

Technique	Provide guidelines for the design of maintainable equipment for compatibility with dexterous robots by outlining selection criteria for associated fasteners and handling fixtures.
 <h2 style="margin: 0;">SELECTION OF ROBOTICALLY COMPATIBLE FASTENERS AND HANDLING MECHANISMS</h2> <p style="margin: 0;"><i>Optimization of robotics design via selection and use of compatible resources will reduce system downtime and increase availability</i></p>	
Benefits	The application of these guidelines to the design process will increase the effectiveness of dexterous robots by allowing for optimized design of robotics components used during maintenance tasks. In addition, because Extra Vehicular Activity (EVA) tasks performed with robots must be simplified to accommodate robotics dexterity (which is intrinsically inferior to that of a human crew member), robotically compatible designs will facilitate the simplified (less time consuming) EVA tasks. This equates to less system downtime and higher availability for both ground and on-orbit systems.
Key Words	Robotically compatible; maintenance; fasteners; handling fixtures
Application Experience	International Space Station Program
Technical Rationale	The following selection guidelines enable design engineers to identify the criteria required for robotics compatibility and to tailor their specifications to different robotics systems and environments. They provide general concepts for using robotically compatible fasteners and handling fixtures that have been applied on the Space Station program and state the advantages of these concepts.
Contact Center	Johnson Space Center (JSC)

Selection of Robotically Compatible Fasteners and Handling Mechanisms
Technique DFE-1

Before designing an ORU or other component for robotics compatibility, the feasibility of such an effort must first be assessed. Some items (e.g., thermal blankets), because of their flexibility, cannot be manipulated by robotics systems. The assessment should show (1) if the ORU or component can be manipulated by a robot, (2) if not, whether a major redesign of the item will be required to make it robot compatible, and (3) what effect the redesign will have on weight and cost (a factor that can be determined by simple analyses).

Reference 1 describes a preliminary analysis that might be used to determine the feasibility of designing for robotics compatibility. Once it is determined that the item can be designed to be manipulated by a robot, it must then be determined how the design relates to and affects the design of (1) other components in the system, (2) the system's layout, and (3) the robotics system with which it will interface.

Figure 1, which illustrates the process for redesigning for robotics compatibility as detailed in Reference 1, shows the sequence by which the design of items higher in a process flow impact the design of the lower items. Although the sequence may be altered, the alteration may result in increased costs, in schedule delays, and in less flexibility in applying robotics compatibility. The bidirectional arrows indicate processes that should be performed using an integrated approach that considers the impacts the ORU, system, and robot design have on each other. Once the above mentioned analysis is performed and design of the robotically compatible fasteners or handling fixtures is begun, the objectives then must be to:

- Provide for alignment.
- Avoid jamming and binding.
- Withstand the loads that may be imparted by the robotics systems.
- Provide adequate access.
- Simplify the operation.
- Assist ORU alignment and softdock and harddock functions. "Softdock" is defined as the initial temporary attachment between two or more pieces of equipment to prevent inadvertent release prior to permanent attachment.

Reference 2 lists a number of guidelines and requirements that may be applicable to designing for robotics compatibility of Space Station hardware. Reference 3 lists a number of different robotically compatible fasteners and handling fixtures for Space Station use. The purpose of this technique, however, is to assist designers in applying the stated concepts to their system ORU's and not to list contractual requirements. The six design objectives for fastener and handling fixture design requirements are addressed in the following section.

FASTENER AND HANDLING FIXTURE DESIGN REQUIREMENTS

Provide for alignment

Alignment provisions may be implemented as (1) markings, (2) alignment guides, and (3) design of the robotics system and its control system. Only the second of these options, alignment guides, is addressed in this section. Markings and robotics system designs are described in References 1, 2, and 3.

Fasteners

There are more options available for aligning fasteners than there are for handling fixtures. For example, fasteners are captive and are an integral part of an ORU. Therefore, if the ORU contains proper alignment features and is

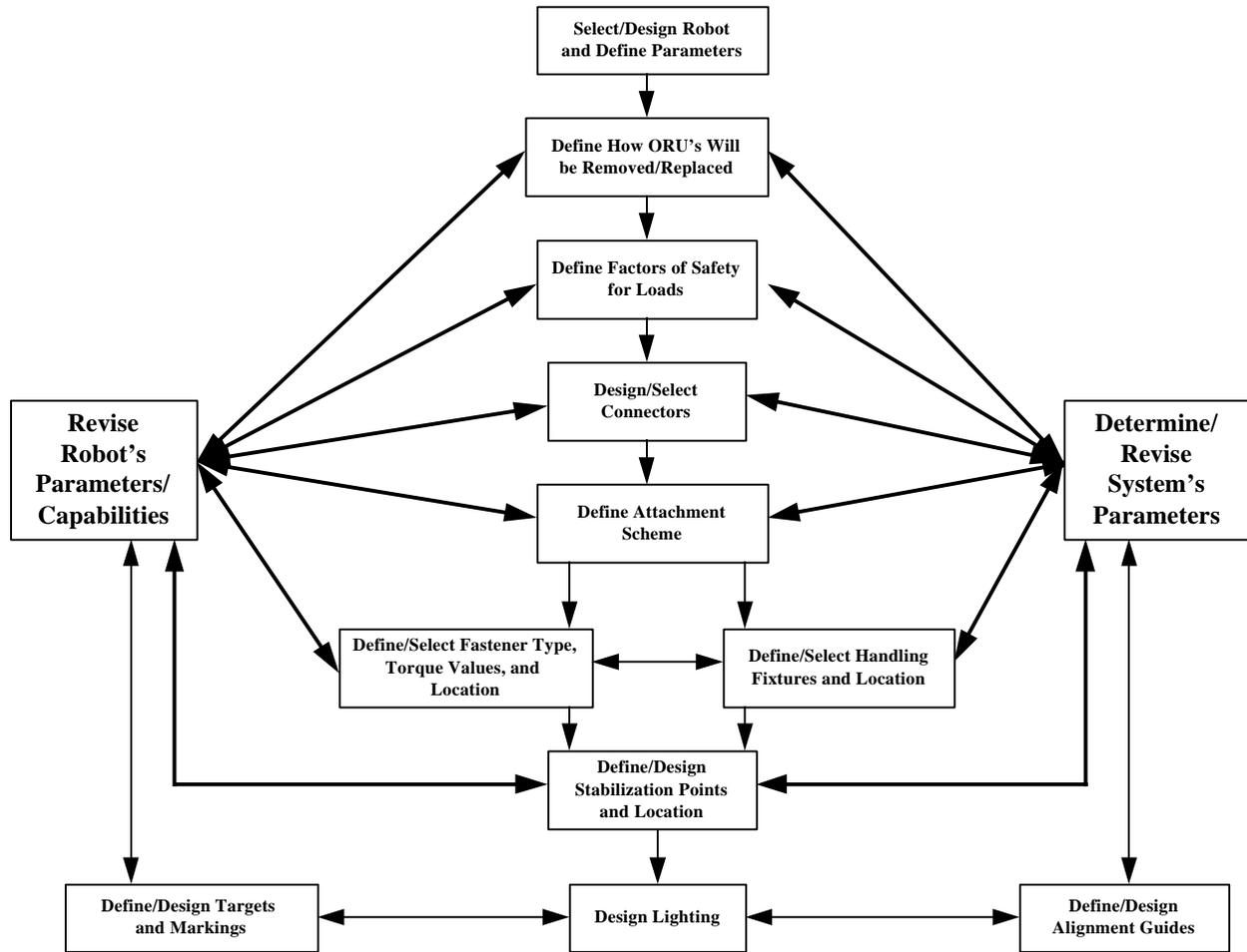


Figure 1. Process for Robotics Compatibility Design

properly aligned and inserted, the fasteners will be properly aligned as well. However, since handling fixtures are grappled independent of the insertion and alignment of the ORU, the

incorporation of alignment features is confined to the fixture and end effector. The ORU alignment feature design, which is discussed in References 2 and 3, is an important

consideration, since it can lessen fastener complexity. The alignment techniques being used for Space Station fasteners are described below.

Alignment of Tool to Fastener Head

Robotic testing has shown that, provided there is proper visual contrast between the fastener head and the surrounding structure, a 7/16- inch fastener with a flat head can be easily captured by the robotics end effector (nut driver). Earlier concepts specified or recommended rounded heads because it was believed the rounded head would accommodate greater misalignment tolerances. It was found, however, that a flat-headed fastener provided the robot with the same misalignment tolerances as the same fastener with a rounded top.

Alignment of Fastener to Nut

The bolt is aligned to a nut by tapering the end (pilot) of the bolt and by having a cone or countersink around the nut. For fasteners that form an assembly or that are, in Space Station terminology, "attachment mechanisms," there are housings which contain tapered "fingers."

Handling Fixtures

The two alignment techniques for Space Station handling fixtures are described below.

V-slot Insertion

The V-slot insertion technique is used with the microfixture and H handle, which interface with the Special Purpose Dextrous Manipulator (SPDM) end effector or the ORU tool changeout mechanism (OTCM). The OTCM fits as a V into the grooves of the H handle closes its V-shaped grooves around the corners of the microinterface (see reference 2 for a detailed description). The positional misalignment tolerance allowed for the H fixture is approximately 0.5 inch with angular misalignment tolerance of about $\pm 2^\circ$. The

microfixture allows positional misalignments of about 0.3 inch and angular misalignments of about $\pm 3^\circ$.

Cylinder-over-cone

The microconical tool slips over and attaches collets to the microconical interface, which is shaped like a cone. The allowable translational and angular misalignment tolerances for the microconical tool are 0.25 inch and $\pm 1^\circ$, respectively.

AVOID JAMMING AND BINDING

Fasteners

Once alignment is accomplished and the fastener begins to enter the nut, there is still the possibility of cross-threading. Cross-threading can be avoided by aligning the nut using the unthreaded portion on the bolt, and it can also be avoided by using an expandable thread diameter nut; i.e., a Zipnut. A Zipnut consists of three separate segments within a housing that, when assembled, form the internal threads of a nut. The segments are held against the threads of a bolt or screw by springs that force them to a minimal diameter, and a ramp that allows them to separate or come together, depending on the direction in which the bolt is inserted. When a bolt is inserted, the segments are allowed to slide back and away, allowing the bolt to slide through without obstruction. This type of nut is described in detail in Reference 2.

Handling Fixtures

When using robotically compatible handling fixtures which apply the slot in the V-groove concept as described above (i.e., the microinterface or X handle), care must be taken that the corners are rounded. This precaution must be taken to keep the handle from binding to the end effector, as happened in the JSC robotics laboratories with the first H handle concept which had sharp corners.

The corners of the H handle (renamed the X handle) were rounded, and the binding effect was thus eliminated.

WITHSTAND LOADS THAT MAY BE IMPARTED BY ROBOTICS SYSTEMS FOR FASTENERS AND HANDLING FIXTURES

SSP 30000, table 3-3, "Factors of Safety," specifies that for metallic flight structures, the general factor of safety is a yield of 1.25 and an ultimate of 2.00.

PROVIDE ADEQUATE ACCESS

Fasteners

Adequate access for fasteners is provided by designing a proper layout of the system as described in reference 3. The fastener selection (or fastening scheme) can be influenced by the robotics access if more than 1 degree of freedom is required by the robot to engage and disengage the fastener. A lever, for example, requires more than 1 degree of freedom and therefore requires significantly more access space to operate than that required to engage a bolt. In addition, the higher the torque value, the larger the end effector (motor), lessening the allowable robotics access space. For Space Station, no levers will be used by robots.

Handling Fixtures

Certain small Space Station ORU's are being placed so close to each other that inadequate access space is provided for the robot to open its jaws around the interface. The problem was resolved by using the microconical interface that snaps around the interface in a "stabbing" motion. By using a tool that does not require jaws to open around an interface; i.e., the microconical tool, the required access space is significantly reduced.

Simplify the Operation Fasteners

The robotics operation can be simplified by the

following methods:

Use Captive Fasteners

Use of captive fasteners is the best method for simplifying robotics operation. This eliminates the need for the robot to carry and insert the fasteners and thus increases the probability of mission success.

Reduce Number of Operations

The type of fastener selected can reduce the number of operations required. For example, using the Zipnut eliminates the need for rotation, since the bolt can be slid through the nut and then tightened with a single rotation.

Choose Proper Forms of Fastening

Forms of fastening that require the robot to use more than 1 degree of freedom should be eliminated. Levers, for example, not only will increase the access space requirements (as described previously), but may also necessitate force moment accommodation and more complex control software.

Avoid Fasteners Requiring Excessive Torque

To engage fasteners that require excessive torque (i.e., 50 foot-pounds or over), the robot must stabilize itself with one arm, constricting the allowable configurations for removing and replacing the ORU. This necessitates additional hardware for robot stabilization. In general, care must be taken when using robotic systems for fastening due to the reaction forces that will be present.

Reduce Sizes and Types of Fastener Heads

Using different sizes and types of fastener heads will reduce the number of tools required by the robot.

Handling Fixtures

The grasping of the interface can be simplified by allowing the robot to grasp the interface from a number of different orientations. For

example, the microinterface and the microconical interface can be grasped from two different orientations of the OTCM relative to the handling fixture, while the X handle can only be grasped from one orientation. There may be some instances, however, in which it would be advisable to limit the allowable orientations. For example, if the robot can grasp an ORU from only one orientation, there is less chance that the ORU will be improperly inserted in its base plate.

ASSIST ORU ALIGNMENT AND SOFTDOCK AND HARDDOCK FUNCTIONS

Fasteners

When designing robotically compatible ORU's, the alignment guides and softdock features may be incorporated as part of the ORU, or fasteners with these features may be designed or selected. Softdock fasteners are thus more complex and are called "attachment mechanisms" in the Space Station Program. Alignment and softdock functions are described below.

Alignment Functions

If alignment features are lacking for the ORU, they can be incorporated via the tapering of pins, or fingers, located on the housings of the attachment mechanisms.

Softdock Functions

For the Space Station Freedom Program, attachment mechanisms achieve softdock either through the use of detents that are housed on an outer casing of the attachment mechanisms or via the Zipnut method. The Zipnut is ramped such that if an attempt is made to separate the bolt from the nut, the segments are pulled together allowing the bolt to be removed via rotation only. The Zipnut thereby functions as an excellent softdock attachment.

Handling Fixtures

Alignment and softdock functions are described below.

Alignment Functions

The location of the handling fixture can significantly impact ORU alignment. The further the handling fixture is from the ORU's center of gravity, for example, the more difficult it is for the robot to maintain a line of insertion that will be perpendicular to its attachment plate.

Other factors to be considered when placing handling fixtures are the size of the ORU, the location and type of alignment guides, and the placement of fasteners. These items are discussed in Reference 3 because of their dependence on ORU features.

Softdock Function

Softdock features may be used to prevent an ORU from "floating away" prior to its being fastened. This may also be achieved by fastening the ORU without releasing the handling fixture. The three above mentioned handling fixtures for Space Station have holes in their centers for fasteners, which allows the OTCM to grasp the ORU, insert it, and then drive the bolt with its nut driver without ever releasing the ORU handle.

References

1. *Robotics Systems Interface Standards, Volume 1, Robotics Accommodation Requirements (Draft)*, SSP 30550.
2. *Robotics Systems Interface Standards, Volume 2, Robotics Interface Standards (Draft)*, SSP 30550.
3. *The Design Process for Achieving Robotics Compatibility*, Contractor Report No. <TBD>.