Integration to OMH and Worksites

3.4.13.1.1 Cables

Cables SHALL not be manipulated by the dexterous robotic system.

3.4.13.1.2 Umbilicals

Umbilicals SHALL not be manipulated by the dexterous robotic system.

3.4.13.2 Cable and Umbilical Design DELETED

3.4.14 Tool Integration and Design Requirements

3.4.14.1 Tool Integration to OMH and Worksites.

3.4.14.1.1 Direct Interface DELETED

3.4.14.1.2 Tool Stowage

Robotic tools SHALL be stowed in dedicated tool holsters.

3.4.14.1.3 Standard Robot Tool Stowage

The standard robot tools identified in SSP 42004 Section G, J, and M SHALL be stowed in tool holsters as defined in SSP 42004, Section F.

3.4.14.2 Tool Design

3.4.14.2.1 Tool Complexity DELETED

3.4.14.2.2 End Effector Tool Complexity DELETED

3.4.14.2.3 Direct Interface DELETED

3.4.14.2.4 Uncommanded Release DELETED

3.4.14.2.5 Attachment DELETED

3.4.14.2.6 Standardization

Tools for use by dexterous robotic systems SHALL incorporate a robotic system-to-tool grasp interface in accordance with SSP 42004 Section L.

3.4.14.2.7 Alignment DELETED

3.4.14.2.8 Direct Worksite Interface

Tools SHALL be designed to interface directly with the OMH.

3.4.14.2.9 Alignment Features DELETED

3.4.14.2.10 Status Indicators DELETED

3.4.14.2.11 Fastener Head Engagement

Fastener Drive Sockets SHALL be designed in accordance with SSP 42004 Section G, J, L, or M. The socket SHALL fully engage the fastener head flats prior to the application of tightening or loosening torque.

3.4.14.2.12 Equipment Access Envelope

Tools SHALL be designed to operate using the equipment access envelopes defined in SSP 42004 Section G paragraph G3.2.1.1.1 for a non-collocated fastener torque tool; Section J paragraph J3.2.1.1.1 for an offset socket tool; and Section M paragraph M3.2.1.1.1 for a Micro Conical tool.

3.4.14.2.13 Tool Utilities

When a tool requires power, data, or video interface, the tool SHALL be designed to draw the power, or receive and transmit the data, or transmit the video via the robotic system manipulator arm as specified in SSP 42004, paragraphs L3.2.1.5, L3.2.1.6, and L3.2.1.7.

3.4.14.2.14 Actuation

Robotic tool actuation SHALL be achieved by utilizing the force and torque capabilities of the end effector torque driver or the power and data capabilities of the dexterous robot end effector.

3.4.14.2.15 Uncommanded Release

The tool-to-OMH interface SHALL be designed and controlled such that no combination of two failures, or two operator errors, or one of each can cause an uncommanded release to occur. Tools which do not grasp are not subject to this requirement.

3.4.14.2.16 Identification Labels <u>DELETED</u>

3.4.14.2.17 Content <u>DELETED</u>

3.4.14.2.18 Orientation <u>DELETED</u>

3.4.14.2.19 Tool Length <u>DELETED</u>

3.4.14.2.20 Robot-To-Tool Interface Loads <u>DELETED</u>

3.4.14.2.21 Tool-To-OMH Interface Loads <u>DELETED</u>

3.4.15 Thermal Blankets

All worksites and OMH, including access closures, SHALL be designed such that the dexterous grasp interfaces and non-collocated fasteners are accessible by a tool or end effector and such that the OMH can be inserted, removed, and actuated without removal or rearrangement of thermal blankets unless the thermal blankets are integrated with access closures. A one time EVA to remove thermal blankets which are not designed to be robot compatible is allowable.

3.5 HAZARDS TO ROBOTIC SYSTEMS

Protection of robotic systems from natural and induced environments will be treated similarly to externally located equipment (a shared responsibility between the robotic system developer and the equipment designer). In addition to this, the following robot-specific environmental hazard requirements are defined below.

3.5.1 Warning Labels

Robotic system compatible warning labels of hazards to robotic systems SHALL be provided at global worksites within robotic systems field of view.

3.5.2 Electrical Hazards

3.5.2.1 Grounding

External metal parts subject to robotic system contact SHALL be at ground potential.

3.5.2.2 Static Discharge

Equipment SHALL be designed so that the robotic systems are protected from static charge buildup.

3.5.2.3 Electrical Hazards <u>DELETED</u>

3.5.3 Physical Hazards

3.5.3.1 Stored Energy Hazards

Equipment to be inserted, removed, or manipulated by robotic systems SHALL not present stored mechanical energy greater than 5.0 Joules to the robotic system which will be reacted through the manipulator to its base or stabilization point.

3.5.3.2 Entanglements

All equipment that presents entanglement hazards SHALL employ a cable management system to prevent the entanglement of robotic systems.

3.5.4 Thermal Hazards <u>DELETED</u>

3.5.4.1 Continuous Contact <u>DELETED</u>

3.5.4.2 Incidental Contact <u>DELETED</u>

4.0 VERIFICATION REQUIREMENTS

This section contains the formal qualification requirements that are necessary to show compliance with each “SHALL” statement in Section 3 of this document. Verification of non “SHALL” statements is not required.

4.1 GENERAL

Compliance with the requirements stated in Section 3 SHALL be proven using one or more of the following methods:

Inspection (I) Inspection is a method that determines conformance to requirements by the review of drawings, data, or by visual examination of the item using standard quality control methods, without the use of special laboratory procedures.

Analysis (A) Analysis is a process used in lieu of, or in addition to, other methods to ensure compliance to specification requirements. The selected techniques may include but are not limited to, engineering analysis, statistics and qualitative analysis, computer and hardware simulations, and analog modeling. Analysis may also include assessing the results of lower level qualification activity.

Verification by similarity is the process of analyzing the specification criteria for hardware configuration and application for an article to determine if it is similar or identical in design, manufacturing process, and quality control to an existing article that has previously been qualified to equivalent or more stringent specification criteria. Efforts will be made to avoid duplication of previous test from this or similar programs. If the previous application is considered to be similar, but not equal to or greater in severity, additional qualification tests SHALL concentrate on the areas of new or increased requirements.

Demonstration (D) Demonstration consists of a qualitative determination of the properties of a test article. This qualitative determination is made through observation, with or without special test equipment or instrumentation, which verifies characteristics such as human engineering features, services access features, and transportability. Demonstration requirements are normally implemented within a test plan, operations plan, or test procedures.

Test (T) Test is a method in which technical means, such as the use of special equipment, instrumentation, simulation techniques, and the application of established principles and procedures, are used for the evaluation of components, subsystems, and systems to determine compliance with requirements. Test SHALL be selected as the primary method when analytical techniques do not produce adequate results; failure modes exist which could compromise personnel safety, adversely affect flight systems or payload operation, or result in a loss of mission objectives; or for any components directly associated with Space Station and Orbiter interfaces. The analysis of data derived from tests is an integral part of the test program, and should not be confused with analysis as defined above. Tests SHALL be used to determine quantitative compliance to requirements and produce quantitative results.

4.1.1 Responsibility for Verifications.

Unless otherwise specified in the contract, the OMH provider is responsible for the performance of verification activities as specified herein.

4.2 DESIGN REQUIREMENT CONFORMANCE INSPECTIONS

Demonstrations, analysis, inspections, and test requirements are specified herein. Individual verification requirements do not require a stand-alone verification to be performed but may be combined satisfying other verification requirements to prevent redundancy and optimize commonalty. The use of similarity is acceptable as defined in paragraph 4.1. As an example, to reduce cost Demonstrations can be executed on a suite of validated test articles. This suite must satisfy the robotic related geometrical, functional, operational performance criteria across all of the similar ORU types they represent.

4.2.1 Requirement/Verification Cross Reference Verification

For each requirement in 3.0 there is a one-to-one correspondence to the paragraphs in Section 4.3. The numbering of the paragraphs in Section 4 is identical with those of Subsection 3.X.X except there is a 4 in front of the number. For example 4.3.4.3.2.1 is the corresponding verification paragraph to requirement in 3.4.3.2.1.

4.3 DESIGN REQUIREMENT CONFORMANCE VERIFICATIONS

4.3.1 Introduction

This section describes the specific verification procedures to be used in executing the method assigned in 4.2 to verify the respective requirement.

4.3.2 ORU/Manipulated Hardware Design Requirements

4.3.2.1 OMH General Requirements

4.3.2.1.1 Installation/Attachment Configuration Standardization DELETED

4.3.2.1.2 Standard Tools

Verification of Standard Tool SHALL be by inspection of flight element drawings. Verification SHALL be considered successful when inspection shows that OMH designs are compatible with the standard robotic end effector or tool set recorded in SSP 42004 Sections G, J, L, and M respectively.

4.3.2.1.3 Standard Interfaces and Hardware

Verification of Standard Interfaces and Hardware SHALL be by inspection of flight element drawings. Verification SHALL be considered successful when inspection shows that external equipment designated for operation, maintenance, and integration with robotic systems employs interfaces, hardware, and associated access envelopes as defined in SSP 42004 Section C, D, E, F, G, H, J, and K.

4.3.2.1.4 Lockwire and Staking DELETED

4.3.2.1.5 Single End Effector Operations

Verification of Single End Effector Operation SHALL be by analysis or inspection. Verification SHALL be considered successful when kinematic analysis or inspection of flight drawings shows that the OMH can be inserted, removed, and actuated by a single robot end effector.

4.3.2.1.6 Soldering, Welding, and Brazing DELETED

4.3.2.1.7 Interchangeability

Verification of Interchangeability SHALL be by inspection of flight element drawings. Verification SHALL be considered successful when inspection shows that OMH of the same or similar form but having different functional properties are not physically interchangeable. The OMH data, power, and video connector interfaces SHALL be inspected and functionally compared to determine capability. Verification SHALL be considered successful when it is shown that OMH of the same or similar form but having different functional properties have unique interfaces to the harness or panel to prevent physical interchangeability.

4.3.2.1.8 Keying

Verification of Keying SHALL be by inspection of flight element drawings. Verification SHALL be considered successful when inspection shows that each OMH design configuration provides a keying feature to prevent damage due to incorrect physical installation.

4.3.2.1.9 Thermal Interface

Verification of Thermal Interface SHALL be by analysis. The verification SHALL be considered successful when a thermal analysis shows that the OMH can survive and function after transportation while exposed to the on-orbit space station environment for TBD hours without an active thermal interface.

4.3.2.1.10 Hazards DELETED

4.3.2.1.11 Straight Line Motion DELETED

4.3.2.1.12 End-to-End Robot Compatibility DELETED

4.3.2.1.13 OMH Color Selection

Verification of OMH Color Selection SHALL be by inspection. Verification SHALL be considered successful when inspection of flight element drawings shows that the OMH colors are in accordance with the requirement as specified.

4.3.2.2 OMH Forces and Loads

4.3.2.2.1 Maximum OMH Size

Verification of Maximum OMH Size SHALL be by inspection of flight element drawings. Verification SHALL be considered successful when inspection shows that the maximum external dimensions of OMH which is to be inserted, removed, stowed, and transported by the dexterous robotic system complies with the requirement as specified.

4.3.2.2.1.1 Maximum Support Equipment Size

Verification of Maximum Support Equipment Size SHALL be by inspection of flight element drawings. Verification SHALL be considered successful when inspection shows that the maximum external dimensions of support equipment required to stow and transport OMH with the dexterous robotic system complies with the requirement as specified.

4.3.2.2.1.2 Maximum Size Stowed and Translated Equipment

Verification of Maximum Support Equipment Size SHALL be by inspection of flight element drawings. Verification SHALL be considered successful when inspection shows that the maximum external dimensions of the combination of OMH and associated support equipment which is to be stowed and transported by the dexterous robotic system complies with the requirement as specified.

4.3.2.2.2 Maximum OMH Mass and Moment of Inertia

Verification of Maximum OMH Mass and Moment of Inertia SHALL be by inspection of flight element drawings and analysis. Inspection SHALL be considered successful when it is shown that the mass of the equipment designated to be manipulated by the dexterous robotic system does not exceed 1320 lbm (600 kg). Verification SHALL be considered successful when in addition to the inspection, analysis shows that the mass moment of inertia of OMH having a Micro, Modified Micro, or a H-handle grasp fixture computed about the grasp interface reference frame axes does not exceed 202 slug-ft^2 (275 kg-m^2) or that the mass moment of inertia of OMH having a Micro Conical or Modified Micro Conical grasp fitting does not exceed 148 slug-ft^2 (200 kg-m^2) measured from the fitting.

4.3.2.2.3 Standard Grasp Area Maximum Loads

Verification of Standard Grasp Area Maximum Loads SHALL be by analysis. Verification SHALL be considered successful when analysis, using validated structural analysis models, shows the standard grasp areas and associated load paths have the strength to withstand combined loads as follows: H-handle fixture 250 ft-lbf (339 N-m) torque, 50 lbf (222 N); Micro and Modified Micro fixture 125ft-lbf (169.5 N-m) torque, 50 lbf (222 N); Micro Conical and Modified Micro Conical Fitting 125 ft-lbf (169.5 N-m) torque, 50 lbf (222 N). This verification requirement SHALL apply to both inertia loads and constrained loads.

4.3.2.2.4 Maximum Force

Verification of Maximum Force SHALL be by analysis. Verification SHALL be considered successful when analysis of test data shows that the force required for insertion, removal, and actuation of the OMH does not exceed 20 lb (89N) when the gravity vector is parallel with the insertion direction. The gravity force SHALL be compensated for in the final values.

4.3.2.2.5 Maximum Size Translated Equipment <u>DELETED</u>

4.3.2.2.6 Maximum Size Movable Equipment <u>DELETED</u>

4.3.3 Worksite Design Requirements

4.3.3.1 Worksite General Requirements

4.3.3.1.1 Straight Line Motion

Verification of Straight Line Motion for worksite approach SHALL be by analysis. Verification SHALL be considered successful when the analysis shows that the OMH worksite allows the OMH to be inserted and removed or actuated using sequential single Cartesian degree-of-freedom motions. The sequential single Cartesian degree-of-freedom motions for ORU insertion begins at the point when the ORU back plane enters the receptacle volume (3 inches (76 mm) from coarse alignment guides).

4.3.3.1.2 Color Selection <u>DELETED</u>

4.3.3.1.3 Worksite Color Selection

Verification of Worksite Color Selection SHALL be by inspection of flight element drawings. Verification SHALL be considered successful when inspection shows that worksite colors are in accordance with the requirement as specified.

4.3.3.1.4 Controls and Displays

Verification of Controls and Displays SHALL be by inspection of flight element drawings. Verification SHALL be considered successful when inspection shows that no robotic controls and displays exist at the external robotic system worksites.

4.3.3.1.5 Worksite Interfaces

Verification of Worksite Interfaces SHALL be by inspection of flight element drawings. Verification SHALL be considered successful when inspection shows that OMH of the same size, shape, and function incorporates the same common ORU-to-worksite interface hardware.

4.3.3.2 Worksite Identification and Labeling <u>DELETED</u>

4.3.3.2.1 Consistent Vertical Orientation (Local Vertical) <u>DELETED</u>

4.3.3.2.2 Unique Identification DELETED

4.3.3.3 Worksite Accessibility and Clearance

4.3.3.3.1 Unobstructed Remote Visual Access

Verification of Unobstructed Worksite Remote Visual Access SHALL be by analysis. Camera position and field of view data from the February 17, 1995 release of the SPDM model SHALL be used for this analysis. Verification SHALL be considered successful when viewing analysis shows that the OMH can be inserted and removed without visual obstruction by adjacent hardware and structure.

4.3.3.3.2 OMH Translation Clearance DELETED

4.3.3.3.3 Manipulator Clearance

Verification of Manipulator Clearance SHALL be by analysis. The February 17, 1995 release of the SPDM model SHALL be used for this analysis. Verification SHALL be considered successful when kinematic analysis shows a minimum clearance of 3 inches (76 mm) is provided between the manipulator (excluding the end effector, associated tooling, and OMH) and adjacent equipment for translation paths and worksite structure.

4.3.3.3.4 End Effector/Tool Clearance

Verification of End Effector/Tool Clearance at the worksite SHALL be by analysis. Verification SHALL be considered successful when kinematic analysis shows that the access envelopes defined in SSP 42004 Section C paragraph C3.2.2.1; Section D paragraph D3.2.2.1; Section E paragraph E3.2.1.1; Section G paragraph G3.2.2.1; Section H paragraph H3.2.2.1; and Section K paragraph K3.2.2.1 are provided.

4.3.3.3.5 OMH Clearance

Verification of OMH Clearance at the worksite SHALL be by analysis. Verification SHALL be considered successful when analysis shows that element equipment within 3 inches (76 mm) of the OMH when translating along the OMH insertion and removal design corridor can withstand a force of 35 lbf [156 N].

4.3.3.3.6 Accessibility DELETED

4.3.3.3.7 Equipment Spacing DELETED

4.3.3.3.8 Rear Access DELETED

4.3.3.3.9 Thermal Blankets DELETED

4.3.3.4 Maintenance Support Facility Requirements

4.3.3.4.1 Service Points for Fluid Systems DELETED

4.3.4 Feature Integration and Design Requirements

4.3.4.1 Grasp Interface Integration and Design Requirements

4.3.4.1.1 Grasp Interface Integration to OMH and Worksites

4.3.4.1.1.1 Standardization

Verification of Grasp Interface Standardization for OMH and Worksites SHALL be by inspection of flight element drawings. Verification SHALL be considered successful when inspection shows that the dexterous robotic grasp interfaces for OMH of the same size, shape and function are the same with respect to type and position of the grasp interface.

4.3.4.1.1.2 Interface Quantity

Verification of Interface Quantity on OMH SHALL be by inspection of flight element drawings. Verification SHALL be considered successful when inspection shows that the OMH has one dexterous robotic grasp interface for inserting, manipulating, actuating, and removing the OMH except when multiple fasteners require actuation, in which case more than one grasp interface can be used for actuation.

4.3.4.1.1.3 Location

Verification of Grasp Interface Location SHALL be by inspection of flight element drawings. Verification SHALL be considered successful when inspection shows that the dexterous robotic grasp interfaces is placed in accordance with the requirement as specified.

4.3.4.1.1.4 Local Torque Reaction <u>DELETED</u>

4.3.4.1.1.5 Standard Grasp Area

Verification of Standard Grasp Area SHALL be by inspection and analysis. Inspection of flight element drawings SHALL be considered successful when it is shown that the OMH uses a standard grasp interface as specified in paragraph 3.4.1.2. Verification SHALL be considered successful when, in addition to the above inspection, an analysis shows that the mass moment of inertia of the OMH computed about the grasp interface reference frame axes does not exceed 73 slug-ft^2 (98.9 kg-m^2).

4.3.4.1.1.6 Reinforced Grasp Area

Verification of Reinforced Grasp Area SHALL be by inspection and analysis. Inspection of flight element drawings SHALL be considered successful when it is shown that the OMH uses an H-handle fixture in accordance with SSP 42004 Section C. Verification SHALL be considered successful, in addition to the above inspection, analysis shows that the mass moment of inertia of the OMH computed about the grasp interface reference frame axes is between 73 slug-ft^2 (98.9 kg-m^2) and 202 slug-ft^2 (275 kg-m^2).

4.3.4.1.1.7 Load Path Strength <u>DELETED</u>

4.3.4.1.1.8 Interference <u>DELETED</u>

4.3.4.1.1.9 Clearance <u>DELETED</u>

4.3.4.1.1.10 Relocatable Grasp Interfaces

Verification of Relocatable Grasp Interfaces SHALL be analysis. The February 17, 1995 release of the SPDM model SHALL be used for this analysis. Verification SHALL be considered successful when kinematic analysis shows that the relocatable dexterous robotic grasp interface can be installed, removed, and stowed with a single manipulator arm while using the stabilization points provided for the associated worksite.

4.3.4.1.2 Grasp Interface Design

Verification of Grasp Interface Design SHALL be by inspection of flight element drawings. Verification SHALL be considered successful when it is shown that each robotically compatible grasp interface is in accordance with the requirement as specified.

4.3.4.1.2.1 Shape <u>DELETED</u>

4.3.4.1.2.2 Surface <u>DELETED</u>

4.3.4.1.2.3 Alignment <u>DELETED</u>

4.3.4.1.2.4 Status Indicators <u>DELETED</u>

4.3.4.2 Fastener Integration And Design Requirements

4.3.4.2.1 Fastener Integration To OMH and Worksites

4.3.4.2.1.1 Easily Distinguishable <u>DELETED</u>

4.3.4.2.1.2 Direct Access

Verification of Direct Access SHALL be performed by analysis. Verification SHALL be considered successful when analysis shows compliance with the requirement as specified.

4.3.4.2.1.3 Fastener Clearance <u>DELETED</u>

4.3.4.2.1.4 Fastener Engagement

Verification of Fastener Engagement SHALL be by analysis. Verification SHALL be considered successful when analysis of demonstration data shows that the hardware status indicator correctly displays the fastener engagement state or that the number of turns and torque values used to seat the fastener matches with specified values for each type of fastener.

4.3.4.2.1.5 Fastener Alignment Provisions

Verification of Fastener Alignment Provisions SHALL be by inspection. Verification SHALL be considered successful when inspection of the flight element drawings show that alignment aids are provided to assist in mating the robotic tool with the non-collocated fastener head and position the fastener into its proper location.

4.3.4.2.1.6 Safety DELETED

4.3.4.2.2 Fastener Design

4.3.4.2.2.1 General Fastener Requirements

4.3.4.2.2.1.1 Latches/Handle/Operating Mechanism

Verification of Latches/Handle/Operating Mechanism SHALL be by inspection. Verification SHALL be considered successful when inspection of the flight element drawings shows that latches, handle, fasteners, and operating mechanism which are designed to be operated by the dexterous robot can be latched, unlatched, opened, and closed by one manipulator arm.

4.3.4.2.2.1.2 Fastener Actuation

Verification of Fastener Actuation SHALL be by analysis. Verification SHALL be considered successful when an analysis shows that a fastener actuated by the dexterous robot requires no more than one degree of freedom of torque and one degree of freedom of force for actuation.

4.3.4.2.2.1.3 Captive Fasteners

Verification of Captive Fasteners SHALL be by inspection. Verification SHALL be considered successful when inspection of the flight element drawing shows that captive fasteners are held in place in a free state ready for use, such that the normal forces imparted on the fastener during engagement and disengagement does not dislodge any part of the fastener mechanism.

4.3.4.2.2.1.4 Captive Fasteners DELETED

4.3.4.2.2.1.5 Fastener Actuation Load Limits

4.3.4.2.2.1.5.1 Fastener Actuation Load Limits DELETED

4.3.4.2.2.1.5.2 Minimum Installation Torque - All Fasteners

Verification SHALL be by inspection. Verification SHALL be considered successful when inspection of flight element drawings shows that the minimum torque required to be applied to tighten a single threaded fastener is greater than or equal to 3.9 ft-lbf.

4.3.4.2.2.1.5.3 Tightening and Loosening Torque Accuracies <u>DELETED</u>

4.3.4.2.2.1.5.4 Minimum Removal Torque - All Fasteners <u>DELETED</u>

4.3.4.2.2.1.5.5 Maximum Installation Torque - Collocated Fasteners

Verification of Maximum Installation Torque of Collocated Fasteners SHALL be by inspection or analysis. Verification SHALL be considered successful when either an inspection of the flight element drawings or analysis of the fastening system design shows that a single threaded fastener collocated with a grasp interface requires the application of no more than 42.5 ft-lbf (61 N-m) of torque to the fastener head.

4.3.4.2.2.1.5.6 Maximum Removal Torque - Collocated Fasteners

Verification of Maximum Removal Torque of Collocated Fasteners SHALL be by analysis. Verification SHALL be considered successful when analysis, using a validated model of the fastening system and mating structure, shows that a single threaded fastener, which is collocated with a grasp interface, can be removed with no more then 42.5 ft-lbf (61 N-m) of torque after maximum tightening as specified for the subject bolts flight element specification is applied.

4.3.4.2.2.1.5.7 Maximum Installation Torque - Non-Collocated Fasteners

Verification of Maximum Installation Torque of Non-Collocated Fasteners SHALL be by inspection. Verification SHALL be considered successful when inspection of the flight element drawings shows that a single threaded fastener which is not collocated with a grasp interface requires the application of no more than 25 ft-lbf (33.89 N-m) of torque to the fastener head.

4.3.4.2.2.1.5.8 Maximum Removal Torque - Non-Collocated Fasteners

Verification of Maximum Removal Torque of Non-Collocated Fasteners SHALL be by analysis. Verification SHALL be considered successful when analysis, using a validated model of the fastening system and mating structure, shows that a single threaded fastener which is not collocated with a grasp interface can be removed with no more then 25 ft-lbf (33.89 N-m) of torque after maximum tightening as specified for the subject bolts flight element specification is applied.

4.3.4.2.2.1.5.9 Maximum Actuation Force - All Fasteners

Verification of Maximum Actuation Force of all Fasteners SHALL be by analysis. Verification SHALL be considered successful when analysis of test data shows that the axial force required to acquire and actuate fastener mechanisms and any associated locking mechanisms is no greater then 5 lbf.

4.3.4.2.2.1.5.10 Maximum Survivable Actuation Force - All Fasteners

Verification of Maximum Survivable Actuation Force of all Fasteners SHALL be by analysis. Verification SHALL be considered successful when analysis shows that an axial force of 20 lbf (89 N) can be applied to the bolt head mechanism without mechanism damage.

4.3.4.2.2.1.6 Push Force DELETED

4.3.4.2.2.1.7 Ruggedness DELETED

4.3.4.2.2.1.8 Head Configuration

Verification of Fastener Head Configuration SHALL be by inspection. Verification SHALL be considered successful when inspection of flight element drawings shows that all fastener heads used on robot compatible equipment and OMH are configured in accordance with the requirement as specified.

4.3.4.2.2.1.9 Fastener Knobs/Handles DELETED

4.3.4.2.2.1.10 Self-Tapping Fasteners

Verification that there are no Self-Tapping Fasteners SHALL be by inspection. Verification SHALL be considered successful when inspection of the flight element drawings show that all fasteners are not self tapping.

4.3.4.2.2.1.11 Non-Actuation Loads on Fasteners DELETED

4.3.4.2.2.1.11.1 Non-Actuation Forces DELETED

4.3.4.2.2.1.11.2 Non-Actuation Torques - All Fasteners DELETED

4.3.4.2.2.2 Threaded Fastener Requirements

4.3.4.2.2.2.1 Thread Type DELETED

4.3.4.2.2.2.2 Maximum Installation Torque DELETED

4.3.4.2.2.2.3 Maximum Removal Torque DELETED

4.3.4.2.2.2.4 Locking DELETED

4.3.4.2.2.2.5 Left-Handed Threads DELETED

4.3.4.2.2.2.6 Thread Fastening Direction

Verification of Thread Fastening Direction SHALL be by inspection. Verification SHALL be considered successful when an inspection of flight element drawings shows that all threaded fasteners and fastening mechanisms designed to secure OMH and associated support equipment to robotic worksites or the robotic system itself engage with clockwise application of torque and disengage with counter clockwise application of torque.

4.3.4.2.2.2.7 Positive Disengagement <u>DELETED</u>

4.3.4.2.2.3 Non-Threaded Fastener Requirements <u>DELETED</u>

4.3.4.2.2.3.1 Fastener Force/Torque <u>DELETED</u>

4.3.4.2.2.3.2 Minimum Fastener Size <u>DELETED</u>

4.3.4.2.2.4 Quick Release Fastener Requirements

4.3.4.2.2.4.1 Connect/Disconnect

Verification of Quick-Release Connect/Disconnect SHALL be by analysis. The verification SHALL be performed for each type of quick-release fastener. Verification SHALL be considered successful when analysis of demonstration data shows that validated test article quick-release fasteners require no more than a 45 degree turn or a single linear motion to operate to soft dock or hard dock.

4.3.4.2.2.4.2 Positive Lock

Verification of Quick-Release Positive Lock SHALL be by analysis. Verification SHALL be considered successful when analysis of demonstration data shows that quick-release fasteners provide a positive lock position when opened and closed.

4.3.4.2.2.5 Pin Fastener Requirements

4.3.4.2.2.5.1 Locking Devices

Verification of Pin Fastener Locking Devices SHALL be by analysis. Verification SHALL be considered successful when analysis of demonstration data shows that the teleoperator can see and operate dexterous robot compatible pin fastener locking devices using camera positions and fields of view in accordance with the February 17, 1995 release of the SPDM model.

4.3.4.2.2.5.2 Guides

Verification of Pin Fastener Guides SHALL be by inspection of the flight element drawing. Verification SHALL be considered successful when the flight element drawings show that dexterous robot compatible pin fasteners have guide mechanisms.

4.3.4.3 Mechanical Alignment System Integration and Design Requirements

4.3.4.3.1 Mechanical Alignment System Integration to OMH and Worksites

4.3.4.3.1.1 Alignment Guides

Verification of OMH Alignment Guides SHALL be by inspection. Verification SHALL be considered successful when inspection of the flight element drawings shows that OMH and its associated worksites have coarse and fine alignment guides.

4.3.4.3.1.2 Coarse Alignment

Verification of OMH Coarse Alignment mechanisms SHALL be by analysis. Verification SHALL be considered successful when analysis of demonstration data shows that the coarse alignment mechanisms can be used to guide OMH until the fine alignment guides are fully engaged.

4.3.4.3.1.3 Fine Alignment <u>DELETED</u>

4.3.4.3.1.4 Fine Alignment

Verification of Fine Alignment SHALL be by analysis. Verification SHALL be considered successful when analysis of demonstration data shows that only the fine alignment mechanisms and not the robotic positioning accuracy are used to guide equipment until berthing is complete. Initial positioning of the fine alignment system on the OMH to the fine alignment system on the worksite SHALL reflect the worst case positioning accuracies of the fine alignment capture envelope for the purposes of this analysis.

4.3.4.3.1.5 Coarse/Fine Alignment Transition <u>DELETED</u>

4.3.4.3.2 Mechanical Alignment System Design

4.3.4.3.2.1 Coarse Alignment Guide Capture Envelope

Verification of Coarse Alignment Guide Capture Envelope SHALL be by analysis. Analysis SHALL be considered successful when it is shown that the coarse alignment guides are capable of accommodating simultaneous misalignments (measured at the tip of the end effector) of up to +/- 0.25 inches (6.4 mm) in each translational axis and +/- 0.5 degrees in each rotational axis. Verification SHALL be considered successful when, in addition to the above analysis, analysis of demonstration data shows that equipment coarse alignment guides are successful in guiding the OMH into the capture envelope of its fine alignment mechanisms. Initial positioning of the OMH to the coarse alignment system on the worksite SHALL reflect the worst case positioning accuracies specified herein for the purposes of this analysis.

4.3.4.3.2.2 Misalignments <u>DELETED</u>

4.3.4.3.2.3 Worst Case Operational Loads

Verification of Worst Case Operational Loads SHALL be by analysis. Verification SHALL be considered successful when a structural analysis shows that the OMH and worksite guide system can withstand an insertion/removal force of 35 lbf [156 N] and a moment of 125 lbf-ft [169.5 N-m].

4.3.4.3.2.4 Thermal Deformation DELETED

4.3.4.3.2.5 Connectors

Verification of Connector structural use SHALL be by inspection. Verification SHALL be considered successful when the flight element drawings show that robotic compatible connectors do not use the shell body as alignment guides but have dedicated guides for connection and disconnection forces.

4.3.4.4 Visual Cue Integration and Design Requirements

4.3.4.4.1 Visual Cue Integration to OMH and Worksites

4.3.4.4.1.1 Robotic System-To-Equipment Visual Cues - Targets

Verification of the use of targets for robotically compatible grasp interfaces/fasteners SHALL be by inspection. Verification SHALL be considered successful when the flight element drawings show that targets are provided for all robotically compatible grasp interfaces/fasteners in accordance with the requirement as specified.

4.3.4.4.1.2 Grasp Area Identification DELETED

4.3.4.4.1.3 Visual Cue Usage DELETED

4.3.4.4.1.4 Robotic System-To-Equipment Visual Cue-Target Accuracy

Verification of Robotic System-to-Equipment Visual Cue Accuracy SHALL be by analysis. Verification SHALL be considered successful when analysis shows that targets associated with the grasp interface or fastener allow the IVA teleoperator, using validated robotic and ISS camera optical specification and eye-points, to orient and position the dexterous robot end effector or tool from free space to within the grasp interface or fastener capture envelope specified in paragraph 3.4.4.1.4 without violating the associated approach envelopes specified in SSP 42004 Section C paragraph C3.2.2.1 for the H-handle and Micro Fixture; Section D paragraph D3.2.2.1 for the Micro Conical Fitting; Section G paragraph G3.2.2.1 for the non-collocated fastener head; Section H paragraph H3.2.2.1 for the Modified Micro Fixture; and Section K paragraph K3.2.2.1 for the Modified Micro Conical.

4.3.4.4.1.5 Equipment-to-Worksite Visual Cues

Verification of Equipment to Worksite Visual Cues SHALL be by inspection. Verification SHALL be considered successful when an inspection of the flight element drawings show that multiple marking visual cues consisting of parallel and/or perpendicular features, single unit leave behind targets, or both features are provided on the OMH and worksite.

4.3.4.4.1.6 Equipment-to-Worksite Visual Cue Accuracy

Verification of Equipment-to-Worksite Visual Cue Accuracy SHALL be by analysis. Verification SHALL be considered successful when analysis of demonstration data shows that using only the alignment markings, or leave behind targets, or a combination of both types of cues, the IVA teleoperator can orient and position the OMH from free space to within its coarse alignment guide capture envelope.

4.3.4.4.1.6.1 Targets DELETED

4.3.4.4.2 Visual Cue Design

4.3.4.4.2.1 Visual Cue Accuracy (2) DELETED

4.3.4.4.2.2 Visual Cue Color_ DELETED

4.3.4.4.2.3 Visual Orientation Cue DELETED

4.3.4.4.2.4 Alignment Markings for Visual Cues DELETED

4.3.4.4.2.5 Targets for SDGFs DELETED

4.3.4.4.2.5.1 Targets for Fasteners DELETED

4.3.4.4.2.5.2 Targets for Berthing Visual Cues DELETED

4.3.4.4.2.6 Visual Cue Contrast

4.3.4.4.2.6.1 Alignment Markings

Verification of Alignment Marking contrast SHALL be by inspection. Verification SHALL be considered successful when inspection of the flight element drawings shows that alignment markings are in accordance with the requirement as specified.

4.3.4.4.2.6.2 Targets

Verification of Target color contrast SHALL be by inspection. Verification SHALL be considered successful when the inspection of the flight element drawings shows that target design colors are in accordance with the requirement as specified.

4.3.4.5 Soft Capture Integration and Design Requirements DELETED

4.3.4.5.1 Soft Capture Integration to OMH and Worksites DELETED

4.3.4.5.1.1 Soft Capture (Inadvertent Release) Integration DELETED

4.3.4.5.2 Soft Capture Design DELETED.

4.3.4.6 Status Indicator Integration and Design Requirements

4.3.4.6.1 Status Indicator Integration to OMH and Worksites DELETED

4.3.4.6.2 Status Indicator Design

4.3.4.6.2.1 Use

Verification of the Use of status indicators SHALL be by analysis. Verification SHALL be successful when analysis of demonstration data shows state changes of OMH in accordance with the requirement as specified.

4.3.4.6.2.2 Standardization

Verification of status indicator Standardization SHALL be by inspection. Verification SHALL be considered successful when inspection of flight element drawings shows the indicator features designed to be viewed by the dexterous robot cameras are common for OMH of the same size, shape, and function within a segment-level major component or within multiple segment-level major components.

4.3.4.6.2.3 Compatibility

Verification of status indicator Compatibility SHALL be by inspection or analysis. Verification SHALL be considered successful when either inspection of flight drawings shows that status indication information is provided within the field of view of the robot end effector camera as defined in Section H3.2.2.2 of SSP 42004 or analysis of demonstration data shows that the operator can identify a repeatable indication of fastener turns count through the video system when fine alignment is completed.

4.3.4.6.2.4 Indicator State Restriction

Verification of Status Indicator State Restriction SHALL be by inspection of flight drawings. The verification SHALL be considered successful when the inspection shows that status indicators have been restricted to not more than four states.

4.3.4.6.2.5 Failed Condition Indication DELETED

4.3.4.7 Utility Connector Integration and Design Requirements

4.3.4.7.1 Utility Connector Integration to OMH and Worksites

4.3.4.7.1.1 Warning Labels and Recessed Connectors DELETED

4.3.4.7.1.2 Maintenance

Verification of Robotic Maintenance of Utility Connector Integration SHALL be by analysis. Verification, using validated test articles, SHALL be considered successful when analysis of test data shows that robot compatible electrical connectors retain pin functionality after a robot disconnects and reconnects the connector. Functional tests include power quality tests.

4.3.4.7.1.3 Structural Loads DELETED

4.3.4.7.1.4 Connector Access DELETED

4.3.4.7.1.5 Fluid Connectors

Verification of Fluid Connector remote visual access SHALL be by analysis. Verification SHALL be considered successful when viewing analysis shows that fluid connectors that are not blind-mate connectors can be viewed when using camera positions and field of views in accordance with the February 17, 1995 release of the SPDM model.

4.3.4.7.2 Utility Connector Design

4.3.4.7.2.1 Blind Mate

Verification of Blind Mate Connector design SHALL be by inspection. Verification SHALL be considered successful when inspection of flight element drawings shows compliance with the requirement as specified.

4.3.4.7.2.2 Mate/Demate Force

Verification of Mate/Demate Force of connectors not integrated into OMH SHALL be by analysis. Verification SHALL be considered successful when analysis of test data shows that utility connectors that are not integrated into OMH can be mated and demated with a maximum of 20 lbf (89 N) axial force or 10 lbf (45 N) lateral force or 10 ft-lbf (13.6 N-m) torque.

4.3.4.7.2.3 Single Manipulator Operation DELETED

4.3.4.7.2.4 Accessibility

Verification of individual connector Accessibility SHALL be by analysis. Verification SHALL be considered successful when analysis shows conformance to the requirement as specified.

4.3.4.7.2.5 Ease of Disconnect

Verification of single axis disconnect SHALL be by analysis. Verification SHALL be considered successful when analysis of demonstration data shows that each type of connector that is manipulated without the aid of a tool requires no more than one rotary turn by the dexterous robot arm to mate or demate.

4.3.4.7.2.6 Connector Guides DELETED

4.3.4.7.2.7 Soft Dock DELETED

4.3.4.7.2.8 Positive Lock

Verification of connector Positive Lock SHALL be by analysis. Verification SHALL be considered successful when analysis of demonstration data shows that each type of connector has a positive lock function, unless the connector is incorporated into OMH which is positively locked.

4.3.4.7.2.9 Status Indicators <u>DELETED</u>

4.3.4.7.2.10 Protective Caps

Verification of the passive activation of connector protective caps SHALL be by analysis. Verification SHALL be considered successful when analysis of demonstration data shows that protective caps for dexterous robotically mated connectors are passively activated by the mating operation of the connector.

4.3.4.7.2.11 Compatibility <u>DELETED</u>

4.3.4.7.2.12 Stowage/Retention

Verification of an Interim Stowage position for demated connectors SHALL be by inspection. Verification SHALL be considered successful when the flight element drawings show that an interim attachment point at the OMH worksite is provided for demated connectors requiring manipulation by the dexterous robot.

4.3.4.7.2.13 Power/Data Interface <u>DELETED</u>

4.3.4.7.2.14 End Effector Actuation <u>DELETED</u>

4.3.4.8 Label and Marking Integration and Design Requirements

4.3.4.8.1 Labeling and Marking Integration to OMH and Worksites

4.3.4.8.1.1 Label and Marking General Requirements

4.3.4.8.1.1.1 Label and Marking <u>DELETED</u>

4.3.4.8.1.1.2 Association Errors <u>DELETED</u>

4.3.4.8.1.1.3 Robotic Vision System Compatibility

Verification of label and marking Compatibility SHALL be by inspection. Verification SHALL be considered successful when inspection of flight OMH and element level assembly drawings shows that robotic labels are visually accessible.

4.3.4.8.1.2 Label and Markings Requirements

4.3.4.8.1.2.1 Orientation <u>DELETED</u>

4.3.4.8.1.2.2 Identification Labels / Markings DELETED

4.3.4.8.1.3 Marking Requirements

Verification of Marking SHALL be by inspection. Verification SHALL be considered successful when inspection of the flight element drawings shows conformance to the requirement as specified.

4.3.4.8.1.3.1 Identification DELETED

4.3.4.8.1.3.2 Identification DELETED

4.3.4.8.1.3.3 Location

Verification of the existence and location of caution and warning labels and markings in the global worksite SHALL be by inspection of flight element drawings. Verification SHALL be considered successful when inspection shows that caution and warning labels and markings are provided with in the global worksite for all robot hazards identified within the worksite in accordance with the requirement as specified.

4.3.4.8.1.4 Coding Requirements DELETED

4.3.4.8.1.4.1 Location Code DELETED

4.3.4.8.1.4.2 Location Code DELETED

4.3.4.8.1.4.3 Brightness Coding DELETED

4.3.4.8.1.4.4 Color Coding DELETED

4.3.4.8.1.4.5 Flash Coding DELETED

4.3.4.8.1.4.6 Pattern Coding DELETED

4.3.4.8.1.4.7 Shape Coding Usage DELETED

4.3.4.8.1.4.8 Position and Orientation Independence DELETED

4.3.4.8.2 Labeling and Marking Design

4.3.4.8.2.1 Engraved Lettering/Numerals

Verification of Engraved Lettering/Numeral coloring SHALL be by inspection. Verification SHALL be considered successful when inspection of the flight element drawings shows that engraved characters are colored in accordance with the requirement as specified.

4.3.4.8.2.2 Zone Markings

Verification of Zone Marking colors SHALL be by inspection. Verification SHALL be considered successful when inspection of supplier source control drawings shows that zone marking colors are in accordance with the requirement as specified.

4.3.4.8.2.3 Label Quantity

Verification of common Labels and Markings for EVA/Robotics use SHALL be by inspection. Verification SHALL be considered successful when inspection of flight element drawings shows that when any label or marking is required for both EVA and robotic system operations, a common label or marking is provided.

4.3.4.9 Access Closure Integration and Design Requirements

4.3.4.9.1 Access Closure Integration To OMH and Worksites DELETED

4.3.4.9.2 Access Closure Design

4.3.4.9.2.1 Cover Compatibility

Verification of access closure Cover Compatibility SHALL be by inspection. Verification SHALL be considered successful when inspection of logistics Support Analysis Records (LSARs) and flight element drawings shows that closures which provide access to dexterous compatible equipment can be opened and closed by the dexterous robot.

4.3.4.9.2.2 Loads DELETED

4.3.4.9.2.3 Thermal Blankets DELETED

4.3.4.9.2.4 Protective Covers DELETED

4.3.4.9.2.5 Single Manipulator

Verification of access closure actuation SHALL be by analysis. Verification SHALL be considered successful when kinematic analysis shows that it is possible for one manipulator arm to open and close the access door along a single degree of freedom path (one translation or one rotation) while stabilizing with the other arm.

4.3.4.9.2.6 Captured/Self-Supporting Closures

Verification of access closure capture and stability SHALL be by inspection and analysis. Inspection of access door flight element drawings SHALL be considered successful when it is shown that the closure is captured and in a stable configuration when in the fully opened position. Verification SHALL be considered successful when in addition to the above inspection, analysis shows that the access closures provide the structural integrity required to be self-supporting in the fully opened position.

4.3.4.9.2.7 Grasp Interface **DELETED**

4.3.4.9.2.8 Pinching Latches

Verification of Pinching Latches SHALL be by inspection. Verification SHALL be considered successful when inspection of flight element drawings shows that pinching latch mechanisms are not implemented on access closure equipment designated for robotic manipulation.

4.3.4.9.2.9 Positive Lock **DELETED**

4.3.4.9.2.10 Flexible Materials **DELETED**

4.3.4.10 Mobility/Stability Aid and Reinforced Grasp Area Integration and Design Requirements

4.3.4.10.1 Mobility/Stability Aid and Reinforced Grasp Area Integration to OMH and Worksites

4.3.4.10.1.1 ORU/Manipulated Hardware **DELETED**

4.3.4.10.1.2 Required Usage

Verification of the use of mobility/stability aids SHALL be by inspection. The verification SHALL be considered successful when the inspection of flight element drawings shows that mobility/stability aids are provided at worksites that require a dexterous robotic system to operate from a robotic positioning system.

4.3.4.10.1.3 Equipment Accessibility

Verification of equipment accessibility adjacent to mobility/stability aids SHALL be performed by inspection. Verification SHALL be considered successful when inspection of flight element drawings shows that mobility/stability aids are positioned more than 3 inches away from any adjacent equipment.

4.3.4.10.1.4 Spacing

Verification of Spacing of mobility/stability aids SHALL be by analysis. Verification SHALL be considered successful when kinematic analysis shows that the mobility/stability aid spacing is in accordance with the requirement as specified. .

4.3.4.10.1.5 Spacing **DELETED**

4.3.4.10.2 Mobility/Stability Aid and Reinforced Grasp Area Design

4.3.4.10.2.1 Status Indication

Verification of Portable mobility/stability aid Status Indication SHALL be by analysis. Verification SHALL be considered successful when analysis of demonstration data shows that portable mobility stability aids provide a positive status indication of when they are in the locked position when mated with structure.

4.3.4.10.2.2 Removal and Relocation

Verification of robotic removal and relocation of portable mobility/stability aids SHALL be by analysis. The verification SHALL be considered successful when analysis of demonstration data shows that a dexterous manipulator arm can successfully install, remove, and relocate the portable mobility/stability aid.

4.3.4.10.2.3 Reinforced Grasp Area Interface Strength

Verification of reinforced grasp area strength SHALL be by test or analysis. The verification SHALL be considered successful when analysis or tests, using validated structural analysis models or test articles, shows that the reinforced grasp area to structural interface has the strength to withstand combined loads of 50 lbf (222.5 N) and 250 ft-lbf (339 N-m) torque (applied in any direction) in accordance with the guidelines of SSP 30559.

4.3.4.10.2.3.1 Mobility/Stability Aid Mounting Plane Strength <u>DELETED</u>

4.3.4.10.2.3.2 Mobility/Stability Aid Mounting Plane Stiffness

Verification of mobility/stability aid stiffness SHALL be by test or analysis. The verification SHALL be considered successful, when the test or analysis, using validated structural analysis models or test articles, shows that the mobility/stability aid mounting plane stiffness is not less than 5000 ft-lbf/rad (6780 N-m/rad) around any axis and 1000 lbf/in (175127 N/m) along any axis.

4.3.4.10.2.4 Alignment <u>DELETED</u>

4.3.4.10.2.5 Identification

Verification that Reinforced grasp areas are identified differently from standard grasp areas SHALL be by inspection. Verification SHALL be considered successful when inspection of flight element drawings shows that reinforced grasp areas are visibly distinguishable from standard grasp areas.

4.3.4.10.2.6 Equipment Restraints <u>DELETED</u>

4.3.4.10.2.7 Surface Quality <u>DELETED</u>

4.3.4.10.2.8 Standardization

Verification that standard Mobility/stability aids are employed SHALL be by inspection. Verification SHALL be considered successful when inspection shows that only the mobility/stability aids defined in SSP 42004, Section C are used.

4.3.4.10.2.9 Securing Pins <u>DELETED</u>

4.3.4.11 Berthing Point Integration and Design Requirements DELETED

4.3.4.11.1 Berthing Point Integration to OMH and Worksites DELETED

4.3.4.11.1.1 Required Usage DELETED

4.3.4.11.1.2 Location DELETED

4.3.4.11.1.3 Access DELETED

4.3.4.11.1.4 Orientation Requirements DELETED

4.3.4.11.1.5 Hazard Protection DELETED

4.3.4.11.1.6 Utilities DELETED

4.3.4.11.1.7 Berthing Point Rigidity DELETED

4.3.4.11.2 Berthing Point Design DELETED

4.3.4.12 Stowage and Restraint Integration and Design Requirement

4.3.4.12.1 Stowage and Restraint Integration To OMH and Worksites DELETED

4.3.4.12.1.1 Captive Equipment and Fasteners DELETED

4.3.4.12.1.2 Access DELETED

4.3.4.12.1.3 Placement DELETED

4.3.4.12.1.4 Straps DELETED

4.3.4.12.1.5 Adhesive Equipment Restraints DELETED

4.3.4.12.2 Stowage and Restraint Design

4.3.4.12.2.1 Removal

Verification of Stowage and Restraint removal Design SHALL be by inspection. The verification SHALL be considered successful when the inspection of flight element drawings and analysis shows that OMH items mounted on pallets and carriers are individually restrained, removed, and replaced.

4.3.4.12.2.2 Retainer Operation DELETED

4.3.4.12.2.3 Container Labeling DELETED

4.3.4.12.2.4 Single Manipulator Operation DELETED

4.3.4.12.2.5 Adjustability DELETED

4.3.4.12.2.6 Preferred Location Of Restrained Items DELETED

4.3.4.12.2.7 Minimum Load DELETED

4.3.4.12.2.8 Maximum Load (1) DELETED

4.3.4.12.2.9 Maximum Load (2) DELETED

4.3.4.12.2.10 Commonality

4.3.4.12.2.11 Attachment DELETED

4.3.4.12.2.12 Obstructions DELETED

4,3.4.12.2.13 Tethers DELETED

4.3.4.12.2.14 Stowage DELETED

4.3.4.13 Cable and Umbilical Integration and Design Requirements

4.3.4.13.1 Cable and Umbilical Integration to OMH and Worksites

4.3.4.13.1.1 Cables

Verification that cables are not manipulated SHALL be by inspection. The verification SHALL be considered successful when inspection of Logistics Support Analysis Records (LSARs) show that no dexterous robotic tasks require the manipulation of cables by the dexterous robotic system.

4.3.4.13.1.2 Umbilicals

Verification that umbilicals are not manipulated SHALL be by inspection. The verification SHALL be considered successful when inspection of Logistics Support Analysis Records (LSARs) show that no dexterous robotic tasks require the manipulation of umbilicals by the dexterous robotic system.

4.3.4.13.2 Cable and Umbilical Design DELETED

4.3.4.14 Tool Integration and Design Requirements

4.3.4.14.1 Tool Integration to OMH and Worksites.

4.3.4.14.1.1 Direct Interface <u>DELETED</u>

4.3.4.14.1.2 Tool Stowage

Verification of Tool Stowage SHALL be by inspection. The verification SHALL be successful when flight element drawings show that there is a dedicated holster allocated for each robotic tool.

4.3.4.14.1.3 Standard Robot Tool Stowage

Verification of Standard Robot Tool Stowage SHALL be by inspection and analysis. Verification SHALL be considered successful when inspection shows the tool holsters designed in accordance with SSP 42004 Section F accommodate the tools specified in SSP 42004 Sections G, J, and M. Verification SHALL be considered successful when in addition to the above inspection, analysis of demonstration data shows successful mating and demating of the tool to holster.

4.3.4.14.2 Tool Design

4.3.4.14.2.1 Tool Complexity <u>DELETED</u>

4.3.4.14.2.2 End Effector Tool Complexity <u>DELETED</u>

4.3.4.14.2.3 Direct Interface <u>DELETED</u>

4.3.4.14.2.4 Uncommanded Release <u>DELETED</u>

4.3.4.14.2.5 Attachment <u>DELETED</u>

4.3.4.14.2.6 Standardization

Verification of the Standardized robotic system-to-tool grasp interface SHALL be by inspection. Verification SHALL be considered successful when it can be shown that the tools used by dexterous robotic systems incorporate a robotic grasp interface as defined in SSP 42004 Chapter Section L.

4.3.4.14.2.7 Alignment <u>DELETED</u>

4.3.4.14.2.8 Direct Worksite Interface

Verification of tool Direct Worksite Interface SHALL be by analysis. The verification SHALL be considered successful when analysis of demonstration data shows that the tool interfaces to the OMH without the need for additional tool hardware.

4.3.4.14.2.9 Alignment Features <u>DELETED</u>

4.3.4.14.2.10 Status Indicators <u>DELETED</u>

4.3.4.14.2.11 Fastener Head Engagement

Verification of Fastener Head Engagement SHALL be by inspection of flight element drawings and analysis. The inspection SHALL be considered successful when it is shown that the fastener drive sockets for robotic tools comply with the respective socket specifications in Sections G, J, L, or M of SSP 42004. The demonstration used to produce analysis data SHALL use a laboratory model robot having a validated dexterous robot end effector to operate a validated robotic tool test article. Verification SHALL be considered successful when analysis of demonstration data shows that the socket of the robot tool fully engages the Fastener Head in an ORU/Fastener Head test article prior to the application of tightening and loosening torque.

4.3.4.14.2.12 Equipment Access Envelope

Verification of Tool Equipment Access Envelopes SHALL be by analysis. The verification SHALL be considered successful when kinematic analysis shows that the subject Tool can fit into the prescribed access envelope specified in the requirement.

4.3.4.14.2.13 Tool Utilities

Verification of Tool Utilities SHALL be by inspection. The inspection SHALL identify where each Tool's external connector pin function is sourced or sinked. The verification SHALL be considered successful when it is shown that the Tool's connector, connector pin pattern, pin sizes and style, and pin functions are in accordance with the requirement as specified.

4.3.4.14.2.14 Actuation

Verification of Tool Actuation SHALL be by analysis. The demonstration used to produce analysis data SHALL use a laboratory model robot having a validated dexterous robot end effector to operate a validated robotic tool test article. Verification SHALL be considered successful when analysis of demonstration data shows that the tool can be actuated utilizing only the force and torque capabilities of the dexterous robot end effector torque drive or the power and data capabilities of the dexterous robot end effector.

4.3.4.14.2.15 Uncommanded Release

Verification of Tool design to prevent Uncommanded Release SHALL be by analysis. The analysis SHALL use FMEA data to define possible failures and then determine whether any combination of two failures, or two operator errors, or one of each can cause an uncommanded release of OMH to occur. The verification SHALL be considered successful when the analysis shows that uncommanded release cannot occur as a result of the specified failure/human error combinations.

4.3.4.14.2.16 Identification Labels <u>DELETED</u>

4.3.4.14.2.17 Content <u>DELETED</u>

4.3.4.14.2.18 Orientation <u>DELETED</u>

4.3.4.14.2.19 Tool Length DELETED

4.3.4.14.2.20 Robot-To-Tool Interface Loads DELETED

4.3.4.14.2.21 Tool-To-OMH Interface Loads DELETED

4.3.4.15 Thermal Blankets

Verification of the thermal blankets robot compatibility SHALL be by inspection. Verification SHALL be considered successful when review of flight element drawings verifies that all worksites and OMH, including access closures, are designed such that the dexterous grasp interfaces and non-collocated fasteners are accessible by a tool or end effector and such that the OMH can be inserted, removed, and actuated without removal or rearrangement of thermal blankets unless the thermal blankets are integrated with access closures. A one time EVA to remove thermal blankets which are not designed to be robot compatible is allowable.

4.3.5 HAZARDS TO ROBOTIC SYSTEMS

4.3.5.1 Warning Labels

Verification of the warnings label robot compatibility SHALL be performed by inspection. Verification SHALL be considered successful when inspection of flight element drawings has identified all identified hazards to robotic systems and these hazards are shown to have a warning label meeting the requirements of paragraph 3.4.8.1.

4.3.5.2 Electrical Hazards

4.3.5.2.1 Grounding

Verification of Grounding electrical hazards SHALL be performed by analysis. The verification SHALL be considered successful when analysis of flight element schematics and installation drawings show that external metal parts within 3 inches of planned robotic translation paths for robotically manipulated hardware have bonding provisions in accordance with SSP 30245 and are grounded in accordance with SSP 30420.

4.3.5.2.2 Static Discharge

Verification of static discharge from non-robotic hardware SHALL be performed by inspection of installation drawings showing the bonding configuration and by review of engineering trade studies which led to the placement of bonding provisions. Verification SHALL be considered successful when inspection shows that a Class S bonding design in accordance with SSP 30243 and SSP 30245 has been implemented.

4.3.5.2.3 Electrical Hazards DELETED

4.3.5.3 Physical Hazards

4.3.5.3.1 Stored Energy Hazards

Verification of the Stored Energy Hazards to the robot system SHALL be performed by inspection and analysis. Flight element drawings SHALL be inspected to determine if the subject equipment contains any energy storage mechanisms which will be reacted through the manipulator to its base or stabilization point due to insertion, removal, or manipulation operations. The verification SHALL be considered successful when an analysis of items that present stored mechanical energy to the robotic system identified in the above inspection shows that the stored mechanical energy cannot exceed 5.0 Joules.

4.3.5.3.2 Entanglements

Verification of Entanglement hazards SHALL be performed by analysis. The verification SHALL be considered successful when the analysis shows that all equipment that presents potential entanglement hazards (e.g., tethers, umbilicals, cabling, etc.) employs a cable management system preventing entanglement of robotic systems.

4.3.5.4 Thermal Hazards <u>DELETED</u>

4.3.5.4.1 Continuous Contact <u>DELETED</u>

4.3.5.4.2 Incidental Contact <u>DELETED</u>

APPENDIX A
ABBREVIATIONS AND ACRONYMS

AIT	Analysis and Integration Team
C	Centigrade
CCW	Counter Clockwise
CSA	Canadian Space Agency
CW	Clockwise
Deg	Degree
DOF	Degree of Freedom
e.g.	Example Given
etc.	Etceteras
EVA	Extravehicular Activity
EVR	Extravehicular Robotics
EVR AIT	Extravehicular Robotics Analysis & Integration Team
F	Fahrenheit
FMEA	Failure Mode Effects Analysis
ft-lb	Foot-pound
ICD	Interface Control Document
i.e.	That is
ISS	International Space Station
ISSP	International Space Station program
IVA	Intravehicular Activity
JSC	Johnson Space Center
Kg	Kilogram
lb	pounds
lbf	pound force
lbm	pound mass
LSAR	Logistics Support Analysis Record
m	Meters
MIP	MSS Integration Panel
mm	Millimeters
MSS	Mobile Servicing System
N	Newtons
NASA	National Aeronautics and Space Administration
N-m	Newton-meters
NSTS	National Space Transportation System

OMH	ORU/Manipulated Hardware
ORU	Orbit Replaceable Unit
OTCM	ORU Tool Changeout Mechanism
PDGF	Power Data Grapple Fixture
POR	Point of Resolution
RMS	Remote Manipulator System
RSIS	Robotic Systems Integration Standard
RSUG	Robotic Systems User's Guide
SEC	Second
SEE	Standard End Effector
SGF	Standard Grapple Fixture
SPDM	Special Purpose Dexterous Manipulator
SRD	System Requirements Document
SRMS	Shuttle Remote Manipulator System
SSCB	Space Station Control Board
SSPO	Space Station Program Office
SSP	Space Station Program
SSRMS	Space Station Remote Manipulator System
TBD	To Be Determined
TBR	To Be Resolved
V	Volts

APPENDIX B
GLOSSARY OF TERMS

ALIGNMENT GUIDE

A device used to provide increased position and orientation accuracy when mating two objects. Guide mechanisms can be external to the objects or an integral part of the object' s configuration.

Coarse Alignment Guide

A device of design geometry (e.g., cones, tapers, chamfers) that provide increased accuracy on approach between mating objects. The guide forces the two objects into a specific position and orientation relative to one another.

Fine Alignment Guide

A device (e.g., pins, rails, grooves) that permits coarsely aligned mating objects to correctly engage attachment mechanisms.

ANTHROPOMORPHIC

Resembling the human body in form, function, or attributes.

BERTHING POINT

See Robotic System Berthing Point.

CAPTURE

To restrict of confine motion (degrees of freedom) of an object.

COARSE ALIGNMENT

The dexterous robotic system coarsely aligns the ORU with respect to the corresponding berthing site by mechanically guiding the ORU within the coarse alignment guides. The IVA operator controls the insertion rate. Coarse Alignment begins after contact between the ORU and the berthing site. Coarse alignment is completed when an indication, detected by the dexterous robotic system, is generated indicating the fastening system is to be engaged.

COMMON TOOL

An independent device designed for use by both Extravehicular Activity (EVA) crew members and robotic systems to perform tasks that exceed their baseline capabilities. Tool compatibility is accomplished by providing appropriate interfaces to a robotic system's end effector and an EVA crew member.

COMMONALTY

The use of the same standardized and compatible items or methods.

COMPATIBILITY

The ability for multiple types of systems to interact with a particular piece of equipment.

COMPONENT

See Hardware.

CONNECTOR

A mechanical device designed to allow the transfer of utilities (e.g., electrical, fluid, optical).

CONTROL

A manually operated hardware item used to operate or change the performance of machine or system.

DEGREES OF FREEDOM (DOF)

The number of joint axes or independent movements a manipulator or positioning system can perform.

DEXTEROUS MANIPULATOR

An action or task that generally mimics anthropomorphic abilities using multiple degrees of freedom with fine control, accuracy, and precision.

DEXTEROUS ROBOTIC SYSTEM

A robotic system that can perform precise operations on specific objects. Its manipulators have multiple degrees of freedom and are capable of highly accurate movements.

DISPLAY

Hardware item used to present system information visually.

END EFFECTOR

The part of a robotic manipulator that physically interfaces with a workpiece or tool.

ENVELOPE

See Reach Envelope, Task Envelope, and Work Envelope

EXTRAVEHICULAR ACTIVITY

EVAs are activities performed by a space-suited crew member with or without the use of hand or power tools in an unpressurized or space environment.

EXTRAVEHICULAR ROBOTICS (EVR)

Activities performed by a robotic system in an unpressurized or space environment.

FASTENER

A mechanical device designed to attach two or more objects together securely (e.g., screws, bolts, latches, catches, clamps).

FINE ALIGNMENT

Fine alignment is achieved by the fastening system. The fastening system rigidly attaches the ORU to the berthing site. The fastening system aligns the ORU with respect to the berthing site as part of the fastening process. Fine alignment begins after a torque or force is applied to the fastening system. Fine alignment is completed when an indication, detected by the dexterous robotic system, is generated indicating the fastening system has been correctly tightened.

Distinguish the coarse/fine alignment process from coarse/fine alignments guides and mechanisms which are not clearly identifiable.

What is critical from the perspective of robotic integration is the detection of the coarse/fine transition. That is when to apply torque from the socket drive.

GRASP AREA

A rigid interface between a robotic system and/or EVA crew member and movable object (i.e., ORU) specially designed for grasping and handling the object. (Also refer to Mobility/Stability Aid)

HANDLE

See Grasp Area.

HARDWARE

Any mechanical, electrical, electronic, pneumatic, or hydraulic devices that compose Space Station.

HAZARD

A condition or changing set of circumstances that presents a potential for damage (in this document, to a robotic system).

IMPROVED WORKSITE

An extravehicular worksite that provides an interface for power, data, video, and structural stability (i.e., robotic system berthing point) and possibly mobility/stability aids and/or reinforced grasp areas for robotic system use.

INTEGRATED TORQUE REACTION POINT

An area configured into an interface assembly (E.g., end effector/tool-to-ORU, robotic system-to-worksite) to resist the reactive torque imposed on the robotic system, end effector, or tool.

JOINT

Point of articulation, with one or more degrees of freedom, between two manipulator segments.

KINEMATICS

The geometric characteristics of manipulator motion.

LEAVE BEHIND TARGET

A Target or visual cue device which in conjunction with a video overlay allows the operator to resolve misalignment in six degrees of freedom simultaneously. This device is located on the mating structure of a OMH receptacle and used as both a visual cue for acquiring the DGF and a berthing cue for mating the OMH to the coarse alignment capture envelope of the OMH receptacle.

LOCAL VERTICAL

A consistent arrangement of perpendicular cues within a given visual field to provide a definable orientation to the worksite.

MAINTAINABILITY

Characteristics of design and installation of an item that enable it to be preserved in or restored to a specific operational condition by using prescribed resources and procedures

MANIPULATOR

One or more articulating mechanical segments terminating at the end effector interface.

MICROGRAVITY

A level of acceleration force in the Space Station approximately on millionth of that produced on Earth's surface by gravity. Microgravity is generally defined as the gravitational acceleration ranging between 10^{-7} and 10^{-2} Earth gravity.

MOBILITY/STABILITY AID

An interface (e.g., H-Handle) between a permanent structure and a robotic system. It provided rigid structural attachment, local force and torque reaction, and could be used to facilitate translation in a microgravity environment.

OBSTRUCTION

- any physical barrier preventing OMH, manipulator arms, body, or positioning system motions required during translation or performance of the task.
- any physical barrier preventing full view of the visual cues used for insertion/removal or manipulation of the hardware.

ORBIT REPLACEABLE UNIT

A modular piece of external equipment (a single item or an assembly of components) that is designed for removal and replacement under normal on-orbit conditions. (ORUs may be “box type,” such as battery modules and avionics boxes, or may be other shapes, such as truss members, radiator panels, fluid lines, or wiring harnesses.)

ORU/MANIPULATED HARDWARE (OMH)

All hardware designed to be grasped, actuated, relocated or manipulated directly by the dexterous robot end-effector and/or its tools. Examples of this hardware include, but are not limited to, the following: connectors, ORUs, hinged radiators, sub-carriers, stowage retainers, robotic tools, fasteners/actuation mechanisms and stabilization fixtures.

POINT OF RESOLUTION (POR)

A point and orientation, in Cartesian space, about which the manipulator is controlled.

POWER DATA GRAPPLE FIXTURE (PDGF)

Support interface and locking device at designated worksites and a transportation interface for the robot that provides alignment, mechanical attachment, power, and data connection when mated with a Latching End Effector.

REACH ENVELOPE

The boundary of the volume described by the maximum reach capability of a robotic device from a fixed origin (usually the base). It describes only range, not the dexterity within that range. The reach envelope includes any equipment attached to the robotic system.

REINFORCED GRASP AREA

An interface designed to withstand and react the loads associated with a standard grasp area as well as those associated with robotic system and/or EVA crew member worksite stabilization. (This type of grasp area is used when there are no mobility/stability aids within the work envelope.)

ROBOTIC POSITIONING SYSTEM

A robotic system (e.g., SSRMS) that is capable of moving an object (usually large) from one position to another and placing the object in a specific orientation.

ROBOTICS

The technology and devices (sensors, effectors, and computers) for carrying out, under human or automatic control, physical tasks that would otherwise require human intervention.

ROBOTIC SYSTEM

Any dexterous robotic system, robotic positioning system, robotic transportation system, or combination thereof used on Space Station Freedom. In the context of teleoperations, the human operator is included as an integral part of the robotic system.

ROBOTIC SYSTEM BERTHING POINT

A specialized interface between a robotic system and an improved worksite. The purpose of this interface is to provide a stable rigid link between a relocatable robotic system and a fixed worksite. It provides for he location, alignment, and orientation of the robotic system and a fixed worksite. It provides for the location, alignment, and orientation of the robotic system as well as a path for utility transmission and a local force and torque reaction point. Berthing points can be fixed or attached to mobile structures.

ROBOTIC TOOL

An independent device designed for use by a robotic system to perform tasks which exceed the robotic system's baseline capabilities.

SOFT CAPTURE

See Soft Dock.

SOFT DOCK

An initial temporary attachment made between two or more pieces of equipment that prevents inadvertent release prior to permanent attachment. The soft dock mechanism is actuated by the physical engagement of mating equipment. Release of the soft dock mechanism may be accomplished through a reversal of the attachment procedure or may require additional procedural steps.

STANDARD END EFFECTOR

Standard End Effector (SEE) is a interface and locking device on the end of the Shuttle Remote Manipulator System (RMS) arm that provides alignment and mechanical attachment (grapple) for the transportation of objects, including a robot, when operating from the Shuttle payload bay. Mates with the Standard Grapple Fixture (SGF) (or the PDGF without the power and data connection).

STANDARD GRAPPLE FIXTURE

A support and transportation interface on an object that provides alignment and mechanical attachment when mated with SEE.

STANDARD GRASP AREA

An interface designed to react loads associated with the operational requirements of grasping, transporting, positioning, and manipulating moveable objects.

STANDARDIZATION

The consistent use of a specific approach (e.g., hardware, software, interface, configuration, etc.) to perform a given function.

STATUS INDICATOR

A device or marking that provides immediate information about equipment. Typical information might include whether an element is locked, active or inactive, or indicate the presence of forces, torques, electricity, or fluid flow.

TARGET

A visual cue device which in conjunction with a video overlay allows the operator to resolve misalignment in six degrees of freedom simultaneously.

TASK ENVELOPE

The volume of space required to move an object during task performance.

TELEOPERATION

Remote control of a robotic device.

Ten or less sequential single linear Cartesian degree-of-freedom motions

The ten or less sequential single linear Cartesian degree-of-freedom motions, for ORU insertion, begins at the point when the ORU back plane enters the receptacle volume (3 inches from secondary hardware).

TOOL

A device utilized by a robotic system or EVA crew member to perform tasks that exceed baseline capabilities.

TRANSPORTATION SYSTEM

A robotic system capable of moving an object from one location to another over a long distance. A transport device is usually not capable of changing the orientation of the object or placing the object in a specific orientation.

UMBILICAL

A flexible device of varied length used to transfer electrical power, electronic signals, and fluids from one system to another.

UTILITIES

Resources required by a system for operation. Utilities may include power, data, video, and fluids.

WORKSITE

The defined location where a specified task or set of tasks is performed by a robotic system.

There are two types of Worksites:

(1) ORU/Manipulated Hardware (OMH) Worksite:

The hardware, including primary and secondary structure and ORUs, requiring visual and/or physical contact by the robotic system or the manipulated hardware for task completion. Each OMH Worksite must meet the requirements for straight line motion, worksite color selection, controls and displays, worksite interfaces, and worksite accessibility.

(2) GLOBAL Worksite:

The area containing one or more OMH worksites within 12 feet of a robotic stabilization point. The Global Worksite includes the dexterous robot berthing point (fixed or mobile). Each Global Worksite must meet the requirements for straight line motion, controls and displays, consistent local vertical orientation, unique identification, worksite interfaces, worksite accessibility, clearance, equipment spacing and hazards.

Visual Cues

A alignment marking system which allows a robotic system teleoperator, through video monitoring, to align mating equipment in 3 position axes and 3 orientation axes to a specific accuracy. These marking are generally located on both the manipulated hardware and the mating hardware. Video overlays are not commonly required but not precluded.

Worksite Visual Cue/Worksite Visual Cue Capture Condition

The point at which the OMH has been positioned from “an unconstrained approach position” to within the capture envelope of its coarse alignment guides.

WORKSTATION

The defined location where a specified task or set of tasks is performed by Intravehicular Activity (IVA) crew members.