

International External Robotic Interface Interoperability Standards (IERIIS)

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REVISION AND HISTORY

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PREFACE

**INTERNATIONAL EXTERNAL ROBOTIC INTERFACE INTEROPERABILITY STANDARDS
(IERIIS)**

This International External Robotic Interface Interoperability Standards (IERIIS) establishes a set of standard common mounting interfaces to enable on-orbit robotic operations and collaborative endeavors utilizing different robotic compatible spacecraft or equipment in deep space.

Configuration control of this document is the responsibility of the Multilateral Coordination Board (MCB). The National Aeronautics and Space Administration (NASA) will maintain the IERIIS under Human Exploration and Operations Mission Directorate (HEOMD) Configuration Management. Any revisions to this document will be approved by the MCB.

Baseline

**INTERNATIONAL EXTERNAL ROBOTIC INTERFACE INTEROPERABILITY STANDARDS
(IERIIS)**

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1.0 INTRODUCTION

This International External Robotic Interface Interoperability Standards (IERIIS) is the result of a collaboration by the International Space Station (ISS) membership to establish interoperable interfaces, terminology, and techniques to facilitate collaborative endeavors of space exploration in cislunar and deep space environments. These standards are available for international and commercial partnerships.

Standards that are established and internationally recognized have been selected where possible to enable a variety of providers. Increasing hardware commonality among providers while decreasing unique configurations has the potential to reduce the traditional barriers in space exploration: overall mass and volume required to execute a mission. Standardizing interfaces reduces the scope of the development effort.

The information within this document represents a set of parameters, which if accommodated in the system architecture support greater efficiencies, promote cost savings, and increase the probability of mission success. These standards are not intended to specify system details needed for implementation nor do they dictate design features behind the interface; specific requirements will be defined in unique documents.

1.1 PURPOSE AND SCOPE

The purpose of the IERIIS is to provide a set of common design parameters to allow module, visiting vehicle, and on-orbit relocatable or replaceable unit (ORU) providers to architect and design elements which are compatible with an external robotic system, and vice versa for human exploration and associated interfaces in deep space environments. The focus of this document version is on cislunar space missions, specifically crewed orbital platforms. Future revisions of the document will incorporate additional deep space missions. This standard leverages ISS robotic interface heritage and lessons learned, as well as related technology development activities.

Similar to terrestrial robotic interface standards, the scope of this document is focused on standard common mounting interfaces for robotic manipulator fixtures; it does not define the fixtures.

This standard similarly does not address internal robotic compatible systems, vehicle to vehicle berthing only interfaces (e.g. ISS Common Berthing Mechanism (CBM)), or vehicle to vehicle berthing compatible docking interfaces (e.g. berthing compatible International Docking System Standard (IDSS) implementation (IDSS-B)).

1.2 RESPONSIBILITY AND CHANGE AUTHORITY

Any proposed changes to this standard by the participating partners of this agreement shall be brought forward to the IERIIS working group for review.

Configuration control of this document is the responsibility of the Multilateral Coordination Board (MCB). The National Aeronautics and Space Administration (NASA) will maintain the IERIIS under Human Exploration and Operations Mission

Directorate (HEOMD) Configuration Management. Any revisions to this document will be approved by the MCB.

2.0 DOCUMENTS

2.1 APPLICABLE DOCUMENTS

The following documents include specifications, models, standards, guidelines, handbooks, or other special publications. The documents listed in this paragraph are applicable to the extent specified herein.

None

2.2 REFERENCE DOCUMENTS

The following documents contain supplemental information to guide the user in the application of this document. These reference documents may or may not be specifically cited within the text of this document.

IDSS IDD	International Docking System Standard (IDSS) Interface Definition Document (IDD)
ISO 9409-1	Manipulating industrial robots - Mechanical interfaces – Part 1: Plates
SLS-ESD 30000	SLS Mission Planners Guide

3.0 INTERNATIONAL EXTERNAL ROBOTIC INTERFACE INTEROPERABILITY STANDARDS

3.1 GENERAL

The following subsections describe the classes of external robotics interfaces for the IERIIS.

3.1.1 DESCRIPTION

Lessons learned from robotic operations on board the ISS have identified that the use of a limited number of standardized interfaces would be beneficial for improving efficiency and reducing overall complexity, which are critical considerations for future space exploration robotics.

The goals of the IERIIS are:

1. Establish common generic mounting interfaces for all external robotic interface classes. Creating standards ensures interchangeability and is consistent with other international standards such as those developed for the manipulation of industrial robots (International Organization for Standardization (ISO) 9409-1, Manipulating industrial robots - Mechanical interfaces – Part 1: Plates).
2. Maximize use of simple interface designs. IERIIS should direct the module/vehicle/payload designers to simple and robust robotic interfaces that have been accepted by the international community.
3. Enable provision of robotic fixture hardware as part of the robotic system if desired.

The IERIIS document is divided into several sections to define each of the unique robotic interface classes.

In this document, ORU will be used interchangeably with ORU/Payload to represent both ORU and generic non-ORU payloads.

- Large Fixture Interfaces (Section 4.0)
 - Fixtures used for robotic handling of vehicles/modules, large payloads or as robotic bases. Applicable to operations including free flyer capture, relocation and tool handling.
- Small ORU Platform Interfaces (SORI)s (Section 5.0)
 - Platforms designed for supporting smaller ORUs that are mounted to a vehicle/module.
- Large ORU Platform Interfaces (LORI)s (Planned for Section 6.1)
 - Platforms designed for supporting larger ORUs that are mounted to a vehicle/module.
- Dexterous Fixture Interfaces (Planned for Section 6.2)

- A small dexterous interface used to robotically manipulate smaller payloads/ORUs.
- ORU Direct Interfaces (Planned for Section 6.3)
 - An interface that directly mounts to an ORU and vehicle/module without an intermediary platform.

Within IERIIS, the use of Small and Large with respect to robotic interfaces is meant to distinguish the magnitude of the loads expected to be imparted at the interface. These loads may be derived from a combination of mass and geometry of the attached payloads. Therefore, the selection of large or small interfaces will be determined by the user's needs on a basis of loads, mass, and geometric constraints.

A sixth interface class may be added to IERIIS in the future for interfaces that deal with the direct mounting of large ORUs/payloads.

A distinction must be made between interface user and interface developer level requirements. User level requirements are those that are of interest to parties who intend to mount an external robotics interface onto hardware. User level requirements can include interface loads, mounting details or fixture clearance approach envelopes. These requirements comprise the body of IERIIS. Developer level requirements can include details that are pertinent to the design of specific implementations of external robotic interface classes. These details can include geometric, structural, thermal details of particular components of the interface. These developer level requirements can be extensive for each specific interface specified in IERIIS, and will be detailed in separate documents.

3.1.2 COMMON MOUNTING INTERFACE PLANES

The subsequent sections describe common mounting interface planes for each external robotic interface class.

Rationale: Common mounting interfaces are defined for each interface class so that module and ORU providers can have a common set of requirements at the mounting plane. These will apply to all interfaces of that class.

3.1.2.1 LARGE FIXTURE INTERFACE

The common large fixture mounting interface plane is the interface located between the large fixture and the vehicle/module. The large fixture will interface with a large fixture compatible End Effector (EE) or tool. A conceptual example of the large fixture and corresponding mounting interface is depicted in Figure 3.1.2.1-1, Example of a Large Fixture and the Common Mounting Interface Plane.

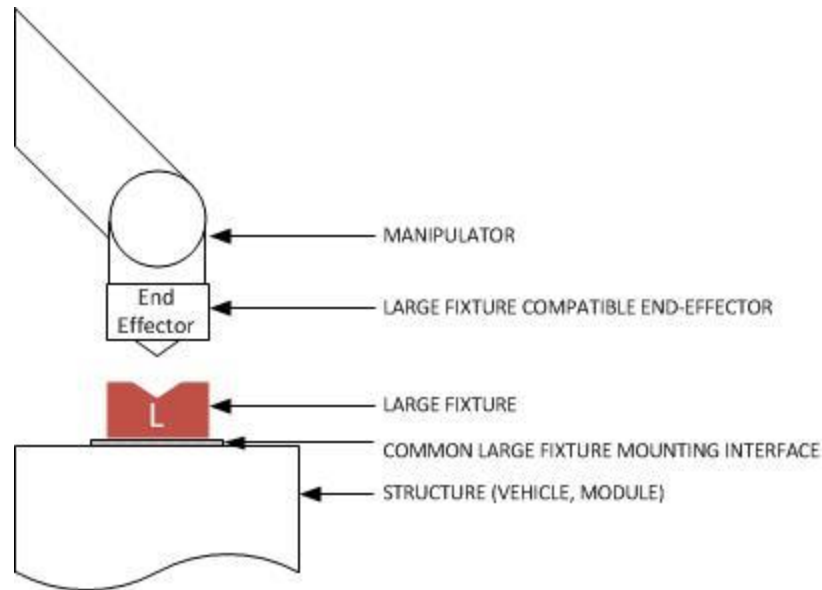


FIGURE 3.1.2.1-1 EXAMPLE OF A LARGE FIXTURE AND THE COMMON MOUNTING INTERFACE PLANE

3.1.2.2 SMALL ORU PLATFORM INTERFACES

For the small ORU platform, two common interface mounting planes can be defined.

- The common small platform mounting interface plane is the mounting plane between the ORU and the small platform.
- The common small receptacle mounting interface plane is the mounting plane located between the platform and the vehicle/module.

A conceptual example of the small ORU platform and corresponding mounting interfaces is depicted in Figure 3.1.2.2-1, Example of a Small ORU Platform and Common Mounting Planes. The small platform is manipulated by a dexterous fixture, which is included in the figure for reference.

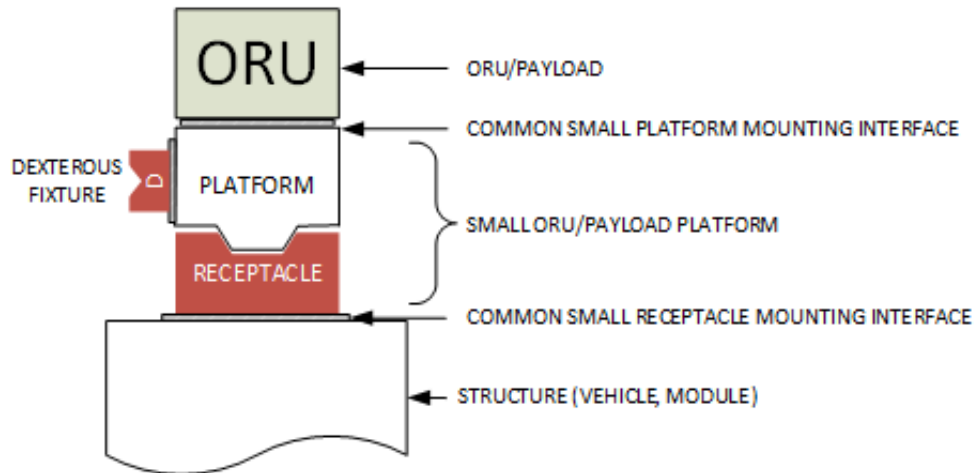


FIGURE 3.1.2.2-1 EXAMPLE OF A SMALL ORU PLATFORM AND COMMON MOUNTING PLANES

3.1.2.3 LARGE ORU PLATFORM INTERFACE

For the large ORU platform, two common interface mounting planes can be defined.

- The common large platform mounting interface plane is the mounting plane located between large ORU and the large platform.
- The common large receptacle mounting interface plane is the mounting plane located between the large platform and the vehicle/module.

A conceptual example of the large ORU platform and corresponding mounting interfaces is depicted in Figure 3.1.2.3-1, Example of a Large ORU Platform and Common Mounting Planes. The large platform is manipulated by a dexterous fixture, which is included in the figure for reference.

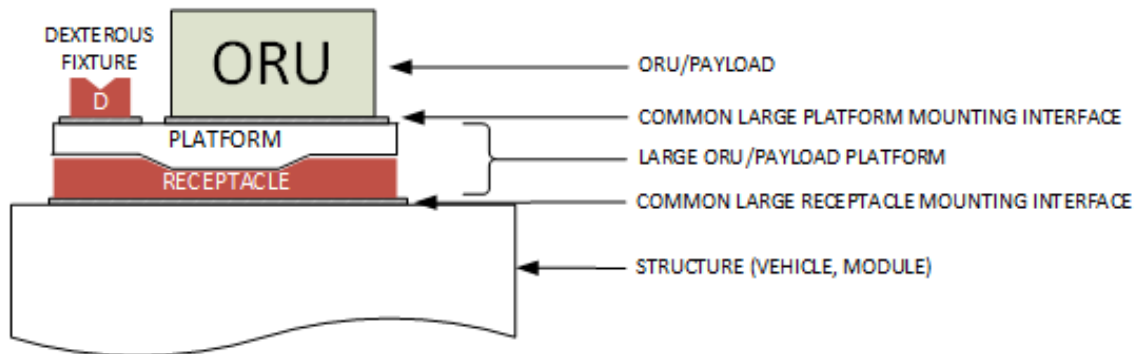


FIGURE 3.1.2.3-1 EXAMPLE OF A LARGE ORU PLATFORM AND COMMON MOUNTING PLANES

3.1.2.4 DEXTEROUS FIXTURE INTERFACE

The common dexterous fixture mounting interface plane is the mounting plane located between the dexterous fixture and the vehicle/module or ORU. The dexterous fixture will interface with a dexterous fixture compatible EE. A conceptual example of the large

fixture and corresponding mounting interface is depicted in Figure 3.1.2.4-1, Example of a Dexterous Fixture and Common Mounting Interface Plane.

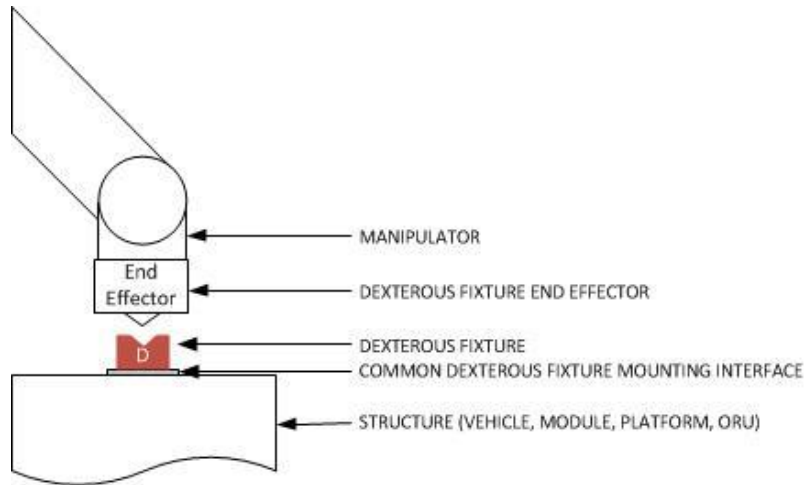


FIGURE 3.1.2.4-1 EXAMPLE OF A DEXTEROUS FIXTURE AND COMMON MOUNTING INTERFACE PLANE

3.1.2.5 SMALL ORU DIRECT INTERFACE

For the ORU direct interface two specific interface mounting planes can be defined.

- The specific mate/demate mounting interface plane is the mounting plane between the ORU and the mate/demate structure.
- The specific receptacle mounting interface plane is the mounting plane between the mate/demate receptacle and the vehicle/module.

A conceptual example of the ORU direct interface is depicted in Figure 3.1.2.5-1, Example of an ORU Direct Interface and Common Mounting Planes. The direct interface is manipulated by a dexterous fixture, which is included in the figure for reference.

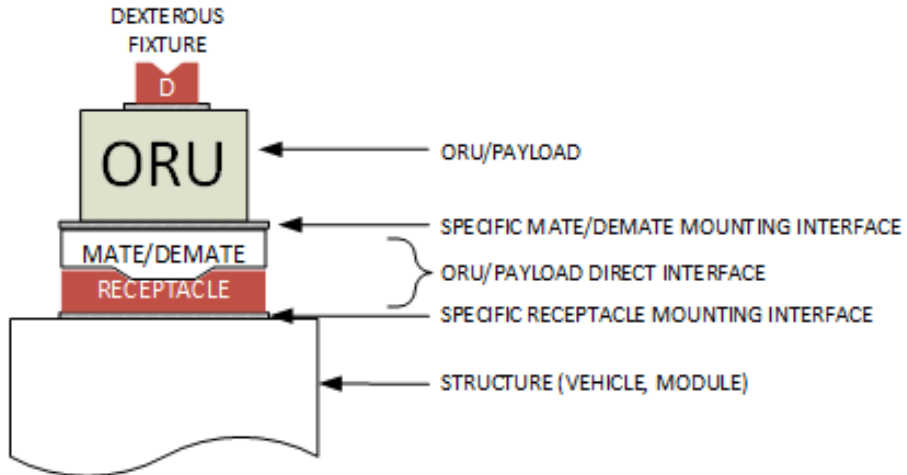


FIGURE 3.1.2.5-1 EXAMPLE OF AN ORU DIRECT INTERFACE AND COMMON MOUNTING PLANES

3.1.2.6 IERIIS ROADMAP

The organization of IERIIS is represented pictorially in Figure 3.1.2.6-1, IERIIS Roadmap.

IERIIS defines a set of common requirements for each member of the interface class defined at the interface plane.

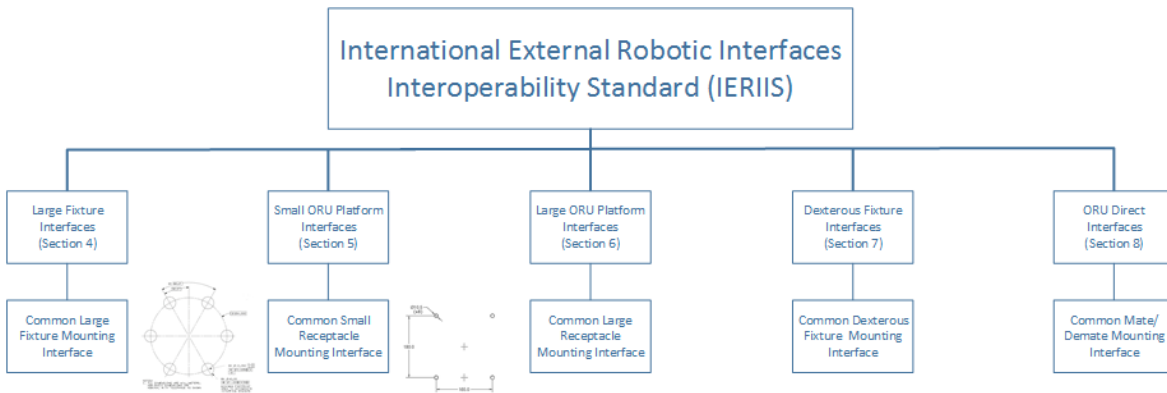


FIGURE 3.1.2.6-1 IERIIS ROADMAP

3.1.2.7 INTERFACE SUMMARY

An overview of external robotic interface classes is presented conceptually in Figure 3.1.2.7-1, Overview of Interface Classes and Common Mounting Planes for a Notional Station.

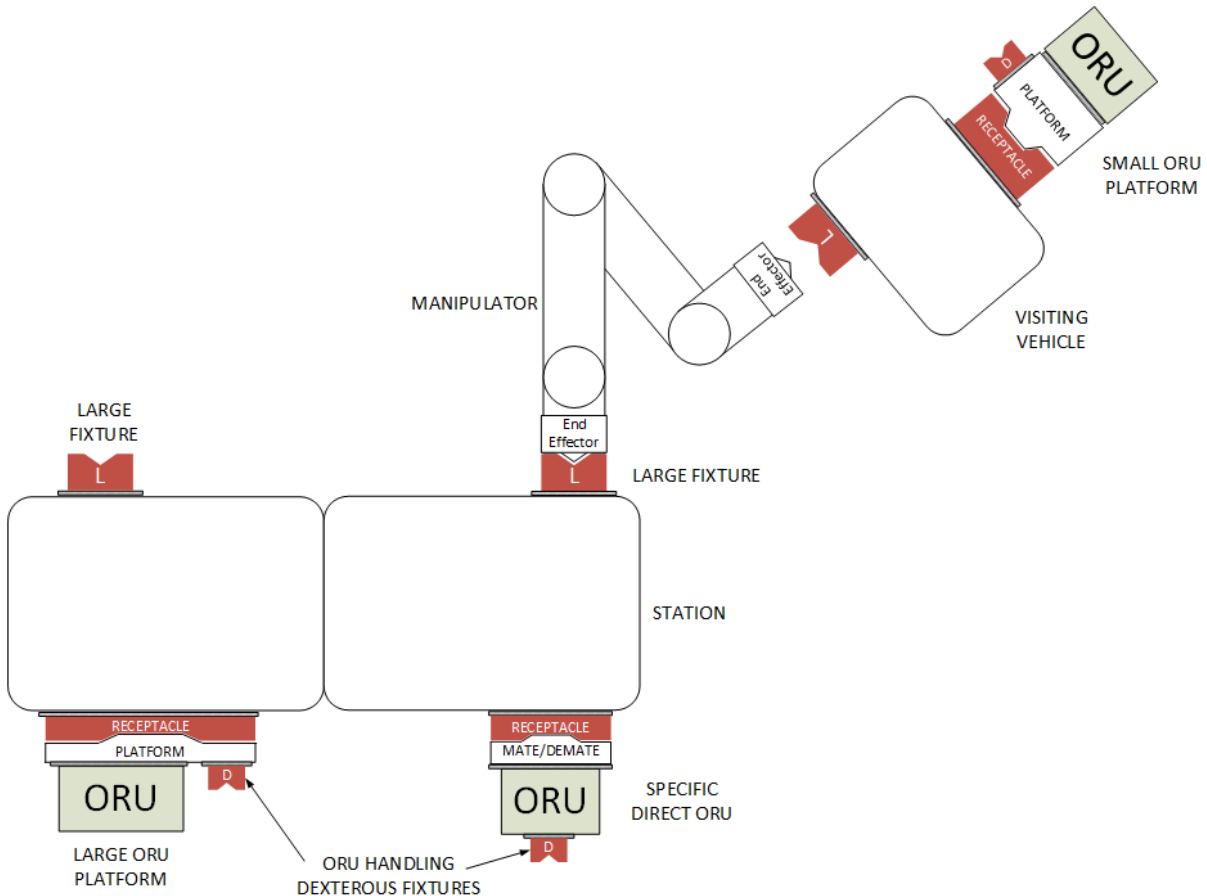


FIGURE 3.1.2.7-1 OVERVIEW OF INTERFACE CLASSES AND COMMON MOUNTING PLANES FOR A NOTIONAL STATION

3.1.3 STANDARD OPERATIONS REFERENCE FRAMES

For all robotics interfaces (large fixtures, dexterous fixtures, ORU interfaces, etc.), there will be two standard operation frames that will be aligned at the interface plane. The operations coordinate system on the manipulator side will be oriented such that the +x-axis is aligned in the mating direction, and the +z-axis is aligned such that it points away from the interface alignment sensor (where applicable). The y-axis is oriented to complete the right-handed Cartesian system. When no alignment sensor is present, or if the sensor is installed along the x-axis, the orientation of the operations frame will be based on the orientation of the passive (stationary) side of the interface. Figure 3.1.3-1, Standard Operations Coordinate System, depicts a Standard Operations (SO) coordinate system (CS) for a conceptual manipulator end effector.

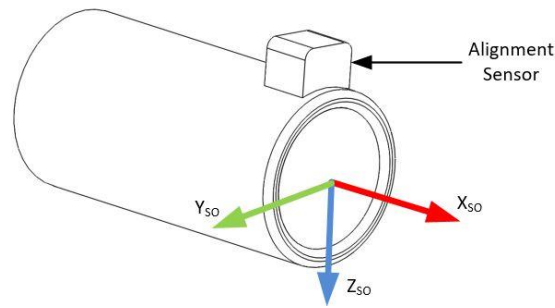


FIGURE 3.1.3-1 STANDARD OPERATIONS COORDINATE SYSTEM

Similarly, a standard operations frame will be located on the stationary half of the mating interface such that the two coordinate systems will be coincident when the interfaces are fully mated. The alignment feature will match the sensor position, and will normally be a visual target. If no alignment feature is present, or if the feature is centered on the x-axis, then the coordinate system will be aligned with the fixture mounting plane. It is recommended that an alignment reference marking be used to indicate the direction of the z-axis on the stationary interface. Figure 3.1.3-2, Standard Operation Mating Frame, depicts an example of a stationary fixture with a mating coordinate system aligned with the EE standard operations coordinate system from Figure 3.1.3-1, Standard Operations Coordinate System. The mating interface coordinate systems are defined in the specific sections of each fixture class within the standard.

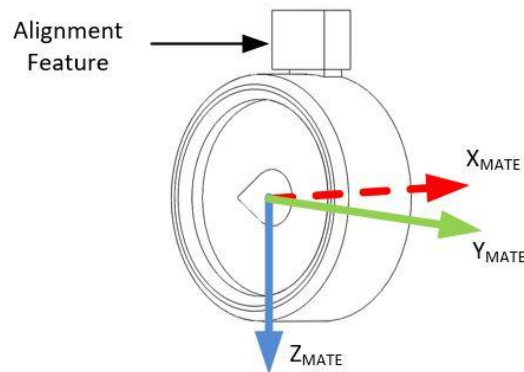


FIGURE 3.1.3-2 STANDARD OPERATION MATING FRAME

3.1.4 ENGINEERING UNITS OF MEASURE

All dimensions are in International System of Units (SI units) (metric). Note that wire gages are in American Wire Gage (AWG).

All linear dimensions are in millimeters and all angular dimensions are in degrees. Unless otherwise specified, the dimensional tolerances shall be as follows:

- xx implies $xx \pm 1$ mm
- $xx.x$ implies $xx.x \pm 0.5$ mm
- xx° implies $xx^\circ \pm 30'$

4.0 LARGE FIXTURE INTERFACE

4.1 GENERAL

The large fixture interface class is comprised of fixtures that support robotic handling of large payloads/vehicles/modules or that can be used as robotic bases. These fixtures are applicable to operations including free flyer capture, relocation and tool handling.

The large fixture interface family share a common large fixture mounting interface plane (Figure 3.1.2.1-1, Example of a Large Fixture and the Common Mounting Interface Plane).

It is recommended that the contingency release capability of the large fixture interfaces should be incorporated into the manipulator end-effector, rather than in the fixture, to reduce overall system mass. (See Appendix E for a detailed explanation.)

Details and requirements pertaining to the specific large fixture interface implementations are detailed in sections below.

Common and specific interface requirements are based on ISS heritage and represent best available information at the time of document release.

The common large fixture mounting interface establishes a generic mounting interface standard for large fixtures. The goal is to furnish the module/vehicle designers with the simplest possible mounting interface in a bid to develop robotic fixture hardware as part of the total robotic system architecture.

4.1.1 COMMON INTERFACE FUNCTIONS

The common large fixture interface shall perform the following functions.

- ROBO-1:** The common large fixture interface shall support mechanical and structural attachments to the user.
- ROBO-2:** The common large fixture interface shall provide an electrical bonding capability for the user.
- ROBO-3:** The common large fixture interface shall provide manipulator and Extravehicular Activity (EVA) access to interface attachments and connections.

Rationale: These requirements define the functional services that the platform provides to the user and to the manipulator system.

4.2 COMMON REQUIREMENTS

4.2.1 COORDINATE SYSTEMS

The common Large Fixture Mounting (LFM) coordinate system is defined in Figure 4.2.1-1, Common Large Fixture Mounting Coordinate Systems. An overview and description of the coordinate system is provided in Table 4.2.1-1, Coordinate System Description for Common Large Mounting Interface.

Not all large fixtures will have a dedicated off-axis alignment feature (visual target). Alternatively, the large fixture mounting coordinate system may be aligned with a common location pin hole.

ROBO-4: The location pin hole center shall be aligned with the $-Z_{LFM}$ axis vector.

Rationale: For consistency, the LFM coordinate system is aligned with the standard operations coordinate system (3.1.3) when mated.

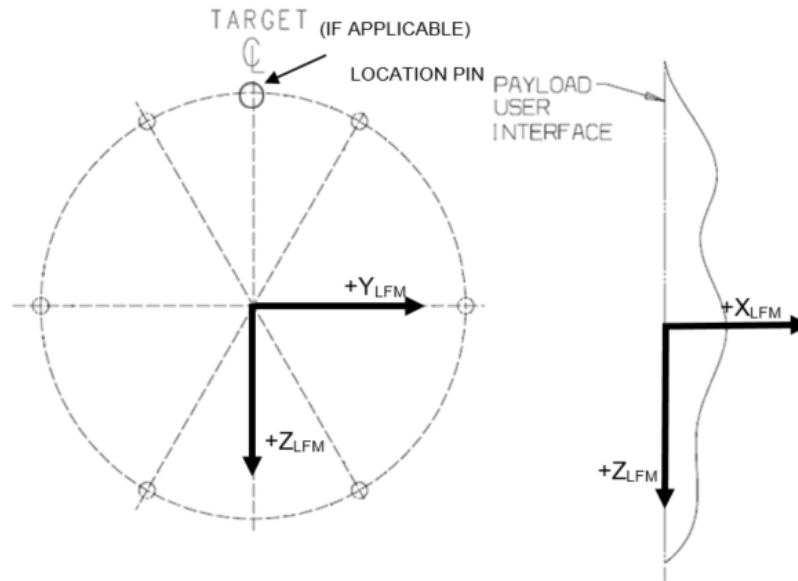


FIGURE 4.2.1-1 COMMON LARGE FIXTURE MOUNTING COORDINATE SYSTEMS

TABLE 4.2.1-1 COORDINATE SYSTEM DESCRIPTION FOR COMMON LARGE MOUNTING INTERFACE

Name	Symbol	Position	Orientation	Purpose
Common large fixture mounting interface coordinate system	X_{LFM} , Y_{LFM} , Z_{LFM}	Center of bolt pattern	Aligned nominally with robotic end effector operations frame $+X_{LFM}$: Normal to mounting plane and away from the large fixture (towards structure) $+Y_{LFM}$: Completes the right-handed coordinate system $+Z_{LFM}$: Away from centerline of intended large fixture target or fixture alignment aid	Description of large fixture mounting coordinate system

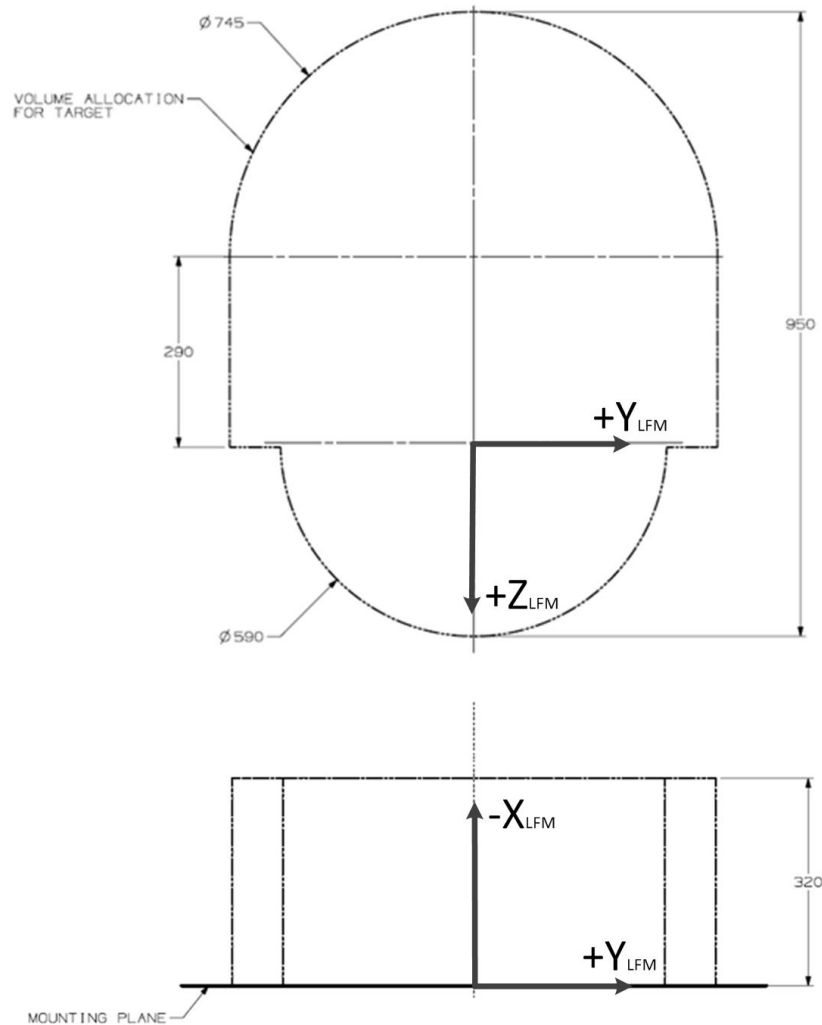
4.2.2 ENVELOPES

4.2.2.1 FIXTURE ENVELOPE

The maximum envelope occupied by a large fixture installed on the mounting interface is defined in Figure 4.2.2.1-1, Large Fixture Maximum Envelope.

Intrusions into the fixture envelope may preclude installation of the fixture or result in interference with the manipulator during operations.

Rationale: This volume envelopes historical large fixtures from ISS operations and concepts for future large fixtures.



Note

All linear dimensions are in millimeters.

FIGURE 4.2.2.1-1 LARGE FIXTURE MAXIMUM ENVELOPE

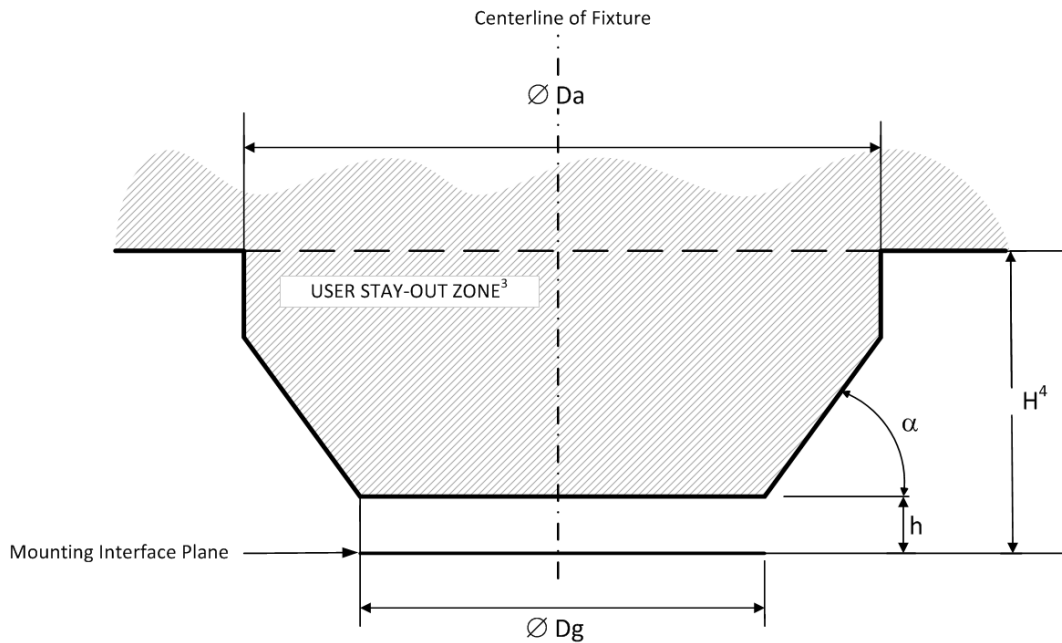
4.2.2.2 CLEARANCE APPROACH ENVELOPE

The common large fixture clearance approach envelope is defined in Figure 4.2.2.2-1, Common Large Fixture Clearance Approach Envelope.

ROBO-5: The user equipment shall provide an approach envelope around the large fixture that is kept clear of intrusions.

Intrusions into the approach envelope's keep out zone may result in impact and contact loads with the manipulator during operations.

Rationale: The common large fixture approach envelope is a conservative boundary that encompasses several large fixture designs. For clearance envelopes that are specific to particular large fixture design implementations, refer to the supporting large fixture interface detailed documentation.



Envelope	Ø Da	Ø Dg	H	h	α
	mm	mm	mm	mm	deg
Approach to static or station-attached payload	1475	995	510	89	56

Notes:

User Stay-out Zone (a.k.a. Clearance Volume) is centered on the centerline of the LFM coordinate system.

Envelope does not include consideration for attached payloads, which need to be evaluated separately for clearance.

Clearances required beyond dimension "H" from attachment plane will be dependent on the user and the required manipulator configuration.

The clearance envelope does not account for manipulator runaway. The approach envelope will be revised to include runaway in a future update.

Hardware Clearance Envelope is a function of the EE.

FIGURE 4.2.2.2-1 COMMON LARGE FIXTURE CLEARANCE APPROACH ENVELOPE

4.2.3 MECHANICAL INTERFACE

4.2.3.1 MOUNTING BOLT HOLE PATTERNS

The standard mounting bolt hole pattern and interface details for large fixtures are defined in Figure 4.2.3.1-1, Large Fixture Mounting Bolt Hole Patterns. Access is required to the rear of the interface for mounting fasteners and cable routing (if applicable).

Rationale: The bolt pattern presented is a heritage mounting interface that has been used on the Shuttle and the International Space Station Programs.

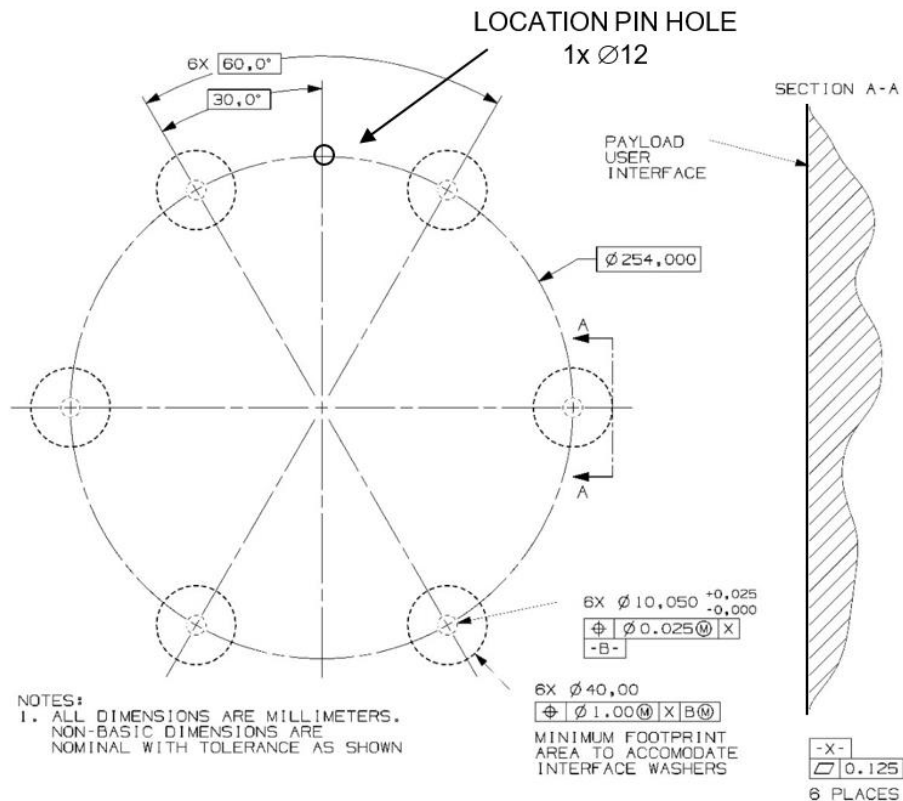


FIGURE 4.2.3.1-1 LARGE FIXTURE MOUNTING BOLT HOLE PATTERNS

4.2.3.2 MOUNTING FASTENERS

The mounting joint configuration for the large fixture is shown in Figure 4.2.3.2-1, Large Fixture Mounting Joint Configuration.

Rationale: The mounting joint configuration illustrated is based on the mounting of heritage NASA Space Transportation System (NSTS) and ISS grapple fixtures.

NOTE: Standoffs are used in some but not all large fixtures.

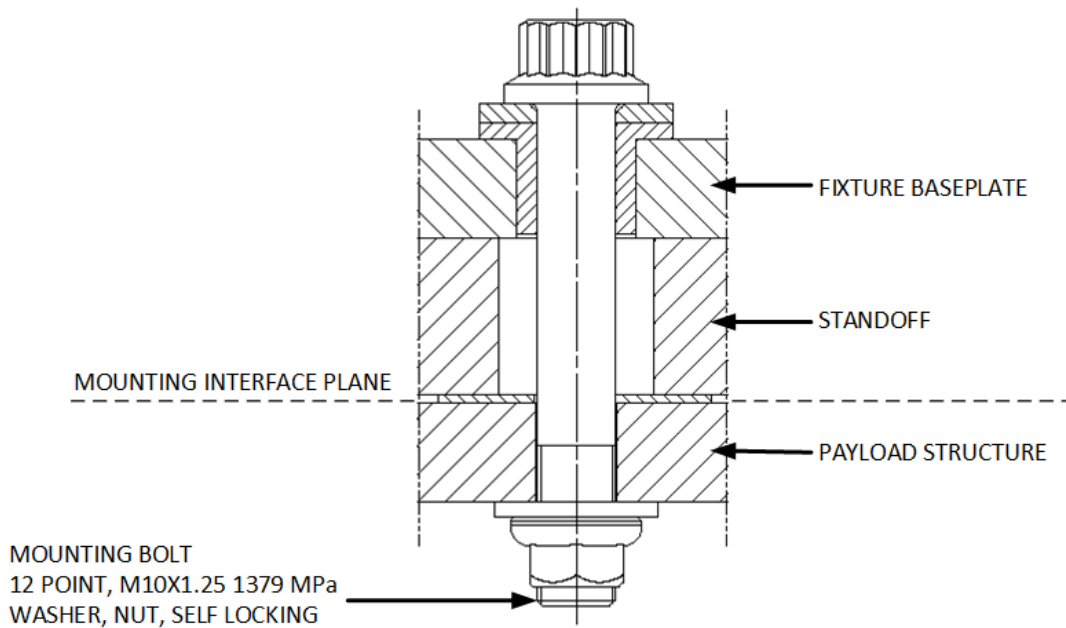


FIGURE 4.2.3.2-1 LARGE FIXTURE MOUNTING JOINT CONFIGURATION

4.2.4 STRUCTURAL INTERFACE

4.2.4.1 MOUNTING INTERFACE LOADS

ROBO-6: The common large fixture to vehicle interface shall meet all performance requirements while being subjected to the robot arm loads defined in Table 4.2.4.1-1, Common Large Fixture Mounting Loads.

NOTE: These loads represent the maximum expected loads for all large fixtures. Some implementations of large fixtures may be rated for lower loads.

Rationale: The specified loads bound the worst-case loads expected to be exerted by the base of a manipulator on a crewed orbital platform required to perform free flyer captures, berthing and EVA support.

TABLE 4.2.4.1-1 COMMON LARGE FIXTURE MOUNTING LOADS

Torsion Moment (about X_{LFM})	Bending Moment (about axis perpendicular to X_{LFM})	Shear Load (perpendicular to X_{LFM})	Axial Load (along X_{LFM})
3100 Nm	3100 Nm	2000 N	1000 N

Notes:

- a) Forces and moments will be applied simultaneously.
- b) Forces and moments are applicable for any direction.
- c) Shear force is applied in a plane 152 mm above ($+X_{LFM}$) mounting interface plane.

4.2.4.2 MOUNTING INTERFACE STIFFNESS

ROBO-7: The user equipment shall provide a stiffness at the large fixture mounting interface to support robotic operations.

Rationale: The mounting interface stiffness for large fixtures must be sufficiently stiff to limit oscillations that could affect the manipulators ability to perform operations at the end-effector.

4.2.4.2.1 MANIPULATOR BASE MOUNTING INTERFACE STIFFNESS

ROBO-8: When the large fixture is to be used as an operating base for the manipulator, the minimum rotational stiffness about X, Y, and Z shall be $1.5e6 \text{ Nm/rad}$ <TBR 4-1>.

Rationale: The mounting interface stiffness must be high enough to ensure that the structural natural frequency of the combined manipulator-payload system is sufficient for controllability.

4.2.4.2.2 MANIPULATOR PAYLOAD MOUNTING INTERFACE STIFFNESS

ROBO-9: When the large fixture is to be used for handling a payload only, and not as a base for the manipulator, the user shall provide a stiffness at the interface that maintains a fundamental structural frequency as defined in Figure 4.2.4.2.2-1, Payload Frequency at Large Fixture Mounting Interface, and Table 4.2.4.2.2-1, Large Fixture User Stiffness Requirements, while constrained only at the large fixture mounting interface.

Note the figure can be used to linearly interpolate for the payloads that fall within the range of mass values. The acceptable region is above the line.

Rationale: The mounting interface stiffness must be high enough to ensure that the payload's structural frequency is higher than the natural frequency of the manipulator to ensure controllability.

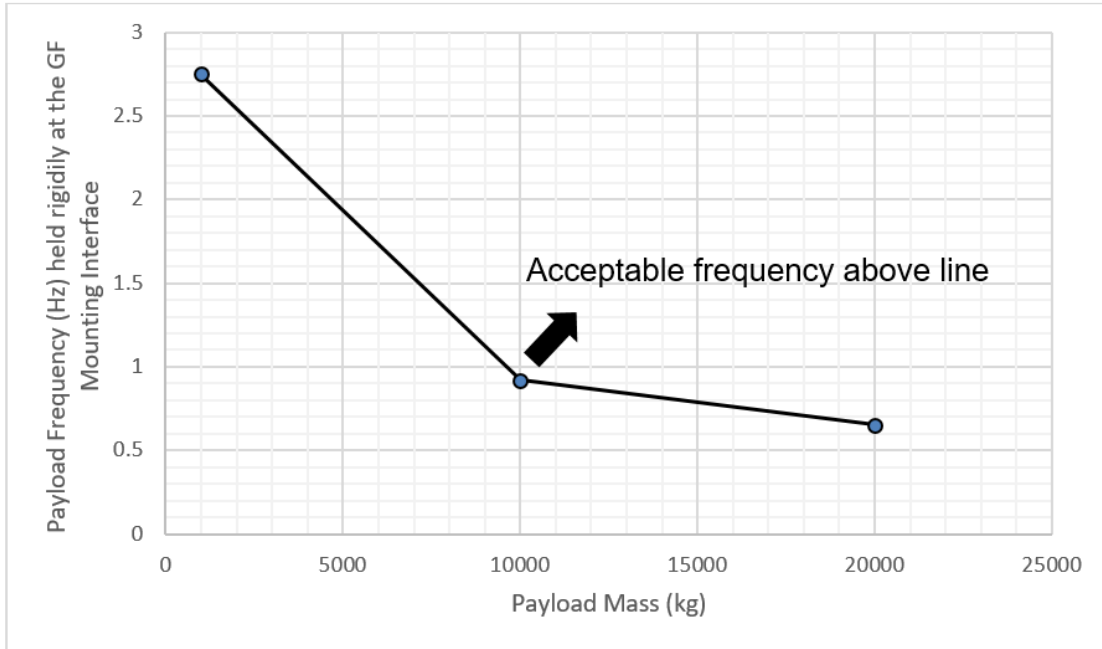


FIGURE 4.2.4.2.2-1 PAYLOAD FREQUENCY AT LARGE FIXTURE MOUNTING INTERFACE

TABLE 4.2.4.2.2-1 LARGE FIXTURE USER STIFFNESS REQUIREMENTS

User/Payload Mass (kg)	Minimum Structural Frequency (Hz)
1000	2.5 Hz
10,000	0.8 Hz
20,000	0.6 Hz

4.2.5 ELECTRICAL INTERFACE

Note that some large fixture types will have electrical services and hence will have an electrical interface definition. This will be defined in the detailed documentation of specific fixtures.

4.3 VERIFICATION

It is the responsibility of the spacecraft developer to perform verification and validation. The majority of the standards will be verified using a combination of interface/compatibility testing, integrated end-to-end testing and analysis at the subsystem and system level.

4.3.1 PLACEHOLDER FOR FUTURE VERIFICATION GUIDELINE CONTENT

Guidance for verification of SORI platform interfaces is <TBD 4-1>.

5.0 SMALL ORU PLATFORM INTERFACE

5.1 GENERAL

The small ORU platform provides the interface between various ORU families and vehicles or modules. This interface allows ORUs or payloads to be reliably berthed to a worksite or transfer-site via the manipulator, EVA, or Intravehicular Activity (IVA) (for transfer through an airlock). The small platform can also be utilized for surface mobility applications such as sample canister return from the lunar surface.

The small ORU platform has two common mounting interface planes (Figure 3.1.2.2-1, Example of a Small ORU Platform and Common Mounting Planes): the common small receptacle mounting interface between the platform and the host vehicle/module/carrier to which it attaches, and the common small platform mounting interface between the platform and the ORU.

Common interface requirements are based on ISS heritage. Information represents the best available information at the time of document release.

5.1.1 COMMON INTERFACE DESCRIPTION

The common small ORU platform interface establishes a generic mounting interface standard for small payloads. The goal is to furnish payload designers with generic interface hardware that isolates the payload from the mate/demate operation thus facilitating simple and repeatable robotic handling while supporting standard electrical services.

5.1.2 COMMON INTERFACE FUNCTIONS

The small platform interface shall perform the following functions:

- ROBO-10:** The small platform interface shall support mechanical and structural attachment to the user.
- ROBO-11:** The small platform interface shall provide EVA/Extravehicular Robotics (EVR) access to interface attachments and connections.
- ROBO-12:** The small platform interface shall provide an electrical bonding capability to the user.
- ROBO-13:** The small platform interface shall provide power and data utility distribution to the user via a harness.

Rationale: These requirements define the functional services that the platform provides to the user. ROBO-11 ensures that the design of the platform does not prevent EVA/EVR from performing the installation and removal of the payloads.

5.2 COMMON REQUIREMENTS, ORU TO SMALL PLATFORM INTERFACE

5.2.1 COORDINATE SYSTEMS

The common Small Platform Mounting (SPM) coordinate system is defined in Figure 5.2.1-1, Small Platform ORU Mounting Coordinate System. An overview and description of the coordinate system is provided in Table 5.2.1-1, Common Small Platform ORU Mounting Coordinate System Description.

Rationale: For consistency, the SPM coordinate system is aligned with the Small Receptacle Mounting (SRM) coordinate system 5.4) when mated. Similar to the mounting frame for the large fixture, the x-axis points into the mounting interface.

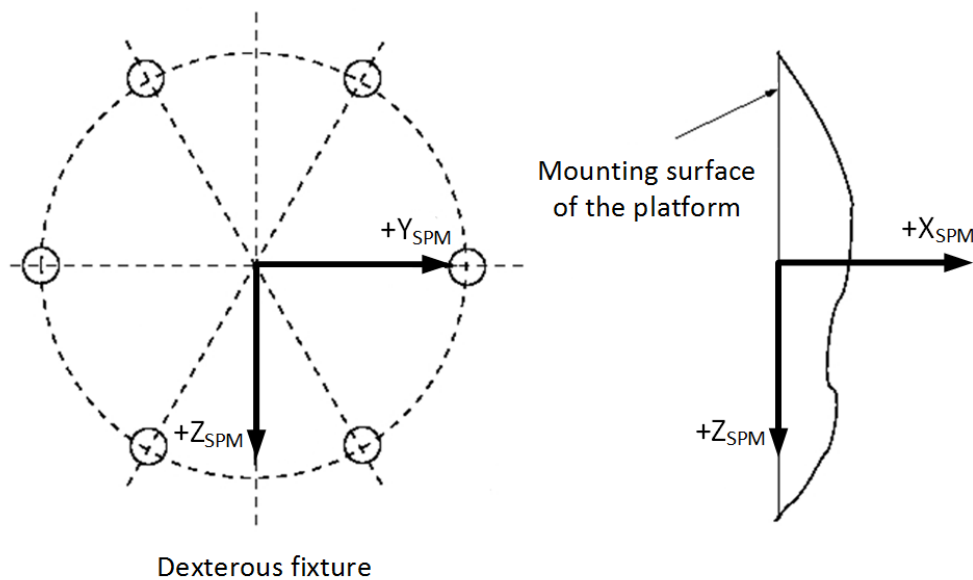


FIGURE 5.2.1-1 SMALL PLATFORM ORU MOUNTING COORDINATE SYSTEM

TABLE 5.2.1-1 COMMON SMALL PLATFORM ORU MOUNTING COORDINATE SYSTEM DESCRIPTION

Name	Symbol	Position	Orientation	Purpose
Common small platform mounting interface coordinate system	X _{SPM} Y _{SPM} Z _{SPM}	Geometric center of bolt pattern	+X _{SPM} : Normal to the mounting plane into the ORU platform +Y _{SPM} : Completes the right-handed coordinate system +Z _{SPM} : Parallel to the mating surface and pointing towards the dexterous fixture	Description of the small platform mounting coordinate system

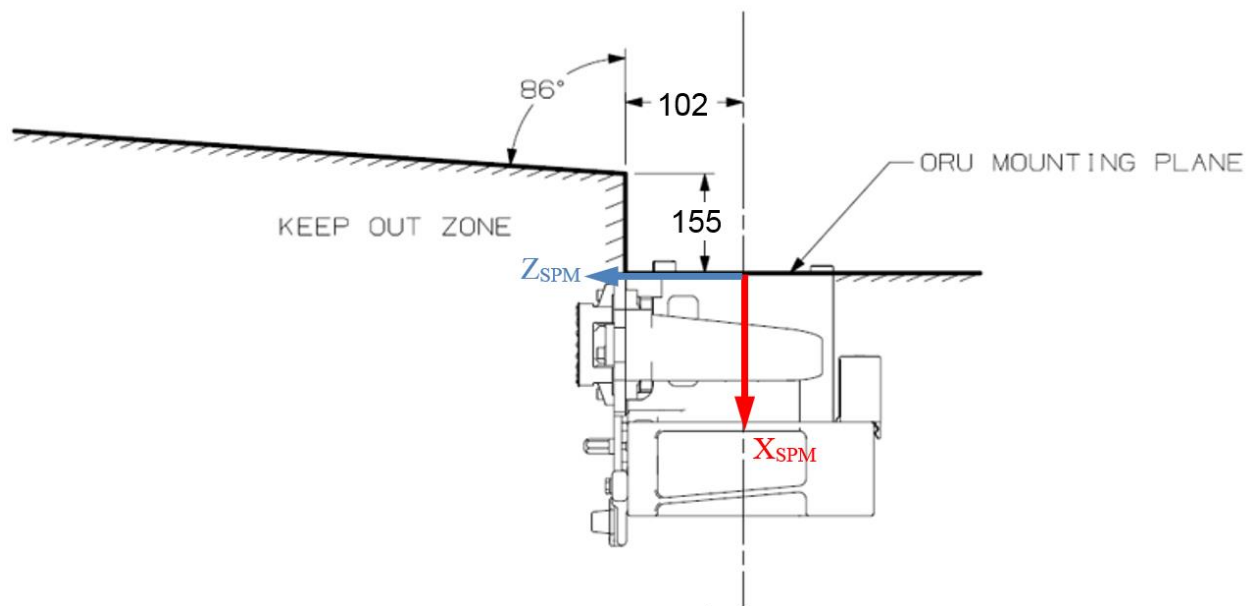
5.2.2 ENVELOPES

Small ORU platform clearance approach envelope is defined in Figure 5.2.2-1, Common Small ORU Platform Clearance Approach Envelope.

ROBO-14: The user equipment shall provide an approach envelope around the small ORU platform.

Intrusions into the approach envelope's keep out zone may result in impact and contact loads with the manipulator during operations.

Rationale: The current envelope is based on the conceptual design for the dexterous end-effector and is based on assumptions regarding the dexterous fixture type.



Notes

Clearances required beyond the volume height from the attachment plane will be dependent on the user and the required manipulator configuration.

Mounting coordinate frame is shown.

All linear dimensions are in millimeters.

FIGURE 5.2.2-1 COMMON SMALL ORU PLATFORM CLEARANCE APPROACH ENVELOPE

5.2.3 MECHANICAL INTERFACE

5.2.3.1 ORU MOUNTING BOLT HOLE PATTERNS

The mounting bolt hole pattern and details of the mechanical interface for the Small Platform Interface are defined in Figure 5.2.3.1-1, Platform ORU Mounting Bolt Hole Pattern.

Rationale: The bolt pattern presented is derived from a heritage mounting interface that has been used on the ISS program.

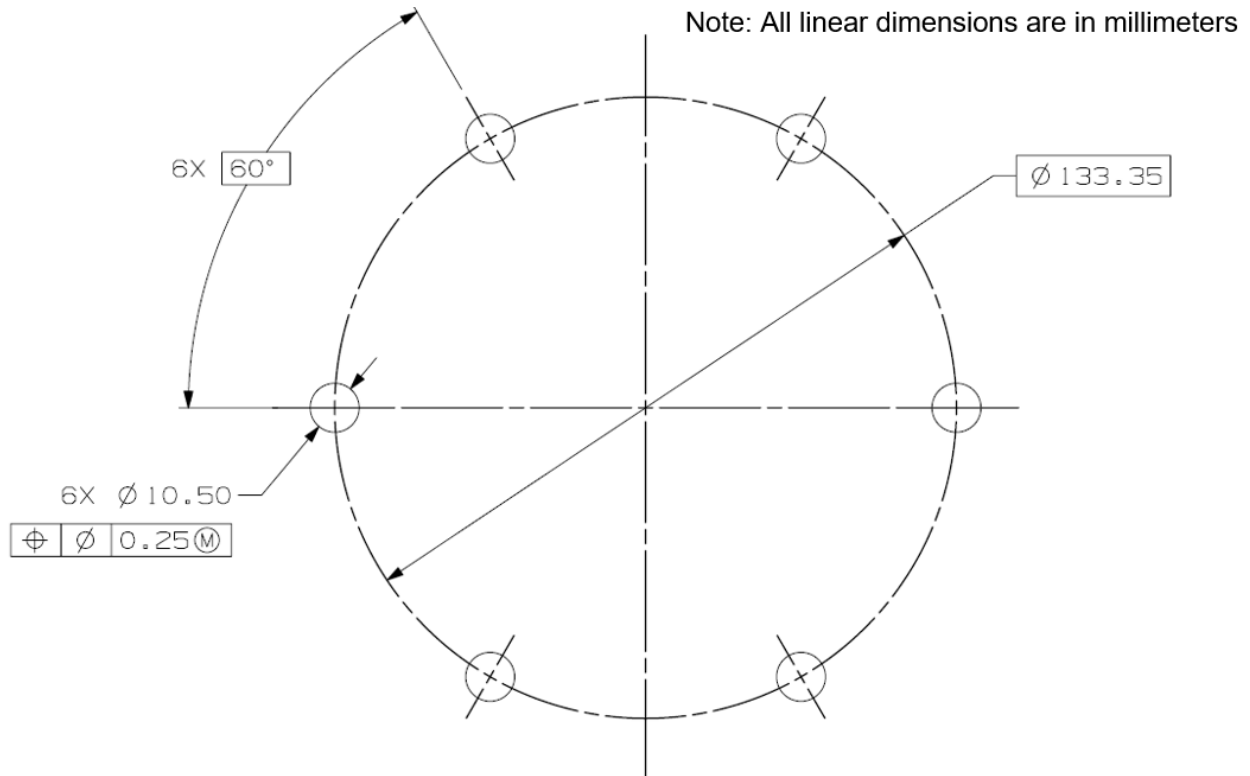


FIGURE 5.2.3.1-1 PLATFORM ORU MOUNTING BOLT HOLE PATTERN

5.2.4 STRUCTURAL INTERFACE

5.2.4.1 PAYLOAD MASS CAPACITIES

The payload mass capacity of the small ORU platform interfaces as a function of operational environment are defined in separate interface requirements documents for specific interface implementations.

Rationale: Payload capacities are derived from the maximum loads that the interface can experience. Payloads that are launched while mounted to the small platform will experience significantly higher acceleration and vibration environments than interfaces that are installed and handled on-orbit.

5.2.4.2 MOUNTING INTERFACE LOADS

ROBO-15: The SORI-to-Payload structural interface shall withstand a bending moment of up to 3460 Nm and forces of up to 8590 N in any axis.

Rationale: Based on analysis of a 25 kg reference case payload and a quasi-static launch load of 35 g.

5.2.5 ELECTRICAL INTERFACE

ROBO-16: The small ORU Platform shall have two electrical interfaces: 1) a worksite electrical interface to support power/video/data to the payload when mated to the small ORU receptacle at the worksite, and 2) an umbilical electrical interface to support power/video/data to the payload when grasped/operated by EVR.

Rationale: Some ORUs may require access to both worksite and EE connectors, to permit operation while stowed at a worksite or while being handled by the manipulator. These are not intended to be used concurrently.

5.2.5.1 ELECTRICAL CONNECTOR

The worksite electrical interface consists of two connectors: a female connector on the small ORU receptacle and a complimentary male connector on the small ORU Platform to interface with it (only the male connector of the worksite electrical interface is to be wired to the ORU payload).

The umbilical electrical interface consists of one connector: a male connector positioned relative to the dexterous fixture such that it interfaces with the manipulator EE. For both the worksite and umbilical electrical interfaces, the small ORU platform will be designed with the connectors physically located appropriately for EVR and mate/demate operation with platform cable harnesses leading to the payload in the form of a pigtail. These pigtails will provide the payload with a means to receive electrical services where:

The user may integrate the pigtail wire end of the platform cable harnesses with a connector of their choice.

ROBO-17: The user equipment provider shall be responsible for routing and securing the platform cable harnesses to ensure they remain outside of the EVR/EVA clearance envelopes for the platform.

Rationale: The user is the design authority for cable routing on their equipment. IERIIS is not intended to impose constraints on that.

5.2.6 POWER, DATA AND VIDEO INTERFACE

ROBO-18: The small ORU platform cable harnesses to both the worksite electrical interface (to support power/video/data to the payload when mated to the small ORU receptacle at the worksite) and to the EVR electrical umbilical interface (to support power/video/data to the payload when grasped/operated by EVR) shall provide power and data services to the payload.

Rationale: Power and data are the standard services expected to be required by all payload users. Specifics such as power type, voltage and data format will be defined in more detail in project specific documents.

5.2.7 ELECTROMAGNETIC ENVIRONMENTS

5.2.7.1 ELECTROMAGNETIC COMPATIBILITY

ROBO-19: The user equipment shall meet the requirements of the agreed-to Electromagnetic Compatibility (EMC) standards.

Rationale: Attachment of the user equipment to the robotics interface needs to be designed to avoid introducing electromagnetic interference.

5.2.7.2 BONDING AND GROUNDING

ROBO-20: When interfacing with the small ORU platform the user equipment shall meet the agreed-to bonding and grounding standards.

Rationale: Attachment of the user equipment to the robotics interface needs to be designed to avoid electrical static charge build-up and floating chassis ground.

5.3 VERIFICATION, ORU TO SMALL PLATFORM INTERFACE

It is the responsibility of the spacecraft developer to perform verification and validation. The majority of the standards will be verified using a combination of interface/compatibility testing, integrated end-to-end testing and analysis at the subsystem and system level.

5.3.1 PLACEHOLDER FOR FUTURE VERIFICATION GUIDELINE CONTENT

Guidance for verification of SORI platform interfaces is <TBD 4-1>.

5.4 COMMON REQUIREMENTS, VEHICLE/MODULE TO SMALL RECEPTACLE INTERFACE

5.4.1 COORDINATE SYSTEMS

The common SRM coordinate system is defined in Figure 5.4.1-1, Small Receptacle Mounting (SRM) Coordinate System. An overview and description of the coordinate system is provided in Table 5.4.1-1, Common Small Receptacle Mounting Coordinate System Description.

Rationale: For consistency, the SRM coordinate system is aligned with the SPM coordinate system (5.2.1) when mated. Similar to the mounting frame for the large fixture, the x-axis points into the mounting interface.

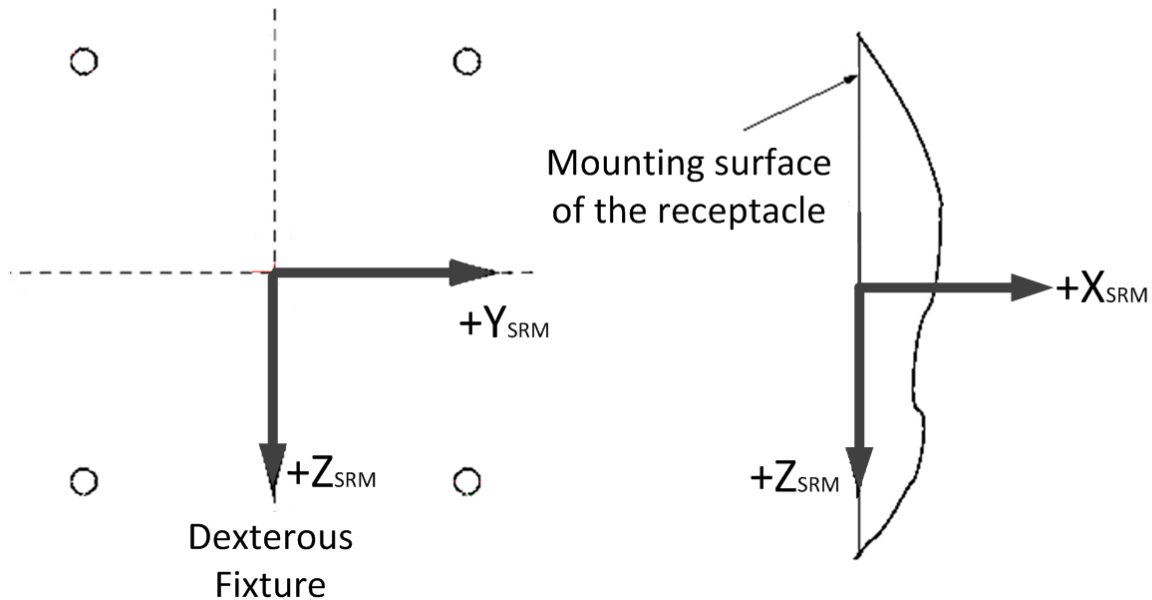


FIGURE 5.4.1-1 SMALL RECEPTACLE MOUNTING (SRM) COORDINATE SYSTEM

TABLE 5.4.1-1 COMMON SMALL RECEPTACLE MOUNTING COORDINATE SYSTEM DESCRIPTION

Name	Symbol	Position	Orientation	Purpose
Common small receptacle mounting coordinate system	X _{SRM} Y _{SRM} Z _{SRM}	Geometric center of the bolt patterns	+X _{SRM} : Normal to the mounting plane into the receptacle mounting surface +Y _{SRM} : Completes the right-handed coordinate system +Z _{SRM} : Parallel to the mating surface and pointing towards the dexterous fixture	Description of the small receptacle mounting frame

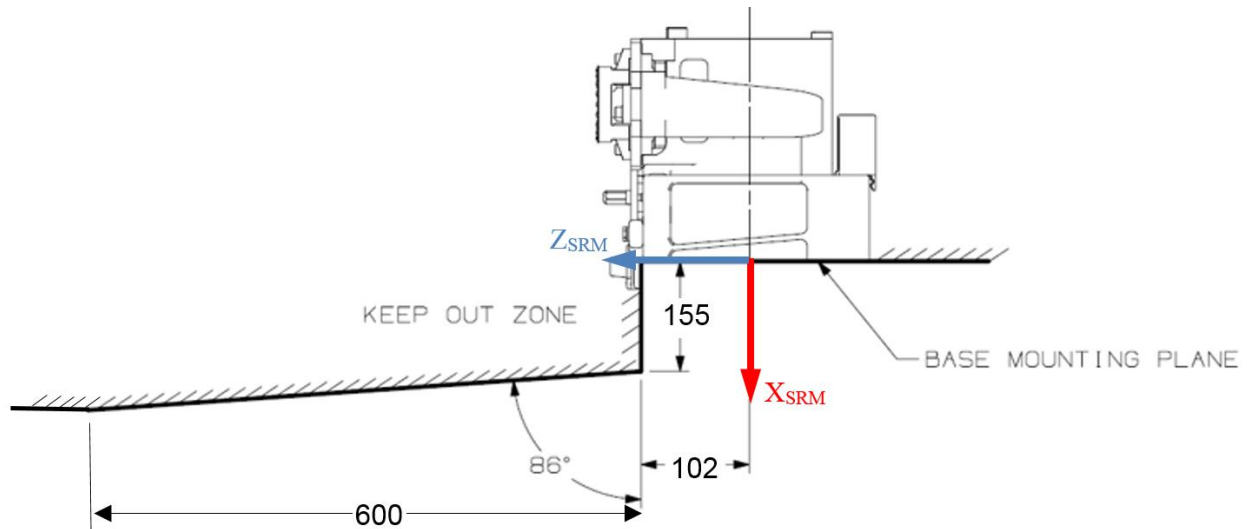
5.4.2 ENVELOPES

Small ORU platform receptacle clearance approach envelope is defined in Figure 5.4.2-1, Common Small ORU Platform Receptacle Clearance Approach Envelope.

ROBO-21: The user equipment shall provide an approach envelope around the small ORU platform receptacle.

Intrusions into the approach envelope's keep out zone may result in impact and contact loads with the manipulator during operations.

Rationale: The current envelope is based on the conceptual design for the dexterous end-effector and is based on assumptions regarding the dexterous fixture type.



Notes

1. Clearances required beyond the volume height from the attachment plane will be dependent on the user and the required manipulator configuration.
2. Mounting coordinate frame is shown.
3. All linear dimensions are in millimeters.

FIGURE 5.4.2-1 COMMON SMALL ORU PLATFORM RECEPTACLE CLEARANCE APPROACH ENVELOPE

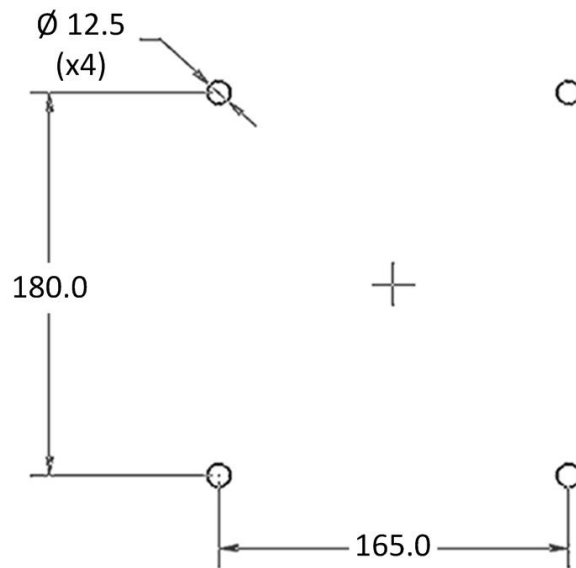
5.4.3 MECHANICAL INTERFACE

5.4.3.1 MOUNTING BOLT HOLE PATTERNS

The mounting bolt pattern and details of the mechanical interface for the small ORU platform receptacle are defined in Figure 5.4.3.1-1, Receptacle Mounting Bolt Hole Pattern.

The standard bolt hole pattern for the small ORU platform is comprised of four bolt holes arranged in a rectangular pattern. The common bolt hole pattern supports both launch capable and on-orbit platform variants.

Rationale: Four bolt hole pattern is adapted from an existing Wedge Mating Interface (WMI) receptacle design from ISS.



Note:
All linear dimensions are in millimeters

FIGURE 5.4.3.1-1 RECEPTACLE MOUNTING BOLT HOLE PATTERN

5.4.4 STRUCTURAL INTERFACE

5.4.4.1 MOUNTING INTERFACE LOADS

ROBO-22: When the platform assembly is secured in a mounting receptacle the SORI-to-support structure interface shall withstand a bending moment of up to 6750 Nm and forces of up to 11120 N in any axis.

Rationale: Based on analysis of a 25 kg reference case payload and a quasi-static launch load of 35 g. Specific payload capabilities will be determined for different configurations per section 5.2.4.1 within this envelope. When no platform is installed, the loads are only due to the mass of the receptacle.

5.4.4.2 MOUNTING STIFFNESS

ROBO-23: The support structure stiffness shall be <TBD 5-5>.

Rationale: The stiffness of the support structure affects robot dynamics during insertion and extraction, and the behavior of the assembly during launch vibrations.

5.4.5 POWER, DATA AND VIDEO INTERFACE

All electrical interface connections at the small platform receptacle interface are pass through wiring.

ROBO-24: The small ORU platform receptacle cable harness shall provide, as a minimum, power and data services.

Rationale: Power and data are the standard services expected to be required by all payload users. Specifics such as power type, voltage and data format will be defined in more detail in project specific documents.

5.4.6 ELECTROMAGNETIC ENVIRONMENTS

5.4.6.1 ELECTROMAGNETIC COMPATIBILITY

ROBO-20: The user equipment shall meet the agreed-to EMC standards.

5.4.6.2 BONDING AND GROUNDING

ROBO-25: When interfacing with the small ORU receptacle, the user equipment shall meet the agreed-to bonding and grounding standards.

5.4.6.3 ELECTROSTATIC DISCHARGE

ROBO-26: When interfacing to the small ORU receptacle, the user equipment shall meet the agreed-to electro-static discharge standards.

5.4.7 CONTAMINATION ENVIRONMENT

5.4.7.1 DUST

Requirements for dust-tolerance are <**TBD 5-6**>.

5.5 VERIFICATION, VEHICLE/MODULE TO SMALL RECEPTACLE INTERFACE

It is the responsibility of the spacecraft developer to perform verification and validation. The majority of the standards will be verified using a combination of interface/compatibility testing, integrated end-to-end testing and analysis at the subsystem and system level.

5.5.1 PLACEHOLDER FOR FUTURE VERIFICATION GUIDELINE CONTENT

Guidance for verification of SORl receptacle interfaces is <**TBD 4-1**>.

6.0 FUTURE TOPICS FOR POSSIBLE STANDARDIZATION

6.1 LARGE ORU PLATFORM INTERFACE

For ORUs and payloads exceeding the mass and power capacity of the SORI, a new interface is planned to be defined LORI.

6.2 DEXTEROUS FIXTURE INTERFACE

Similar to the Low Profile Grapple Fixture (LPGF), a grasp interface will be defined for smaller manipulators and loads.

6.3 ORU DIRECT INTERFACE

Platform-type interfaces like the SORI and LORI may not cover all situations, for example a highly mass-optimized interface where robotic interface components are integrated into the ORU and the worksite may be required as a trade-off for interchangeability.

6.4 SMALL SATELLITE DEPLOYER INTERFACES

Deployers for launching small satellites have been used on ISS and may be used on other platforms. Additional requirements covering dynamics, shock and vibration may need to be added to this document to control interaction with robotic systems.

6.5 FUTURE MISSION SCENARIOS

New mission scenarios such as crewed lunar bases, deep-space transit vehicles, Mars orbital platforms and Mars surface vehicles will need to be investigated to determine whether additional requirements need to be levied at the interfaces.

Baseline

APPENDIX A - ACRONYMS AND ABBREVIATIONS

a.k.a.	also known as
AWG	American Wire Gauge
CBM	Common Berthing Mechanism
comm.	Communication
CS	Coordinate System
deg	degree
EE	End Effector
e.g.	exempli gratia (for example)
EMC	Electromagnetic Capability
EVA	Extravehicular Activity
EVR	Extravehicular Robotics
FDIR	Failure Detection, Isolation, and Recovery
FEL	First Element Launch
FRGF	Flight Releasable Grapple Fixture
FSGF	Flight Standard Grapple Fixture
g	grams
HEOMD	Human Exploration and Operations Mission Directorate
HTV	H-II Transfer Vehicle
Hz	Hertz
IDD	Interface Definition Document
IDSS	International Docking System Standard
IDSS-B	berthing compatible IDSS implementation
i.e.	id est (that is)
IERIIS	International External Robotic Interface Interoperability Standards
I/F	Interface
ISO	International Organization for Standardization
ISS	International Space Station
IVA	Intravehicular Activity
Kg	kilogram
LFM	Large Fixture Mounting (Coordinate System)
LORI	Large ORU Platform Interface
LPGF	Low Profile Grapple Fixture
MCB	Multilateral Coordination Board
mm	millimeter
N	Newton
NASA	National Aeronautics and Space Administration

Baseline

Nm	Newton meter
NSTS	NASA Space Transportation System
ORU	On-orbit Relocatable or Replaceable Unit
rad	radian
Ref.	Reference
SI	International System of Units
SO	Standard Operations
SORI	Small ORU Platform Interface
SPM	Small Platform Mounting (Coordinate System)
SRM	Small Receptacle Mounting (Coordinate System)
SRMS	Shuttle Remote Manipulator System
TBD	To Be Determined
TBR	To Be Resolved
TDSP	Tie-Down Separation Plane
temp	temporary
V&V	Verification and Validation
vs.	versus
WMI	Wedge Mating Interface (<i>from ISS heritage</i>)

APPENDIX B - GLOSSARY OF TERMS

ALLOCATION

The portioning of resources and accommodations to the space system users. Total space system resources and accommodations are allocated between system and utilization. Utilization resources and accommodations are allocated between International Partners.

CAPTURE

An operation where a manipulator grasps onto a free-flying vehicle (i.e. a robotic interface fixture that is not stationary/rigid with respect to the base of the manipulator).

GRASP/GRAPPLE

An operation where a manipulator secures itself onto a robotic interface fixture, which is stationary/rigid with respect to the base of the manipulator. Grasp is commonly used for smaller interfaces and grapple is commonly used for larger fixtures.

INTERFACE DEVELOPER

A party who is involved with the manufacture of external robotics interfaces. Developer level requirements deal with detailed design specifications that are required to ensure proper functionality and compatibility of the designed robotics interface.

INTERFACE USER (“THE USER”)

A party who will directly install an external robotics interface on their hardware. User level requirements deal with specifications pertinent to the mounting and installation interface, and not to the detailed design of the external robotic interface components.

ON-ORBIT REPLACEABLE UNIT (ORU)

A piece of equipment that is designed for removal and replacement as a unit on orbit by either EVA or EVR.

Baseline

APPENDIX C - OPEN WORK

Table C-1 lists the specific To Be Determined (TBD) items in the document that are not yet known. The TBD is inserted as a placeholder wherever the required data is needed and is formatted in bold type within brackets. The TBD item is numbered based on the section where the first occurrence of the item is located as the first digit and a consecutive number as the second digit (i.e., <TBD 4-1> is the first undetermined item assigned in Section 4 of the document). As each TBD is resolved, the updated text is inserted in each place that the TBD appears in the document and the item is removed from this table. As new TBD items are assigned, they will be added to this list in accordance with the above described numbering scheme. Original TBDs will not be renumbered.

TABLE C-1 TO BE DETERMINED ITEMS












TBD	Section or Requirement ID	Description
4-1	4.3.1, 5.3.1, 5.5.1	Guidance on verification of interfaces is planned to be defined and inserted.
5-5	5.4.4.2	(SORI) The support structure stiffness shall be TBD.
5-6	5.4.7.1	Requirements for dust tolerance of the SORI will be determined in the future.

Table C-2 lists the specific To Be Resolved (TBR) issues in the document that are not yet known. The TBR is inserted as a placeholder wherever the required data is needed and is formatted in bold type within brackets. The TBR issue is numbered based on the section where the first occurrence of the issue is located as the first digit and a consecutive number as the second digit (i.e., <TBR 4-1> is the first unresolved issue assigned in Section 4 of the document). As each TBR is resolved, the updated text is inserted in each place that the TBR appears in the document and the issue is removed from this table. As new TBR issues are assigned, they will be added to this list in accordance with the above described numbering scheme. Original TBRs will not be renumbered.

TABLE C-2 TO BE RESOLVED ISSUES

TBR	Section or Requirement ID	Description
4-1	4.2.4.2.1	When the large fixture is to be used as an operating base for the manipulator, the minimum rotational stiffness about X, Y, and Z shall be 1.5e6 Nm/rad. Value to be finalized.

APPENDIX D – SYMBOLS DEFINITION

$\omega = [\omega_x, \omega_y, \omega_z]^T$	Angular Velocity Vector
	Basic (Theoretical) Dimension
	Between
	Centerline
	Circularity
	Concentricity
	Datum Feature
	Depth / Deep
	Diameter
	Difference
TRUE	Dimension in a view that does not show true feature shape
	Flatness
θ_y	Pitch Angle (relative to Y Axis)
	Position
ϕ_x	Roll Angle (relative to X Axis)
SR	Spherical Radius
ψ_z	Yaw Angle (relative to Z Axis)

APPENDIX E – SUMMARY OF KEY TRADE OFF STUDIES

Lessons learned from robotic operations on board the ISS and the results of key trade studies have been used to inform the requirements developed for this IERIIS. The sections below document the key findings of the following trade studies;

1. Contingency Release Methods – assessment of options for implementing a contingency release function at a robot end-effector/grapple fixture interface;
2. Methods for Controlling Interface (I/F) Loads During Berthing Operations – assessment of options for protecting against excessive interface loads during off-nominal robotic berthing operations;
3. ORU Style: Platform vs. Direct Handling – assessment of different approaches to incorporating robotically compatible interfaces into an ORU.

E.1 CONTINGENCY RELEASE METHODS

E.1.1 PURPOSE

The purpose of the contingency release trade was to compare options for implementing a grapple fixture contingency release function in future exploration missions. A contingency release function is a backup method of separating a robotic end-effector from its grapple fixture in the event that a failure occurs which results in a loss of function of its primary and redundant release methods.

E.1.2 BACKGROUND

Historically, on the NSTS and the International Space Station, the grapple fixture contingency release function has been implemented through features on either the active (end-effector) or passive (grapple fixture) side.

Contingency release methods implemented on the passive side of the interface include,

- Flight Releasable Grapple Fixture (FRGF), shown in Figure E.1.2-1, Flight Releasable Grapple Fixture, and used throughout the Space Shuttle and ISS programs, which incorporated an EVA drive to release the grapple shaft in the event that the end-effector failed.



FIGURE E.1.2-1 FLIGHT RELEASABLE GRAPPLE FIXTURE

- Tie-Down Separation Plane (TDSP), shown in Figure E.1.2-2, Tie-Down Separation Plane, and used on the H-II Transfer Vehicle (HTV), is a commandable mechanism to mechanically release the entire grapple fixture from the vehicle.

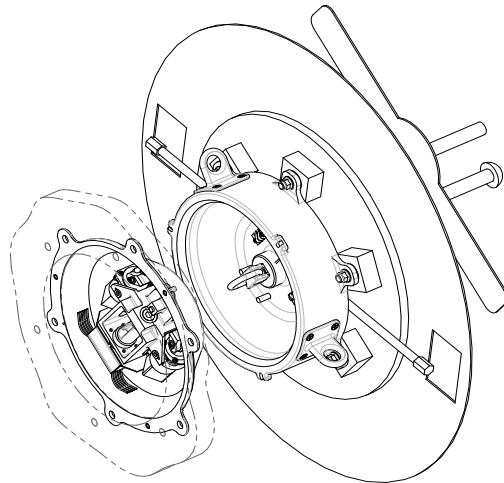


FIGURE E.1.2-2 TIE-DOWN SEPARATION PLANE

Contingency release methods implemented on the active side of the interface include,

- The NSTS Shuttle Robotic Arm End-Effector incorporated a commandable backup release mechanism to open the snares and release the grapple fixture. While the backup release method was checked out on each mission to verify function, it was never used operationally to perform an emergency release of a payload.
- The Canadarm2 End-Effector on the ISS incorporated a redundant electromechanical drive capability to provide functional fault tolerance. The end-

effector also included an EVA drive to provide the ability to manually unlatch the end-effector from a grapple fixture.

- The Dextre End-Effector on the ISS incorporated backup electromechanical drive capability as well as an EVA drive to manually open the jaws of the mechanism to release a grasped fixture.

E.1.3 TRADE

To compare the various methods of providing a contingency release function, each method was assessed using the following figures of merit;

1. Time Criticality

- Where the interface is used can dictate the type of contingency release required (EVA vs. commandable).
- If the hazard associated with a loss of release capability has a short time to effect then EVA methods for release are not suitable.
- Release of Free-Flyers / Visiting Vehicles typically require contingency release function to be remotely commandable.

2. Mass/Volume

- Implementation of a contingency release function on the end-effector/manipulator or grapple fixture/payload impacts the total life cycle mass.
- Allocation of the contingency release function to the end-effector may permit a mass savings when the total mission life cycle is considered.
- For example,
 - FRGF on ISS provides an EVA release function and has a unit mass of ~12 kg.
 - Flight Standard Grapple Fixture (FSGF) does not include the EVA release mechanism and has a unit mass of only ~8 kg.
 - 4 kg mass savings per use.
- Lowest life cycle mass will depend on the total quantities of end-effectors and grapple fixtures in the mission and their associated contingency release mechanism mass.
- Release functions implemented on the grapple fixture side can impact size, particularly if it is an EVA release function where EVA access must be possible while end-effector is attached.

3. Verification

- Implementation of a contingency release function on the end-effector/manipulator or grapple fixture/payload impacts the verification and total life cycle costs.

- Allocation of the contingency release function to the grapple fixture requires each unit to be tested, impacting the recurring costs of grapple fixtures.

4. Debris Generation

- Some historical contingency release implementations generate debris should they ever be operated.
 - FRGF implementation releases a grapple shaft which must be retrieved by EVA from the end-effector snare cables.
 - ISS Visiting Vehicle (HTV, Cygnus, Dragon) grapple fixture release systems result in the release of an entire >12 kg grapple fixture assembly which may or may not be restrained in the end-effector snare cables.
- Debris-free release implementations are preferred to avoid potential hazards associated with unconstrained debris.

5. Compatibility with Autonomy

- Future robotic systems aim to implement a larger degree of automation, including Failure Detection, Isolation, and Recovery (FDIR).
- An EVA implementation for contingency release precludes automated FDIR responses.

6. Complexity

- Depending on criticality of loss of function failure (critical vs. catastrophic), one or two methods of contingency release may be required to satisfy safety requirements.
 - Critical Hazard = Loss of Mission
 - Requires 1 fault tolerance (primary and redundant methods).
 - Catastrophic Hazard = Loss of Vehicle and/or Life
 - Requires 2 fault tolerance (primary, redundant, and tertiary methods).
- A single method of release to control critical hazards may be simply implemented through redundancy in the end-effector.
- A second method of release to control catastrophic hazards may require a third control string which adds complexity, cost, and mass.
 - An EVA release mechanism may be the simplest option.

Table E.1.3-1, Grapple Fixture vs. End-Effector Implementation, and Table E.1.3-2, EVA vs. Commandable Implementation, below provide a summary of the comparison between the various contingency release implementation options.

TABLE E.1.3-1 GRAPPLE FIXTURE VS. END-EFFECTOR IMPLEMENTATION

Contingency Release Implementation	Pros	Cons
Grapple Fixture Side	- Potentially higher reliability release function since verification of function is more recent (test before launch)	- Higher recurring costs for grapple fixture - Can have higher life cycle mass due to quantity of grapple fixtures used in a mission* - Restricted access if release is through EVA
End-Effector Side	- Can have lower life cycle mass due to low quantity of end-effectors*	- Single mechanism for release throughout mission life (dormant failure risk if no checkout capability exists)

*Key discriminator

TABLE E.1.3-2 EVA VS. COMMANDABLE IMPLEMENTATION

Contingency Release Implementation	Pros	Cons
EVA	- Can be simplest option	- Does not support automated FDIR - Not suitable for time-critical applications*
Commandable	- Supports automated FDIR - Required for time-critical applications*	- Implementation may be complex if tertiary release capability needed

*Key discriminator

E.1.4 CONCLUSIONS & RECOMMENDATIONS

Based on the results of the trade, the following recommendations were developed for the International External Robotic Interface Interoperability Standards (IERIIS):

- Contingency release functions shall separate the interface without generating debris;
- Contingency release functions shall be implemented on the end-effector side of the interface;
- All contingency release functions for free-flyer capture fixtures shall be remotely commandable to separate (i.e. not require EVA). Contingency release functions for non-free-flyer capture fixtures may be EVA but commandable implementations are preferred;
- Contingency release functions should be implemented in a manner which enables on-orbit checkout/verification of function.

NOTE: The integration of a contingency release mechanism to demate a payload from a robot end-effector may introduce additional failure modes in the design and therefore should be technically justified and its implications considered in the general failure/safety analysis.

E.2 METHODS FOR CONTROLLING I/F LOADS DURING BERTHING OPERATIONS

E.2.1 PURPOSE

The purpose of this trade was to assess options for protecting against high interface loads that can be generated during off-nominal berthing to a mechanism external to the robotic system. Through the trade, determine if any requirements should be added to the body of the International External Robotic Interface Interoperability Standards and identify whether a handshaking standard is required between an external berthing mechanism and the robotic system.

E.2.2 BACKGROUND

One of the historical concerns with robotic berthing operations on the ISS has been the high loads that can be generated if an external active berthing mechanism (like the Common Berthing Mechanism) is attempting to rigidize an interface while the manipulator is not in a compliant mode (i.e. has mechanical brakes engaged). Typically, the automated response of a manipulator to a fault condition (termed the “Safing response”) is to halt all motion through the application of brakes and inhibiting of motors. Analysis is typically performed to define the necessary safety controls to implement in order to protect against the build-up of excessive loads in the unlikely event that the off-nominal/failure condition occurs.

For future missions, a more robust approach that mitigates the need for extensive analysis is required.

E.2.3 TRADE

The strategies considered for controlling this hazard in future systems include:

1. Avoid exposure to the Hazard – Perform berthing in a different way to avoid exposure to the hazard, such as;
 - a. Avoid designs that require the manipulator to remain attached to a payload while the berthing mechanism rigidizes the interface. For example, for berthing-compatible International Docking Systems (Ref. IDSS IDD), the recommended operational sequence is for the manipulator to berth the active/passive docking interfaces together to engage the soft capture latches and then release to allow the docking system to retract to fully align and seat the interface and engage hard capture hooks. This operational sequence ensures that only one system is active at any given time.
 - b. Design interface to allow the manipulator to achieve full alignment/seating (passive berthing).
2. Control/Protect against the Hazard – Provide ability to stop the active mechanism before loads can build up to exceed structural load limits. Implementation options include;
 - a. Provide a method for the manipulator to signal a stop to the mechanism’s controller in the event of a failure, and vice-versa.

- b. Design incremental control capability into the active mechanism whereby the active mechanism moves a prescribed/safe distance.
 - c. Design manipulator safing response to be situation dependent. For example, during a berthing operation, do not engage the brakes in response to a failure condition.
3. Reduce Consequences of the Hazard - Design system so that hardware can withstand the loads that are generated when an active mechanism keeps pulling while the manipulator is braked. Implementation approaches include;
- a. Limit forces and moments that the active mechanism can generate (e.g. design active mechanisms with variable pulling force).
 - b. Design system to provide mechanical load limiting to protect interfaces (e.g. size mechanical brakes on the manipulator so that they will slip before robotic interface and active mechanism load limits are exceeded).

The pros and cons of the various methods are summarized in Table E.2.3-1, Methods for Controlling Off-Nominal Berthing Loads.

**TABLE E.2.3-1 METHODS FOR CONTROLLING OFF-NOMINAL BERTHING LOADS
(2 PAGES)**

	Method	Pros	Cons
1a	Use designs which do not require manipulator to remain attached to payload during interface seating	<ul style="list-style-type: none"> - Adds fault tolerance (requires multiple failures before hazard effect occurs) - No analysis required for coupled active system behavior (arm/mechanism) 	<ul style="list-style-type: none"> - Imposes requirement on robotic interface to implement a soft-capture system capable of safely restraining payload - Requires status (soft capture) handshaking to support automation
1b	Use designs which allow manipulator to achieve full seating	<ul style="list-style-type: none"> - Adds fault tolerance (requires multiple failures before hazard effect occurs) - No analysis required for coupled active system behavior (arm/mechanism) 	<ul style="list-style-type: none"> - Imposes requirement on robotic interface to implement alignment guides which enable full seating by manipulator - Requires manipulator to have force/moment accommodation - Requires status (fully mated) handshaking to support automation
2a	Provide a method for manipulator to signal a stop to the mechanism's controller in the event of a failure	<ul style="list-style-type: none"> - Software "only" solution (no mass) 	<ul style="list-style-type: none"> - Requires interface-specific analysis to identify required driving speed of mechanism and maximum communication latency to limit loads - Requires software/comm. interface between manipulator and external mechanism
2b	Design incremental control capability into active mechanism	<ul style="list-style-type: none"> - Software "only" solution (no mass) 	<ul style="list-style-type: none"> - Requires interface-specific analysis to identify minimum increment to limit loads - Increased operational timelines unless scripting/automation adopted

**TABLE E.2.3-1 METHODS FOR CONTROLLING OFF-NOMINAL BERTHING LOADS
(2 PAGES)**

	Method	Pros	Cons
2c	Incorporate context-specific Safing response (i.e. do not engage brakes in response to a failure during certain operations)	<ul style="list-style-type: none"> - Adds fault tolerance - Extensible to other operational scenarios where load limits can be exceeded (e.g. free-flyer capture) - Reduces demands/requirements on users 	<ul style="list-style-type: none"> - Requires joint brakes to be designed to be fault tolerant against inadvertent brake application
3a	Limit forces & moments that active mechanism can generate	<ul style="list-style-type: none"> - Robust – system is not capable of overloading itself 	<ul style="list-style-type: none"> - Requires interface-specific analysis to identify required mechanism driving torque to limit loads on the manipulator/interface - Risk of operational nuisances (mechanism stall) if on-orbit friction higher than expected
3b	Size manipulator brakes so that interface loads are not easily exceeded in off-nominal scenarios	<ul style="list-style-type: none"> - Robust – system is less capable of overloading itself - Extensible to other operational scenarios where load limits can be exceeded (e.g. free-flyer capture) - Reduces demands on users 	<ul style="list-style-type: none"> - Reducing brake friction increases the stopping distance of the manipulator in emergency scenarios. Requires slower maneuvering speeds - Reduces the “holding” force of the manipulator for applications where the arm is expected to passively hold position while being pushed on by an external force

E.2.4 CONCLUSIONS & RECOMMENDATIONS

The merit of each of the options were evaluated against the following criteria (in order of priority):

- Hazard Avoidance – Whether hazard is avoided
 - Hazard avoidance/elimination is preferred over mitigation methods.
- Extensible – Applicability of method other operational scenarios (i.e. can also help to reduce loads in scenarios other than berthing)
 - Extensibility is preferred.
- Level of Analysis - Need for mission specific integrated analysis
 - Lower analysis is preferred to reduce Phase E effort.
- External Impacts - Burden (verification) imposed on external systems
 - No impact to external systems is preferred.
- Operational Impact – Impact to timeline or operations complexity
 - Minimal complexity is preferred but less critical with automation.
- Manipulator Impacts – Burden/complexity imposed on manipulator
 - Lower impact is preferred to reduce development complexity.

Based on the evaluation criteria the recommended order of preference for addressing the hazard associated with berthing to an externally controlled mechanism are;

1. Adopt designs which do not require manipulator to remain attached to payload during interface full seating (method 1.a).
2. Adopt designs which enable the manipulator to achieve full seat (method 1.b).
3. Size manipulator brakes so that interface loads are not easily exceeded in off-nominal scenarios (method 3.b).
4. Incorporate context-specific safing response (i.e. do not engage brakes in response to a failure during certain operations) (method 2.c).
5. Incorporate method for manipulator to halt the active mechanism (method 2.a).
6. Design incremental control capability into active mechanism (method 2.b).
7. Limit forces and moments that active mechanism can generate (method 3.a).

No IERIIS updates are identified at this time since, no externally controlled berthing mechanisms are currently included in IERIIS, and the IDSS already captures the preference identified by this trade (i.e. for berthing-compatible implementations, do not require manipulator to remain attached to payload during interface full seating).

E.3 ORU STYLE: PLATFORM VS. DIRECT HANDLING

E.3.1 PURPOSE

The purpose of this trade was to compare different approaches to incorporating robotically compatible interfaces into an ORU.

E.3.2 BACKGROUND

Historically ORUs have been designed in two fashions;

1. Direct Handling – Where ORU features (soft-docks, tie-downs, mate/demate mechanisms, targets, alignment guides) are directly incorporated into equipment. A historical example from ISS is shown in Figure E.3.2-1, Example of Direct Grasp Style ORU.

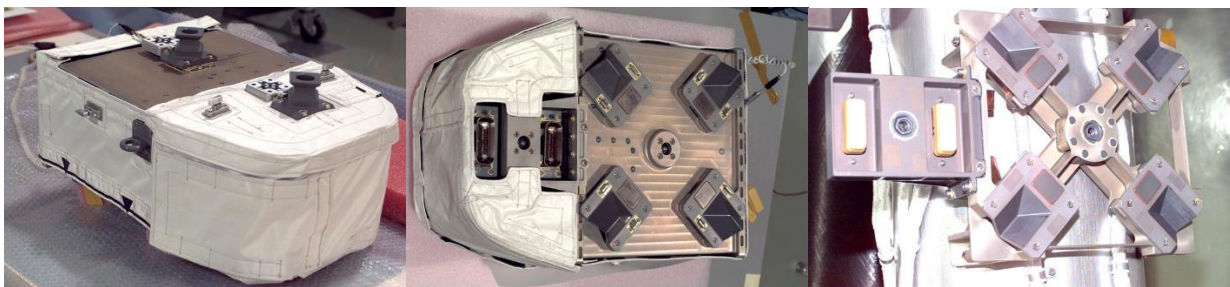


FIGURE E.3.2-1 EXAMPLE OF DIRECT GRASP STYLE ORU

2. Platform Style – Where ORU features are incorporated into a generic platform, onto which equipment can be mounted via standardized bolt patterns and connectors. A historical example from ISS is shown in Figure E.3.2-2, Example of Platform Style ORU Interface.

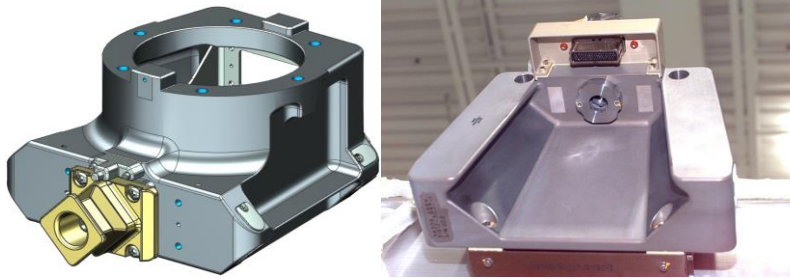


FIGURE E.3.2-2 EXAMPLE OF PLATFORM STYLE ORU INTERFACE

E.3.3 TRADE

The factors considered when evaluating the two ORU styles included;

1. Commonality
2. Complexity
3. Verification
4. Thermal Considerations
5. Accessibility
6. Mass “Tax” for ORU Interface

A comparison of platform-based and direct handling style ORUs is summarized in Table E.3.3-1, Comparison of Platform-Based and Direct Handling Style ORUs.

TABLE E.3.3-1 COMPARISON OF PLATFORM-BASED AND DIRECT HANDLING STYLE ORUS

	Criteria	Platform-Based	Direct Handling
1	Commonality	<ul style="list-style-type: none"> - Enable a standardized mating interface which can be used in a family of ORUs - Supports a common set of robotic operations for using the family of ORUs, which can increase the reliability of operations (i.e. lessons learned from one ORU is applicable to other ORUs) 	<ul style="list-style-type: none"> - Can be more challenging to standardize due to different ORU form factors and constraints (e.g. a tie-down bolt through the centre of the box may be too onerous to accommodate on some designs) - Tend to be optimized/tailored to the size/shape of the equipment which leads to more ORU-specific robotic operations/procedures
2	Complexity	<ul style="list-style-type: none"> - Equipment developers have less external interfaces and requirements to design to 	<ul style="list-style-type: none"> - In instances where tie-down bolts penetrate through the box, low level designers (e.g. circuit card assembly placement) need to work around the ORU features - Equipment is directly in the load path during robotic operations and therefore must be designed to withstand nominal and off-nominal robotic loading events
3	Verification & Validation	<ul style="list-style-type: none"> - In instances where tie-down bolts penetrate through the box, low level designers (e.g. circuit card assembly placement) need to work around the ORU features - Equipment is directly in the load path during robotic operations and therefore must be designed to withstand nominal and off-nominal robotic loading events 	<ul style="list-style-type: none"> - Each ORU design iteration likely requires its own V&V - ORU developer is responsible for verifying EVA/EVR maintainability requirements
4	Thermal Considerations	<ul style="list-style-type: none"> - Tend to thermally isolate the user from the station mounting interface 	<ul style="list-style-type: none"> - Can better support heat transfer between the ORU and the mounting interface
5	Accessibility	<ul style="list-style-type: none"> - When large volume ORUs are mounted on platforms, robotic access to handling features can be restricted 	<ul style="list-style-type: none"> - Robotic access to ORU handling interfaces can be optimized and less restrictive
6	Mass "Tax" for ORU Interface	<ul style="list-style-type: none"> - If platform is designed to accommodate a range of equipment shapes/sizes then it will be overdesigned for smaller ORUs and therefore not mass-optimized - Scalable designs would enable mass-optimization - Support the use of common on-orbit logistics support equipment (e.g. temp stow locations) 	<ul style="list-style-type: none"> - Since ORU design features can be tailored to the equipment, more mass optimization may be possible - Unique mounting interfaces may require dedicated logistics support equipment (carriers and temp stowage locations) to support end-to-end maintenance concepts

E.3.4 CONCLUSIONS & RECOMMENDATIONS

The trade found that there are merits with both styles of ORU interfaces as follows;

- Platform style ORU designs are easier to support commonality which can reduce non-recurring engineering costs in design and verification, as well as the recurring costs to conduct the on-orbit operations on the ORUs.
- Direct ORU grasp style ORU designs may be necessary for some applications where thermal conduction across the mating interface is required.