ABSTRACT

Title of Thesis:	ANALYSIS OF GRASP REQUIREMENTS FOR TELEROBOTIC SATELLITE SERVICING
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There is an established need to service satellites while on-orbit. Teleoperated robots may conduct this servicing, if the grasps required to perform these tasks are identified and understood. By studying Hubble Space Telescope Servicing Mission 3B, the human grasps used for servicing satellites are identified. Based on the human grasps, a robotic grasp taxonomy is developed. The grasps required for robotic satellite servicing are described in this study in terms of end-effector requirements. Also presented is the relative use of each end-effector. In order to apply the findings here for Servicing Mission 3B to general satellite servicing mission, a task analysis is presented. This displays the end-effector requirements for each type of task performed, which may be applied to similar tasks on future servicing missions.

ANALYSIS OF GRASP REQUIREMENTS FOR TELEROBOTIC SATELLITE SERVICING

By

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Dedication

To my mom and dad. Thanks for being there and helping me every step of the way.

Acknowledgements

There are so many people to acknowledge for their help in this thesis and in general my graduate school career, I'm positive I'm going to leave somebody out so I'm sorry in advance if (WHEN!) I do.

I'd like to thank my advisor, Dr. Dave Akin, and my other committee members, Dr. Ella Atkins and Dr. Craig Carignan for their valuable input leading up to and during my defense. Three million drafts later, it seems like everything is finally done.

To all the kids at the Space Systems Lab, especially Elisa Shapiro, Meghan Baker, Todd Hermann, and Jeff Braden, who've probably known me the longest there and have been able to put up with me—and even read my drafts and keep me moderately sane.

Finally I'd like to thank Brian Roberts for all of his help and encouragement, particularly in the early phases of my research and writing. All of his knowledge and experience with Hubble made my tasks that much more manageable.

It's been a wild time and I suppose now I'm ready to join "the real world." Thanks to all!

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Chapter 1: Introduction

In a little over half a century, humanity's presence in space has increased from Sputnik to a permanently manned station. In the early days, there were only a few satellites launched, and the time between successive missions could stretch for months or years. Today, satellites are launched for commercial, private, government, and/or military purposes. Failures early in the satellite's life or failures in mid-life are often mission ending. With more satellites in space, it may be more economical to upgrade the existing satellites than to decommission the older satellite and launch a new one.

Humans have repeatedly serviced the National Aeronautics and Space Administration's (NASA's) Hubble Space Telescope (HST), demonstrating that on-orbit satellite servicing is possible. However, the increased risk to astronauts in performing these missions, as well as the inability of humans to do missions outside of low Earth orbit (LEO) prompts the question, "Can robots perform space-based satellite servicing tasks?"

Research at the University of Maryland (UMd) Space Systems Laboratory (SSL) suggests that approximately 5-10% of the satellites launched each year encounter mission-ending failures at the beginning of life (BOL) [46]. Such failures include solar deployment failures, orbit placement errors, and component failures. This research also suggests that these failures are repairable while the satellite is on-orbit [46]. Additionally, with more satellites in space for commercial purposes, it may be more

economical for a company to upgrade and service satellites on-orbit rather than decommission them and launch new ones.

To date, on-orbit servicing has not been widely practiced. The National Aeronautics and Space Administration's (NASA's) Hubble Space Telescope (HST) is the most prominent satellite to be serviced on-orbit. Astronauts have conducted this servicing during four missions using extra-vehicular activity (EVA). EVA is obviously limited locations that humans can reach, i.e. LEO. With so many satellites in space, most out of reach of human maintenance, several options for on-orbit robotic servicing have surfaced.

A robotic servicer must be capable of performing all of the tasks required to repair the satellite. At the simplest level, MD Robotics and the Canadian Space Agency (CSA) have developed Dextre, a robot with two dexterous arms and simple end-effectors. It is primarily designed for tasks specifically simplified to accommodate its limitations. At the most complex level, NASA's Johnson Space Center (JSC) has developed a humanoid robot called Robonaut. Robonaut's design gives it the same size, reach, and grasp characteristics as an astronaut in EVA; Robonaut can work directly with existing EVA tools and interfaces. An intermediate level is UMd's Ranger Telerobotic Shuttle Experiment (RTSX) robot. RTSX features a positioning leg, two 8-degree of freedom (DOF) arms, and an interchangeable end-effector mechanism (IEEM). This allows the use of different tools by the teleoperator depending on the situation.

All three systems are telerobots—that is, the human operator may control them from an on-orbit base, such as the space shuttle or ISS, or from the ground. However,

before deciding which of these robot designs might best accomplish on-orbit servicing tasks, one needs to determine what level of dexterity is required to perform the tasks.

In this thesis, a robotic grasp taxonomy for space-based satellite servicing will be developed. Chapter 2 will cover previous work in robotic satellite servicing. In Chapter 3, human and robotic dexterity will be discussed. In Chapter 4, a case study of HST Servicing Mission 3B (SM3B) will be presented and the methods for the analysis for robotic servicing potential will be discussed. In Chapter 5, the results of the analysis performed for this study will be reviewed. Finally, Chapter 6 will cover conclusions and possibilities for future study.

Chapter 2: Previous Work in Satellite Servicing

This chapter will present information about previous satellite failure types and instances of on-orbit repair. An introduction to the types of servicers that may be used will also be presented.

2.1 Failure Types and Instances

There have been many instances of on-orbit satellite failures at BOL and mid-life. Three examples will be presented here, including NASA's HST and the repairs performed on it.

For example, consider the Orion 3 satellite. Launched in May 1999, the satellite encountered a failure of the second stage of the Delta III launch vehicle terminating too early, thus the satellite entered the wrong orbit. This problem could easily have been remedied while on-orbit by launching a vehicle that could dock to the satellite and provide the propulsion to correct the orbit. In this case, the satellite suffered reduced function, though was not abandoned [45].

PanAmSat (PAS) 8 was a satellite launched in November, 1998. Intended to provide video and data services to the Asia-Pacific region, a major mechanism failure caused two of the antenna surfaces to deploy improperly. This resulted in a reduced ability of the satellite to perform its tasks, and the company had to launch another satellite to provide the full range of services that were supposed to be offered by PAS 8.

NASA's HST was the first spacecraft to receive routine and repeated on-orbit servicing. Between December 1993 and March 2002, four servicing missions went to HST to install, repair, and upgrade the satellite's components. The shuttle astronauts conducted all of the HST servicing missions over multiple days of EVA. A summary of the servicing missions is found in Table 2.1 at the end of this section.

Servicing Mission 1 (SM1) was the first servicing mission to HST and demonstrated that complex on-orbit servicing was possible. Launched in December 1993 on STS-61, the primary mission goal was to install the Corrective Optics Space Telescope Axial Replacement (COSTAR) unit to minimize the effects of a flaw in HST's primary mirror. COSTAR, a phone-booth sized instrument with five corrective mirrors, was successfully installed. Also during this mission, solar arrays were replaced, and two of the Rate Sensor Units (RSU's) were upgraded. Another camera, the Wide Field Planetary Camera (WFPC), was upgraded by replacing the old WFPC with a newer and better model, WFPC 2 [47]. SM1 was a success and opened the door for future servicing possibilities.

In February 1997, Servicing Mission 2 (SM2) was launched. With the success of SM1, the goal of this mission was to improve HST's science productivity by installing new components. The Space Telescope Imaging Spectrograph (STIS) was installed to aid scientists in studying super massive black holes. Also installed were the Near Infrared Camera and Multi-Object Spectrometer (NICMOS). NICMOS extended the viewable wavelengths of HST into the near-infrared range, which also allowed viewing of objects farther away in the universe than viewable with optical and ultraviolet methods. Among the parts upgraded during SM2 were the Fine Guidance Sensor (FGS),

Solid State Recorder (SSR), and Reaction Wheel Assemblies (RWA's) [47]. SM2 greatly expanded the science capabilities of HST, demonstrating it was possible to upgrade satellites on-orbit to extend their useful life.

Servicing Mission 3A (SM3A) was launched in December, 1999, as the first of a "two-part" mission to repair many parts of HST. In total, three RSU's, each with two gyroscopes, were replaced. This was necessary because four of the six gyroscopes had failed, and three are necessary to function for normal science operations. Other improvements included the installation of voltage/temperature improvement kits (VIKs) on HST's batteries, replacement of the spacecraft's central computer, and repair of the outer thermal protection layer of the satellite [17, 47]. SM3A was followed by SM3B in 2002, which is the focus of this research effort and will be addressed in much greater detail later.

Mission	Date	Old Tasks	New Tasks
SM1	12/1993	-N/A	-COSTAR installation -SA replacement -RSU upgrade -WF/PC replacement/upgrade -SA drive equipment maintenance
SM2	2/1997	-SA drive equipment upgrade -Insulation repair &installation	-STIS installation -NICMOS installation -FGS upgrade -SSR upgrade -RWA upgrade
SM3A	12/1999	-RSU upgrades -SSR upgrades -Insulation upgrades -FGS replacement	-VIK installation

Table 2.1 Servicing Missions 1-3A

2.2 Types of Servicers

On-orbit servicing to date is almost exclusively limited to astronauts performing the servicing tasks during extravehicular activity (EVA). An alternative is to perform these tasks with teleoperated dexterous robots, controlled either from inside a space vehicle in a parking orbit near the satellite or from the ground.

2.2.1 Human Servicers

Astronauts in EVA have conducted all complex on-orbit servicing performed to date. This includes four HST servicing missions, and extensive EVA for the construction and repair of the International Space Station (ISS). Over 120 hours of EVA servicing on HST have demonstrated that on-orbit servicing is feasible, though costly and arduous. In performing on-orbit servicing tasks on HST and ISS, astronauts use specially designed tools, cataloged in the Swales Aerospace Crew Aids and Tools (CATS) guide. Many of the tools required to perform on-orbit satellite servicing are modified versions of tools used on Earth. For example, one class of tool used is the Pistol Grip Tool (PGT) (see Figure 2.1). This is a bolt driver with variable torque and turn-rate settings, and includes various attachments to extend the reach of the driver. Many of the CATS are simply "reach extenders" to allow a gloved and suited astronaut to reach deep into the instrument to remove connectors or bolts. It is evident that on-orbit servicing methods are adequate to upgrade and repair satellites; however, operational experiences have also exposed the limitations of human on-orbit servicing.

Figure 2.1 CATS Pistol Grip Tool, from the CATS catalog

2.2.2 Robotic Servicers

Manipulative robots will play a large role in on-orbit satellite servicing. Some of these robots have space flight heritage, while others are still in the research and development phase of design. There is a broad spectrum of manipulative space robots, including Dextre, the Manipulator Flight Demonstration (MFD) robot arm, Engineering Test Satellite VII (ETS-VII), Ranger Telerobotic Shuttle Experiment (RTSX), and Robonaut.

Dextre (Figure 2.2) is a Canadian robot currently undergoing testing for flight as a part of the ISS Mobile Servicing System (MSS). The MSS is composed of the Space Station Remote Manipulator System (SSRMS), also known as CanadArm2, Dextre, and a moveable work platform called the Mobile Base System (MBS). It is a two-armed robot that "will provide an alternative to astronauts, considerably reducing the amount of time

that the have to venture out of the ISS to perform demanding spacewalks and providing more time for them to perform science on the ISS" [8]. Each of Dextre's arms has seven joints ending with an Orbital Replacement Unit/Tool Changeout Mechanism (OTCM). Each OTCM has parallel jaws and a retractable nut drive. Due to the limited dexterity ad limited degrees of freedom in the OTCM, Dextre is intended to be primarily used for tasks dedicated to robotic repair, and incorporating specialized interfaces and visual targets for the robot. The system also incorporates lights, cameras, a tool platform, and four tool holders [22].

Figure 2.2 Dextre, from [42]

Dextre is designed to be teleoperated by astronauts from a workstation on ISS; its primary role is to perform maintenance and servicing tasks on ISS. Under normal circumstances, Dextre sitting on the MBS would perform these tasks and CanadArm2 would manipulate the payload to Dextre's workspace. Alternatively, Dextre can be grappled by CanadArm2 and moved to the payload worksite [22].

The MFD robot arm was installed in the shuttle cargo bay for STS-85, launched in August 1997. Flight demonstration tests were conducted on flight days 2, 4, 5, and 7. MFD demonstrated orbital replacement unit (ORU) replacement and the opening and closing of a hinged door [27]. For these demonstrations, the shuttle crew in the aft flight deck operated the arm via hand controllers [23]. This mission provided early robotic flight experience for the Japanese Small Fine Arm, under development for ISS.

NASDA's ETS-VII is another manipulative robot with flight heritage. NASDA designed, tested, and flew this robot to demonstrate on-orbit robotic capabilities. ETS-VII attempted to perform many tasks including visual inspection of a worksite, ORU handling, a fuel supply experiment, and handling of small equipment such as switches and electric connectors [31].

While the mission was considered a success, ETS-VII completed only about 50% of its desired mission tasks. Most notably, it was unable to complete tasks for electric connector mate/de-mate, solar cell sheet handling, and electric wire handling. This failure was due to the inadequate level of dexterity in the manipulators—the manipulators could not perform tasks with intricate, small, or delicate interfaces. As a result, the designers of ETS-VII recognized that in order to perform the more complex tasks required for on-orbit satellite servicing completely robotically, manipulators needed greater function, manipulability, and reliability in the end-effector [21, 33].

Another manipulative robot, the Ranger Telerobotic Shuttle Experiment (RTSX), is currently being used for research at the SSL. RTSX consists of a 6 degree of freedom positioning leg (PXL), two eight degree of freedom dexterous arms, and a video arm (see Figure 2.3 for a photograph of an RTSX dexterous arm). RTSX's design relies on using

a variety of 2 degree of freedom end-effectors, allowing the robot to perform most satellite servicing tasks. It can switch between end-effectors stored in its "tool box" on its main body. This is done by moving the arm to the toolbox, where the Interchangeable End Effector Mechanism (IEEM) is used to place on end-effector back onto the toolbox and pick up another (see Figures 2.4 and 2.5 of the IEEM).

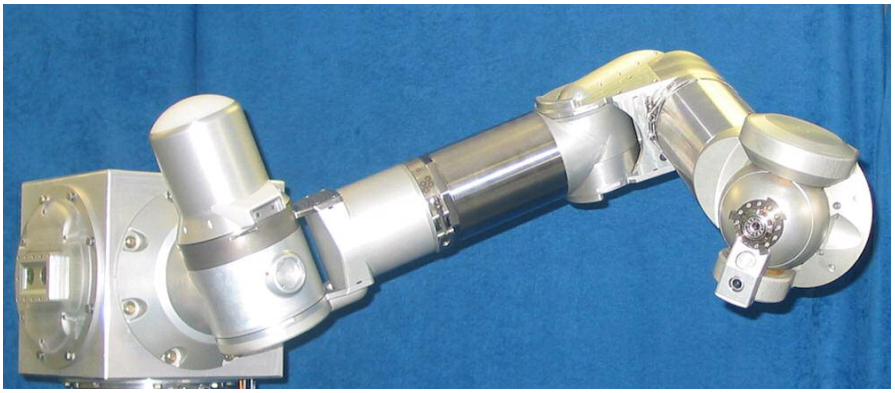

Figure 2.3 RTSX Dexterous Arm, from [35]

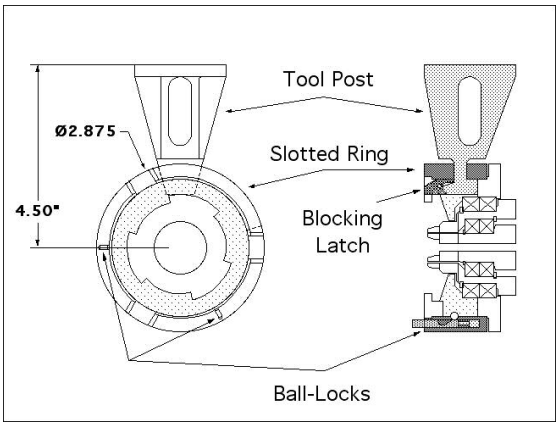

Figure 2.4 IEEM locked to tool post, from [34]

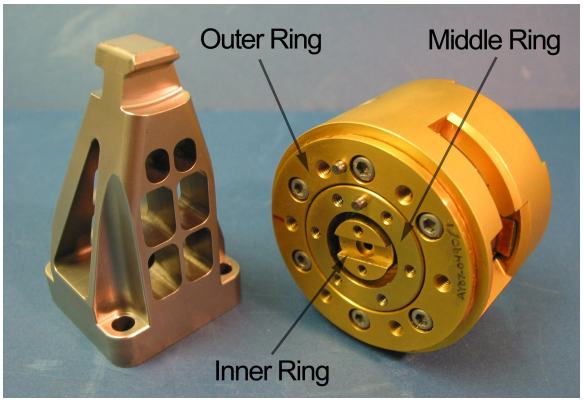

Figure 2.5 IEEM and tool post disengaged, from [34]

The expectation with this design is that the required end-effectors can be designed for all tasks on each different servicing mission without redesigning the entire robot, limited only by the two arm-mounted actuators used to drive the interchangeable end-effectors. That is, it allows for custom-made end-effectors for the given tasks. RTSX was originally designed to perform tasks while stationed in the shuttle payload bay. It is teleoperated from a workstation with hand controllers located either in the shuttle flight deck or on the ground.

The final servicing robot considered here is Robonaut (see Figure 2.6). Robonaut is a highly dexterous manipulative robot designed at NASA's Johnson Space Center (JSC) in Houston, Texas. It is an anthropomorphic telerobot, designed to carry out the same tasks as an EVA astronaut, and in the same manner. Robonaut has over 47 total degrees of freedom and is the same size as a suited astronaut [39]. The assumption behind Robonaut's design is that it is more cost- and mass-effective to make a robot that can interface with all existing EVA crew interfaces and tools, instead of making special dedicated tools and end-effectors for robots [20]. Robonaut is teleoperatively controlled though a virtual reality link, a novel technique for space servicing robots.

Figure 2.6 Robonaut, from [37]

There are many approaches to manipulative robot design. All the robots presented here are teleoperated robots, with varying degrees of freedom in the arm and end-effector—that is, with varying levels of dexterity. Table 2.2 summarizes these robots and their characteristics.

In summary, of the five robots presented, only MFD and ETS-VII have flight experience to date. The other three robots are in various stages of development and have all demonstrated some capabilities to perform tasks on the ground. The primary reason for the wide spectrum of designs is that the requirements for on-orbit servicing by robots are not well understood yet. This thesis will specifically analyze the grasp requirements for robots to perform spacecraft servicing tasks. In the future, based on these dexterity requirements, designs can be tested to determine which robots can meet the requirements and are easily implemented for telerobotic servicing, in terms of ease of use and reliability. In the next chapter, dexterity will be defined for humans and robots to form a basis for the analysis conducted in this thesis.

Robot	Designer	Notable Characteristics
Dextre	MD Robotics/ Canadian Space Agency	-Unflown -2 arms -15 total DOF -Works in conjunction with CanadArm2
MFD	NASDA	-Flown in 8/1997 (STS-85) -Demonstrated ORU replacement & door opening
ETS-VII	NASDA	-Flown in 11/1997 -Demonstrated ORU replacement & fuel supply exchange -Could not complete tasks with small, intricate, or delicate interfaces
RTSX	UMd SSL	-Unflown -3 arms (DXR, DXL, video arm), 1 leg (PXL) -22 total DOF -Utilizes IEEM
Robonaut	NASA JSC	-Unflown -Anthropomorphic w/ 2 arms -Over 47 total DOF -Virtual reality tele-operation

Table 2.2 Manipulative Space Robots

Chapter 3: Human and Robotic Dexterity

3.1 "Dexterity" Definition

Dexterity has been studied in both humans and robots. In order to develop a robotic grasp taxonomy similar to existing taxonomies for humans, it is important to study the dexterity of humans and robots and the capabilities and limitations of each. Dexterity is widely studied in ergonomics, engineering, physical and occupational therapy, medicine, and biomechanics and is defined as, "Skill and grace in physical movement, especially in the use of the hands" [11]. In literature studies, dexterity usually encompasses either the number of degrees of freedom or possible grasp types; it is a combination of range of motion, strength, and response to sensory cues. Studies also review manipulation of single or multiple objects [29].

3.2 Human Dexterity/Grasps

Human dexterity has been studied extensively. Most studies have incorporated the definition of types of grasps used in different settings, and the number and type of grasps achieved most often define human dexterity. Schlesinger (1919) identified six basic human grasping patterns: cylindrical, tip, hook, palmar, spherical, and lateral [41]. Napier further broke down grasps into two types, power, and precision. High contact forces and large contact surface area between the grasping surface and grasped object categorize power grasps. Contrarily, precision grasps involve high sensitivity and complex object manipulation, often with objects with small contact areas. In humans, then, power grasps are characterized by palmar grasping with significant use of arm

muscles, while precision grasps are characterized by fingertip grasps [24, 25, 26, 53]. More recently, Cutkosky developed a grasp taxonomy based on hand usage by machine builders. Cutkosky's taxonomy based grasp types on functions of the "grasping surfaces," in terms of "object-supporting, pressing, and wrapping functions" [40]. Combining task requirements and object attributes, Cutkosky built a tree-like taxonomy to describe the grasps, dividing them into "power" grasps and "precision" grasps. Power grasps are those that involve large contact areas with grasped object and where "considerations of stability and security predominate" [9]. It is also noted that power grasps do not involve using the fingers to impart motion. Precision grasps are used activities that require high levels of control but not as much force; these grasps often involve only the fingers and thumb [9]. Cutkosky's taxonomy is shown in Figures 3.1 and 3.2.

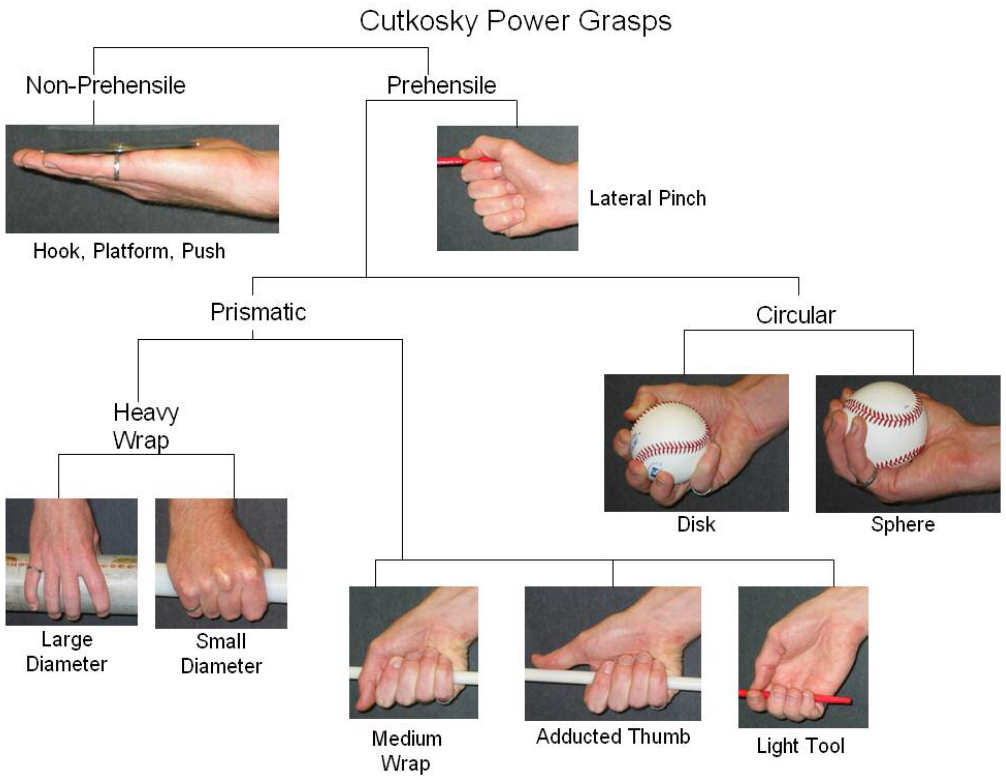

Figure 3.1 Tree of Cutkosky power grasps, adapted from [9]

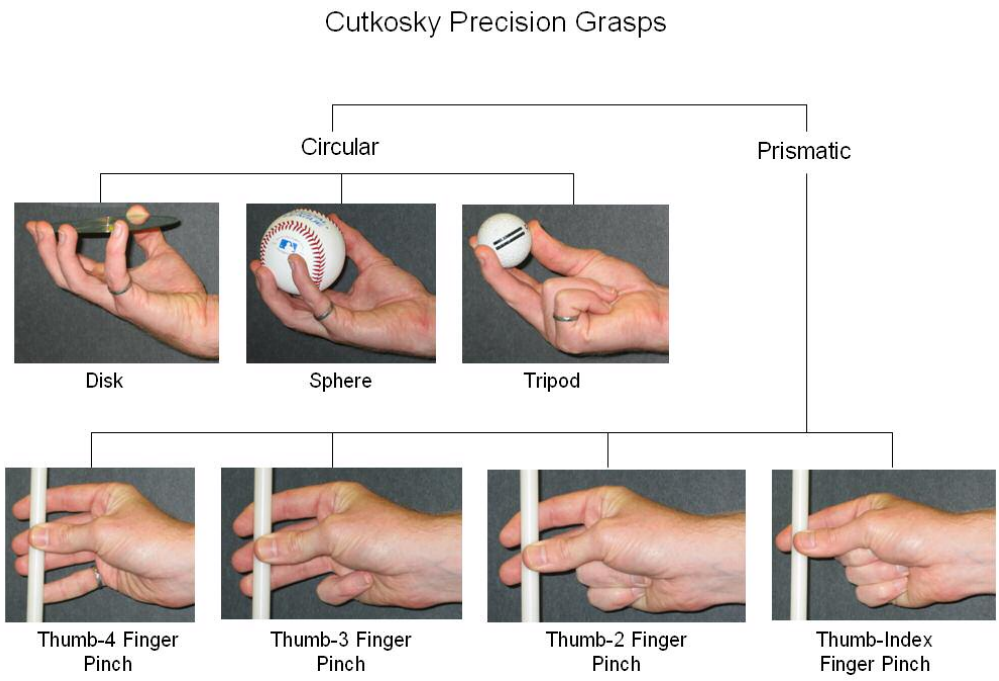

Figure 3.2 Tree of Cutkosky precision grasps, adapted from [9]

These taxonomies are not without limitations. Cutkosky has pointed out, for example, that "...[there are] numerous everyday grasps, such as the grasp that people use in writing with a pencil or in marking items with a scribe that are not included" [9]. The authors suggest using an "object-oriented expert system," to identify types of grasps that not included in a "tree-like taxonomy," including combinations of grasps. They suggest that an object-oriented expert system makes it easier to add constraints to grasp types needed and used [9].

3.3 Robotic Dexterity

Robotic dexterity is generally studied for research in industrial robotics and prosthetic devices. There are two general classification systems for robotic dexterity:

those based on control and kinematics parameters (i.e. the Jacobian) and those based on grasp types/functions and number of degrees of freedom in the manipulator [25].

3.3.1 Dexterity Definitions

Most studies of robotic manipulator dexterity assume that dexterity is a function of the number of degrees of freedom in the hand. This contrasts with studies in humans, where dexterity is a function of what types of tasks and manipulations can be performed. Studies of robotic dexterity as a function of task analysis are rarely performed, even though they draw the best parallel to human dexterity definitions. Task analysis occurs in a series of steps, in which the task is broken into subtasks, and then into primitive steps of each subtask. Then, categorization of these primitives occurs based on similar primitives and primitive location (that is, where the tasks are performed in relation to other tasks, subtasks, and other worksite features).

Categorization also reflects the skills required to perform the tasks [49]. This procedure is rarely done, because most robots are designed first, and then tested for dexterity. Thus, many robot hands either possess very few degrees of freedom and therefore have limited motion, or have many degrees of freedom and therefore are quite complex. Complex robots may be expensive to design and build, and difficult to maintain in case of failure. Conversely, simple robots may not be capable of performing all of the desired tasks. A compromise between these extremes is robots with simple "hands" that have multiple specialized end-effectors to perform certain tasks. These robots can exchange their own end-effectors to perform a wide variety of tasks. The advantage is that it allows robot designers to develop simple end-effectors for the desired

task set, instead of developing complete robots for each individual task, which may be more cost-effective and flexible than either of the other approaches [38].

An alternative to robots with interchangeable end-effectors may be found in more complex hands that have reconfigurable fingers. This is the principle behind the BarrettHand, a commercially available robotic end-effector (see Figure 3.3). The hand's design makes it "automatically reconfigurable and highly programmable, matching the functionality of virtually any gripper shaper or fixture function..." [48].

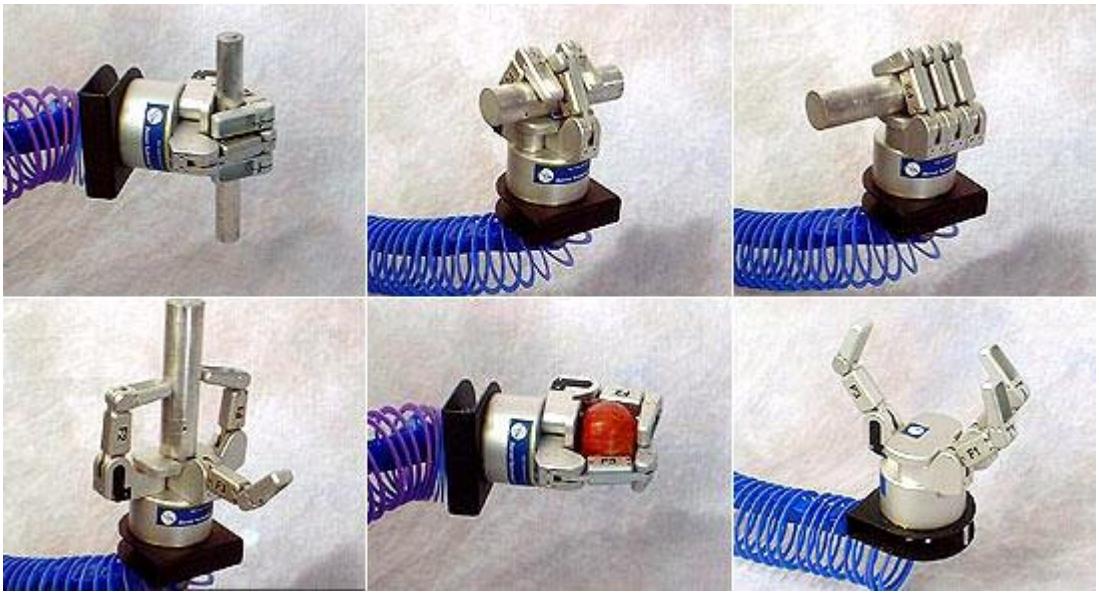

Figure 3.3 BarrettHand in various grasp configurations, from [6]

This style of robot may be considered for space-based satellite servicing operations if the fingers can interface with the required tools and manage the required grasps. In this case, the reconfiguration of the fingers is effectively the same as changing an end-effector, and so it is assumed that any grasp-based "change of end-effector" implies either reconfiguring the fingers to accommodate a different grasp or to use a specific tool, or physically changing the end-effector.

In this study, "dexterity" will be studied with reference to the number of end effectors required to complete a given primitive, a given task, and a given series of tasks.

The number of degrees of freedom required to control the end effector and the grasp required by the end-effector are also considered. For example, the end effector may need to rotate about a single axis as in turning a bolt, or it may need to open and close along one or two axes to properly grasp an object. In many situations, dexterity also has to do with wrist coordination. In this study, however, it will be assumed that the wrist can move the end-effector to the required orientation and position at the worksite as required.

In order to determine what grasps are required to perform space-based servicing tasks, on-orbit servicing tasks must be identified and studied. A large amount of data is available from the four HST servicing missions. This data encompasses the tasks performed on each mission and the steps required to complete each task. Using information from HST Servicing Mission 3B (SM3B)—STS 109—a scheme was developed to quantify a level of dexterity associated with each servicing task. The analysis conducted will be described in the next chapter.

Chapter 4: Hubble Space Telescope Servicing Mission 3B Case Study

4.1 HST SM3B Mission Background

The Hubble Space Telescope SM3B mission lasted from March 1, 2002 until March 12, 2002. Of these, five days were spent in EVA. Four astronauts participated and were divided into two pairs, each pair performing tasks on alternate days. Some of these tasks were similar to those performed on previous servicing missions, such as solar array installation and installation of the Advanced Camera for Surveys (ACS). However, some of the servicing items had never been conducted on-orbit, and thus the mission expanded the repertoire of servicing techniques performed in space.

An important new task was the installation of the Power Control Unit (PCU). This was quite an impressive accomplishment because the task required the complete power-down of HST for its installation. Prior to this mission, HST had never been completely powered down on-orbit, and a mission-critical computer had never been replaced on-orbit. Failure to complete the power-down and changeout procedure properly could result in permanent damage or total failure to HST.

Another new task to the EVA repertoire, installation of the NICMOS cryocooler, occurred on SM3B. This was important because the NICMOS instrument had been non-functional since 1999, when the solid helium used to cool it was depleted. The installation of the cryocooler thus extended the life of the NICMOS instrument.

4.2 Selection of SM3B

Many factors influenced the choice of SM3B for this analysis. SM3B offered several tasks that either were done before or were similar to those done on previous missions. Some of these were known, from previous missions, to be difficult for EVA astronauts to perform. These tasks were of particular interest in the analysis of required grasp types, to determine if they could be more easily done robotically. The mission also included many jobs that were completely unique from those previously accomplished, therefore offering an extension of the EVA repertoire. Based on the scope and complexity of servicing tasks, it was felt that SM3B subsumed a complete set of tasks within the current EVA or robotic state-of-the-art.

In addition, the photography that took place on SM3B made it an ideal mission to study. The quality and quantity of pictures from SM3B far exceeded those of previous missions, allowing a more thorough investigation of each servicing task and primitive step, thereby best determining the dexterity requirements for on-orbit satellite servicing missions.

4.3 Definitions

Description of the analysis of SM3B requires a few definitions. A *task* was defined as an individual job that must be done. Each task has any number of individual steps required to be completed in order, called *task primitives*, or, simply, *primitives*. To conduct the analysis, the EVA checklist for the mission was broken down into its individual tasks and further reduced to a systematic listing of primitives.

The *number of manipulative primitives* was defined as the number of individual task steps that require a manipulation of a tool or worksite interface. The *number of*

manipulative instances was the number of times a specific manipulation might occur. This definition is necessary because some of the individual primitives require two hands making simultaneous manipulations. In this case, the hands may be performing either the same grasp or different grasps. The number of instances also increases when there is more than one aspect to the task primitive. For example, if the primitive calls for disengaging four latches or disconnecting more than one connector, the primitive remains one primitive but the number of instances is equal to the number of repetitions of that step. Thus, there are more manipulative instances than primitives.

The *total number of primitives* is the total number of manipulative and non-manipulative primitives for a given scenario. The *total number of instances* is the total number of manipulative instances plus the total number of the non-manipulative primitives. Using these definitions and the human grasp taxonomy developed by Cutkosky, analysis was carried out first for the EVA scenario, and then for a proposed robotic servicing scenario.

4.4 Record of SM3B Tasks, Primitives, and Instances

The complete listing of tasks and the primitives associated with each task was entered into a Microsoft Excel spreadsheet. By using Excel, columns could be added to the spreadsheet for each step of the analysis. Excel lent itself to this analysis because of its data organization and graphing functions.

Included in the preliminary spreadsheet was a record of the each task's name and which EVA astronaut performed each primitive for each task. An added column indicated the number of primitive instances for each primitive. For example, one primitive called to remove approximately 20 connectors. This primitive was listed as

only one primitive; however, 20 instances were recorded for it. This helped make the quantitative analysis easy to complete using Excel's built-in addition function. For reference, Table 4.1 shows a portion of the spreadsheet used in the analysis. The full spreadsheet built from the EVA Checklist can be found in Appendix A. Table 4.1 includes all of the columns used in this analysis. This includes a column for whether or not the task primitive was required for the robotic servicing scenario and a categorization of the broad primitive type. The "1st EE" column lists the robotic end-effector used, extended from the human grasp requirement. In the "2nd EE" column is a listing of a second required end-effector for task primitives that require two hands to complete. Again, in this column, the robotic end-effector is listed as extended from the human grasp.

Ref #	EV	Primitive	Task Name	Need?	Broad Prim	1st EE	Inst #	2nd EE	Inst #
3|11		**PCU-R Mate**							
3226	R MS	Mate connectors (2-bottom PCU-R)	PCU-R Mate	Yes	mate/demate PCU connector	Pinch on retainer	2	HT Pinch	2
3227	R MS	Mate connectors (34-left PCU-R)	PCU-R Mate	Yes	mate/demate PCU connector	Pinch on retainer	34	HT Pinch	34
3228	R MS	Stow J13/J14 saver caps in trash bag	PCU-R Mate	Yes	stow connector cap	Pinch	2		
3|12		**V2 Aft Shroud Handrail Covers**							
3230	FF	inspect +/- V2 handrails used for ACS and NCS	V2 Aft Shroud Handrail Covers	Yes	inspect worksite	Camera	1		
3231	FF	retrieve handrail covers from ASIPE	V2 Aft Shroud Handrail Covers	Yes	retrieve handrail covers	Unknown	1		
3232	FF	install handrail covers	V2 Aft Shroud Handrail Covers	Yes	install handrail covers	Unknown	1		
3233	FF	config. HST PFR (aft ASIPE) for ACS	V2 Aft Shroud Handrail Covers	No		Unknown	1		

Table 4.1 Portion of the master spreadsheet used in task analysis of SM3B

4.5 Analysis of Grasps and Tools Used By EVA Astronauts

This study required an analysis of each task performed by the EVA astronauts in conducting the servicing mission. The specific grasp types and tools used by the astronauts were determined and recorded in a separate column in the Excel spreadsheet. This was done by reviewing video- and photographic footage taken during the mission. When possible, as many different views of each primitive as possible were studied to fully understand and properly categorize the grasps and tools used for each primitive. Grasp types were assigned based on the Cutkosky taxonomy, which breaks grasp types into power and precision grasps (see Figures 3.1 & 3.2, refer to section 3.2). In the instances where a tool was used to perform a task primitive, that tool was recorded in lieu of a specific grip type.

The tools used by the astronauts are cataloged in the Crew Aids and Tools (CATS) reference. It was noted during the analysis that many of the grips used by the astronauts used only one degree of freedom. This is likely due to the bulk and limited range of motion permitted by the EVA gloves. The restriction of the gloves makes coordinated motion virtually impossible. This will be revisited in the discussion section.

Finally, a quantitative analysis was conducted for the EVA servicing scenario. The frequency of use of each grip type or tool was determined, as was the total relative use of each grip type compared to the other grip types. This was done primarily using Excel to group primitives with the same grasp and tool requirements, summing the total instances of each grasp or tool listing, and then comparing the sums. This database could then be used to better understand grasp effects in EVA servicing, as described in Chapter

5. It also allowed the development of an approach to analyzing robotic servicing, detailed in the following sections.

4.6 Assumptions Used in Robotic Servicing Scenario

In order to analyze the dexterity requirements of a robot for an on-orbit servicing mission, certain assumptions had to be made. The primary assumption used was that the servicing robot would consist of two robotic arms, each with eight degrees of freedom: six degrees of positioning freedom, and two actuated degrees of freedom in the end-effector. In addition, it was assumed that the arms would be capable of reaching any point on the worksite in any orientation, effectively ignoring singularities in the manipulator workspace. While this simplifying assumption would not be acceptable for a complete kinematic analysis, it is acceptable for this study focusing specifically on end-effectors. This assumption also assumes that the robot has sufficient wrist articulation to position the end-effector for servicing at the worksite.

It was also assumed that the robotic servicer has the ability to use different end-effectors, and the ability to switch end-effectors on-orbit to complete a task. To accommodate this, an interchangeable end-effector mechanism (IEEM) such as the one shown in Figure 2.4 for Ranger was assumed. As discussed in Chapter 3, a robot hand with reconfigurable fingers may also be a means to this end. However, the IEEM assumption was used to fully explore the style of end-effectors required for a generic robot arm. The final hardware assumption made was that the robot arms are two-fault tolerant in the end-effector. That is, once the robot has gripped onto an interface, it will not release in the event of a system failure in the robot, thus eliminating the need for safety tethers or other external restraints in robotic payloads.

4.7 Task and Primitive Elimination

In the analysis, it became evident that certain tasks could be eliminated. Owing to the two-fault tolerance of the end-effector, most of the tether tasks fell into this category of steps unnecessary for a robotic servicing scenario. Tethers are used by astronauts to restrain equipment during tasks, so that the equipment cannot drift away and possibly damage other equipment at the worksite. However, with two-fault end-effector tolerance, there is no need for these tethers.

Other tasks eliminated include those that relate to the setup, takedown, movement, or adjustment of equipment specifically used to aid the astronauts' mobility around the worksite. For example, the translation aid is a tool that the astronaut uses to move around the worksite. However, a robot would not need this, so the associated primitives were eliminated. This was also the case for primitives involving the mobile foot restraint, the portable foot restraint (PFR), the articulating PFR extender, the boot plate, and the mini translation aid.

Based on these eliminations, the Excel spreadsheet was modified to include a column to denote whether or not each primitive was required in a robotic servicing scenario (Table 4.1).

4.8 Rules Used for Conversion From EVA to Robotic Scenario

As discussed in Sections 4.6 and 4.7, owing to the difference between the human and robotic servicing, the conversion between human and robotic servicing scenarios requires a few rules. These rules, the assumptions used in the conversion, and any noted exceptions, are summarized in Table 4.2.

Human Scenario Task Item	Robotic Conversion	Exceptions/Comments
Translation Aid setup	Eliminated	
MFR activities	Eliminated	
Tether tasks	Eliminated due to two fault tolerance assumed in end-effector.	Tasks for tethering the object to the worksite remain in the scenario, using the Tether Tool end-effector.
APFR/APE activities	Eliminated	
Primitives that both astronauts participate in, such as transfer of a tool or equipment.	One instance eliminated since it is assumed that a two-armed robot would do the same transfer in one step.	
Tool stowage and retrieval activities	Eliminated	Tool changes in the robotic scenario are performed as end-effector changes denoted by different end-effector listings in the checklist. To make a robotic scenario efficient, ordering of primitives may minimize these changes and thus changes are not included as specific primitives.
Boot plate activities	Eliminated	

Table 4.2 Rules for conversion from human to robotic servicing scenario (continued on next page)

Human Scenario Task Item	Robotic Conversion	Exceptions/Comments
EVA Ratchet or Power Ratchet Tool used	Bolt Drive end-effector used; assuming the end-effector has ratchet capabilities.	
Fingertip motion required	Assume that the Bolt Drive end-effector may be used as a finger.	
HT Connector Tool used	HT Connector end-effector used	
Large Diameter Heavy Wrap grasp used	Large Handrail end-effector used	
Lubricant Applicator used	Lubricant Applicator end-effector used	
MWS Tool used	MWS end-effector used	
Pistol Grip Tool used	Bolt Drive end-effector used, assuming the end-effector has variable drive speeds.	
Small Diameter Heavy Wrap grasp used	Handrail Gripper ("Small Handrail") end-effector used.	
Thumb-2 Finger Pinch grasp used	Delicate Pinch end-effector used	Most notably, this is a grasp/end-effector used for handling delicate materials such as insulation blankets.
Thumb-Index Finger grasp used	Pinch end-effector used	

Table 4.2 Rules for conversion from human to robotic servicing scenario

4.9 Analysis of Grasps and Tools Used in Robotic Servicing

Analysis of grasps and tools used in the robotic servicing scenario was conducted in a similar fashion to the EVA servicing scenario. The record of EVA primitives and grasp required to perform each primitive was examined, and all primitives involving tethers or astronaut mobility aids dropped for this analysis. Each human grasp type was

then studied. Based on the identified human grasp type, general robot grasp types were developed. In the case where a primitive required the astronaut to use a tool from the CATS catalog, the tool was noted and the assumption made that an end-effector could be made to match the tool's function.

For each primitive in the robotic servicing scenario, an end-effector was identified to perform it, based on the human grasp, or on the CATS tool required. Also recorded were the number of degrees of freedom required to drive each end-effector and if the primitive required one or two hands to complete (upon completion of the analysis, when it was recognized that all end-effectors required only one controllable degree of freedom, the associated column was removed from the spreadsheet for clarity). The complete master spreadsheet can be found in Appendix A. The quantitative analysis was conducted again for the robotic servicing scenario, noting the total number of primitives and the number of instances of each robotic end-effector, and the frequency of use of each end-effector. In the next chapter, the results of these analyses will be presented and discussed.

Chapter 5: Results and Discussion of SM3B Analysis

5.1 EVA Servicing Analysis

Table 5.1 displays a summary of the grasp types used by EVA astronauts based on a broad categorization of grasp types and CATS tools. Table 5.2 displays an expanded summary using the specific grasp types and tools.

As can be seen from the tables, most of the manipulative grip types for the EVA servicing scenario are heavy wraps (both small- and large-diameter) and pinch grasps. Primitives requiring CATS tools to drive a bolt were also found frequently. Of the 2,563 total instances in this scenario, 374, or 14.59% were non-manipulative primitives. These primitives include both instances for movement about the worksite and those that call for visual inspection of the worksite. An example of these latter instances is the primitive, "check light is on," where all that is required is an observation of a panel to ensure that an indicator light is on or off or that a switch is in the proper position. A final non-manipulative primitive class is the type where the primitive calls for communication with the other EVA astronaut, the astronauts inside the vehicle, or the ground.

"Unknown" grasp types are labeled in the master spreadsheet (Appendix A) and identified in the tables presented in this chapter. These are unknown due to, in the photographs and videos, obstruction of the view of the hands performing the manipulation. Despite best efforts, the grasps required could not be identified and it remains a goal of future work to identify these grasps.

Broad Grasp/*Tool*	**Instances**	**Description**	**% overall**	**% manipulative**
Bolt Drive	476	CATS: PGT, PRT, EVA Ratchet	18.57	21.75
Heavy Wraps	426	Small & Large Dia. Heavy Wraps	16.62	19.46
HT Connector Tool	100	CATS: HT Connector Tool	3.90	4.57
Lubricant Applicator	9	CATS: Lubricant Applicator	0.35	0.41
Non-Manipulative	374	Non-manipulative Instances	14.59	N/A
Other	24	Fingertip, MWS, Stow/Retrieve Tool	0.94	1.10
Pinch	739	Thumb-Index, Thumb-2 Finger Pinch	28.83	33.76
PIP Grasp	73	Grip for PIP, similar to Tripod Grasp	2.85	3.33
Unknown	342	Unknown Grasp Type	13.34	15.62

Table 5.1 Broad categorization of grasps and tools used on EVA for SM3B (tools italicized)

Specific Grasp/Tool	Instances	Description	% overall	% manipulative
EVA Ratchet (CATS)	33	Bolt drive	1.29	1.51
Fingertip	6	Use fingertip to flip switch	0.23	0.27
HT Connector Tool (CATS)	100		3.90	4.57
Large Dia. Heavy Wrap	89		3.47	3.59
Lubricant Applicator (CATS)	9		0.35	0.41
Motion About Worksite	184	Move about worksite	7.18	N/A
MWS	1		0.04	0.05
PGT (CATS)	422	Bolt drive	16.47	19.28
PRT (CATS)	21	Bolt drive	0.82	0.96
Retrieve Tool	2	Retrieve tool from stowage	0.08	0.09
Small Dia. Heavy Wrap	354		13.81	16.17
Stow Tool	15	Put tool away	0.59	0.69
Thumb-2 Finger Pinch	305		11.90	13.93
Thumb-Index Finger Pinch	507		19.78	20.27
PIP Grasp	73	Grip for PIP, similar to Tripod Grasp	2.85	3.33
Unknown	342	Unknown grasp type	13.34	15.62
Visual	145	Visual inspection task	5.66	N/A
Vocal	45	Communication with EV/IV/Ground	1.76	N/A

Table 5.2 Specific grasp and tool breakdown used on EVA for SM3B (tools italicized)

There is one specific grasp described in the tables that is not a heavy wrap or pinch derivative. This is the grasp for removing a PIP pin, a grasp that could not be classified based on the Cutkosky taxonomy. The type of grip required to remove a standard PIP pin requires action by three fingers, similar to Cutkosky's tripod grasp. However, the tripod grasp involves the force of all three fingertips pushed towards the center of the fingers. In the PIP grasp, two perpendicular forces are used. There is force between the index and middle fingers to hold the pin, while the thumb exerts a force perpendicular to the holding force in order to push the release button to release the PIP pin. Thus, the tripod grasp referenced in the tables is not the same tripod grasp as in the Cutkosky taxonomy.

However, in recent missions, there has been a move to replace standard PIP pins with "dual-acting" PIP pins, ones that can be released by applying an amount of pulling force above a certain threshold to the PIP pin. Future missions and satellites will likely incorporate this latter type of PIP pin. The grasp type required for this type of PIP pin is a simple pinch grasp. Table 5.3 shows the broad grasp breakdown for each EVA day using the assumption that PIP pins can be removed with a simple pinch.

Broad Grip/Tool	**Instances**	**% overall**	**% manipulative**
Bolt Drive	476	18.57	21.75
Heavy Wraps	426	16.62	19.46
HT Connector Tool	100	3.90	4.57
Lubricant Applicator	9	0.35	0.41
Non-Manipulative	374	14.59	N/A
Other	24	0.94	1.10
Pinch	812	31.68	37.09
Unknown	342	13.34	15.62

Table 5.3 Broad categorization of grasps and tools used on EVA for SM3B assuming PIP pins can be removed with a simple pinch grasp

Based on this classification scheme, it is evident that the types of grasps and tools used most often are bolt drive tools (CATS tools), heavy wraps, and pinch variants. The analysis shows that the large diameter heavy wrap is used most often when grasping CATS tools to transfer them from one site to another. Astronauts, when grasping handrails to move about the worksite, use the small diameter heavy wrap. It is also used to grasp task elements at the worksite. Most of the worksite elements have handrails that can be grasped and moved as required, as in the case of removing one instrument to replace it with another.

Similarly, the pinch grasp is often used. Cutkosky's thumb-index finger pinch is often used to grasp connectors and other small objects. The thumb-two finger pinch is used when the astronaut is handling a delicate interface. Velcro strap and thermal blankets are examples of these delicate interfaces.

It is interesting to note that all of the grasps identified in the EVA servicing scenario require motion in only one direction. That is, all of the grasps involve the application of force and movement along a straight line, usually directed from opposite sides of the grasped object in towards its center. This is likely due to the restrictiveness of the EVA gloves.

5.2 Conversion to Robotic Servicing Scenario

Generally, a human grasp type lends itself to a similar robotic grasp type. However, because of changes from the EVA scenario to the robotic servicing scenario, not all of the grasps for EVA are used in the robotic scenario. Specifically, a robotic version of the large diameter heavy wrap is not used in the robotic servicing scenario. This grasp is used in the EVA servicing scenario when astronauts grasp CATS tools or

positioning plates. Since the robot's tools are incorporated into each end-effector, and end-effector exchanges are done as non-manipulative tasks, there is no need for a large diameter heavy wrap.

Robotic end-effectors are assumed to be functionally the same as human grasps, so their design idea mimics the human grasp. In the cases where CATS tools are used, the end-effector principle is modeled on the function of the tool. Table 5.4, based partially on the rules found in Table 4.2, lists the manipulative human grasps, CATS tools, and their comparable robotic end-effectors.

Human Grasp/CATS Tool	**Robotic End-effector**
EVA Ratchet (CATS)	Bolt Drive EE
Fingertip Motion	Bolt Drive EE used as "finger"
HT Connector Tool (CATS)	HT Connector EE
Large Dia. Heavy Wrap	Not Used
Lubricant Applicator (CATS)	Lubricant Applicator EE
MWS Tool	MWS EE
Pistol Grip Tool	Bolt Drive EE
Power Ratchet Tool	Bolt Drive EE
Small Dia. Heavy Wrap	Handrail Gripper EE
Thumb-2 Finger Pinch	Delicate Pinch EE
Thumb-Index Finger Pinch	Pinch EE

Table 5.4 Human grasps/tools and equivalent robotic end-effectors

Based on this general end-effector assignment, it is evident that seven total end-effectors would be required to complete most of HST SM3B with a robotic servicer. This relies on two assumptions:

1. The Bolt Drive EE is configurable to meet all the ratchet and variable drive speed requirements to match the function of the PGT and PRT.

2. The PIP pins are “dual-acting” so a simple pinch grasp is all that is required to remove them. If this is not the case, a specialized end-effector for removing PIP pins is required.

This **does not** include two end-effectors used for specific interfaces. A Hitch Pin end-effector and a Tether Tool end-effector are also required to complete the SM3B toolbox. There was not enough photographic evidence to properly identify the grasps required to perform tasks of installing or removing hitch pins and using a tether. Further analysis may demonstrate that one or both grasps may be achieved with end-effectors already identified, such as the Pinch end-effector. Thus, in this analysis, it is assumed that specific end-effectors are unique to those interfaces and that the two end-effectors must be included in a complete SM3B servicing end-effector set.

5.3 Reduction in Primitives

It is interesting to see the level of reduction of primitives when comparing the EVA and robotic servicing scenarios. By eliminating primitives from the EVA scenario not required for the robotic scenario, the total number of primitives is reduced from 1,829 total primitives for EVA servicing to 1,349 total primitives for robotic servicing, a reduction of about 26.2%. However, the total number of manipulative primitives was reduced by approximately 38.9% in the robotic servicing scenario (see Table 5.5).

The large difference in the number of manipulative primitives between the human and robotic servicing scenarios is mainly accounted for by the elimination of primitives related to human mobility aids and tethers in the robotic servicing scenario. That is, a large proportion of the manipulative primitives performed by astronauts in EVA (nearly 40%) are used to manipulate safety restraints/tethers and devices for movement about the

worksite. This results in a lot of energy in EVA spent not on actual servicing tasks, rather on moving to do the servicing tasks, which is highly inefficient. This large amount of inefficiency is one indicator that robots may be better suited to conducting future servicing missions.

	Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Total**
# Primitives EVA	361	374	373	352	369	1829
# Primitives Robotic	268	271	269	277	264	1349
% Reduction Primitives	25.76	27.54	27.88	21.31	28.46	26.24
# Manipulative Primitives EVA	300	315	317	274	304	1510
# Manipulative Primitives Robotic	175	170	210	173	195	923
% Reduction Manipulative Primitives	41.67	46.03	33.75	36.86	35.86	38.87
# Manipulative Instances EVA	384	439	579	407	380	2189
# Manipulative Instances Robotic	248	276	466	290	267	1547
% Reduction Manipulative Instances	35.42	37.13	19.52	28.75	29.74	29.33

Table 5.5 Reductions in primitives from EVA scenario to robotic servicing scenario

As shown in Table 5.5, the number of total primitives is reduced by at least 20% on each workday between the EVA servicing scenario to the robotic servicing scenario. Breaking these primitives down further, it is evident that the number of manipulative primitives is reduced by at least one-third on each servicing day between the two scenarios.

5.4 End-effector Design Specifications

The end-effectors suggested by the human grasps are relatively simple in design and function. The bolt drive end-effector and the handrail end-effector are expected to be similar in design to the Ranger bare bolt drive and EVA handrail gripper (see Figures 5.1 and 5.2).

Figure 5.1 Ranger Bare Bolt Drive Tool with tool post attached, from [34]

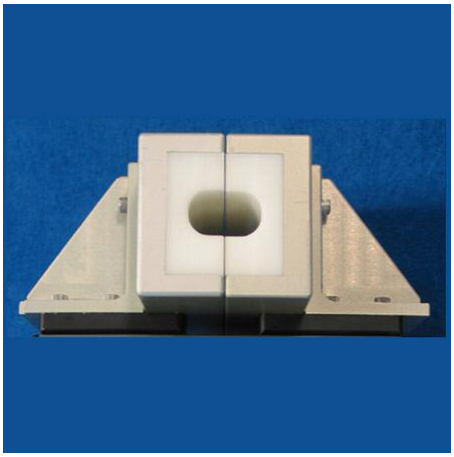

Figure 5.2 Ranger EVA Handrail Gripper Fingers, from [34]

The pinch and delicate pinch end-effectors would be similar in design, though narrower, to the handrail end-effector. That is, where the handrail end-effector would be approximately 14 cm wide—about as wide as a gloved astronaut's hand, the pinch end-effector would only be about 3.8 cm wide, or about the width of a gloved astronaut's forefinger. The delicate pinch end-effector would be approximately the same size as the Pinch end-effector, though would have rounded edges for a gentler gripping surface on delicate materials. The HT connector end-effector (Figure 5.3), lubricant applicator end-effector (Figure 5.4), and MWS end-effector would all be modifications of existing CATS tools. The estimated size of any of these end-effectors is, at most, the size of an

astronaut's gloved hand. All of the end-effectors proposed here either are designed to mimic the size of the astronaut, or are modifications of existing flight hardware. Thus, it is expected that these end-effectors will be able to reach and perform manipulations in the same workspace envelope as a gloved astronaut. This assumption is also predicated on the physical envelope of the manipulator being comparable with EVA reach envelopes. This was a design requirement for Ranger and Robonaut, but is not necessarily true of the other robotic systems discussed in Section 2.2.2.

Figure 5.3 CATS High Torque (HT) Connector Tool

As might be expected from the analysis of the human grasps presented in Section 5.1, all of the end-effectors described here require only one actuated degree of freedom to perform the necessary grasp. In both cases, the grasps require only one degree of freedom in the end-effector or hand. In the human servicing scenario, as discussed, this is a product of the bulk of the EVA glove. In the robotic servicing scenario, it greatly simplifies the design of the manipulator.

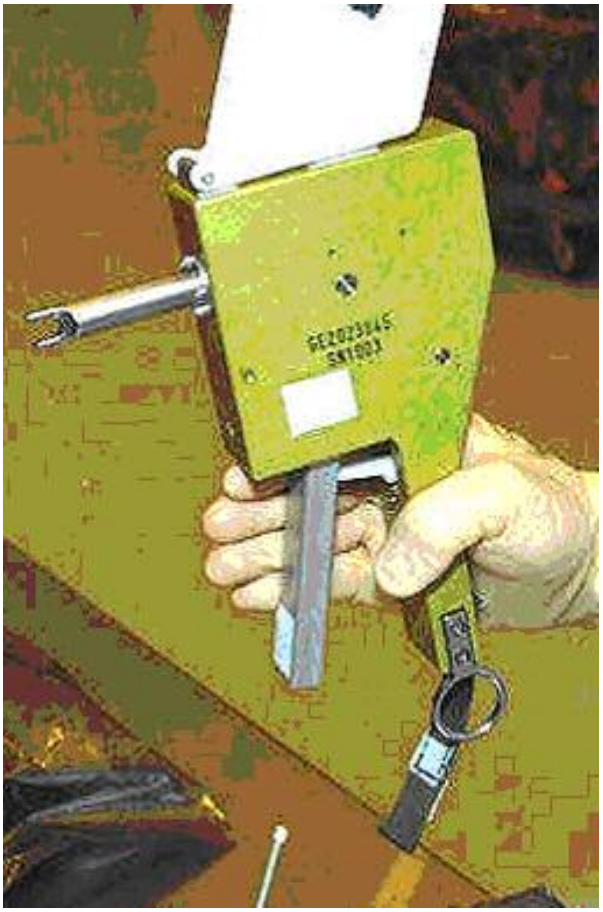

Figure 5.4 CATS Lubricant Applicator

Using these end-effector assignments, the analysis of the robotic servicing scenario was carried out in the same manner it was for the EVA servicing scenario. It was expected that the end-effector usage breakdown would differ from the human grasp usage due to the elimination of certain primitives in the robotic servicing scenario. The results of the robotic servicing analysis can be found in Tables 5.6 and 5.7.

In the specific end-effector breakdown, it is evident that there are some end-effectors and primitive types that have yet to be discussed. Of these, there are three non-manipulative primitive types: computer task, motion about worksite, and camera view. Computer tasks are those primitives where a check with the astronauts on board or with the ground is necessary. This happens when verifications are necessary, for example to

verify that the power to HST is shut off before disconnecting the PCU. Motion about the worksite refers to steps from the EVA checklist where the astronaut is required to move around the worksite. When using a teleoperated robot, it is expected that a positioning leg or other positioning mechanism can complete this step. A camera view primitive is one where a specific feature on the worksite must be viewed. It is assumed that, when doing a servicing mission telerobotically, there will be many camera views of the task and of the robot while performing the task. However, this primitive type describes a step where a visual check must be made before moving to the next step.

	EE Instances							
Broad EE	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Total**	**% overall**	**% manipulative**
Bolt Drive	71	122	37	55	50	335	16.54	21.65
Handrail Gripper	43	44	54	53	42	236	11.65	15.26
HT Pinch	0	0	100	0	0	100	4.94	6.46
Lubricant Tool	0	0	0	4	4	8	0.39	0.52
Non-Manipulative	103	112	60	124	80	479	23.64	N/A
Other	3	0	0	9	5	17	0.84	1.10
Pinch	110	97	251	142	115	715	35.29	46.22
Unknown	21	13	24	27	51	136	6.71	8.79

Table 5.6 Broad categorization of end-effectors used for robotic servicing scenario of SM3B assuming PIP pins may be removed using the pinch end-effector (tool equivalents italicized)

	EE Instances							
Specific EE	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Total**	**% overall**	**% manipulative**
Bolt Drive	71	122	37	55	50	335	16.54	21.65
Camera	25	27	5	44	26	127	6.27	N/A
Computer	45	52	21	51	23	192	9.48	N/A
Delicate Pinch	54	36	63	52	62	267	13.18	17.26
Hitch	2	0	0	4	0	6	0.30	0.39
HT Pinch	0	0	100	0	0	100	4.94	6.46
Lubricant Tool	0	0	0	4	4	8	0.39	0.52
Motion	33	33	34	29	31	160	7.90	N/A
MWS EE	1	0	0	0	0	1	0.05	0.06
Pinch	56	61	188	90	53	448	22.11	28.96
Handrail Gripper	43	44	54	53	42	236	11.65	15.26
Tether Tool	0	0	0	5	5	10	0.49	0.65
Unknown	21	13	24	27	51	136	6.71	8.79

Table 5.7 Specific end-effector breakdown of end-effectors used for robotic servicing scenario of SM3B assuming PIP pins can be removed with the pinch end-effector (tool equivalents italicized)

The tether tool end-effector is one that has yet to be defined. As discussed in Section 5.3, most of the tether tasks in the EVA checklist refer to points when an astronaut is required to tether to an object or a place at the worksite. This was done either to prevent the object from leaving the range of control of the astronaut or to secure the astronaut to a given site. With a two-fault tolerant end-effector, this type of tether task is eliminated. However, a few primitives require securing a sort of tether built into the worksite. It has not been determined what type of an attachment this will be. It may be a tether similar to those astronauts use for the equipment, or it may be similar to an attachment made by Velcro or snap closure. For this analysis, it was assumed that this tether is the former type and could not be completed with the Delicate Pinch end-effector, as a Velcro or snap closure tether could be. Hence, the tether tool end-effector was included in the end-effector listing, knowing that further analysis may eliminate its need.

The tether case is similar to the case for the hitch pin end-effector. It was unable to be determined exactly what the interface of the hitch pin required. This is because the hitch pin was identified in the EVA Checklists as a different style of pin than the PIP pin. However, none of the photos or videos analyzed showed an unobstructed view of the hitch pin or the grasp required to remove it. Therefore, it is not known whether the hitch pin could be engaged or disengaged with the pinch end-effector and a separate end-effector was designated for this primitive type. Again, further analysis may eliminate the need for the hitch pin end-effector.

Tables 5.6 and 5.7 both include information about the relative use—overall and when only including manipulative primitive instances—of each end-effector for the robotic servicing scenario. This is compared to the analysis of the relative use of each

human grasp for the EVA servicing scenario. This comparison revealed that for each servicing scenario, the primary grasp types or comparable end-effectors were similar, and were used with approximately the same relative frequency, although it showed a general reduction of instances in the robotic scenario when compared with the EVA scenario (see Tables 5.8 & 5.9).

Broad Grasp/EE Type	# EVA instances	# Robotic instances
PGT, PRT/Bolt Drive EE	476	335
Heavy Wraps/Handrail Gripper EE	426	236
HT Connector Tool/HT Pinch EE	100	100
Lubricant Applicator/Lubricant Applicator EE	9	8
Non-Manipulative	374	479
Other Grasps/Other EE's	24	17
Pinch/Pinch EE's	812	715
Unknown	342	136

Table 5.8 Comparison of EVA grasp/tool use and robotic end-effector use based on number of instances

Broad Grasp/EE Type	EVA % overall	Robot % overall
PGT, PRT/Bolt Drive EE	18.57	16.54
Heavy Wraps/Handrail Gripper EE	16.62	11.65
HT Connector Tool/HT Pinch EE	3.90	4.94
Lubricant Applicator/Lubricant Applicator EE	0.35	0.39
Non-Manipulative	14.59	23.64
Other Grasps/Other EE's	0.94	0.84
Pinch/Pinch EE's	31.68	35.29
Unknown	13.34	6.71

Table 5.9 Comparison of EVA grasp/tool use and robotic end-effector use based on relative frequency

There are notable differences in the relative frequency of use between the human and robotic servicing scenarios for the pinch end-effector, non-manipulative, heavy wrap/handrail gripper end-effector, and the unknown end-effector categories. The large

reduction in the number of instances and frequency of use for the pinch grasp/pinch end-effector is accounted for by the elimination of the tether and mobility aid adjustment primitives. The pinch grasp, used frequently in the human servicing scenario when adjusting PFR, APE, or MFR or when adjusting tethers, is not used at all in the robotic servicing scenario. Thus, the number of instances decreases and, correspondingly, the relative frequency of pinch end-effector use decreases. Conversely, because of the large decrease in total number of instances between the human and robotic scenarios, the relative frequency of non-manipulative primitives increased markedly in the robotic servicing analysis. While the number of non-manipulative primitives was close for both scenarios, the fewer total number of instances meant that the non-manipulative primitives occurred with higher relative frequency.

In Tables 5.8 and 5.9, the pinch grasp/pinch end-effectors category refers to both the standard pinch and the pinch used for delicate task objects in both servicing scenario analyses. The row for heavy wraps/handrail end-effectors accounts for all the large- and small-diameter heavy wraps used in the EVA scenario, and the instances of the handrail end-effector in the robotic servicing scenario. The decrease in relative use of the handrail end-effector in the robotic scenario is expected, due to the elimination of primitives requiring the large diameter heavy wrap from the EVA analysis. Similarly, many of the unknown grip types from the EVA servicing scenario analysis were eliminated in the robotic servicing scenario, accounting for the sharp decrease in the relative frequency of unknown end-effector use. Finally, it should be stated that the "other grasps/other end-effectors" category includes the grasps or end-effectors used for the hitch pins, the tether

tool, and the MWS tool. These three accounted for such a small fraction of the total primitive instances that they could effectively be lumped together.

Excepting the few discrepancies already addressed, the difference in percent usage of each grasp/end-effector type between the two servicing scenarios can be accounted for by the reduction of primitives and primitive instances from the EVA servicing scenario to the robotic servicing scenario (Section 5.3).

5.5 End-effectors and Specific Tasks

Further analysis was conducted using the spreadsheets developed from the EVA Checklists. By reviewing each servicing task individually, it was possible to determine the necessary end-effectors for each. This is particularly useful for future servicing mission planning. It is possible to determine which tasks studied here in SM3B are identical or similar to those for another satellite servicing mission. Based on the similarity of tasks, the end-effector(s) required for each task can be identified and the mission may considered for robotic servicing capabilities. The breakdown of end-effectors required for each servicing activity in SM3B can be found in Table 5.10. A similar table was created depicting the required end-effector(s) for each primitive type based on "broad primitive." Though it was not directly used in this analysis, it can be found in Appendix B for future reference.

Task/End-Effector	Bolt Drive	Delicate Pinch	Hitch	HT Pinch	Lubricant Tool	MWS	Pinch	PIP	Small Handrail	Tether Tool	Unknown	**Number EE's Req'd**
ACS Installation (day 4)	x	x					x		x			4
ACS Retrieval (day 4)	x	x					x		x	x		5
Aft Fixture Setup (day 4)			x					x			x	2
BAPS Post Installation (day 1)		x						x	x		x	3
BAPS Post Setup (day 2, 3, 4, 5)								x				1
Bay 2 Battery Demate (day 3)	x						x		x			3
Bay 2 Battery Mate (day 3)	x						x		x			3
Bay 3 Battery Demate (day 3)	x						x		x			3
Bay 3 Battery Mate (day 3)	x						x		x			3
Bay 4 Cleanup (day 3)	x	x					x		x		x	4
Bay 4 Setup (day 3)	x	x					x		x		x	4
Bay 5 & 10 Thermal Cover (day 1)		x					x		x			3
Bay 5 & 6 NOBL Installation (day 3)		x					x				x	2
Bay 5 & 6 NOBL Retrieval (day 3)		x					x		x			3
Bay 5 MLI Removal (day 3)		x									x	1
Bay 5 Thermal Cover (day 3)		x										1
Bay Door Bolt Disengage (day 2)	x											1
Bay Door Bolt Engage (day 4)	x											1
CASH Installation (day 4)		x									x	1
Close +V2 Doors (day 5)	x						x	x	x			4
Close –V2 Doors (day 4)	x						x	x	x			4
Conduit Installation (day 5)	x	x					x		x	x	x	5
DBA Changeout (days 1, 2)	x	x					x		x			4
DBA Connector Demate (days 1, 2)	x	x									x	2

Table 5.10 Task/end-effector breakdown for HST SM3B (continued on next page)

Task/End-Effector	Bolt Drive	Delicate Pinch	Hitch	HT Pinch	Lubricant Tool	MWS	Pinch	PIP	Small Handrail	Tether Tool	Unknown	**Number EE's Req'd**
ESM Installation (day 4)	x	x					x		x	x		5
ESM Retrieval (day 4)	x	x							x			3
FHST & WF/PC Cover Removal (day 3, 4)		x					x		x		x	3
Final PLB Cleanup (day 5)								x			x	1
FOC Installation (day 4)	x							x	x		x	3
FOC Removal (day 4)	x	x					x	x	x	x	x	6
LGAP Cover Installation (day 1)			x					x			x	2
NCC Installation (day 5)	x	x					x		x		x	4
NCC Power Cable Installation (day 5)		x					x		x		x	3
NCC Prep (day 5)							x		x	x	x	3
NCC Retrieval (day 5)	x	x							x		x	3
NICMOS Prep (day 5)	x	x					x		x	x	x	5
Open +V2 Doors (day 5)	x				x		x	x	x			5
Open -V2 Doors (day 4)	x	x			x		x	x	x			5
P600 Retrieval (day 5)		x							x		x	2
P601 Mate (day 1)	x	x				x	x					4
PCU Demate (day 3)	x			x			x		x		x	4
PCU Swap (day 3)	x	x					x		x			4
PCU-R Mate (day 3)				x			x					2
PDM Retract (day 1, 2)	x	x							x		x	3
PLB Cleanup (day 5)								x			x	1
Radiator Harness Mate (day 5)	x	x					x			x	x	4
Radiator Installation (day 5)									x		x	1
Radiator Retrieval (day 5)									x	x	x	2

Table 5.10 Task/end-effector breakdown for HST SM3B (continued on next page)

Task/End-Effector	Bolt Drive	Delicate Pinch	Hitch	HT Pinch	Lubricant Tool	MWS	Pinch	PIP	Small Handrail	Tether Tool	Unknown	**Number EE's Req'd**
RWA Installation (day 2)	x						x		x		x	3
RWA Swap (day 2)	x	x							x			3
RWA1 Removal (day 2)	x	x					x		x			4
SA Closeout (day 1, 2)	x											1
SA-2 Removal from HST (day 1, 2)	x	x					x	x	x		x	5
SA-3 Installation (day 1, 2)	x	x					x		x		x	4
SA-3 Panel Deploy (day 1, 2)	x	x					x		x		x	4
SA-3 Removal (day 1, 2)	x	x						x	x		x	4
Sortie Cleanup (day 5)		x							x		x	2
Thermal Cover Installation (day 3)		x							x		x	2
Thermal Cover Removal (day 3, 4)		x					x		x		x	3
Tool Setup (day 5)		x					x		x		x	3
Translation Adaption (day 1, 2)		x						x			x	2
WF/PC Cover Installation (day 1)		x							x		x	2
Y-Harness Retrieval (day 4)									x	x	x	2
Total # Tasks Where each EE Used	37	40	2	2	2	1	36	15	46	9	38	

Table 5.10 Task/end-effector breakdown for HST SM3B

Based on the end-effector requirements for a given task, a decision about what style of robot to use for the servicing mission may be made. This analysis was conducted using a Ranger-style interchangeable end-effector mechanism as the base design of the robot. This is a simple robot design that can, based on this study, accomplish each task. The larger number of end-effectors required, however, means a larger number of end-effector changeouts required, and thus may be impractical for some mission. If the task

requires many end-effectors to complete, one may consider using a different style of robot—one that has reconfigurable fingers, for example. Robots with reconfigurable fingers can change grasp styles quickly, without physically changing the end-effector. This may be useful for some tasks. In the worst-case scenario, a fully anthropomorphic robot such as Robonaut may be required for completing a task, especially if there are numerous changes in end-effectors and grasp types more complex than can be achieved by a reconfigurable-finger robot.

As an example of using the task/end-effector breakdown to develop a robotic servicing scenario, the DBA Changeout task from SM3B EVA day 1 is expanded here (Table 5.11). Based on Table 5.10, the DBA Changeout task requires four unique end-effectors: Bolt Drive, Delicate Pinch, Pinch, and Small Handrail. In order to determine how each end-effector is used, the task is broken down into its individual primitives. These primitives were taken from the EVA Checklist and are the step-by-step procedures for doing each task. For each manipulative primitive, an "A" in the end-effector columns indicates which end-effector is required. Some of the primitives require using two end-effectors simultaneously. For these cases, a "B" is used to denote the second required grasp type. In the systematic listing, an end-effector changeout occurs whenever consecutive primitives require different end-effectors. In this manner, the EVA checklists may be implemented with robots.

Step	Primitive	# Inst.	Non-manip. Name	Bolt Drive	Delicate Pinch	Hitch	HT Pinch	Lubricant Tool	MWS	Pinch	PIP	Small Handrail	Tether Tool	Unknown
1	translate to -V2 FR8	1	Motion											
2	PGT: A2, CW 3, 5.5	1	Computer											
3	drive Y and Z keyway bolts 7-9 turns (4-engage)	4		A										
4	PGT: A3, CCW 3, 10.5	1	Computer											
5	drive X connector keyway bolts 5-6 turns (2-disengage)	2		A										
6	PGT: B6, CCW 1, 10.5	1	Computer											
7	drive drive stud 5+ turns (disengage)	1		A										
8	PGT: A3, CCW 3, 10.5	1	Computer											
9	drive j-bolts 4-6 turns (4)	4		A										
10	exchange DBA/DBA-2	1										A, B		
11	mnvr to DBA-2	1	Motion											
12	open DBA-2 thermal cover	1			A									
13	PGT: A3, CCW 3, 10.5 short-adj ext	1	Computer											
14	drive j-bolts 4-6 turns (4)	4		A										
15	remove DBA-2 from RAC	1										A		

Table 5.11 DBA Changeout task breakdown (continued on next page)

Step	Primitive	# Inst.	Non-manip. Name	Bolt Drive	Delicate Pinch	Hitch	HT Pinch	Lubricant Tool	MWS	Pinch	PIP	Small Handrail	Tether Tool	Unknown
16	mnvr to DBA-2 swap	1	Motion											
17	inspect connectors	1	Camera											
18	mnvr to RAC stbd shelf	1	Motion											
19	install DBA on outboard stbd shelf (connectors inboard)	1										A		
20	PGT: A3, CW 3, 10.5	1	Computer											
21	drive j-bolts 4-6 turns (4-engage)	4		A										
22	close thermal cover (DBA)	1			A									
23	install DBA-2	1										A		
24	drive j-bolts 4-6 turns (4-engage)	4		A										
25	inspect X connector--check no spring interference with keyhole	1	Camera							A				
26	position connector on keyway bolts (X)	1								A				
27	EVA Ratchet: CW	1	Computer											

Table 5.11 DBA Changeout task breakdown (continued on next page)

Step	Primitive	# Inst.	Non-manip. Name	Bolt Drive	Delicate Pinch	Hitch	HT Pinch	Lubricant Tool	MWS	Pinch	PIP	Small Handrail	Tether Tool	Unknown
28	drive drive stud 3.5 turns (engage)	1		A										
29	PGT: A2, CW 2, 5.5 or EVA Ratchet: CW	1	Computer											
30	drive drive stud 1.5 turns (engage)	1		A										
31	check bracket flush with rail	1	Camera											
32	PGT: A3, CW 3, 10.5	1	Computer											
33	drive keyway bolts 4-6 turns (2-engage)	2		A										
34	demate harness (TLM) P3 from DBA-2 J1	1			A					B				

Table 5.11 DBA Changeout task breakdown (continued on next page)

Step	Primitive	# Inst.	Non-manip. Name	Bolt Drive	Delicate Pinch	Hitch	HT Pinch	Lubricant Tool	MWS	Pinch	PIP	Small Handrail	Tether Tool	Unknown
35	retrieve DBC cross strap	1			A									
36	Remove turn around plug (-V2 P1)	1								A				
37	Stow turn around plug in trash (-V2 P1)	1			A									
38	mate DBC cross strap P1(-) to DBA-2 J1	1			A					B				
39	notify MCC X connector mated and FF clear of worksite	1	Computer											

Table 5.11 DBA Changeout task breakdown (continued on next page)

In this example, fourteen total end-effector exchanges are necessary between both arms. The changeouts are summarized in Table 5.12. The table lists the starting end-effector and what it is changed to. In the "Change From" column, the arm—A or B—that requires the changed end-effector is labeled.

Between Step #'s	Change From	Change To
STARTING END-EFFECTOR	A:N/A	Bolt Drive
STARTING END-EFFECTOR	B: N/A	Small Handrail
9 & 10	A: Bolt Drive	Small Handrail
11 & 12	A: Small Handrail	Delicate Pinch
13 & 14	A: Delicate Pinch	Bolt Drive
14 & 15	A: Bolt Drive	Small Handrail
20 & 21	A: Small Handrail	Bolt Drive
21 & 22	A: Bolt Drive	Pinch
22 & 23	A: Pinch	Small Handrail
23 & 24	A: Small Handrail	Bolt Drive
24 & 25	A: Bolt Drive	Small Handrail
27 & 28	A: Small Handrail	Bolt Drive
33 & 34	A: Bolt Drive	Delicate Pinch
33 & 34	B: Small Handrail	Pinch
35 & 36	A: Delicate Pinch	Pinch
36 & 37	A: Pinch	Delicate Pinch

Table 5.12 End-effector exchanges for DBA Changeout task

Obviously, fourteen end-effector changeouts over 39 task primitives is a bit excessive. In the case of using a Ranger-style robot to accomplish these servicing tasks, each end-effector exchange takes time. Having so many exchanges may be a limiting factor against using robots for satellite servicing. The number and type of end-effector changeouts required may also lead to using one style of robot over another; i.e. using a BarrettHand or Robonaut-style robot instead of a Ranger-style robot. Thus, this level of task analysis may prove beneficial for determining which system to use for a given servicing mission, if the tasks for the mission are known in advance.

However, the checklists presented here have been specifically designed and planned for human servicing. The checklist minimizes inefficiencies for human performance. Since robots are different servicers, these checklists may be modified for robotic optimization. Such optimization includes minimizing the number of end-effector changeouts by scheduling task primitives in a proper order to maintain the spacecraft's

systems and to lump together as many primitives requiring the same end-effector as possible. This is beyond the scope of this study; however, it is an important aspect of robotic servicing mission planning.

Based on these analyses, a parallel was drawn between human and robotic satellite servicing. In EVA, the grasps most often used were pinch and heavy wrap variants. These grasp types were translated into comparable robotic end-effectors, all requiring one controllable degree of freedom. Other robotic end-effectors were based on CATS tools used on EVA. In the next chapter, the implications of these findings will be discussed, in addition to possible directions for future work.

Chapter 6: Conclusions and Future Work

6.1 Conclusions

The analysis conducted in this study suggests that EVA astronauts, in conducting on-orbit servicing, use only a few of the grasps described by Cutkosky's taxonomy. Excluding the primitives involving PIP pins, all of the direct manipulations performed on the mission were one degree of freedom manipulations. It is expected that with the change to the newer style of PIP pin, this style of primitive will also require a one degree of freedom manipulation. All of the human grasps were developed into proposed comparable robotic end-effectors. In the case where the EVA astronauts used CATS or other tools to complete a primitive, it is proposed that end-effectors can be made by modifying the existing tools for use on a robotic arm.

6.1.1 Implications for Robotic HST Servicing Missions

SM3B was the most complex servicing mission to date. The analysis presented in this thesis suggests that a toolbox of nine end-effectors would suffice to complete all the tasks of SM3B, assuming the PIP tasks can be done with a pinch end-effector. These end-effectors include a bolt drive, delicate pinch and pinch end-effectors, and a handrail gripper end-effector. The "bare-hand" end-effectors, those directly extended from a grasp, not a tool, are the delicate pinch, handrail gripper, and pinch end-effectors. These end-effectors account for approximately 47% of the overall instances and about 61.5% of the manipulative instances.

Approximately 8% of the manipulative primitives in the robotic servicing scenario can be completed with end-effectors uniquely necessary for this particular

mission. These end-effectors are the HT pinch end-effector, the hitch pin end-effector, the tether tool end-effector, the lubricant applicator end-effector, and the MWS end-effector. These end-effectors are all "special purpose" end-effectors for this mission. Depending on the needs of future missions, these may or may not be included in future servicing mission toolboxes as robotic end-effectors. The final 9% of manipulative primitives were identified as unknown end-effector type.

The analysis presented here suggests that the number of primitives and manipulative instances required for a robotic servicing scenario may be significantly fewer than the number required for the EVA servicing. This does not imply, however, that a robotic servicing mission would take a shorter time to complete than a human servicing mission would. A timeline analysis comparing the two missions using demonstrated robotic capabilities should be completed as a part of future work. Indeed, rather than working from an EVA timeline, it will be important to find the optimal task schedule for a robotic mission which takes into account the capabilities and limitations of the robotic system.

It is interesting to note that all of the robotic end-effectors presented for this mission required only one controllable degree of freedom. This suggests that any robot capable of reaching all of the points at the worksite should be able to complete a similar servicing mission. Future tests should be conducted to determine which robot style might accomplish these tasks most efficiently and effectively. It may be determined that one robot design style would be best for certain missions, while other design styles are best for other situations, depending on environment and control needs. For example, a trade

study should be performed to compare a reconfigurable end-effector to a system using multiple fixed-grip end-effectors.

6.1.2 Implications for General Satellite Servicing

Based on the analysis for the human servicing scenario, the most prevalent grasp types were the pinch and heavy wrap variants, and the most prevalent tool used was the bolt drive and its variants. This translates to the pinch end-effectors, the handrail end-effector, and the bolt drive end-effector for the robotic servicing scenario. In this scenario, these four end-effectors are used for approximately 83% of the manipulative primitives. The ubiquity of these four end-effectors in SM3B suggests that they will be an important part of an end-effector tool set in any robotic servicing mission.

As stated previously, all of the end-effectors proposed here require only one controllable degree of freedom. All of the end-effectors, excluding the bolt drive end-effector, are prismatic end-effectors. That is, their range of motion is in one line perpendicular to the worksite face. The bolt drive end-effectors inherently requires revolute motion of the end-effector mechanism to serve its function. It is possible, using various mechanisms, to convert rotational motion into translational motion. Thus, it is only *required* for the end-effector mechanism to have one controllable degree of freedom, which may be rotational. However, incorporating a design with two controllable degrees of freedom allows the possibility for other types of end-effectors as the need arises. If this analysis were to be applied to other servicing missions, a need for two controllable degrees of freedom may be revealed. This *may* be the case for missions involving PIP pins that are not “dual-acting.” In this case, two perpendicular forces are required in the grasp to remove and install the PIP pin, which will require two actuated degrees of freedom to accomplish. It may be possible to create a one degree of freedom

end-effector to remove the standard PIP pin, though it is specifically a two degree of freedom task.

This study demonstrates that robotic on-orbit satellite servicing is possible, and reveals a basic set of end-effector requirements for on-orbit robotic servicers. For a servicing mission equivalent to SM3B, a robot would require two arms, each with at least six degrees of positioning freedom and two controllable degrees of freedom in the end-effector. Given the specific mission, the robot should be capable of reaching and performing manipulations at any point in the workspace. It was assumed herein that the robot would incorporate a design to be able to exchange end-effectors for different tasks. At a minimum, four basic end-effectors would be included in the robot's toolbox. These end-effectors would be a bolt drive, a pinch end-effector, a handrail gripper, and a delicate pinch end-effector. Other end-effector needs would be addressed by analyzing the specific mission and determining what other grasp types are necessary.

The results of this study do not suggest that one style of telerobotic servicer may be preferable over another type. That is, each servicer type offers distinct advantages and disadvantages. While a humanoid robot with anthropomorphic hands may be preferred for operational, or even public outreach reasons, this research does clearly demonstrate that servicing complexity does not mandate robotic complexity.

6.2 Future Work

This study was an initial effort to understanding the basic end-effector requirements for a robotic on-orbit servicing mission. However, there are a number of areas that need to be addressed further.

Most importantly, the primitives with unknown grasp types or end-effectors should be studied so that the end-effectors can be identified. While the unknown end-effector requirements only account for 9% of the manipulative task primitives, it may be determined that certain primitives cannot be accomplished robotically and may expose a weakness in robotic on-orbit servicing. At the same time, it will be useful to expand this study to other servicing missions, including ISS, to determine if any other end-effectors would be required.

Once each primitive end-effector requirement has been identified, it will be important to develop a systematic primitive checklist for robotic servicing. For this study, the primitive steps were developed from the HST EVA checklists published for each mission. While these steps would make sense for a human performing the servicing tasks, they are not necessarily the proper sequence of steps for a robotic servicer to use. In order to maximize productivity, ideally one would want to minimize the number of end-effector change-outs completed, since each change-out takes an amount of time that can be significant when totaled and compared with actual task-interface time.

A natural extension of the study presented here would be to produce each end-effector described here and perform a hardware study using the end-effectors on a robot similar to the Ranger robot, or any robot that has the capability to change end-effectors. This sort of study would provide useful data about whether or not it is possible and practical to use a simple robot to conduct on-orbit servicing tasks. Incorporated into this study should be a timeline of events in order to compare robotic on-orbit servicing with human on-orbit servicing, and as a way to compare different robotic servicers. Comparing the performance, reliability, and cost of a simple robot to a more complex one

would build on this study to determine which type of servicer is more appropriate for a servicing mission; or it may suggest certain types of mission where one is favored over the other and vice-versa.

The study presented here has demonstrated the feasibility for state-of-the-art robots with a selection of simple end-effectors to perform complex satellite servicing. Given the ambitious new program in human planetary exploration and the ever-expanding presence of satellites in space, this work should be continued, in order to effectively utilize our investment in space.

Appendix A: Master Excel Spreadsheets

Ref #	EV	Primitive	Task Name	Need?	Broad Prim	1st EE	Inst #	2nd EE	Inst #
		DAY 1							
1|1		**Translation Aid Setup**							
1002	FF	remove PIP pin from mini-TA	Translation Aid Setup	No		PIP	1		
1003	FF	rotate mini-TA handle 140 deg	Translation Aid Setup	No		Small handrail	1		
1004	FF	install PIP pin to mini-TA	Translation Aid Setup	No		PIP	1		
1005	FF	install hitch pin to mini-TA	Translation Aid Setup	No		Hitch	1		
1006	FF	extend TA tube (stbd) if nec	Translation Aid Setup	No		Small handrail	1	Small handrail	1
1007	FF	rotate TA joint (stbd)	Translation Aid Setup	No		Small handrail	1		
1008	FF	extend TA tube (port) if nec	Translation Aid Setup	No		Small handrail	1	Small handrail	1
1009	FF	rotate TA joint (port)	Translation Aid Setup	No		Small handrail	1		
1|2		**Translation Adaption**							
1011	RMS	perform translation adaption	Translation Adaption	unk	perform translation adaption	Unknown	1		
1012	RMS	release groundstrap (SA-3)	Translation Adaption	Yes	release groundstrap	delicate pinch	1		
1013	RMS	stow groundstrap (SA-3)	Translation Adaption	Yes	stow/retrieve groundstrap	delicate pinch	1		
1014	RMS	remove PIP pin (fwd latch)	Translation Adaption	unk	install/remove PIP	PIP	1		
1015	RMS	stow PIP pin (fwd latch)	Translation Adaption	unk	install/remove PIP	PIP	1		
1016	RMS	remove PIP pin (aft latch)	Translation Adaption	unk	install/remove PIP	PIP	1		

1017	RMS	stow PIP pin (aft latch)	Translation Adaption	unk	install/remove PIP	PIP	1		
1018	RMS	retrieve MLI tent	Translation Adaption	Yes	stow/retrieve MLI tent	delicate pinch	1		
1019	RMS	stow MLI tent	Translation Adaption	Yes	stow/retrieve MLI tent	delicate pinch	1		
1|3		**MFR Setup**							
1021	FF	translate to orbiter bay 10	MFR Setup	Yes	move about worksite	Motion	1		
1022	FF	tether MFR to APC	MFR Setup	No		Tether tool	1		
1023	FF	unlatch MFR	MFR Setup	No		Unknown	1		
1024	FF	install MFR in RMS grapple fixture	MFR Setup	No		Unknown	1		
1025	FF	remove APC tether	MFR Setup	No		Tether tool	1		
1026	FF	install tether (MFR/RMS)	MFR Setup	No		Tether tool	1		
1027	FF	tighten tether (MFR/RMS)	MFR Setup	No		Unknown	1		
1|4		**LGAP Cover Installation**							
1029	FF	remove PIP pin 1 from LGAP cover	LGAP Cover Installation	Yes	install/remove PIP	PIP	1		
1030	FF	remove PIP pin 2 from LGAP cover	LGAP Cover Installation	Yes	install/remove PIP	PIP	1		
1031	FF	remove hitch pin 1 from LGAP cover	LGAP Cover Installation	Yes	install/remove hitch pin	Hitch	1		
1032	FF	remove hitch pin 2 from LGAP cover	LGAP Cover Installation	Yes	install/remove hitch pin	Hitch	1		
1033	FF	translate to LGA (fwd/stbd)	LGAP Cover Installation	Yes	move about worksite	Motion	1		
1034	FF	install PIP pin (LGAP cover)	LGAP Cover Installation	Yes	install/remove PIP	PIP	1		
1035	FF	pull LGAP cover latch assembly knob	LGAP Cover Installation	Yes	pull LGAP cover latch assy knob	Unknown	1		

1036	FF	rotate LGAP cover dome (while hold latch assembly knob)	LGAP Cover Installation	Yes	rotate LGAP cover dome	Unknown	1		
1|5		**BAPS Post Installation**							
1038	FF	release Velcro straps (BAPS umbilical)	BAPS Post Installation	unk	secure/remove Velcro	delicate pinch	2		
1039	FF	remove PIP pin (port)	BAPS Post Installation	unk	install/remove PIP	PIP	1		
1040	FF	remove PIP pin (stbd)	BAPS Post Installation	unk	install/remove PIP	PIP	1		
1041	FF	tether BAPS fwd end to wrist (lg. hook-fwd)	BAPS Post Installation	No		Tether tool	1		
1042	FF	remove BAPS post	BAPS Post Installation	unk	remove BAPS post	Small handrail	1		
1043	FF	install BAPS post fwd end	BAPS Post Installation	unk	install BAPS end	Unknown	1		
1044	FF	secure Velcro (BAPS)	BAPS Post Installation	unk	secure/remove Velcro	delicate pinch	2		
1045	FF	release BAPS post mechanism	BAPS Post Installation	unk	release BAPS post mechanism	Unknown	1		
1046	FF	extend BAPS post	BAPS Post Installation	unk	extend BAPS post	Small handrail	1	Small handrail	1
1047	FF	install BAPS post aft end	BAPS Post Installation	unk	install BAPS end	Unknown	1		
1048	FF	secure Velcro (BAPS)	BAPS Post Installation	unk	secure/remove Velcro	delicate pinch	2		
1049	FF	install PIP pins (BAPS center)	BAPS Post Installation	unk	install/remove PIP	PIP	2		
1050	FF	inspect p105 and p106 covers	BAPS Post Installation	Yes	inspect worksite	Camera	2		
1|6		**PFR Retrieval**							
1052	FF	remove PIP pin to retrieve APE	PFR Retrieval	No		PIP	1	Large handrail	1
1053	FF	install APE on HST	PFR Retrieval	No		PIP	1	Large handrail	1

		PFR							
1054	FF	config APE 0 deg	PFR Retrieval	No		Unknown	1		
1055	FF	remove HST PFR	PFR Retrieval	No		Large handrail	1		
1056	FF	transfer HST PFR to RMS EV	PFR Retrieval	No		Large handrail	1		
1057	RMS	maneuver to FSS APC	PFR Retrieval	No		Motion	1		
1058	RMS	receive HST PFR	PFR Retrieval	No		Large handrail	1		
1059	RMS	pull slide lock on APE (hold)	PFR Retrieval	No		Pinch	1		
1060	RMS	rotate locking lever on APE (still holding slide lock on APE)	PFR Retrieval	No		Pinch	1		
1061	RMS	rotate socket on APE	PFR Retrieval	No		Large handrail	1		
1062	RMS	rotate locking lever on APE back to locked	PFR Retrieval	No		Pinch	1		
1|7		**PDM Retract**							
1064	FF	translate to port ATM	PDM Retract	Yes	move about worksite	Motion	1		
1065	FF	pull tee handle out 90 deg (port ATM)	PDM Retract	Yes	push/pull tee handle	Small handrail	1		
1066	FF	rotate tee handle 90 deg (port ATM)	PDM Retract	Yes	rotate tee handle	Small handrail	1		
1067	FF	open ATM (port)	PDM Retract	Yes	open/close ATM	Small handrail	1		
1068	RMS	mnvr to FR8	PDM Retract	Yes	move about worksite	Motion	1		
1069	FF	retrieve DBC cross strap	PDM Retract	Yes	retrieve cross strap	delicate pinch	1		
1070	FF	close ATM (port)	PDM Retract	Yes	open/close ATM	Small handrail	1		
1071	FF	rotate tee handle 90 deg (port ATM)	PDM Retract	Yes	rotate tee handle	Small handrail	1		
1072	FF	push tee handle down 90 deg (port ATM)	PDM Retract	Yes	push/pull tee handle	Small handrail	1		

1073	FF	stow DBC on handrail (temp)	PDM Retract	Yes	stow DBC	Unknown	1		
1074	FF	ingress PFR	PDM Retract	No		Large handrail	1		
1075	FF	EVA Ratchet: CCW, 6-in rigid	PDM Retract	Yes	set bolt drive	COMPUTER	1		
1076	FF	drive PDM 5.7 turns	PDM Retract	Yes	drive bolt	Bolt drive	1		
1077	FF	maintain SA slew at 0 deg	PDM Retract	Yes	maintain SA slew	Bolt drive	1	Small handrail	1
1078	RMS	maintain SA slew at 0 deg	PDM Retract	No		Unknown	1		
1079	RMS	grasp handrails on SA-2 (fwd) when SA-2 near fwd latch	PDM Retract	Yes	grasp SA handrail	Small handrail	1		
1080	RMS	give GO to remove tool	PDM Retract	Yes	check GO	COMPUTER	1		
1081	FF	EVA Ratchet: CW	PDM Retract	Yes	set bolt drive	COMPUTER	1		
1082	RMS	seat SA-2 into latch fitting	PDM Retract	Yes	install/remove SA	Small handrail	1		
1083	RMS	give GO to engage PDM lock	PDM Retract	Yes	check GO	COMPUTER	1		
1084	FF	drive PDM 1/2 turn CW (lock)	PDM Retract	Yes	drive bolt	Bolt drive	1		
1085	FF	install connector strap (SA-2)	PDM Retract	Yes	install/remove connector strap	delicate pinch	1	delicate pinch	1
1|8		**WF/PC Cover Installation**							
1087	RMS	mnvr to WF/PC cover	WF/PC Cover Installation	Yes	move about worksite	Motion	1		
1088	RMS	retrieve WF/PC cover	WF/PC Cover Installation	Yes	stow/retrieve WF/PC cover	Small handrail	1		
1089	RMS	retrieve FHST covers	WF/PC Cover Installation	Yes	stow/retrieve FHST covers	delicate pinch	2		
1090	RMS	mnvr to -V3 aft shroud	WF/PC Cover Installation	Yes	move about worksite	Motion	1		

1091	RMS	install WF/PC cover	WF/PC Cover Installation	Yes	install/remove WF/PC cover	delicate pinch	1	Small handrail	1
1092	RMS	install FHST covers (2)	WF/PC Cover Installation	Yes	install/remove FHST cover	Unknown	2		
1|9		**DBA Connector Demate**							
1094	FF	release Velcro restraint strap (Y/Z)	DBA Connector Demate	Yes	secure/remove Velcro	delicate pinch	2		
1095	FF	PGT: A3, CCW 3, 10.5, 6-in wobble	DBA Connector Demate	Yes	set bolt drive	COMPUTER	1		
1096	FF	drive Z and Y keyway bolts 4-6 turns (4-disengage)	DBA Connector Demate	Yes	drive bolt	Bolt drive	4		
1097	FF	PGT: A3, CCW 1, 10.5	DBA Connector Demate	Yes	set bolt drive	COMPUTER	1		
1098	FF	drive Z drive stud, 5+ turns (disengage)	DBA Connector Demate	Yes	drive bolt	Bolt drive	1		
1099	FF	stow connector bracket on connector strap	DBA Connector Demate	Yes	stow connector bracket on connector strap	Unknown	1		
1100	FF	PGT: A3, CCW 1, 10.5	DBA Connector Demate	Yes	set bolt drive	COMPUTER	1		
1101	FF	drive Y drive stud, 5+ turns (disengage)	DBA Connector Demate	Yes	drive bolt	Bolt drive	1		
1102	FF	pull slide lock on APE (hold)	DBA Connector Demate	No		Pinch	1		
1103	FF	rotate locking lever (while still holding slide lock)	DBA Connector Demate	No		Pinch	1		
1104	FF	rotate socket so APE=K	DBA Connector Demate	No		Large handrail	1		
1105	FF	rotate locking lever on APE back to locked	DBA Connector Demate	No		Pinch	1		

1106	FF	release Velcro restraint strap (W)	DBA Connector Demate	Yes	secure/remove Velcro	delicate pinch	1		
1107	FF	PGT: A3, CCW 3, 10.5	DBA Connector Demate	Yes	set bolt drive	COMPUTER	1		
1108	FF	drive W keyway bolts 4-6 turns (2-disengage)	DBA Connector Demate	Yes	drive bolt	Bolt drive	2		
1109	FF	PGT: A3, CCW 1, 10.5	DBA Connector Demate	Yes	set bolt drive	COMPUTER	1		
1110	FF	drive W drive stud, 5+ turns (disengage)	DBA Connector Demate	Yes	drive bolt	Bolt drive	1		
1111	FF	stow connector bracket on connector strap	DBA Connector Demate	Yes	stow connector bracket on connector strap	Unknown	1		
1|10		**SA-2 Removal From HST**							
1113	RMS	mnvr to -V2 SA-2	SA-2 Removal From HST	Yes	move about worksite	Motion	1		
1114	RMS	setup MFR	SA-2 Removal From HST	No		Unknown	1		
1115	RMS	grasp SA-2 aft handrails (stabilize)	SA-2 Removal From HST	Yes	grasp SA handrail	Small handrail	1		
1116	FF	PGT: B2, CW 2, 2.5	SA-2 Removal From HST	Yes	set bolt drive	COMPUTER	1		
1117	FF	drive SADA clamp (left) 20 turns (disengage)	SA-2 Removal From HST	Yes	drive bolt	Bolt drive	1		
1118	FF	CHECK OPEN	SA-2 Removal From HST	Yes	inspect worksite	Camera	1		
1119	RMS	Remove SA-2	SA-2 Removal From HST	Yes	install/remove SA	Small handrail	1	Small handrail	1
1120	FF	maintain SADA clearance with HST	SA-2 Removal From HST	Yes	maintain SADA clearance	Unknown	1		
1121	RMS	mnvr to RAC stbd shelf	SA-2 Removal From HST	Yes	move about worksite	Motion	1		

1122	FF	inspect SADA clamp for damage, distortion	SA-2 Removal From HST	Yes	inspect worksite	Camera	1		
1123	FF	inspect surrounding MLI for soft dock interference	SA-2 Removal From HST	Yes	inspect worksite	Camera	1		
1124	FF	translate to RAC stbd SADA clamp	SA-2 Removal From HST	Yes	move about worksite	Motion	1		
1125	FF	release SADA clamp spindle lock	SA-2 Removal From HST	Yes	engage/disengage SADA clamp spindle lock	Unknown	1		
1126	FF	guide SA-2 into SADA clamp	SA-2 Removal From HST	Yes	guide SA into SADA clamp	Small handrail	1	Small handrail	1
1127	FF	rotate SA-2 into latches	SA-2 Removal From HST	Yes	rotate SA	Small handrail	1	Small handrail	1
1128	RMS	guide SA-2 into SADA clamp	SA-2 Removal From HST	No		Small handrail	1	Small handrail	1
1129	RMS	rotate SA-2 into latches	SA-2 Removal From HST	No		Small handrail	1	Small handrail	1
1130	FF	PGT: B2, CW 2, 2.5 MTL	SA-2 Removal From HST	Yes	set bolt drive	COMPUTER	1		
1131	FF	drive SADA clamp 22 turns until MTL slips (engage)	SA-2 Removal From HST	Yes	drive bolt	Small handrail	1	Bolt drive	1
1132	RMS	grasp SA-2 while FF EV engage SADA clamp	SA-2 Removal From HST	No		Small handrail	1		
1133	FF	CHECK CLOSED	SA-2 Removal From HST	Yes	inspect worksite	Camera	1		
1134	RMS	engage SADA clamp spindle lock	SA-2 Removal From HST	Yes	engage/disengage SADA clamp spindle lock	Unknown	1		
1135	FF	translate to fwd end SA-2	SA-2 Removal From HST	Yes	move about worksite	Motion	1		
1136	RMS	inspect fwd latch alignment	SA-2 Removal From HST	Yes	inspect worksite	Camera	1		

1137	FF	remove PIP pin (fwd constraint)	SA-2 Removal From HST	Yes	install/remove PIP	PIP	1		
1138	RMS	grasp SA-2 in latches (stabilize) while FF EV insert PIP pin	SA-2 Removal From HST	No		Small handrail	1	Small handrail	1
1139	FF	slide bracket against SA-2	SA-2 Removal From HST	Yes	slide bracket against SA	Small handrail	1		
1140	FF	Install PIP pin while hold bracket against SA-2	SA-2 Removal From HST	Yes	install/remove PIP	Small handrail	1	PIP	1
1141	FF	secure Velcro	SA-2 Removal From HST	Yes	secure/remove Velcro	delicate pinch	1		
1|11		**DBA Changeout**							
1143	FF	translate to -V2 FR8	DBA Changeout	Yes	move about worksite	Motion	1		
1144	FF	ingress HST PFR	DBA Changeout	No		Large handrail	1		
1145	FF	PGT: A2, CW 3, 5.5	DBA Changeout	Yes	set bolt drive	COMPUTER	1		
1146	FF	drive Y and Z keyway bolts 7-9 turns (4-engage)	DBA Changeout	Yes	drive bolt	Bolt drive	4		
1147	FF	PGT: A3, CCW 3, 10.5	DBA Changeout	Yes	set bolt drive	COMPUTER	1		
1148	FF	drive X connector keyway bolts 5-6 turns (2-disengage)	DBA Changeout	Yes	drive bolt	Bolt drive	2		
1149	FF	PGT: B6, CCW 1, 10.5	DBA Changeout	Yes	set bolt drive	COMPUTER	1		
1150	FF	drive drive stud 5+ turns (disengage)	DBA Changeout	Yes	drive bolt	Bolt drive	1		
1151	FF	PGT: A3, CCW 3, 10.5	DBA Changeout	Yes	set bolt drive	COMPUTER	1		
1152	FF	drive j-bolts 4-6 turns (4)	DBA Changeout	Yes	drive bolt	Bolt drive	4		
1153	FF	exchange DBA/DBA-2	DBA Changeout	Yes	exchange DBA	Small handrail	1	Small handrail	1
1154	FF	receive DBA-2	DBA Changeout	No		Small handrail	1		

1155	RMS	mnvr to DBA-2	DBA Changeout	Yes	move about worksite	Motion	1		
1156	RMS	open DBA-2 thermal cover	DBA Changeout	Yes	open/close thermal cover	Delicate Pinch	1		
1157	RMS	PGT: A3, CCW 3, 10.5 short-adj ext	DBA Changeout	Yes	set bolt drive	COMPUTER	1		
1158	RMS	drive j-bolts 4-6 turns (4)	DBA Changeout	Yes	drive bolt	Bolt drive	4		
1159	RMS	remove DBA-2 from RAC	DBA Changeout	Yes	install/remove DBA	Small handrail	1		
1160	RMS	mnvr to DBA-2 swap	DBA Changeout	Yes	move about worksite	Motion	1		
1161	RMS	inspect connectors	DBA Changeout	Yes	inspect worksite	Camera	1		
1162	RMS	receive DBA from FF EV	DBA Changeout	No		Small handrail	1		
1163	RMS	transfer DBA-2	DBA Changeout	No		Small handrail	1		
1164	RMS	mnvr to RAC stbd shelf	DBA Changeout	Yes	move about worksite	Motion	1		
1165	RMS	install DBA on outboard stbd shelf (connectors inboard)	DBA Changeout	Yes	install/remove DBA	Small handrail	1		
1166	RMS	PGT: A3, CW 3, 10.5	DBA Changeout	Yes	set bolt drive	COMPUTER	1		
1167	RMS	drive j-bolts 4-6 turns (4-engage)	DBA Changeout	Yes	drive bolt	Bolt drive	4		
1168	RMS	close thermal cover (DBA)	DBA Changeout	Yes	open/close thermal cover	Delicate Pinch	1		
1169	FF	install DBA-2	DBA Changeout	Yes	install/remove DBA	Small handrail	1		
1170	FF	drive j-bolts 4-6 turns (4-engage)	DBA Changeout	Yes	drive bolt	Bolt drive	4		
1171	FF	inspect X connector--check no spring interference with keyhole	DBA Changeout	Yes	inspect worksite	Pinch	1	Camera	1

1172	FF	position connector on keyway bolts (X)	DBA Changeout	Yes	position connector	Pinch	1		
1173	FF	EVA Ratchet: CW	DBA Changeout	Yes	set bolt drive	COMPUTER	1		
1174	FF	drive drive stud 3.5 turns (engage)	DBA Changeout	Yes	drive bolt	Bolt drive	1		
1175	FF	PGT: A2, CW 2, 5.5 or EVA Ratchet: CW	DBA Changeout	Yes	set bolt drive	COMPUTER	1		
1176	FF	drive drive stud 1.5 turns (engage)	DBA Changeout	Yes	drive bolt	Bolt drive	1		
1177	FF	check bracket flush with rail	DBA Changeout	Yes	inspect worksite	Camera	1		
1178	FF	PGT: A3, CW 3, 10.5	DBA Changeout	Yes	set bolt drive	COMPUTER	1		
1179	FF	drive keyway bolts 4-6 turns (2-engage)	DBA Changeout	Yes	drive bolt	Bolt drive	2		
1180	FF	demate harness (TLM) P3 from DBA-2 J1	DBA Changeout	Yes	mate/demate connector	Delicate Pinch	1	Pinch	1
1181	FF	retrieve DBC cross strap	DBA Changeout	Yes	retrieve cross strap	Delicate Pinch	1		
1182	FF	Remove turn around plug (-V2 P1)	DBA Changeout	Yes	install/remove turn-around plug	Pinch	1		
1183	FF	Stow turn around plug in trash (-V2 P1)	DBA Changeout	Yes	stow turn-around plug	Pinch	1		
1184	FF	mate DBC cross strap P1(-) to DBA-2 J1	DBA Changeout	Yes	mate/demate connector	Pinch	1	Delicate Pinch	1
1185	FF	pull slide lock on APE (hold)	DBA Changeout	No		Pinch	1		
1186	FF	rotate locking lever (while still holding slide lock)	DBA Changeout	No		Pinch	1		
1187	FF	rotate socket so APE=K	DBA Changeout	No		Large handrail	1		
1188	FF	rotate locking lever on APE back to	DBA Changeout	No		Pinch	1		

		locked							
1189	FF	notify MCC X connector mated and FF clear of worksite	DBA Changeout	Yes	notify MCC	COMPUTER	1		
1|12		**SA-3 Removal**							
1191	RMS	mnvr to latch 5	SA-3 Removal	Yes	move about worksite	Motion	1		
1192	RMS	PGT: A6, CCW 2, 30.5, 12.0 ft lb	SA-3 Removal	Yes	set bolt drive	COMPUTER	1		
1193	RMS	drive latch 5, 8+ turns (disengage)	SA-3 Removal	Yes	drive bolt	Bolt drive	1		
1194	RMS	PGT: A3, CW 2, 10.5	SA-3 Removal	Yes	set bolt drive	COMPUTER	1		
1195	RMS	drive bolt in lower fitting, engage 8+ turns (stow)	SA-3 Removal	Yes	drive bolt	Bolt drive	1		
1196	RMS	deploy mast 90 deg to engage soft dock	SA-3 Removal	Yes	deploy mast	Unknown	1		
1197	RMS	mnvr to mast bolts	SA-3 Removal	Yes	move about worksite	Motion	1		
1198	RMS	drive mast bolts 8+ turns (2-engage)	SA-3 Removal	Yes	drive bolt	Bolt drive	2		
1199	RMS	GCA to latch 2	SA-3 Removal	Yes	move about worksite	Motion	1		
1200	RMS	PGT: A6, CCW 2, 30.5, 18.3 ft lb	SA-3 Removal	Yes	set bolt drive	COMPUTER	1		
1201	RMS	drive latch 2 12-15 turns (disengage)	SA-3 Removal	Yes	drive bolt	Bolt drive	1		
1202	RMS	report turn count for latch 2	SA-3 Removal	Yes	report turn count	COMPUTER	1		
1203	RMS	GCA to latch 1	SA-3 Removal	Yes	move about worksite	Motion	1		
1204	FF	translate to RAC, latch 3	SA-3 Removal	Yes	move about worksite	Motion	1		
1205	FF	ingress aft PFR	SA-3 Removal	No		Large handrail	1		

1206	FF	PGT: A6, CCW 2, 30.5, 12.0 ft lb	SA-3 Removal	Yes	set bolt drive	COMPUTER	1		
1207	FF	drive latch 3 until clamp clears tang, 7-9 turns (release)	SA-3 Removal	Yes	drive bolt	Bolt drive	1		
1208	FF	pivot latch 3 to clear tang	SA-3 Removal	Yes	pivot latch	Small handrail	1		
1209	FF	tether to tang	SA-3 Removal	No		Tether tool	1		
1210	FF	PGT: A2, CCW 2, 5.5	SA-3 Removal	Yes	set bolt drive	COMPUTER	1		
1211	FF	drive tang bolts 9-10 turns (2-disengage)	SA-3 Removal	Yes	drive bolt	Bolt drive	2		
1212	FF	stow tang on CSS	SA-3 Removal	Yes	stow tang	Bolt drive	1	Small handrail	1
1213	FF	PGT: A2, CW 2, 5.5	SA-3 Removal	Yes	set bolt drive	COMPUTER	1		
1214	FF	drive tang bolts 9-10 turns (2-engage)	SA-3 Removal	Yes	drive bolt	Bolt drive	2		
1215	FF	pivot latch 3 to stowed position	SA-3 Removal	Yes	pivot latch	Small handrail	1		
1216	FF	install PIP pin	SA-3 Removal	Yes	install/remove PIP	PIP	1		
1217	FF	deploy MLI flap over tang interface	SA-3 Removal	Yes	deploy MLI	delicate pinch	1		
1218	FF	PGT: A6, CCW 2, 30.5, 8.7 ft lb	SA-3 Removal	Yes	set bolt drive	COMPUTER	1		
1219	FF	drive latch 4 10-15 turns (release)	SA-3 Removal	Yes	drive bolt	Bolt drive	1		
1220	FF	report turn count for latch 4	SA-3 Removal	Yes	report turn count	COMPUTER	1		
1221	FF	grasp SA during latch 1 release (stabilize)	SA-3 Removal	No		Small handrail	1	Small handrail	1
1222	RMS	PGT: A6, CCW 2, 30.5, 24.0 ft lb	SA-3 Removal	Yes	set bolt drive	COMPUTER	1		
1223	RMS	drive latch 1, 19+ turns (release)	SA-3 Removal	Yes	drive bolt	Bolt drive	1	Small handrail	1
1224	RMS	mnvr to SA-3 top handrails at c.g. mark	SA-3 Removal	Yes	move about worksite	Motion	1		

1225	RMS	remove SA-3 (slide out contingency slots)	SA-3 Removal	No		Small handrail	1	Small handrail	1
1226	FF	remove SA-3	SA-3 Removal	Yes	install/remove SA	Small handrail	1	Small handrail	1
1|13		**SA-3 Installation**							
1228	RMS	evaluate SA-3 mass handling	SA-3 Installation	Yes	evaluate mass handling	COMPUTER	1		
1229	RMS	mnvr to SA-3 rotate	SA-3 Installation	Yes	move about worksite	Motion	1		
1230	RMS	rotate SA-3 for install	SA-3 Installation	Yes	rotate SA	Small handrail	1	Small handrail	1
1231	FF	remove connector from connector strap (W)	SA-3 Installation	Yes	stow/remove connector	Pinch	1	delicate pinch	1
1232	FF	stow connector on RAC connector stowage braket (W)	SA-3 Installation	Yes	stow connector on connector stowage bracket	Pinch	1		
1233	FF	remove connector from connector strap (Y)	SA-3 Installation	Yes	stow/remove connector	Pinch	1	delicate pinch	1
1234	FF	stow connector on RAC connector stowage bracket (Y)	SA-3 Installation	Yes	stow connector on connector stowage bracket	Pinch	1		
1235	FF	Remove connector from connector strap (Z)	SA-3 Installation	Yes	stow/remove connector	Pinch	1	delicate pinch	1
1236	FF	stow connector on RAC connector stowage bracket (Z)	SA-3 Installation	Yes	stow connector on connector stowage bracket	Pinch	1		
1237	FF	translate to -V2, FR8	SA-3 Installation	Yes	move about worksite	Motion	1		
1238	FF	route DBC cross-strap	SA-3 Installation	Yes	route cross strap	delicate pinch	1		
1239	RMS	mnvr to SA-3 pre-install	SA-3 Installation	Yes	move about worksite	Motion	1		
1240	FF	ingress HST PFR yaw foot plate	SA-3 Installation	No		Large handrail	1		

1241	RMS	posn SADM for FF EV access	SA-3 Installation	Yes	position SADM	Unknown	1		
1242	FF	install SA-3	SA-3 Installation	Yes	install/remove SA	Small handrail	1	Small handrail	1
1243	RMS	install SA-3	SA-3 Installation	No		Small handrail	1	Small handrail	1
1244	FF	check soft docks engaged (3)	SA-3 Installation	Yes	inspect worksite	Camera	3		
1245	FF	PGT: B2, CCW 2, 5.5	SA-3 Installation	Yes	set bolt drive	COMPUTER	1		
1246	FF	drive SADA clamp (left) 19-20 turns (engage)	SA-3 Installation	Yes	drive bolt	Bolt drive	1		
1247	FF	check SADA clamp closed	SA-3 Installation	Yes	inspect worksite	Camera	1		
1248	FF	release Velcro restraint strap (W harness)	SA-3 Installation	Yes	secure/remove Velcro	delicate pinch	1		
1249	FF	PGT: A2, CCW 1, 5.5 or EVA Ratchet: CCW	SA-3 Installation	Yes	set bolt drive	COMPUTER	1		
1250	FF	drive W bracket drive stud 5+ turns (disengage)	SA-3 Installation	Yes	drive bolt	Bolt drive	1		
1251	FF	inspect HST and W connector	SA-3 Installation	Yes	inspect worksite	Pinch	1	Camera	2
1252	FF	install connector on HST (W)	SA-3 Installation	Yes	mate/demate connector	Pinch	1		
1253	FF	EVA Ratchet: CW	SA-3 Installation	Yes	set bolt drive	COMPUTER	1		
1254	FF	drive drive stud 3.5 turns (engage)	SA-3 Installation	Yes	drive bolt	Bolt drive	1		
1255	FF	PGT: A2, CW 2, 5.5 or EVA Ratchet: CW	SA-3 Installation	Yes	set bolt drive	COMPUTER	1		
1256	FF	drive drive stud 1.5 turns (engage)	SA-3 Installation	Yes	drive bolt	Bolt drive	1		
1257	FF	check bracket flush with rail	SA-3 Installation	Yes	inspect worksite	Camera	1		

1258	FF	remove palm wheel from EVA ratchet	SA-3 Installation	unk	remove palm wheel	Unknown	1		
1259	FF	Stow palm wheel in trash bag	SA-3 Installation	unk	stow palm wheel	Unknown	1		
1260	FF	PGT: A3, CW 2, 10.5	SA-3 Installation	Yes	set bolt drive	COMPUTER	1		
1261	FF	drive keyway bolts 4-6 turns (2-engage)	SA-3 Installation	Yes	drive bolt	Bolt drive	2		
1262	FF	remove cap (J3) on W bracket	SA-3 Installation	Yes	install/remove connector cap	Pinch	1		
1263	FF	stow cap (J3) in trash bag	SA-3 Installation	Yes	stow connector cap	Pinch	1	Pinch	1
1264	FF	mate TLM harness P3 to J3	SA-3 Installation	Yes	mate/demate connector	delicate pinch	1	Pinch	1
1265	FF	secure W harness to SADA soft-dock	SA-3 Installation	Yes	secure harness to SADA soft-dock	delicate pinch	1	Small handrail	1
1266	FF	pull slide lock on APE (hold)	SA-3 Installation	No		Pinch	1		
1267	FF	rotate locking lever (while still holding slide lock)	SA-3 Installation	No		Pinch	1		
1268	FF	rotate socket to APE=S	SA-3 Installation	No		Large handrail	1		
1269	FF	rotate locking lever on APE back to locked	SA-3 Installation	No		Pinch	1		
1270	FF	release Velcro restraint strap (harness)	SA-3 Installation	Yes	secure/remove Velcro	delicate pinch	1	Deicate narrow pinch	1
1271	FF	inspect P5A	SA-3 Installation	Yes	inspect worksite	Pinch	1	Camera	1
1272	FF	Mate P5A	SA-3 Installation	Yes	mate/demate connector	Pinch	1		
1273	FF	inspect P6A	SA-3 Installation	Yes	inspect worksite	Pinch	1	Camera	1
1274	FF	Mate P6A	SA-3 Installation	Yes	mate/demate connector	Pinch	1		
1275	FF	inspect P7A	SA-3 Installation	Yes	inspect worksite	Pinch	1	Camera	1

1276	FF	Mate P7A	SA-3 Installation	Yes	mate/demate connector	Pinch	1		
1277	FF	inspect P8A	SA-3 Installation	Yes	inspect worksite	Pinch	1	Camera	1
1278	FF	Mate P8A	SA-3 Installation	Yes	mate/demate connector	Pinch	1		
1279	FF	secure harness bundle to Bay A handrail	SA-3 Installation	Yes	secure harness to handrail	Small handrail	1	delicate pinch	1
1280	FF	config HST PFR	SA-3 Installation	No		Unknown	1		
1281	FF	route DBC cross-strap	SA-3 Installation	Yes	route cross strap	delicate pinch	1		
1|14		**SA Closeout**							
1283	RMS	mnvr to RAC stbd shelf aft latch	SA Closeout	Yes	move about worksite	Motion	1		
1284	RMS	EVA Ratchet: CW, MTL 23, short adj ext	SA Closeout	Yes	set bolt drive	COMPUTER	1		
1285	RMS	drive latch 1.5 turns (engage aft latch) 30 deg/sec max	SA Closeout	Yes	drive bolt	Bolt drive	1		
1286	RMS	check preload pointers aligned	SA Closeout	Yes	inspect worksite	Camera	1		
1287	RMS	mnvr to fwd latch	SA Closeout	Yes	move about worksite	Motion	1		
1288	RMS	drive latch 1.5 turns (engage fwd latch) 30 deg/sec max	SA Closeout	Yes	drive bolt	Bolt drive	1		
1289	RMS	check preload poitners aligned	SA Closeout	Yes	inspect worksite	Camera	1		
1290	RMS	GCA to fwd constraint bolts	SA Closeout	Yes	move about worksite	Motion	1		
1291	RMS	EVA Ratchet: CW, MT 23 or PGT: B4, CW 1, 23.5	SA Closeout	Yes	set bolt drive	COMPUTER	1		
1292	RMS	drive fwd constraint bolts 1-2 turns (2-engage)	SA Closeout	Yes	drive bolt	Bolt drive	2		
1293	RMS	stow EVA ratchet	SA Closeout	No		COMPUTER	1		

1294	RMS	boot plate 0 deg	SA Closeout	No		Unknown	1		
1295	RMS	mnvr to SA-3 panel deploy	SA Closeout	Yes	move about worksite	Motion	1		
1|15		**SA-3 Panel Deploy**							
1297	RMS	grasp SA-3 during strap removal (stabilize)	SA-3 Panel Deploy	No		Small handrail	1	Small handrail	1
1298	FF	remove panel restraint strap	SA-3 Panel Deploy	Yes	stow/remove SA panel restraint strap	delicate pinch	1	Small handrail	1
1299	FF	stow panel restraint strap in trash bag	SA-3 Panel Deploy	Yes	stow/remove SA panel restraint strap	delicate pinch	1		
1300	RMS	deploy panel to ~160 deg	SA-3 Panel Deploy	Yes	deploy SA panel	Unknown	1		
1301	RMS	complete deployment 1 deg/sec	SA-3 Panel Deploy	Yes	deploy SA panel	Unknown	1		
1302	FF	route DBC cross-strap	SA-3 Panel Deploy	Yes	route cross strap	delicate pinch	1		
1303	RMS	mnvr to panel lock bolts	SA-3 Panel Deploy	Yes	move about worksite	Motion	1		
1304	RMS	boot plate 90L	SA-3 Panel Deploy	No		Unknown	1		
1305	RMS	PGT: A5, CW 2, 15.5, short adj ext	SA-3 Panel Deploy	Yes	set bolt drive	COMPUTER	1		
1306	RMS	drive panel locking bolts 11-12 turns (2-engage)	SA-3 Panel Deploy	Yes	drive bolt	Bolt drive	2		
1307	RMS	drive panel locking bolts (retorque)	SA-3 Panel Deploy	Yes	drive bolt	Bolt drive	2		
1308	RMS	check no gap at hinge	SA-3 Panel Deploy	Yes	inspect worksite	Camera	1		
1309	RMS	GCA to HST PFR	SA-3 Panel Deploy	No		Motion	1		
1310	RMS	Boot plate 90R	SA-3 Panel Deploy	No		Unknown	1		
1311	FF	EVA Ratchet: CCW	SA-3 Panel Deploy	Yes	set bolt drive	COMPUTER	1		
1312	FF	drive SADM brake B 11-14 turns (release)	SA-3 Panel Deploy	Yes	drive bolt	Bolt drive	1		
1313	FF	report number of	SA-3 Panel Deploy	Yes	report turn count	COMPUTER	1		

		brake B turns							
1314	FF	inspect SADM for MLI interference	SA-3 Panel Deploy	Yes	inspect worksite	Camera	1		
1315	FF	egress PFR	SA-3 Panel Deploy	No		Large handrail	1		
1316	RMS	remove HST PFR	SA-3 Panel Deploy	No		Large handrail	1		
1317	RMS	stow HST PFR on stanchion (temp)	SA-3 Panel Deploy	No		Large handrail	1		
1318	FF	route DBC cross-strap to +V2 side	SA-3 Panel Deploy	Yes	route cross strap	delicate pinch	1		
1319	FF	secure DBC cross-strap on SSM handrail standoffs	SA-3 Panel Deploy	Yes	release/secure cross strap	delicate pinch	1		
1320	FF	secure +V2 turn around plug near +V2 DBA	SA-3 Panel Deploy	Yes	install/remove turn-around plug	Pinch	1		
1321	FF	install DBC cross-strap harness clip near +V2 DBA	SA-3 Panel Deploy	Yes	install cross strap harness clip	Unknown	1		
1322	FF	remove connector from connector strap (W) if required	SA-3 Panel Deploy	Yes	stow/remove connector	Pinch	1	delicate pinch	1
1323	FF	Stow connector on RAC connector stowage bracket (W) if required	SA-3 Panel Deploy	Yes	stow connector on connector stowage bracket	Pinch	1		
1324	FF	remove connector from connector strap (Y) if required	SA-3 Panel Deploy	Yes	stow/remove connector	Pinch	1	delicate pinch	1
1325	FF	Stow connector on RAC connector stowage bracket (Y) if required	SA-3 Panel Deploy	Yes	stow connector on connector stowage bracket	Pinch	1		
1326	FF	Remove connector from connector strap (Z) if required	SA-3 Panel Deploy	Yes	stow/remove connector	Pinch	1	delicate pinch	1

1327	FF	stow connector on RAC connector stowage bracket (Z) if required	SA-3 Panel Deploy	Yes	stow connector on connector stowage bracket	Pinch	1		
1329	RMS	stow PGT	SA-3 Panel Deploy	No		COMPUTER	1		
1|16		**MFR Swap**							
1330	FF	translate to MFR	MFR Swap	No		Motion	1		
1331	FF	Daisy chain extra waist tether to RMS EV	MFR Swap	No		Unknown	1		
1332	RMS	Daisy chain extra waist tether to FF EV	MFR Swap	No		Unknown	1		
1333	FF	Disconnect RMS EV's safety tether from EMU D-ring	MFR Swap	No		Tether tool	1		
1334	RMS	Disconnect FF EV's safety tether from EMU D-ring	MFR Swap	No		Tether tool	1		
1335	FF	Mate RMS EV's safety tether to FF EV EMU D-ring	MFR Swap	No		Tether tool	1		
1336	RMS	Mate FF EV's safety tether to RMS EV EMU D-ring	MFR Swap	No		Tether tool	1		
1337	FF	Check safety tether gate closed	MFR Swap	No		Camera	1		
1338	RMS	Check safety tether gate closed	MFR Swap	No		Camera	1		
1339	FF	Disconnect RMS EV's prime waist tether from EMU D-ring	MFR Swap	No		Tether tool	1		
1340	RMS	Disconnect FF EV's prime waist tether from EMU D-ring	MFR Swap	No		Tether tool	1		

1341	FF	Mate RMS EV's prime waist tether to FF EV EMU D-ring	MFR Swap	No		Tether tool	1		
1342	RMS	Mate FF EV's prime waist tether to RMS EV EMU D-ring	MFR Swap	No		Tether tool	1		
1343	FF	Disconnect extra waist tether daisy chain	MFR Swap	No		Unknown	1		
1344	RMS	Disconnect extra waist tether daisy chain	MFR Swap	No		Unknown	1		
1345	FF	PGT swap if required	MFR Swap	No		Large handrail	1		
1346	RMS	PGT swap if required	MFR Swap	No		Large handrail	1		
1|17		**Bay 5 & 10 Thermal Cover**							
1348	FF	translate to ASIPE	Bay 5 & 10 Thermal Cover	Yes	move about worksite	Motion	1		
1349	FF	retrieve thermal cover (bay 10)	Bay 5 & 10 Thermal Cover	Yes	stow/retrieve thermal cover	delicate pinch	1		
1350	FF	translate stbd to Bay 10	Bay 5 & 10 Thermal Cover	Yes	move about worksite	Motion	1		
1351	FF	install thermal cover	Bay 5 & 10 Thermal Cover	Yes	install/remove thermal cover	delicate pinch	1		
1352	FF	translate to ASIPE	Bay 5 & 10 Thermal Cover	Yes	move about worksite	Motion	1		
1353	FF	retrieve vent plugs (4) (Bay 5)	Bay 5 & 10 Thermal Cover	Yes	retrieve vent plug	Pinch	4		
1354	FF	retrieve thermal cover (bay 5)	Bay 5 & 10 Thermal Cover	Yes	stow/retrieve thermal cover	delicate pinch	1		
1355	FF	translate port to Bay 5; fairlead	Bay 5 & 10 Thermal Cover	Yes	move about worksite	Motion	1		
1356	FF	install thermal cover	Bay 5 & 10 Thermal Cover	Yes	install/remove thermal cover	delicate pinch	1	Small handrail	1
1357	FF	install vent plugs (2)	Bay 5 & 10 Thermal	Yes	install vent plug	Pinch	2		

			Cover						
1|18		**P601 Mate**							
1359	RMS	stanchion 135R	P601 Mate	No		Unknown	1		
1360	RMS	retrieve HST PFR from stanchion	P601 Mate	No		Large handrail	1		
1361	RMS	mnvr to FR19	P601 Mate	No		Motion	1		
1362	RMS	boot plate 90L	P601 Mate	No		Unknown	1		
1363	RMS	pull slide lock on APE (hold)	P601 Mate	No		Pinch	1		
1364	RMS	rotate locking lever (while still holding slide lock)	P601 Mate	No		Pinch	1		
1365	RMS	rotate socket so APE=K	P601 Mate	No		Large handrail	1		
1366	RMS	rotate locking lever on APE back to locked	P601 Mate	No		Pinch	1		
1367	RMS	config HST PFR	P601 Mate	No		Unknown	1		
1368	RMS	Install APE to 75R	P601 Mate	No		PIP	1	Small handrail	
1369	RMS	mnvr to EPS panel	P601 Mate	Yes	move about worksite	Motion	1		
1370	RMS	PGT: 5/32 driver	P601 Mate	Yes	set bolt drive	COMPUTER	1		
1371	RMS	PGT: A2, CCW 2, 5.5	P601 Mate	Yes	set bolt drive	COMPUTER	1		
1372	RMS	drive EPS panel bolts 7 turns (2-disengage)	P601 Mate	Yes	drive bolt	Bolt drive	2		
1373	RMS	remove EPS panel using MWS end effector	P601 Mate	Yes	remove EPS panel	MWS EE	1		
1374	RMS	remove connector cap (P601)	P601 Mate	Yes	install/remove connector cap	Pinch	1		
1375	RMS	remove DBC cross-strap P601 connector cap	P601 Mate	Yes	install/remove connector cap	Pinch	1	delicate pinch	1

1376	RMS	mate DBC cross-strap P601 to EPS P601	P601 Mate	Yes	mate/demate connector	Pinch	1	delicate pinch	1
1377	RMS	notify MCC P601 mated	P601 Mate	Yes	notify MCC	COMPUTER	1		
1378	RMS	retrieve MLI tent from MFR stanchion	P601 Mate	Yes	stow/retrieve MLI tent	delicate pinch	1		
1379	RMS	install MLI tent	P601 Mate	Yes	install MLI tent	delicate pinch	1		
		DAY 2							
2|1		**Translation Adaption**							
2002	RMS	perform translation adaption	Translation Adaption	unk	perform translation adaption	Unknown	1		
2003	RMS	remove PIP pin (fwd latch)	Translation Adaption	unk	install/remove PIP	PIP	1		
2004	RMS	stow PIP pin (fwd latch)	Translation Adaption	unk	install/remove PIP	PIP	1		
2005	RMS	remove PIP pin (aft latch)	Translation Adaption	unk	install/remove PIP	PIP	1		
2006	RMS	stow PIP pin (aft latch)	Translation Adaption	unk	install/remove PIP	PIP	1		
2|2		**BAPS Post Setup**							
2008	FF	install PIP pins (BAPS center)	BAPS Post Setup	unk	install/remove PIP	PIP	2		
2|3		**MFR Setup**							
2010	RMS	attach MWS tether to boot plate lanyard	MFR Setup	No		Tether tool	1		
2011	RMS	ingress MFR	MFR Setup	No		Large handrail	1		
2012	RMS	stow PGT	MFR Setup	No		COMPUTER	1		
2013	RMS	rotate tool interface 180 deg	MFR Setup	No		Unknown	1		
2|4		**Translation Aid Setup**							
2015	FF	remove PIP pin from mini-TA if nec	Translation Aid Setup	No		PIP	1		

2016	FF	rotate handle 140 deg (mini-TA)	Translation Aid Setup	No		Small handrail	1		
2017	FF	install PIP pin (mini-TA)	Translation Aid Setup	No		PIP	1		
2018	FF	install hitch pin (mini-TA)	Translation Aid Setup	No		Hitch	1		
2019	FF	extend TA tube (stbd) if nec	Translation Aid Setup	No		Small handrail	1	Small handrail	1
2020	FF	rotate TA joint (stbd)	Translation Aid Setup	No		Small handrail	1		
2021	FF	extend TA tube (port) if nec	Translation Aid Setup	No		Small handrail	1	Small handrail	1
2022	FF	rotate TA joint (port)	Translation Aid Setup	No		Small handrail	1		
2|5		**PFR Retrieval**							
2024	FF	translate to FSS APC if req	Translation Aid Setup	No		Motion	1		
2025	RMS	Boot plate 0 deg if req	Translation Aid Setup	No		Unknown	1		
2026	RMS	stanchion 180 deg if req	Translation Aid Setup	No		Unknown	1		
2027	RMS	mnvr to FSS APC if req	Translation Aid Setup	No		Motion	1		
2028	FF	retrieve APE if req	Translation Aid Setup	No		PIP	1	Large handrail	
2029	FF	install APE on HST PFR if req	Translation Aid Setup	No		PIP	1	Large handrail	
2030	FF	remove HST PFR	Translation Aid Setup	No		Large handrail	1		
2031	FF	transfer HST PFR to RMS EV if req	Translation Aid Setup	No		Large handrail	1		
2032	RMS	receive HST PFR	Translation Aid Setup	No		Large handrail	1		
2033	RMS	config HST PFR	Translation Aid Setup	No		Unknown	1		
2|6		**PDM Retract**							

2035	FF	translate to +V2 FR 19	PDM Retract	Yes	move about worksite	Motion	1		
2036	FF	ingress PFR	PDM Retract	No		Large handrail	1		
2037	RMS	mnvr to FR 19	PDM Retract	Yes	move about worksite	Motion	1		
2038	RMS	install APE to 75R if req	PDM Retract	No		PIP	1	Large handrail	
2039	FF	EVA Ratchet: CCW, 6-in rigid	PDM Retract	Yes	set bolt drive	COMPUTER	1		
2040	FF	drive PDM 5.7 turns maintain SA slew at 0 deg	PDM Retract	Yes	drive bolt	Small handrail	1	Bolt drive	1
2041	RMS	retract PDM (assist FF EV)	PDM Retract	No		Unknown	1		
2042	RMS	grasp SA-2 fwd handrails	PDM Retract	No		Small handrail	1	Small handrail	1
2043	RMS	check GO to remove tool	PDM Retract	Yes	check GO	COMPUTER	1		
2044	RMS	seat SA-2 into latch fitting	PDM Retract	Yes	install/remove SA	Small handrail	1		
2045	RMS	check GO to engage PDM lock	PDM Retract	Yes	check GO	COMPUTER	1		
2046	FF	EVA Ratchet: CW	PDM Retract	Yes	set bolt drive	COMPUTER	1		
2047	FF	drive PDM lock to ON 1/2 turn CW (engage)	PDM Retract	Yes	drive bolt	Bolt drive	1		
2048	FF	install connector strap (SA-2)	PDM Retract	Yes	install/remove connector strap	delicate pinch	1	delicate pinch	1
2|7		**Bay Door Bolt Disengage**							
2050	RMS	Mnvr to Bay 4	Bay Door Bolt Disengage	Yes	move about worksite	Motion	1		
2051	RMS	Stanchion 135L	Bay Door Bolt Disengage	No		Unknown	1		
2052	RMS	Boot plate 90R	Bay Door Bolt Disengage	No		Unknown	1		

2053	RMS	PGT: A3, CCW 3, 10.5, short adj	Bay Door Bolt Disengage	Yes	set bolt drive	COMPUTER	1		
2054	RMS	drive J-bolts (5) 4-6 turns (disengage)	Bay Door Bolt Disengage	Yes	drive bolt	Bolt drive	5		
2055	RMS	GCA to Bay 3	Bay Door Bolt Disengage	Yes	move about worksite	Motion	1		
2056	RMS	PGT: A3, CCW 3, 10.5	Bay Door Bolt Disengage	Yes	set bolt drive	COMPUTER	1		
2057	RMS	drive J-bolts (5) 4-6 turns (disengage)	Bay Door Bolt Disengage	Yes	drive bolt	Bolt drive	5		
2058	RMS	GCA to Bay 2	Bay Door Bolt Disengage	Yes	move about worksite	Motion	1		
2059	RMS	PGT: A3, CCW 3, 10.5	Bay Door Bolt Disengage	Yes	set bolt drive	COMPUTER	1		
2060	RMS	drive J-bolts (5) 4-6 turns (disengage)	Bay Door Bolt Disengage	Yes	drive bolt	Bolt drive	5		
2|8		**DBA Connector Demate**							
2062	FF	release Velcro restraint strap (Y/Z)	DBA Connector Demate	Yes	secure/remove Velcro	delicate pinch	2		
2063	FF	PGT: A3, CCW 3, 10.5, 6-in wobble	DBA Connector Demate	Yes	set bolt drive	COMPUTER	1		
2064	FF	drive keyway (Z&Y) bolts 4-6 turns (4-disengage)	DBA Connector Demate	Yes	drive bolt	Bolt drive	4		
2065	FF	PGT: A3, CCW 1, 10.5	DBA Connector Demate	Yes	set bolt drive	COMPUTER	1		
2066	FF	drive Z drive stud, 5+ turns (disengage)	DBA Connector Demate	Yes	drive bolt	Bolt drive	1		
2067	FF	stow connector bracket on connector strap	DBA Connector Demate	Yes	stow connector bracket on connector strap	Unknown	1		
2068	FF	drive Y drive stud, 5+ turns (disengage)	DBA Connector Demate	Yes	drive bolt	Bolt drive	1		
2069	FF	pull slide lock on	DBA Connector	No		Pinch	1		

		APE (hold)	Demate						
2070	FF	rotate locking lever (while still holding slide lock)	DBA Connector Demate	No		Pinch	1		
2071	FF	rotate socket so APE=C	DBA Connector Demate	No		Large handrail	1		
2072	FF	rotate locking lever on APE back to locked	DBA Connector Demate	No		Pinch	1		
2073	FF	config PFR YAW=6	DBA Connector Demate	No		Unknown	1		
2074	FF	release Velcro restraint strap (W)	DBA Connector Demate	Yes	secure/remove Velcro	delicate pinch	1		
2075	FF	PGT: A3, CCW 3, 10.5	DBA Connector Demate	Yes	set bolt drive	COMPUTER	1		
2076	FF	drive keyway bolts (W) 4-6 turns (2-disengage)	DBA Connector Demate	Yes	drive bolt	Bolt drive	2		
2077	FF	PGT: A3, CCW 1, 10.5	DBA Connector Demate	Yes	set bolt drive	COMPUTER	1		
2078	FF	drive drive stud (W), 5+ turns (disengage)	DBA Connector Demate	Yes	drive bolt	Bolt drive	1		
2079	FF	stow connector bracket on connector strap	DBA Connector Demate	Yes	stow connector bracket on connector strap	Unknown	1		
2|9		**SA-2 Removal From HST**							
2081	RMS	mnvr to +V2 SA-2	SA-2 Removal From HST	Yes	move about worksite	Motion	1		
2082	RMS	setup MFR	SA-2 Removal From HST	No		Unknown	1		
2083	RMS	grasp SA-2 aft handrails (stabilize SA-2)	SA-2 Removal From HST	Yes	grasp SA handrail	Small handrail	1		
2084	FF	pull slide lock on APE (hold)	SA-2 Removal From HST	No		Pinch	1		

2085	FF	rotate locking lever (while still holding slide lock)	SA-2 Removal From HST	No		Pinch	1		
2086	FF	rotate socket so APE=K	SA-2 Removal From HST	No		Large handrail	1		
2087	FF	rotate locking lever on APE back to locked	SA-2 Removal From HST	No		Pinch	1		
2088	FF	ingress	SA-2 Removal From HST	Yes	move about worksite	Motion	1		
2089	FF	PGT: B2, CW 2, 2.5 turns	SA-2 Removal From HST	Yes	set bolt drive	COMPUTER	1		
2090	FF	drive SADA clamp (right-disengage) 20 turns	SA-2 Removal From HST	Yes	drive bolt	Bolt drive	1		
2091	FF	CHECK OPEN	SA-2 Removal From HST	Yes	inspect worksite	Camera	1		
2092	RMS	Remove SA-2	SA-2 Removal From HST	Yes	install/remove SA	Small handrail	1	Small handrail	1
2093	FF	maintain SADA clearance with HST (assist RMS EV)	SA-2 Removal From HST	Yes	maintain SADA clearance	Unknown	1		
2094	RMS	mnvr to RAC port shelf	SA-2 Removal From HST	Yes	move about worksite	Motion	1		
2095	FF	inspect SADA clamp for damage, distortion	SA-2 Removal From HST	Yes	inspect worksite	Camera	1		
2096	FF	inspect surrounding MLI for soft dock interference	SA-2 Removal From HST	Yes	inspect worksite	Camera	1		
2097	FF	PGT: B2, CW 2, 2.5 MTL	SA-2 Removal From HST	Yes	set bolt drive	COMPUTER	1		
2098	FF	pull slide lock on APE (hold)	SA-2 Removal From HST	No		Pinch	1		
2099	FF	rotate locking lever (while still holding slide lock)	SA-2 Removal From HST	No		Pinch	1		

2100	FF	rotate socket so APE=F	SA-2 Removal From HST	No		Large handrail	1		
2101	FF	rotate locking lever on APE back to locked	SA-2 Removal From HST	No		Pinch	1		
2102	FF	translate to RAC port SADA clamp	SA-2 Removal From HST	Yes	move about worksite	Motion	1		
2103	FF	release groundstrap (SA-3)	SA-2 Removal From HST	Yes	release groundstrap	delicate pinch	1		
2104	FF	stow groundstrap (SA-3)	SA-2 Removal From HST	Yes	stow/retrieve groundstrap	delicate pinch	1		
2105	FF	release SADA clamp spindle lock	SA-2 Removal From HST	Yes	engage/disengage SADA clamp spindle lock	Unknown	1		
2106	FF	guide SA-2 into SADA clamp	SA-2 Removal From HST	Yes	guide SA into SADA clamp	Small handrail	1	Small handrail	1
2107	FF	rotate SA-2 into latches	SA-2 Removal From HST	Yes	rotate SA	Small handrail	1	Small handrail	1
2108	RMS	guide SA-2 into SADA clamp	SA-2 Removal From HST	No		Small handrail	1	Small handrail	1
2109	RMS	rotate SA-2 into latches	SA-2 Removal From HST	No		Small handrail	1	Small handrail	1
2110	FF	drive SADA clamp 22 turns until MTL slips (engage)	SA-2 Removal From HST	Yes	drive bolt	Small handrail	1	Bolt drive	1
2111	RMS	grasp SA-2 while FF EV engage SADA clamp (stabilize)	SA-2 Removal From HST	No		Small handrail	1	Small handrail	1
2112	FF	CHECK CLOSED	SA-2 Removal From HST	Yes	inspect worksite	Camera	1		
2113	FF	engage SADA clamp spindle lock	SA-2 Removal From HST	Yes	engage/disengage SADA clamp spindle lock	Unknown	1		
2114	FF	remove connector from connector strap	SA-2 Removal From HST	Yes	stow/remove connector	Pinch	1	delicate pinch	1

		(W)							
2115	FF	stow connector on RAC connector stowage bracket (W)	SA-2 Removal From HST	Yes	stow connector on connector stowage bracket	Pinch	1		
2116	FF	remove connector from connector strap (Y)	SA-2 Removal From HST	Yes	stow/remove connector	Pinch	1	delicate pinch	1
2117	FF	Stow connector on RAC connector stowage bracket (Y)	SA-2 Removal From HST	Yes	stow connector on connector stowage bracket	Pinch	1		
2118	FF	remove connector from connector strap (Z)	SA-2 Removal From HST	Yes	stow/remove connector	Pinch	1	delicate pinch	1
2119	FF	stow connector on RAC connector stowage bracket (Z)	SA-2 Removal From HST	Yes	stow connector on connector stowage bracket	Pinch	1		
2120	FF	translate to fwd end SA-2	SA-2 Removal From HST	Yes	move about worksite	Motion	1		
2121	FF	inspect fwd latch alignment	SA-2 Removal From HST	Yes	inspect worksite	Camera	1		
2122	FF	remove PIP pin (fwd constraint)	SA-2 Removal From HST	Yes	install/remove PIP	PIP	1		
2123	RMS	grasp SA-2 in latches while FF EV insert PIP pin	SA-2 Removal From HST	No		Small handrail	1	Small handrail	1
2124	FF	Slide bracket against SA-2	SA-2 Removal From HST	Yes	slide bracket against SA	Small handrail	1		
2125	FF	install PIP pin while hold slide bracket against SA-2	SA-2 Removal From HST	Yes	install/remove PIP	Small handrail	1	PIP	1
2126	FF	secure Velcro	SA-2 Removal From HST	Yes	secure/remove Velcro	delicate pinch	1		
2|10		**DBA Changeout**							
2128	FF	translate to +V2 FR19	DBA Changeout	Yes	move about	Motion	1		

					worksite				
2129	FF	ingress HST PFR	DBA Changeout	No		Large handrail	1		
2130	FF	PGT: A2, CW 3, 5.5	DBA Changeout	Yes	set bolt drive	COMPUTER	1		
2131	FF	drive keyway (Z&Y) bolts 7-9 turns (4-engage)	DBA Changeout	Yes	drive bolt	Bolt drive	4		
2132	FF	PGT: A3, CCW 3, 10.5	DBA Changeout	Yes	set bolt drive	COMPUTER	1		
2133	FF	drive connector (X) keyway bolts 5-6 turns (2-disengage)	DBA Changeout	Yes	drive bolt	Bolt drive	2		
2134	FF	PGT: B6, CCW 1, 10.5	DBA Changeout	Yes	set bolt drive	COMPUTER	1		
2135	FF	drive drive stud 5+ turns (disengage)	DBA Changeout	Yes	drive bolt	Bolt drive	1		
2136	FF	drive j-bolts 4-6 turns (4-release)	DBA Changeout	Yes	drive bolt	Bolt drive	4		
2137	FF	exchange DBA/DBA-2	DBA Changeout	Yes	exchange DBA	Small handrail	1	Small handrail	1
2138	FF	receive DBA-2	DBA Changeout	No		Small handrail	1		
2139	RMS	mnvr to DBA-2	DBA Changeout	Yes	move about worksite	Motion	1		
2140	RMS	open DBA-2 thermal cover	DBA Changeout	Yes	open/close thermal cover	delicate pinch	1		
2141	RMS	PGT: A3, CCW 3, 10.5	DBA Changeout	Yes	set bolt drive	COMPUTER	1		
2142	RMS	drive j-bolts 4-6 turns (4-release)	DBA Changeout	Yes	drive bolt	Bolt drive	4		
2143	RMS	remove DBA-2 from RAC	DBA Changeout	Yes	install/remove DBA	Small handrail	1		
2144	RMS	mnvr to DBA-2 swap	DBA Changeout	Yes	move about worksite	Motion	1		
2145	RMS	inspect connectors	DBA Changeout	Yes	inspect worksite	Camera	1	Pinch	1
2146	RMS	receive DBA from FF EV	DBA Changeout	No		Small handrail	1		

2147	RMS	transfer DBA-2	DBA Changeout	No		Small handrail	1		
2148	RMS	mnvr to RAC port shelf	DBA Changeout	Yes	move about worksite	Motion	1		
2149	RMS	install DBA on outboard port shelf (connectors inboard)	DBA Changeout	Yes	install/remove DBA	Small handrail	1		
2150	RMS	PGT: A3, CW 3, 10.5	DBA Changeout	Yes	set bolt drive	COMPUTER	1		
2151	RMS	drive j-bolts 4-6 turns (4-engage)	DBA Changeout	Yes	drive bolt	Bolt drive	4		
2152	RMS	close thermal cover (DBA)	DBA Changeout	Yes	open/close thermal cover	delicate pinch	1		
2153	FF	install DBA-2	DBA Changeout	Yes	install/remove DBA	Small handrail	1		
2154	FF	drive j-bolts 4-6 turns (4-engage)	DBA Changeout	Yes	drive bolt	Bolt drive	4		
2155	FF	inspect connector--check no spring interference with keyhole (X)	DBA Changeout	Yes	inspect worksite	Pinch	1	Camera	1
2156	FF	position connector on keyway bolts (X)	DBA Changeout	Yes	position connector	Pinch	1		
2157	FF	EVA Ratchet: CW	DBA Changeout	Yes	set bolt drive	COMPUTER	1		
2158	FF	drive drive stud 3.5 turns (engage)	DBA Changeout	Yes	drive bolt	Bolt drive	1		
2159	FF	PGT: A2, CW 2, 5.5 or EVA Ratchet: CW	DBA Changeout	Yes	set bolt drive	COMPUTER	1		
2160	FF	drive drive stud 1.5 turns (engage)	DBA Changeout	Yes	drive bolt	Bolt drive	1		
2161	FF	check bracket flush with rail	DBA Changeout	Yes	inspect worksite	Camera	1		
2162	FF	PGT: A3, CW 3, 10.5	DBA Changeout	Yes	set bolt drive	COMPUTER	1		
2163	FF	drive keyway bolts 4-6 turns (2-engage)	DBA Changeout	Yes	drive bolt	Bolt drive	2		

2164	FF	demate harness (TLM) P3 from DBA-2 J1	DBA Changeout	Yes	mate/demate connector	delicate pinch	1	Pinch	1
2165	FF	release DBC cross strap	DBA Changeout	Yes	release/secure cross strap	delicate pinch	1		
2166	FF	remove turn around plug (+V2 P1)	DBA Changeout	Yes	install/remove turn-around plug	Pinch	1		
2167	FF	Stow turn around plug in trash (+V2 P1)	DBA Changeout	Yes	stow turn-around plug	Pinch	1		
2168	FF	mate DBC cross strap P1(+) to DBA-2 J1	DBA Changeout	Yes	mate/demate connector	Pinch	1	delicate pinch	1
2169	FF	check DBC cross strap clip secured to SSM clip	DBA Changeout	Yes	inspect worksite	Camera	1		
2170	FF	check cross strap harness clear of DBA face	DBA Changeout	Yes	inspect worksite	Camera	1		
2171	FF	pull slide lock on APE (hold)	DBA Changeout	No		Pinch	1		
2172	FF	rotate locking lever (while still holding slide lock)	DBA Changeout	No		Pinch	1		
2173	FF	rotate socket so APE=K	DBA Changeout	No		Large handrail	1		
2174	FF	rotate locking lever on APE back to locked	DBA Changeout	No		Pinch	1		
2|11		**SA-3 Removal**							
2176	RMS	mnvr to latch 5	SA-3 Removal	Yes	move about worksite	Motion	1		
2177	RMS	PGT: A6, CCW 2, 30.5, 15.1 ft lb	SA-3 Removal	Yes	set bolt drive	COMPUTER	1		
2178	RMS	drive latch 5, 8+ turns (disengage)	SA-3 Removal	Yes	drive bolt	Bolt drive	1		

2179	RMS	PGT: A3, CW 2, 10.5	SA-3 Removal	Yes	set bolt drive	COMPUTER	1		
2180	RMS	drive bolt in lower fitting, engage 8+ turns (stow)	SA-3 Removal	Yes	drive bolt	Bolt drive	1		
2181	RMS	deploy mast 90 deg to engage soft dock	SA-3 Removal	Yes	deploy mast	Unknown	1		
2182	RMS	mnvr to mast bolts	SA-3 Removal	Yes	move about worksite	Motion	1		
2183	RMS	drive mast bolts 8+ turns (2-engage)	SA-3 Removal	Yes	drive bolt	Bolt drive	2		
2184	RMS	GCA to latch 2	SA-3 Removal	Yes	move about worksite	Motion	1		
2185	RMS	PGT: A6, CCW 2, 30.5, 18.3 ft lb	SA-3 Removal	Yes	set bolt drive	COMPUTER	1		
2186	RMS	drive latch 2 12-15 turns (disengage)	SA-3 Removal	Yes	drive bolt	Bolt drive	1		
2187	RMS	report turn count for latch 2	SA-3 Removal	Yes	report turn count	COMPUTER	1		
2188	RMS	GCA to latch 1	SA-3 Removal	Yes	move about worksite	Motion	1		
2189	FF	translate to RAC, latch 3	SA-3 Removal	Yes	move about worksite	Motion	1		
2190	FF	ingress PFR (fwd)	SA-3 Removal	No		Large handrail	1		
2191	FF	PGT: A6, CCW 2, 30.5, 12.0 ft lb	SA-3 Removal	Yes	set bolt drive	COMPUTER	1		
2192	FF	drive latch 3 until clamp clears tang, 7-9 turns (release)	SA-3 Removal	Yes	drive bolt	Bolt drive	1		
2193	FF	pivot latch 3 to clear tang	SA-3 Removal	Yes	pivot latch	Small handrail	1		
2194	FF	tether to tang	SA-3 Removal	No		Tether tool	1		
2195	FF	PGT: A2, CCW 2, 5.5	SA-3 Removal	Yes	set bolt drive	COMPUTER	1		
2196	FF	drive tang bolts 9-10 turns (2-disengage)	SA-3 Removal	Yes	drive bolt	Bolt drive	2		
2197	FF	stow tang on CSS	SA-3 Removal	Yes	stow tang	Bolt drive	1	Small handrail	1

2198	FF	PGT: A2, CW 2, 5.5	SA-3 Removal	Yes	set bolt drive	COMPUTER	1		
2199	FF	drive tang bolts 9-10 turns (2-engage)	SA-3 Removal	Yes	drive bolt	Bolt drive	2		
2200	FF	pivot latch 3 to stowed position	SA-3 Removal	Yes	pivot latch	Small handrail	1		
2201	FF	install PIP pin	SA-3 Removal	Yes	install/remove PIP	PIP	1		
2202	FF	deploy MLI flap over tang interface	SA-3 Removal	Yes	deploy MLI	delicate pinch	1		
2203	FF	PGT: A6, CCW 2, 30.5, 8. Ft lb	SA-3 Removal	Yes	set bolt drive	COMPUTER	1		
2204	FF	drive latch 4 10-15 turns (release)	SA-3 Removal	Yes	drive bolt	Bolt drive	1		
2205	FF	report turn count for latch 4	SA-3 Removal	Yes	report turn count	COMPUTER	1		
2206	FF	grasp SA during latch 1 release (stabilize)	SA-3 Removal	Yes	grasp SA handrail	Small handrail	1		
2207	RMS	PGT: A6, CCW 2, 30.5, 24.0 ft lb	SA-3 Removal	Yes	set bolt drive	COMPUTER	1		
2208	RMS	drive latch 1, 19+ turns (release)	SA-3 Removal	Yes	drive bolt	Bolt drive	1		
2209	RMS	mnvr to SA-3 top handrails at c.g. mark	SA-3 Removal	Yes	move about worksite	Motion	1		
2210	RMS	remove SA-3	SA-3 Removal	Yes	install/remove SA	Small handrail	1	Small handrail	1
2211	FF	remove SA-3	SA-3 Removal	No		Small handrail	1	Small handrail	1
2|12		**SA-3 Installation**							
2213	RMS	evaluate mass handling	SA-3 Installation	Yes	evaluate mass handling	COMPUTER	1		
2214	RMS	mnvr to SA-3 rotate	SA-3 Installation	Yes	move about worksite	Motion	1		
2215	RMS	rotate SA-3 for install	SA-3 Installation	Yes	rotate SA	Small handrail	1	Small handrail	1
2216	FF	translate to +V2, FR19	SA-3 Installation	Yes	move about worksite	Motion	1		
2217	RMS	mnvr to SA-3 pre-	SA-3 Installation	Yes	move about	Motion	1		

		install			worksite				
2218	FF	ingress HST PFR yaw foot plate	SA-3 Installation	No		Large handrail	1		
2219	RMS	posn SADM for FF EV access	SA-3 Installation	Yes	position SADM	Unknown	1		
2220	FF	install SA-3	SA-3 Installation	Yes	install/remove SA	Small handrail	1	Small handrail	1
2221	RMS	install SA-3	SA-3 Installation	No		Small handrail	1	Small handrail	1
2222	FF	check soft docks engaged (3)	SA-3 Installation	Yes	inspect worksite	Camera	3		
2223	FF	PGT: B2, CW 2, 5.5	SA-3 Installation	Yes	set bolt drive	COMPUTER	1		
2224	FF	drive SADA clamp (right) 19-20 turns (engage)	SA-3 Installation	Yes	drive bolt	Bolt drive	1		
2225	FF	check SADA clamp closed	SA-3 Installation	Yes	inspect worksite	Camera	1		
2226	FF	release Velcro restraint strap (harness)	SA-3 Installation	Yes	secure/remove Velcro	delicate pinch	1		
2227	FF	inspect connector P5A	SA-3 Installation	Yes	inspect worksite	Pinch	1	Camera	1
2228	FF	Mate connector P5A	SA-3 Installation	Yes	mate/demate connector	Pinch	1		
2229	FF	inspect connector P6A	SA-3 Installation	Yes	inspect worksite	Pinch	1	Camera	1
2230	FF	mate connector P6A	SA-3 Installation	Yes	mate/demate connector	Pinch	1		
2231	FF	inspect connector P7A	SA-3 Installation	Yes	inspect worksite	Pinch	1	Camera	1
2232	FF	mate connector P7A	SA-3 Installation	Yes	mate/demate connector	Pinch	1		
2233	FF	inspect connector P8A	SA-3 Installation	Yes	inspect worksite	Pinch	1	Camera	1
2234	FF	mate connector P8A	SA-3 Installation	Yes	mate/demate connector	Pinch	1		

2235	FF	secure harness bundle to SADA soft dock with Velcro strap	SA-3 Installation	Yes	secure harness to SADA soft-dock	Small handrail	1	delicate pinch	1
2236	FF	pull slide lock on APE (hold)	SA-3 Installation	No		Pinch	1		
2237	FF	rotate locking lever (while still holding slide lock)	SA-3 Installation	No		Pinch	1		
2238	FF	rotate socket to APE=B	SA-3 Installation	No		Large handrail	1		
2239	FF	rotate locking lever on APE back to locked	SA-3 Installation	No		Pinch	1		
2240	FF	PGT: A2, CCW 1, 5.5 or EVA Ratchet: CCW	SA-3 Installation	Yes	set bolt drive	COMPUTER	1		
2241	FF	drive W bracket drive stud 5+ turns (disengage)	SA-3 Installation	Yes	drive bolt	Bolt drive	1		
2242	FF	inspect HST and W connector	SA-3 Installation	Yes	inspect worksite	Pinch	1	Camera	1
2243	FF	install connector (W)	SA-3 Installation	Yes	mate/demate connector	Pinch	1		
2244	FF	EVA Ratchet: CW	SA-3 Installation	Yes	set bolt drive	COMPUTER	1		
2245	FF	drive drive stud 3.5 turns (engage)	SA-3 Installation	Yes	drive bolt	Bolt drive	1		
2246	FF	check bracket flush with rail	SA-3 Installation	Yes	inspect worksite	Camera	1		
2247	FF	PGT: A2, CW 2, 5.5 or EVA Ratchet: CW	SA-3 Installation	Yes	set bolt drive	COMPUTER	1		
2248	FF	drive drive stud 1.5 turns (engage)	SA-3 Installation	Yes	drive bolt	Bolt drive	1		
2249	FF	remove palm wheel from EVA ratchet	SA-3 Installation	unk	remove palm wheel	Unknown	1		
2250	FF	Stow palm wheel in	SA-3 Installation	unk	stow palm wheel	Unknown	1		

		trash bag							
2251	FF	PGT: A3, CW 2, 10.5	SA-3 Installation	Yes	set bolt drive	COMPUTER	1		
2252	FF	drive keyway bolts 4-6 turns (2-engage)	SA-3 Installation	Yes	drive bolt	Bolt drive	2		
2253	FF	remove cap (J3) on W bracket	SA-3 Installation	Yes	install/remove connector cap	Pinch	1		
2254	FF	stow cap (J3) from W bracket in trash bag	SA-3 Installation	Yes	stow connector cap	Pinch	1		
2255	FF	mate TLM harness P3 to J3	SA-3 Installation	Yes	mate/demate connector	delicate pinch	1	Pinch	1
2256	FF	secure W harness to Bay J handrail w/ restraint strap	SA-3 Installation	Yes	secure harness to handrail	delicate pinch	1	Small handrail	1
2|13		**SA Closeout**							
2258	RMS	mnvr to RAC port shelf aft latch	SA Closeout	Yes	move about worksite	Motion	1		
2259	RMS	EVA Ratchet: CW, MTL 23, short adj ext	SA Closeout	Yes	set bolt drive	COMPUTER	1		
2260	RMS	drive latch (aft) 1.5 turns (engage) 30 deg/sec max	SA Closeout	Yes	drive bolt	Bolt drive	1		
2261	RMS	check preload pointers aligned	SA Closeout	Yes	inspect worksite	Camera	1		
2262	RMS	mnvr to fwd latch	SA Closeout	Yes	move about worksite	Motion	1		
2263	RMS	drive latch (fwd) 1.5 turns (engage) 30 deg/sec max	SA Closeout	Yes	drive bolt	Bolt drive	1		
2264	RMS	check preload poitners aligned	SA Closeout	Yes	inspect worksite	Camera	1		
2265	RMS	GCA to fwd constraint bolts	SA Closeout	Yes	move about worksite	Motion	1		
2266	RMS	EVA Ratchet: CW, MTL 23 or PGT: B3, CW 1, 23.5	SA Closeout	Yes	set bolt drive	COMPUTER	1		

2267	RMS	drive fwd constraint bolts 1-2 turns (2-engage)	SA Closeout	Yes	drive bolt	Bolt drive	2		
2268	RMS	stow EVA Ratchet	SA Closeout	No		COMPUTER	1		
2269	RMS	mnvr to SA-3 panel deploy	SA Closeout	Yes	move about worksite	Motion	1		
2|14		**SA-3 Panel Deploy**							
2271	RMS	grasp SA-3 during strap removal (stabilize)	SA-3 Panel Deploy	No		Small handrail	1	Small handrail	1
2272	FF	remove panel restraint strap	SA-3 Panel Deploy	Yes	stow/remove SA panel restraint strap	delicate pinch	1	Small handrail	1
2273	FF	stow panel restraint strap in trash bag	SA-3 Panel Deploy	Yes	stow/remove SA panel restraint strap	delicate pinch	1		
2274	FF	pull slide lock on APE (hold)	SA-3 Panel Deploy	No		Pinch	1		
2275	FF	rotate locking lever (while still holding slide lock)	SA-3 Panel Deploy	No		Pinch	1		
2276	FF	set socket so APE=K	SA-3 Panel Deploy	No		Large handrail	1		
2277	FF	rotate locking lever on APE back to locked	SA-3 Panel Deploy	No		Pinch	1		
2278	FF	config HST PFR	SA-3 Panel Deploy	No		Unknown	1		
2279	FF	ingress PFR	SA-3 Panel Deploy	No		Large handrail	1		
2280	RMS	deploy panel to ~160 deg	SA-3 Panel Deploy	Yes	deploy SA panel	Unknown	1		
2281	RMS	complete deployment 1 deg/sec	SA-3 Panel Deploy	Yes	deploy SA panel	Unknown	1		
2282	RMS	stanchion 135R	SA-3 Panel Deploy	No		Unknown	1		
2283	RMS	boot plate 90L	SA-3 Panel Deploy	No		Unknown	1		
2284	RMS	mnvr for panel lock bolts	SA-3 Panel Deploy	Yes	move about worksite	Motion	1		

2285	RMS	PGT: A5, CW 2, 15.5, short adj ext	SA-3 Panel Deploy	Yes	set bolt drive	COMPUTER	1		
2286	RMS	drive panel locking bolts 11-12 turns (2-engage)	SA-3 Panel Deploy	Yes	drive bolt	Bolt drive	2		
2287	RMS	drive panel locking bolts (retorque)	SA-3 Panel Deploy	Yes	drive bolt	Bolt drive	2		
2288	RMS	check no gap at hinge	SA-3 Panel Deploy	Yes	inspect worksite	Camera	1		
2289	FF	drive panel locking bolts 11-12 turns (2-engage)	SA-3 Panel Deploy	Yes	drive bolt	Bolt drive	2		
2290	FF	drive panel locking bolts (retorque)	SA-3 Panel Deploy	Yes	drive bolt	Bolt drive	2		
2291	FF	check no gap at hinge	SA-3 Panel Deploy	Yes	inspect worksite	Camera	1		
2292	FF	EVA Ratchet: CCW	SA-3 Panel Deploy	Yes	set bolt drive	COMPUTER	1		
2293	FF	drive SADM brake B 11-14 turns (release)	SA-3 Panel Deploy	Yes	drive bolt	Bolt drive	1		
2294	FF	report number of brake B turns	SA-3 Panel Deploy	Yes	report turn count	COMPUTER	1		
2295	FF	inspect SADM for MLI interference	SA-3 Panel Deploy	Yes	inspect worksite	Camera	1		
2|15		**HST PFR Stow**							
2297	FF	egress HST PFR	HST PFR Stow	No		Large handrail	1		
2298	RMS	mnvr for HST PFR retrieval	HST PFR Stow	No		Motion	1		
2299	FF	remove HST PFR	HST PFR Stow	No		Large handrail	1		
2300	FF	remove APE	HST PFR Stow	No		PIP	1	Large handrail	
2301	FF	transfer HST PFR to RMS EV	HST PFR Stow	No		Large handrail	1		
2302	FF	trasnfer APE to RMS EV	HST PFR Stow	No		Large handrail	1		
2303	FF	translate to FSS APC	HST PFR Stow	No		Motion	1		
2304	RMS	receive HST PFR from FF EV	HST PFR Stow	No		Large handrail	1		

2305	RMS	receive APE from FF EV	HST PFR Stow	No		Large handrail	1		
2306	RMS	tether to toe loop	HST PFR Stow	No		Tether tool	1		
2307	RMS	mnvr to SA PFR stow for PFR handoff	HST PFR Stow	No		Motion	1		
2308	RMS	config HST PFR =JJ/A/AA/4	HST PFR Stow	No		Unknown	1		
2309	RMS	transfer HST PFR to FF EV	HST PFR Stow	No		Large handrail	1		
2310	FF	receive HST PFR from RMS EV	HST PFR Stow	No		Large handrail	1		
2311	FF	stow HST PFR	HST PFR Stow	No		Unknown	1		
2312	FF	check HST PFR latched	HST PFR Stow	No		Camera	1		
2313	FF	install PIP pin (HST PFR)	HST PFR Stow	No		PIP	1		
2314	FF	remove APE	HST PFR Stow	No		PIP	1	Large handrail	
2315	FF	stow APE at 15R	HST PFR Stow	No		PIP	1	Large handrail	
2316	FF	secure Velcro	HST PFR Stow	No		delicate pinch	1		
2317	FF	config PFR =NN/A/AA/4	HST PFR Stow	No		Unknown	1		
2|16		**RWA1 Removal**							
2319	RMS	mnvr to Bay 6	RWA1 Removal	Yes	move about worksite	Motion	1		
2320	RMS	stanchion 180 deg	RWA1 Removal	No		Unknown	1		
2321	RMS	Boot plate 0	RWA1 Removal	No		Unknown	1		
2322	FF	transfer trash bag to MWS	RWA1 Removal	No		delicate pinch	1		
2323	RMS	PGT: A3, CCW 3, 10.5, short adj	RWA1 Removal	Yes	set bolt drive	COMPUTER	1		
2324	RMS	drive j-bolts 4-6 turns (6-disengage)	RWA1 Removal	Yes	drive bolt	Bolt drive	6		
2325	RMS	open door	RWA1 Removal	Yes	open/close bay door	Small handrail	1		
2326	RMS	install door stay on	RWA1 Removal	Yes	install/remove	Small handrail	1		

		bay door			door stay				
2327	RMS	tighten EVA knob on bay door	RWA1 Removal	Yes	tighten/release EVA knob	Pinch	1		
2328	RMS	install door stay on EVA bolt	RWA1 Removal	Yes	tighten/release EVA knob	Pinch	1		
2329	RMS	tighten EVA knob on EVA bolt	RWA1 Removal	Yes	tighten/release EVA knob	Pinch	1		
2330	RMS	set door opening	RWA1 Removal	Yes	release/set door opening	Pinch	1		
2331	RMS	demate P1 from RWA-1	RWA1 Removal	Yes	mate/demate connector	Pinch	1		
2332	RMS	stow P1 behind RWA mount	RWA1 Removal	Yes	stow/remove connector	Pinch	1		
2333	RMS	demate P3 from RWA-1	RWA1 Removal	Yes	mate/demate connector	Pinch	1		
2334	RMS	stow P3 behind RWA mount	RWA1 Removal	Yes	stow/remove connector	Pinch	1		
2335	RMS	demate P1 from heater	RWA1 Removal	Yes	mate/demate connector	Pinch	1		
2336	RMS	velcro connector P1 to handle	RWA1 Removal	Yes	secure/remove Velcro to connector	Pinch	1	delicate pinch	1
2337	RMS	demate P2 from heater	RWA1 Removal	Yes	mate/demate connector	Pinch	1		
2338	RMS	velcro connector P2 to handle	RWA1 Removal	Yes	secure/remove Velcro to connector	Pinch	1	delicate pinch	1
2339	RMS	PGT: A6, CCW 2, 30.5	RWA1 Removal	Yes	set bolt drive	COMPUTER	1		
2340	RMS	drive keyway bolts 7 turns (3-disengage)	RWA1 Removal	Yes	drive bolt	Bolt drive	3		
2341	RMS	PGT: A4, CW 2, 23.5	RWA1 Removal	Yes	set bolt drive	COMPUTER	1		
2342	RMS	Remove RWA-1	RWA1 Removal	Yes	remove RWA	Small handrail	1	Small handrail	1
2343	FF	translate to LOPE	RWA1 Removal	Yes	move about worksite	Motion	1		

2344	FF	fairlead to LOPE	RWA1 Removal	No		Unknown	1		
2345	FF	PGT: A3, CCW 3, 10.5, 6-in wobble	RWA1 Removal	Yes	set bolt drive	COMPUTER	1		
2346	FF	drive j-bolts 5 turns (4-disengage)	RWA1 Removal	Yes	drive bolt	Bolt drive	4		
2347	FF	open lid	RWA1 Removal	Yes	open/close LOPE	Small handrail	1		
2348	FF	remove connector P1 from pouch	RWA1 Removal	Yes	stow/remove connector	Pinch	1	delicate pinch	1
2349	FF	velcro connector P1 to handle	RWA1 Removal	Yes	secure/remove Velcro to connector	Pinch	1	delicate pinch	1
2350	FF	remove connector P2 from pouch	RWA1 Removal	Yes	stow/remove connector	Pinch	1	delicate pinch	1
2351	FF	velcro connector P2 to handle	RWA1 Removal	Yes	secure/remove Velcro to connector	Pinch	1	delicate pinch	1
2352	FF	PGT: A6, CCW 2, 30.5	RWA1 Removal	Yes	set bolt drive	COMPUTER	1		
2353	FF	drive keyway bolts 7 turns (3-disengage)	RWA1 Removal	Yes	drive bolt	Bolt drive	3		
2354	FF	PGT: A4, CW 2, 23.5	RWA1 Removal	Yes	set bolt drive	COMPUTER	1		
2|17		**RWA Swap**							
2356	FF	Release Velcro strap	RWA Swap	Yes	secure/remove Velcro	delicate pinch	1		
2357	FF	Secure Velcro strap to LOPE lid	RWA Swap	Yes	secure/remove Velcro	delicate pinch	1		
2358	RMS	Mnvr to LOPE	RWA Swap	Yes	move about worksite	Motion	1		
2359	FF	Remove RWA-1R	RWA Swap	Yes	remove RWA	Small handrail	1	Small handrail	1
2360	FF	Translate to stbd MULE	RWA Swap	Yes	move about worksite	Motion	1		
2361	FF	Transfer RWA-1R to RMS EV	RWA Swap	No		Small handrail	1		
2362	RMS	Exhange RWA-1R/RWA-1	RWA Swap	Yes	exchange RWA	Small handrail	1	Small handrail	1

2363	FF	Config RWA tethers	RWA Swap	No		Tether tool	1	Small handrail	1
2364	RMS	Transfer RWA-1 to FF EV	RWA Swap	No		Small handrail	1		
2365	FF	Receive RWA-1 from RMS EV	RWA Swap	No		Small handrail	1		
2366	FF	Stow RWA-1 in LOPE	RWA Swap	Yes	stow RWA	Small handrail	1	Small handrail	1
2367	FF	Secure Velcro strap to LOPE lid	RWA Swap	Yes	secure/remove Velcro	delicate pinch	1		
2368	FF	PGT: A4, CW 2, 23.5	RWA Swap	Yes	set bolt drive	COMPUTER	1		
2369	FF	drive keyway bolts (3) 7 turns (engage)	RWA Swap	Yes	drive bolt	Bolt drive	3		
2370	FF	Stow cable P1 in pouch	RWA Swap	Yes	stow/remove connector	delicate pinch	1	delicate pinch	1
2371		Stow cable P2 in pouch	RWA Swap	Yes	stow/remove connector	delicate pinch	1	delicate pinch	1
2372	FF	PGT: A3, CW 3, 10.5	RWA Swap	Yes	set bolt drive	COMPUTER	1		
2373	FF	Close LOPE	RWA Swap	Yes	open/close LOPE	Small handrail	1		
2374	FF	drive LOPE J-bolts (4) 5 turns (engage)	RWA Swap	Yes	drive bolt	Bolt drive	4		
2|18		**RWA Installation**							
2376	RMS	mnvr to Bay 6	RWA Installation	Yes	move about worksite	Motion	1		
2377	RMS	PGT: A4, CW 2, 23.5	RWA Installation	Yes	set bolt drive	COMPUTER	1		
2378	RMS	drive keyway bolts 7 turns (3-engage)	RWA Installation	Yes	drive bolt	Bolt drive	3		
2379	RMS	drive bolts (3-retorque)	RWA Installation	Yes	drive bolt	Bolt drive	3		
2380	RMS	mate heater P1 cables	RWA Installation	Yes	mate/demate connector	Pinch	1		
2381	RMS	mate heater P2 cables	RWA Installation	Yes	mate/demate connector	Pinch	1		
2382	RMS	remove caps (2)	RWA Installation	Yes	install/remove connector cap	Pinch	2		
2383	RMS	stow caps in trash bag	RWA Installation	Yes	stow connector	Pinch	2		

					cap				
2384	RMS	inspect connector pins	RWA Installation	Yes	inspect worksite	Pinch	2	Camera	2
2385	RMS	mate P1 on RWA-1R	RWA Installation	Yes	mate/demate connector	Pinch	1		
2386	RMS	mate P3 on RWA-1R	RWA Installation	Yes	mate/demate connector	Pinch	1		
2387	RMS	remove door stay	RWA Installation	Yes	install/remove door stay	Small handrail	1		
2388	RMS	stow door stay on stanchion	RWA Installation	Yes	stow/retrieve door stay	Unknown	1		
2389	RMS	PGT: A3, CW 3, 10.5	RWA Installation	Yes	set bolt drive	COMPUTER	1		
2390	RMS	close door	RWA Installation	Yes	open/close bay door	Small handrail	1		
2391	RMS	drive j-bolts 4-6 turns (engage)	RWA Installation	Yes	drive bolt	Bolt drive	6		
2392	RMS	perform tool inventory	RWA Installation	No		Unknown	1		
2393	RMS	egress MFR	RWA Installation	No		Large handrail	1		
		DAY 3							
3|1		**MFR Setup**							
3002	RMS	transfer MFR handle to FF EV	MFR Setup	No		Small handrail	1		
3003	RMS	egress airlock	MFR Setup	No		Motion	1		
3004	RMS	attach MWS tether to boot plate lanyard	MFR Setup	No		Tether tool	1		
3005	RMS	ingress MFR	MFR Setup	No		Large handrail	1		
3006	RMS	receive MFR handle from FF EV	MFR Setup	No		Small handrail	1		
3007	RMS	install MFR handle	MFR Setup	No		Small handrail	1		
3008	RMS	rotate tool interface 180 deg	MFR Setup	No		Unknown	1		
3|2		**BAPS Post Setup**							
3010	FF	install PIP pins (2) (Center BAPS)	BAPS Post Setup	unk	install/remove PIP	PIP	2		

3|3		**Translation Aid Setup**							
3012	FF	remove PIP pin from mini-TA if nec	Translation Aid Setup	No		PIP	1		
3013	FF	rotate handle 140 deg (mini-TA)	Translation Aid Setup	No		Small handrail	1		
3014	FF	install PIP pin (mini-TA)	Translation Aid Setup	No		PIP	1		
3015	FF	install hitch pin (mini-TA)	Translation Aid Setup	No		Hitch	1		
3016	FF	extend TA tube (stbd) if nec	Translation Aid Setup	No		Small handrail	1	Small handrail	
3017	FF	rotate TA joint (stbd)	Translation Aid Setup	No		Small handrail	1		
3018	FF	extend TA tube (port) if nec	Translation Aid Setup	No		Small handrail	1	Small handrail	
3019	FF	rotate TA joint (port)	Translation Aid Setup	No		Small handrail	1		
3|4		**Bay 5 Thermal Cover**							
3021	FF	translate to Bay 5	Bay 5 Thermal Cover	Yes	move about worksite	Motion	1		
3022	FF	fairlead to TA (port)	Bay 5 Thermal Cover	No		Unknown	1		
3023	FF	check vent plugs secure	Bay 5 Thermal Cover	Yes	inspect worksite	Camera	1		
3024	FF	deploy thermal cover	Bay 5 Thermal Cover	Yes	open/close thermal cover	delicate pinch	1		
3025	FF	notify MCC bay 5 thermal cover deployed	Bay 5 Thermal Cover	Yes	notify MCC	COMPUTER	1		
3026	FF	retrieve DBA thermal cover	Bay 5 Thermal Cover	Yes	stow/retrieve thermal cover	delicate pinch	1		
3027	FF	translate to +V2 DBA-2	Bay 5 Thermal Cover	Yes	move about worksite	Motion	1		
3028	FF	install thermal cover	Bay 5 Thermal Cover	Yes	install/remove thermal cover	delicate pinch	1		

3|5		**Thermal Cover Installation**							
3030	FF	translate to Bay 10	Thermal Cover Installation	Yes	move about worksite	Motion	1		
3031	FF	check vent plugs secure	Thermal Cover Installation	Yes	inspect worksite	Camera	1		
3032	FF	deploy thermal cover	Thermal Cover Installation	Yes	open/close thermal cover	delicate pinch	1		
3033	FF	retrieve DBA thermal cover	Thermal Cover Installation	Yes	stow/retrieve thermal cover	delicate pinch	1		
3034	FF	translate to -V2 DBA-2	Thermal Cover Installation	Yes	move about worksite	Motion	1		
3035	FF	install thermal cover	Thermal Cover Installation	Yes	install/remove thermal cover	delicate pinch	1		
3036	FF	translate to FHST	Thermal Cover Installation	Yes	move about worksite	Motion	1		
3037	FF	deploy FHST covers (3)	Thermal Cover Installation	Yes	deploy/retract FHST cover	delicate pinch	3		
3038	FF	inform MCC FHST covers deployed	Thermal Cover Installation	Yes	notify MCC	COMPUTER	1		
3039	FF	translate to SAC	Thermal Cover Installation	Yes	move about worksite	Motion	1		
3040	FF	retrieve HRD	Thermal Cover Installation	Yes	stow/retrieve HRD	Small handrail	1		
3041	FF	translate to Bay 4	Thermal Cover Installation	Yes	move about worksite	Motion	1		
3042	FF	fairlead on aft/port ASIPE latch	Thermal Cover Installation	No		Unknown	1		
3043	FF	transfer HRD to RMS EV	Thermal Cover Installation	Yes	transfer HRD	Small handrail	1	Small handrail	1
3044	FF	translate to SAC	Thermal Cover Installation	Yes	move about worksite	Motion	1		
3045	FF	retrieve PCU handhold	Thermal Cover Installation	Yes	stow/retrieve PCU handhold	Small handrail	1		

3046	FF	stow PCU handhold on +V2 trunnion	Thermal Cover Installation	Yes	stow/retrieve PCU handhold	Small handrail	1		
3047	FF	translate to airlock	Thermal Cover Installation	Yes	move about worksite	Motion	1		
3048	FF	retrieve ASLRs from SAC (2)	Thermal Cover Installation	Yes	retrieve ASLR	Unknown	2		
3049	FF	stow ASLRs in airlock	Thermal Cover Installation	Yes	stow ASLR	Unknown	2		
3050	FF	ingress airlock	Thermal Cover Installation	No		Motion	1		
3051	FF	connect SCU	Thermal Cover Installation	No		Unknown	1		
3052	FF	check EV-1 O2 vlv-OP	Thermal Cover Installation	No		Camera	1		
3053	FF	check O2 P ~ 850 and stable	Thermal Cover Installation	No		Camera	1		
3054	FF	demate SCU	Thermal Cover Installation	No		Unknown	1		
3055	FF	egress airlock	Thermal Cover Installation	No		Motion	1		
3056	FF	close thermal cover	Thermal Cover Installation	Yes	open/close thermal cover	delicate pinch	1		
3057	RMS	stow PGT	Thermal Cover Installation	No		COMPUTER	1		
3058	FF	translate to MFR	Thermal Cover Installation	No		Motion	1		
3059	FF	Daisy chain extra waist tether to RMS EV	Thermal Cover Installation	No		Unknown	1		
3060	RMS	Daisy chain extra waist tether to FF EV	Thermal Cover Installation	No		Unknown	1		
3061	FF	Disconnect RMS EV's safety tether from EMU D-ring	Thermal Cover Installation	No		Tether tool	1		
3062	RMS	Disconnect FF EV's safety tether from	Thermal Cover Installation	No		Tether tool	1		

		EMU D-ring							
3063	FF	Mate RMS EV's safety tether to FF EV EMU D-ring	Thermal Cover Installation	No		Tether tool	1		
3064	RMS	Mate FF EV's safety tether to RMS EV EMU D-ring	Thermal Cover Installation	No		Tether tool	1		
3065	FF	Check safety tether gate closed	Thermal Cover Installation	No		Camera	1		
3066	RMS	Check safety tether gate closed	Thermal Cover Installation	No		Camera	1		
3067	FF	Disconnect RMS EV's prime waist tether from EMU D-ring	Thermal Cover Installation	No		Tether tool	1		
3068	RMS	Disconnect FF EV's prime waist tether from EMU D-ring	Thermal Cover Installation	No		Tether tool	1		
3069	FF	Mate RMS EV's prime waist tether to FF EV EMU D-ring	Thermal Cover Installation	No		Tether tool	1		
3070	RMS	Mate FF EV's prime waist tether to RMS EV EMU D-ring	Thermal Cover Installation	No		Tether tool	1		
3071	FF	Disconnect extra waist tether daisy chain	Thermal Cover Installation	No		Unknown	1		
3072	RMS	Disconnect extra waist tether daisy chain	Thermal Cover Installation	No		Unknown	1		
3073	RMS	PGT swap if nec	Thermal Cover Installation	No		Large handrail	1		
3074	FF	PGT swap if nec	Thermal Cover Installation	No		Large handrail	1		
3075	FF	stow PCU connector	Thermal Cover	No		COMPUTER	1		

		tool	Installation						
3076	FF	stow PCU caddy on stanchion	Thermal Cover Installation	Yes	stow PCU caddy	Unknown	1		
3077	FF	transfer PCU handhold	Thermal Cover Installation	Yes	transfer PCU handhold	Small handrail	1	Small handrail	1
3078	FF	retrieve PCU handhold tether	Thermal Cover Installation	No		delicate pinch	1		
3079	FF	transfer PCU handhold tether to RMS EV	Thermal Cover Installation	No		delicate pinch	1		
3|6		**Bay 3 Battery Demate**							
3081	RMS	mnvr to Bay 3	Bay 3 Battery Demate	Yes	move about worksite	Motion	1		
3082	RMS	stanchion 180 deg	Bay 3 Battery Demate	No		Unknown	1		
3083	RMS	Boot plate 0 deg	Bay 3 Battery Demate	No		Unknown	1		
3084	RMS	PGT: A3, CCW 3, 10.5, 12-in wobble	Bay 3 Battery Demate	Yes	set bolt drive	COMPUTER	1		
3085	RMS	drive j-bolt 4-6 turns (1-disengage)	Bay 3 Battery Demate	Yes	drive bolt	Bolt drive	1		
3086	RMS	open door	Bay 3 Battery Demate	Yes	open/close bay door	Small handrail	1		
3087	RMS	install door stay on bay door	Bay 3 Battery Demate	Yes	install/remove door stay	Small handrail	1		
3088	RMS	tighten EVA knob on bay door	Bay 3 Battery Demate	Yes	tighten/release EVA knob	Pinch	1		
3089	RMS	install door stay on EVA bolt	Bay 3 Battery Demate	Yes	tighten/release EVA knob	Pinch	1		
3090	RMS	tighten EVA knob on bolt	Bay 3 Battery Demate	Yes	tighten/release EVA knob	Pinch	1		
3091	RMS	set door opening	Bay 3 Battery Demate	Yes	release/set door opening	Pinch	1		
3092	RMS	boot plate 90L	Bay 3 Battery	No		Unknown	1		

			Demate						
3093	RMS	inform MCC starting Bay 3 battery demate	Bay 3 Battery Demate	Yes	notify MCC	COMPUTER	1		
3094	RMS	demate P1A	Bay 3 Battery Demate	Yes	mate/demate connector	Pinch	1		
3095	RMS	install cap on J1A	Bay 3 Battery Demate	Yes	install/remove connector cap	Pinch	1	Pinch	1
3096	RMS	mate P1A to cap	Bay 3 Battery Demate	Yes	mate/demate connector	Pinch	1	Pinch	1
3097	RMS	demate P1B	Bay 3 Battery Demate	Yes	mate/demate connector	Pinch	1		
3098	RMS	install cap on J1B	Bay 3 Battery Demate	Yes	install/remove connector cap	Pinch	1	Pinch	1
3099	RMS	mate P1B to cap	Bay 3 Battery Demate	Yes	mate/demate connector	Pinch	1	Pinch	1
3100	RMS	demate P1C	Bay 3 Battery Demate	Yes	mate/demate connector	Pinch	1		
3101	RMS	install cap on J1C	Bay 3 Battery Demate	Yes	install/remove connector cap	Pinch	1	Pinch	1
3102	RMS	mate P1C to cap	Bay 3 Battery Demate	Yes	mate/demate connector	Pinch	1	Pinch	1
3103	RMS	release door opening	Bay 3 Battery Demate	Yes	release/set door opening	Pinch	1		
3104	RMS	Release door stay from EVA bolt	Bay 3 Battery Demate	Yes	tighten/release EVA knob	Pinch	1		
3105	RMS	Remove door stay from EVA bolt	Bay 3 Battery Demate	Yes	tighten/release EVA knob	Pinch	1		
3106	RMS	Release door stay from bay door	Bay 3 Battery Demate	Yes	install/remove door stay	Small handrail	1		
3107	RMS	Remove door stay from bay door	Bay 3 Battery Demate	Yes	install/remove door stay	Small handrail	1		
3108	RMS	close door	Bay 3 Battery Demate	Yes	open/close bay door	Small handrail	1		
3109	RMS	drive j-bolt (engage)	Bay 3 Battery	Yes	drive bolt	Bolt drive	1		

			Demate						
3|7		**Bay 2 Battery Demate**							
3111	RMS	mnvr to Bay 2	Bay 2 Battery Demate	Yes	move about worksite	Motion	1		
3112	RMS	stanchion 180 deg	Bay 2 Battery Demate	No		Unknown	1		
3113	RMS	Boot plate 0 deg	Bay 2 Battery Demate	No		Unknown	1		
3114	RMS	PGT: A3, CCW 3, 10.5	Bay 2 Battery Demate	Yes	set bolt drive	COMPUTER	1		
3115	RMS	drive j-bolt 4-6 turns (disengage)	Bay 2 Battery Demate	Yes	drive bolt	Bolt drive	1		
3116	RMS	open door	Bay 2 Battery Demate	Yes	open/close bay door	Small handrail	1		
3117	RMS	install door stay on bay door	Bay 2 Battery Demate	Yes	install/remove door stay	Small handrail	1		
3118	RMS	tighten EVA knob on bay door	Bay 2 Battery Demate	Yes	tighten/release EVA knob	Pinch	1		
3119	RMS	install door stay on EVA bolt	Bay 2 Battery Demate	Yes	tighten/release EVA knob	Pinch	1		
3120	RMS	tighten EVA knob on EVA bolt	Bay 2 Battery Demate	Yes	tighten/release EVA knob	Pinch	1		
3121	RMS	set door opening	Bay 2 Battery Demate	Yes	release/set door opening	Pinch	1		
3122	RMS	boot plate 90R	Bay 2 Battery Demate	No		Unknown	1		
3123	RMS	inform MCC starting Bay 2 battery demate	Bay 2 Battery Demate	Yes	notify MCC	COMPUTER	1		
3124	RMS	demate P1A	Bay 2 Battery Demate	Yes	mate/demate connector	Pinch	1		
3125	RMS	install cap on J1A	Bay 2 Battery Demate	Yes	install/remove connector cap	Pinch	1	Pinch	1
3126	RMS	mate P1A to cap	Bay 2 Battery Demate	Yes	mate/demate connector	Pinch	1	Pinch	1

3127	RMS	demate P1B	Bay 2 Battery Demate	Yes	mate/demate connector	Pinch	1		
3128	RMS	install cap on J1B	Bay 2 Battery Demate	Yes	install/remove connector cap	Pinch	1	Pinch	1
3129	RMS	mate P1B to cap	Bay 2 Battery Demate	Yes	mate/demate connector	Pinch	1	Pinch	1
3130	RMS	demate P1C	Bay 2 Battery Demate	Yes	mate/demate connector	Pinch	1		
3131	RMS	install cap on J1C	Bay 2 Battery Demate	Yes	install/remove connector cap	Pinch	1	Pinch	1
3132	RMS	mate P1C to cap	Bay 2 Battery Demate	Yes	mate/demate connector	Pinch	1	Pinch	1
3133	RMS	release door opening	Bay 2 Battery Demate	Yes	release/set door opening	Pinch	1		
3134	RMS	Release door stay from EVA bolt	Bay 2 Battery Demate	Yes	tighten/release EVA knob	Pinch	1		
3135	RMS	Remove door stay from EVA bolt	Bay 2 Battery Demate	Yes	tighten/release EVA knob	Pinch	1		
3136	RMS	Release door stay from bay door	Bay 2 Battery Demate	Yes	install/remove door stay	Small handrail	1		
3137	RMS	Remove door stay from bay door	Bay 2 Battery Demate	Yes	install/remove door stay	Small handrail	1		
3138	RMS	close door	Bay 2 Battery Demate	Yes	open/close bay door	Small handrail	1		
3139	RMS	drive j-bolt (engage)	Bay 2 Battery Demate	Yes	drive bolt	Bolt drive	1		
3|8		**Bay 4 Setup**							
3141	RMS	mnvr to Bay 4	Bay 4 Setup	Yes	move about worksite	Motion	1		
3142	RMS	stanchion 135R	Bay 4 Setup	No		Unknown	1		
3143	RMS	Boot plate 0 deg	Bay 4 Setup	No		Unknown	1		
3144	RMS	retrieve manual doorstay from MFR handle	Bay 4 Setup	Yes	stow/retrieve door stay	Small handrail	1		
3145	RMS	transfer connector	Bay 4 Setup	No		COMPUTER	1		

		tool							
3146	RMS	PGT: A3, CCW 3, 10.5	Bay 4 Setup	Yes	set bolt drive	COMPUTER	1		
3147	RMS	drive j-bolt 4-6 turns (disengage)	Bay 4 Setup	Yes	drive bolt	Bolt drive	1		
3148	RMS	open door	Bay 4 Setup	Yes	open/close bay door	Small handrail	1		
3149	RMS	transfer HRD	Bay 4 Setup	Yes	transfer HRD	Small handrail	1	Small handrail	1
3150	RMS	install HRD	Bay 4 Setup	Yes	install/remove HRD	Small handrail	1		
3151	RMS	retrieve door stay	Bay 4 Setup	Yes	stow/retrieve door stay	Small handrail	1		
3152	RMS	install door stay on bay door	Bay 4 Setup	Yes	install/remove door stay	Small handrail	1		
3153	RMS	tighten EVA knob on bay door	Bay 4 Setup	Yes	tighten/release EVA knob	Pinch	1		
3154	RMS	install door stay on EVA bolt	Bay 4 Setup	Yes	tighten/release EVA knob	Pinch	1		
3155	RMS	tighten EVA knob on EVA bolt	Bay 4 Setup	Yes	tighten/release EVA knob	Pinch	1		
3156	RMS	set door opening	Bay 4 Setup	Yes	release/set door opening	Pinch	1		
3157	RMS	retrieve PDU fuse plug caddy from stanchion (on MCC GO)	Bay 4 Setup	Yes	stow/retrieve PDU fuse plug caddy	Pinch	1		
3158	RMS	install PDU fuse plug caddy	Bay 4 Setup	Yes	install/remove PDU fuse plug caddy	Pinch	1	Pinch	1
3159	RMS	open PDU fuse plug caddy	Bay 4 Setup	Yes	open/close PDU fuse plug caddy cover	delicate pinch	1		
3160	RMS	remove fuse plug on MCC GO	Bay 4 Setup	Yes	install/remove fuse plug	Pinch	1		
3161	RMS	stow fuse plug in	Bay 4 Setup	Yes	stow fuse plug	Pinch	1		

		caddy							
3162	RMS	install stringer cap	Bay 4 Setup	Yes	install/remove stringer cap	Unknown	1		
3163	RMS	close PDU fuse plug caddy cover	Bay 4 Setup	Yes	open/close PDU fuse plug caddy cover	delicate pinch	1		
3164	RMS	boot plate 0 deg	Bay 4 Setup	No		Unknown	1		
3165	RMS	PGT: A3, CCW 3, 10.5	Bay 4 Setup	Yes	set bolt drive	COMPUTER	1		
3166	RMS	drive PCU keyway bolts (left-2 & right-5) 6 turns (disengage)	Bay 4 Setup	Yes	drive bolt	Bolt drive	7		
3|9		**PCU Demate**							
3168	RMS	Demate connectors (28-left side PCU)	PCU Demate	Yes	mate/demate PCU connector	HT Pinch	28		
3169	RMS	Stow connectors (PCU) on HRD	PCU Demate	Yes	stow PCU connector	HT Pinch	28	Pinch on HRD	28
3170	FF	Translate to MFR	MFR Swap	No		Motion	1		
3171	FF	Daisy chain extra waist tether to RMS EV	MFR Swap	No		Unknown	1		
3172	RMS	Daisy chain extra waist tether to FF EV	MFR Swap	No		Unknown	1		
3173	FF	Disconnect RMS EV's safety tether from EMU D-ring	MFR Swap	No		Tether tool	1		
3174	RMS	Disconnect FF EV's safety tether from EMU D-ring	MFR Swap	No		Tether tool	1		
3175	FF	Mate RMS EV's safety tether to FF EV EMU D-ring	MFR Swap	No		Tether tool	1		
3176	RMS	Mate FF EV's safety tether to RMS EV EMU D-ring	MFR Swap	No		Tether tool	1		

3177	FF	Check safety tether gate closed	MFR Swap	No		Camera	1		
3178	RMS	Check safety tether gate closed	MFR Swap	No		Camera	1		
3179	FF	Disconnect RMS EV's prime waist tether from EMU D-ring	MFR Swap	No		Tether tool	1		
3180	RMS	Disconnect FF EV's prime waist tether from EMU D-ring	MFR Swap	No		Tether tool	1		
3181	FF	Mate RMS EV's prime waist tether to FF EV EMU D-ring	MFR Swap	No		Tether tool	1		
3182	RMS	Mate FF EV's prime waist tether to RMS EV EMU D-ring	MFR Swap	No		Tether tool	1		
3183	FF	Disconnect extra waist tether daisy chain	MFR Swap	No		Unknown	1		
3184	RMS	Disconnect extra waist tether daisy chain	MFR Swap	No		Unknown	1		
3185	FF	PGT swap (if required)	MFR Swap	No		Large handrail	1		
3186	RMS	PGT swap (if required)	MFR Swap	No		Large handrail	1		
3187	FF	stow PCU connector tool	PCU Demate	No		COMPUTER	1		
3188	FF	stow PCU caddy on stanchion	PCU Demate	Yes	stow PCU caddy	Unknown	1		
3189	RMS	Retrieve PCU connector tool	PCU Demate	No		COMPUTER	1		
3190	RMS	Retrieve inspection mirror	PCU Demate	unk	retrieve inspection mirror	Pinch	1		

3191	RMS	Demate connectors (left-6 & bottom-2) (PCU)	PCU Demate	Yes	mate/demate PCU connector	Pinch on retainer	8	HT Pinch	8
3192	RMS	PGT: A3, CCW 3, 10.5	PCU Demate	Yes	set bolt drive	COMPUTER	1		
3193	RMS	drive PCU keyway bolts (left) 6 turns (3-disengage)	PCU Demate	Yes	drive bolt	Bolt drive	3		
3194	FF	Transfer PCU handhold	PCU Demate	Yes	transfer PCU handhold	Small handrail	1	Small handrail	1
3195	RMS	Receive PCU handhold from FF EV	PCU Demate	No		Small handrail	1		
3196	FF	Retrieve PCU handhold tether	PCU Demate	No		delicate pinch	1		
3197	FF	Transfer PCU handhold tether to RMS EV	PCU Demate	No		delicate pinch	1		
3198	RMS	Install PCU handhold	PCU Demate	Yes	install PCU handhold	Small handrail	1	Small handrail	1
3199	RMS	Receive PCU handhold tether from FF EV	PCU Demate	No		delicate pinch	1		
3200	RMS	PGT: A3, CCW 1, 10.5	PCU Demate	Yes	set bolt drive	COMPUTER	1		
3201	RMS	drive groundstrap bolt 2-3 turns (disengage)	PCU Demate	Yes	drive bolt	Bolt drive	1		
3202	RMS	PGT: A3, CCW 3, 10.5	PCU Demate	Yes	set bolt drive	COMPUTER	1		
3203	RMS	drive PCU keyway bolt (bottom right) 6 turns (disengage)	PCU Demate	Yes	drive bolt	Bolt drive	1		
3|10		**PCU Swap**							
3205	FF	Translate to stbd SAC, PCU-R	PCU Swap	Yes	move about worksite	Motion	1		
3206	FF	Open PCU-R thermal cover	PCU Swap	Yes	open/close thermal cover	delicate pinch	1		

3207	FF	secure Velcro strap on PCU-R thermal cover (restrain)	PCU Swap	Yes	secure/remove Velcro	delicate pinch	1	delicate pinch	1
3208	FF	Ingress PFR	PCU Swap	No		Large handrail	1		
3209	FF	Config HST PFR (AS: 90L, P=10.5, PFR: Y=6, R=A, P=10.5)	PCU Swap	No		Unknown	1		
3210	FF	PGT: A3, CCW 3, 10.5, 12-in wobble	PCU Swap	Yes	set bolt drive	COMPUTER	1		
3211	FF	drive keyway bolts (6) 6 (4-6) turns (disengage)	PCU Swap	Yes	drive bolt	Bolt drive	6		
3212	FF	Remove PCU-R	PCU Swap	Yes	remove PCU	Small handrail	1		
3213	RMS	Remove PCU	PCU Swap	Yes	remove PCU	Small handrail	1		
3214	RMS	Mnvr to SAC	PCU Swap	Yes	move about worksite	Motion	1		
3215	FF	Exchange PCU/PCU-R	PCU Swap	Yes	exchange PCU	Small handrail	1	Small handrail	1
3216	RMS	Receive PCU-R from FF EV	PCU Swap	No		Small handrail	1		
3217	RMS	Transfer PCU to FF EV	PCU Swap	No		Small handrail	1		
3218	FF	Receive PCU from RMS EV	PCU Swap	No		Small handrail	1		
3219	FF	Stow PCU on SAC (connectors inboard)	PCU Swap	Yes	stow PCU	Small handrail	1	Small handrail	1
3220	FF	PGT: A3, CW 3, 10.5	PCU Swap	Yes	set bolt drive	COMPUTER	1		
3221	FF	drive keyway bolts (6) 6 (4-6) turns (engage)	PCU Swap	Yes	drive bolt	Bolt drive	6		
3222	FF	Tighten PCU handhold wing bolts (2)	PCU Swap	Yes	tighten wing bolt	Pinch	2		
3223	FF	Egress PFR	PCU Swap	No		Large handrail	1		

3224	FF	install thermal cover (PCU)	PCU Swap	Yes	install/remove thermal cover	delicate pinch	1		
3|11		**PCU-R Mate**							
3226	RMS	Mate connectors (2-bottom PCU-R)	PCU-R Mate	Yes	mate/demate PCU connector	Pinch on retainer	2	HT Pinch	2
3227	RMS	Mate connectors (34-left PCU-R)	PCU-R Mate	Yes	mate/demate PCU connector	Pinch on retainer	34	HT Pinch	34
3228	RMS	Stow J13/J14 saver caps in trash bag	PCU-R Mate	Yes	stow connector cap	Pinch	2		
3|12		**V2 Aft Shroud Handrail Covers**							
3230	FF	inspect +/- V2 handrails used for ACS and NCS	V2 Aft Shroud Handrail Covers	Yes	inspect worksite	Camera	1		
3231	FF	retrieve handrail covers from ASIPE	V2 Aft Shroud Handrail Covers	Yes	retrieve handrail covers	Unknown	1		
3232	FF	install handrail covers	V2 Aft Shroud Handrail Covers	Yes	install handrail covers	Unknown	1		
3233	FF	config HST PFR (aft ASIPE) for ACS	V2 Aft Shroud Handrail Covers	No		Unknown	1		
3|13		**Bay 4 Cleanup**							
3235	RMS	remove stringer cap	Bay 4 Cleanup	Yes	install/remove stringer cap	Unknown	1		
3236	RMS	read fuse plug serial number	Bay 4 Cleanup	Yes	inspect worksite	Pinch	1	Camera	1
3237	RMS	install fuse plug (reinstall)	Bay 4 Cleanup	Yes	install/remove fuse plug	Pinch	1		
3238	RMS	close PDU fuse plug caddy cover	Bay 4 Cleanup	Yes	open/close PDU fuse plug caddy cover	delicate pinch	1		
3239	RMS	remove PDU fuse plug caddy	Bay 4 Cleanup	Yes	install/remove PDU fuse plug caddy	Pinch	1	Pinch	1

3240	RMS	stow PDU fuse plug caddy on stanchion	Bay 4 Cleanup	Yes	stow/retrieve PDU fuse plug caddy	Pinch			
3241	RMS	remove HRD	Bay 4 Cleanup	Yes	install/remove HRD	Small handrail	1		
3242	RMS	stow HRD on +V2 trunnion (temp)	Bay 4 Cleanup	Yes	stow/retrieve HRD	Small handrail	1		
3243	RMS	remove door stay	Bay 4 Cleanup	Yes	install/remove door stay	Small handrail	1		
3244	RMS	stow door stay on stanchion	Bay 4 Cleanup	Yes	stow/retrieve door stay	Unknown	1		
3245	RMS	PGT: A3, CW 3, 10.5	Bay 4 Cleanup	Yes	set bolt drive	COMPUTER	1		
3246	RMS	close door	Bay 4 Cleanup	Yes	open/close bay door	Small handrail	1		
3247	RMS	drive j-bolt 4-6 turns (engage)	Bay 4 Cleanup	Yes	drive bolt	Bolt drive	1		
3|14		**Thermal Cover Removal**							
3249	FF	translate to +V2 DBA-2	Thermal Cover Removal	Yes	move about worksite	Motion	1		
3250	FF	retrieve thermal cover	Thermal Cover Removal	Yes	stow/retrieve thermal cover	delicate pinch	1		
3251	FF	stow thermal cover on Bay 5	Thermal Cover Removal	Yes	stow/retrieve thermal cover	delicate pinch	1		
3252	FF	retract Bay 5 thermal cover	Thermal Cover Removal	Yes	install/remove thermal cover	delicate pinch	1		
3253	FF	check cross-strap harness clip installed	Thermal Cover Removal	Yes	inspect worksite	Camera	1		
3254	FF	translate to -V2 DBA-2	Thermal Cover Removal	Yes	move about worksite	Motion	1		
3255	FF	retrieve thermal cover	Thermal Cover Removal	Yes	stow/retrieve thermal cover	delicate pinch	1		
3256	FF	stow thermal cover on Bay 10	Thermal Cover Removal	Yes	stow/retrieve thermal cover	delicate pinch	1		
3257	FF	translate to +V2	Thermal Cover	Yes	move about	Motion	1		

		trunnion	Removal		worksite				
3258	FF	retrieve HRD	Thermal Cover Removal	Yes	stow/retrieve HRD	Small handrail	1		
3259	FF	retrieve tether	Thermal Cover Removal	No		delicate pinch	1		
3260	FF	translate to SAC	Thermal Cover Removal	Yes	move about worksite	Motion	1		
3261	FF	stow HRD	Thermal Cover Removal	Yes	stow/retrieve HRD	Small handrail	1		
3262	FF	check MCC GO for FHST cover retraction	Thermal Cover Removal	Yes	check GO	COMPUTER	1		
3263	FF	translate to -V3 doors	Thermal Cover Removal	Yes	move about worksite	Motion	1		
3264	FF	retract FHST covers (center first)	Thermal Cover Removal	Yes	deploy/retract FHST cover	delicate pinch	3		
3265	FF	translate to SAC	Thermal Cover Removal	Yes	move about worksite	Motion	1		
3266	FF	retrieve ASLRs (2)	Thermal Cover Removal	Yes	retrieve ASLR	Unknown	2		
3267	FF	translate to airlock	Thermal Cover Removal	Yes	move about worksite	Motion	1		
3268	FF	stow ASLRs (2) (temp)	Thermal Cover Removal	Yes	stow ASLR	Unknown	2		
3|15		**Bay 3 Battery Mate**							
3270	RMS	check MCC GO for Bay 2 & 3 battery mate	Bay 3 Battery Mate	Yes	check GO	COMPUTER	1		
3271	RMS	mnvr to Bay 3	Bay 3 Battery Mate	Yes	move about worksite	Motion	1		
3272	RMS	stanchion 180 deg	Bay 3 Battery Mate	No		Unknown	1		
3273	RMS	boot plate 0 deg	Bay 3 Battery Mate	No		Unknown	1		
3274	RMS	PGT: A3, CCW 3, 10.5	Bay 3 Battery Mate	Yes	set bolt drive	COMPUTER	1		
3275	RMS	drive j-bolt (release)	Bay 3 Battery Mate	Yes	drive bolt	Bolt drive	1		

3276	RMS	open door	Bay 3 Battery Mate	Yes	open/close bay door	Small handrail	1		
3277	RMS	install door stay on bay door	Bay 3 Battery Mate	Yes	install/remove door stay	Small handrail	1		
3278	RMS	tighten EVA knob on bay door	Bay 3 Battery Mate	Yes	tighten/release EVA knob	Pinch	1		
3279	RMS	install door stay on EVA bolt	Bay 3 Battery Mate	Yes	tighten/release EVA knob	Pinch	1		
3280	RMS	tighten EVA knob on EVA bolt	Bay 3 Battery Mate	Yes	tighten/release EVA knob	Pinch	1		
3281	RMS	set door opening	Bay 3 Battery Mate	Yes	release/set door opening	Pinch	1		
3282	RMS	boot plate 90L	Bay 3 Battery Mate	No		Unknown	1		
3283	RMS	demate P1A	Bay 3 Battery Mate	Yes	mate/demate connector	Pinch	1		
3284	RMS	demate cap from J1A	Bay 3 Battery Mate	Yes	install/remove connector cap	Pinch	1	Pinch	1
3285	RMS	mate P1A to J1A	Bay 3 Battery Mate	Yes	mate/demate connector	Pinch	1	Pinch	1
3286	RMS	demate P1B	Bay 3 Battery Mate	Yes	mate/demate connector	Pinch	1		
3287	RMS	demate cap from J1B	Bay 3 Battery Mate	Yes	install/remove connector cap	Pinch	1	Pinch	1
3288	RMS	mate P1B to J1B	Bay 3 Battery Mate	Yes	mate/demate connector	Pinch	1	Pinch	1
3289	RMS	demate P1C	Bay 3 Battery Mate	Yes	mate/demate connector	Pinch	1		
3290	RMS	demate cap from J1C	Bay 3 Battery Mate	Yes	install/remove connector cap	Pinch	1	Pinch	1
3291	RMS	mate P1C to J1C	Bay 3 Battery Mate	Yes	mate/demate connector	Pinch	1	Pinch	1
3292	RMS	remove door opening	Bay 3 Battery Mate	Yes	release/set door opening	Pinch	1		
3293	RMS	remove EVA knob from EVA bolt	Bay 3 Battery Mate	Yes	tighten/release EVA knob	Pinch	1		

3294	RMS	Remove door stay from EVA bolt	Bay 3 Battery Mate	Yes	tighten/release EVA knob	Pinch	1		
3295	RMS	remove EVA knob from bay door	Bay 3 Battery Mate	Yes	tighten/release EVA knob	Pinch	1		
3296	RMS	Remove door stay from bay door	Bay 3 Battery Mate	Yes	install/remove door stay	Small handrail	1		
3297	RMS	PGT: A3, CW 3, 10.5	Bay 3 Battery Mate	Yes	set bolt drive	COMPUTER	1		
3298	RMS	close door	Bay 3 Battery Mate	Yes	open/close bay door	Small handrail	1		
3299	RMS	drive j-bolt 4-6 turns (engage)	Bay 3 Battery Mate	Yes	drive bolt	Bolt drive	1		
3|16		**Bay 2 Battery Mate**							
3301	RMS	mnvr to Bay 2	Bay 2 Battery Mate	Yes	move about worksite	Motion	1		
3302	RMS	stanchion 180 deg	Bay 2 Battery Mate	No		Unknown	1		
3303	RMS	boot plate 0 deg	Bay 2 Battery Mate	No		Unknown	1		
3304	RMS	PGT: A3, CCW 3, 10.5	Bay 2 Battery Mate	Yes	set bolt drive	COMPUTER	1		
3305	RMS	drive j-bolt (release)	Bay 2 Battery Mate	Yes	drive bolt	Bolt drive	1		
3306	RMS	open door	Bay 2 Battery Mate	Yes	open/close bay door	Small handrail	1		
3307	RMS	install door stay on bay door	Bay 2 Battery Mate	Yes	install/remove door stay	Small handrail	1		
3308	RMS	tighten EVA knob on bay door	Bay 2 Battery Mate	Yes	tighten/release EVA knob	Pinch	1		
3309	RMS	install door stay on EVA bolt	Bay 2 Battery Mate	Yes	tighten/release EVA knob	Pinch	1		
3310	RMS	tighten EVA knob on EVA bolt	Bay 2 Battery Mate	Yes	tighten/release EVA knob	Pinch	1		
3311	RMS	set door opening	Bay 2 Battery Mate	Yes	release/set door opening	Pinch	1		
3312	RMS	boot plate 90R	Bay 2 Battery Mate	No		Unknown	1		
3313	RMS	demate P1A	Bay 2 Battery Mate	Yes	mate/demate connector	Pinch	1		

3314	RMS	demate cap from J1A	Bay 2 Battery Mate	Yes	install/remove connector cap	Pinch	1	Pinch	1
3315	RMS	mate P1A to J1A	Bay 2 Battery Mate	Yes	mate/demate connector	Pinch	1	Pinch	1
3316	RMS	demate P1B	Bay 2 Battery Mate	Yes	mate/demate connector	Pinch	1		
3317	RMS	demate cap from J1B	Bay 2 Battery Mate	Yes	install/remove connector cap	Pinch	1	Pinch	1
3318	RMS	mate P1B to J1B	Bay 2 Battery Mate	Yes	mate/demate connector	Pinch	1	Pinch	1
3319	RMS	demate P1C	Bay 2 Battery Mate	Yes	mate/demate connector	Pinch	1		
3320	RMS	demate cap from J1C	Bay 2 Battery Mate	Yes	install/remove connector cap	Pinch	1	Pinch	1
3321	RMS	mate P1C to J1C	Bay 2 Battery Mate	Yes	mate/demate connector	Pinch	1	Pinch	1
3322	RMS	notify MCC Bay 2 and 3 battery connectors mated	Bay 2 Battery Mate	Yes	notify MCC	COMPUTER	1		
3323	RMS	remove door opening	Bay 2 Battery Mate	Yes	release/set door opening	Pinch	1		
3324	RMS	remove EVA knob from EVA bolt	Bay 2 Battery Mate	Yes	tighten/release EVA knob	Pinch	1		
3325	RMS	Remove door stay from EVA bolt	Bay 2 Battery Mate	Yes	tighten/release EVA knob	Pinch	1		
3326	RMS	remove EVA knob from bay door	Bay 2 Battery Mate	Yes	tighten/release EVA knob	Pinch	1		
3327	RMS	Remove door stay from bay door	Bay 2 Battery Mate	Yes	install/remove door stay	Small handrail	1		
3328	RMS	PGT: A3, CW 3, 10.5	Bay 2 Battery Mate	Yes	set bolt drive	COMPUTER	1		
3329	RMS	close door	Bay 2 Battery Mate	Yes	open/close bay door	Small handrail	1		
3330	RMS	drive j-bolt 4-6 turns (engage)	Bay 2 Battery Mate	Yes	drive bolt	Bolt drive	1		

3331	RMS	drive j-bolts (bays 2-4) 4-6 turns (engage)	Bay 2 Battery Mate	Yes	drive bolt	Bolt drive	3		
3|17		**FHST & WF/PC Cover Removal**							
3333	FF	Remove WF/PC (assist RMS EV as required)	FHST & WF/PC Cover Removal	No		Small handrail	1	delicate pinch	1
3334	FF	Remove FHST covers (assist RMS EV as required)	FHST & WF/PC Cover Removal	No		delicate pinch	3		
3335	RMS	Mnvr to FHST covers	FHST & WF/PC Cover Removal	Yes	move about worksite	Motion	1		
3336	RMS	Remove FHST covers	FHST & WF/PC Cover Removal	Yes	install/remove FHST cover	Unknown	3		
3337	RMS	Slide FHST covers together	FHST & WF/PC Cover Removal	Yes	slide FHST covers together	delicate pinch	3	delicate pinch	3
3338	RMS	secure Velcro restraint to FHST covers	FHST & WF/PC Cover Removal	Yes	secure/remove Velcro	delicate pinch	1		
3339	RMS	Mnvr to WF/PC cover	FHST & WF/PC Cover Removal	Yes	move about worksite	Motion	1		
3340	RMS	Remove WF/PC cover	FHST & WF/PC Cover Removal	Yes	install/remove WF/PC cover	Small handrail	1	delicate pinch	1
3341	RMS	Tighten WF/PC cover zip nuts (2)	FHST & WF/PC Cover Removal	Yes	engage zip nut	Pinch	2		
3342	RMS	Mnvr to SAC	FHST & WF/PC Cover Removal	Yes	move about worksite	Motion	1		
3343	FF	Transfer FHST covers	FHST & WF/PC Cover Removal	Yes	transfer FHST covers	delicate pinch	1	delicate pinch	1
3344	FF	Receive FHST covers from RMS EV	FHST & WF/PC Cover Removal	No		delicate pinch	1		
3345	FF	Stow FHST covers	FHST & WF/PC Cover Removal	Yes	stow/retrieve FHST cover	delicate pinch	1		

3346	FF	secure Velcro (grounding) for FHST cover	FHST & WF/PC Cover Removal	Yes	secure/remove Velcro	delicate pinch	1	delicate pinch	1
3347	RMS	Transfer WF/PC cover	FHST & WF/PC Cover Removal	Yes	transfer WF/PC cover	Small handrail	1	Small handrail	1
3348	FF	Receive WF/PC cover from RMS EV	FHST & WF/PC Cover Removal	No		Small handrail	1		
3349	FF	Stow WF/PC cover	FHST & WF/PC Cover Removal	Yes	stow/retrieve WF/PC cover	Small handrail	1		
3350	FF	secure Velcro (grounding) for WF/PC cover	FHST & WF/PC Cover Removal	Yes	secure/remove Velcro	delicate pinch	1	delicate pinch	1
3|18		**Bay 5 MLI Removal**							
3352	RMS	stanchion setup (if necessary)	Bay 5 MLI Removal	No		Unknown	1		
3353	RMS	boot plate setup	Bay 5 MLI Removal	No		Unknown	1		
3354	FF	translate to stbd ASIPE pouch	Bay 5 MLI Removal	Yes	move about worksite	Motion	1		
3355	FF	retrieve Bay 5 MLI recovery bag	Bay 5 MLI Removal	Yes	stow/retrieve MLI recovery bag	delicate pinch	1		
3356	FF	translate to Bay 5	Bay 5 MLI Removal	Yes	move about worksite	Motion	1		
3357	RMS	mnvr to HST Bay 5	Bay 5 MLI Removal	Yes	move about worksite	Motion	1		
3358	RMS	release Velcro	Bay 5 MLI Removal	Yes	secure/remove Velcro	delicate pinch	1		
3359	RMS	cut Bay 5 door MLI ground straps (2)	Bay 5 MLI Removal	Yes	cut MLI groundstraps	Unknown	2		
3360	FF	transfer Bay 5 MLI recovery bag	Bay 5 MLI Removal	Yes	transfer MLI recovery bag	delicate pinch	1	delicate pinch	1
3361	RMS	receive MLI recovery bag from FF EV	Bay 5 MLI Removal	No		delicate pinch	1		
3362	RMS	stow MLI recovery bag on MWS	Bay 5 MLI Removal	Yes	stow/retrieve MLI recovery	delicate pinch	1		

					bag				
3363	RMS	fold MLI	Bay 5 MLI Removal	Yes	fold MLI	delicate pinch	1	delicate pinch	1
3364	RMS	stow in Bay 5 MLI recovery bag	Bay 5 MLI Removal	Yes	stow MLI	delicate pinch	1		
3365	RMS	transfer MLI recovery bag to stanchion	Bay 5 MLI Removal	Yes	transfer MLI recovery bag	delicate pinch	1	delicate pinch	
3|19		**Bay 5 & 6 NOBL Retrieval**							
3367	RMS	mnvr to NT	Bay 5 & 6 NOBL Retrieval	Yes	move about worksite	Motion	1		
3368	RMS	stanchion 135R	Bay 5 & 6 NOBL Retrieval	No		Unknown	1		
3369	RMS	Boot plate 90L	Bay 5 & 6 NOBL Retrieval	No		Unknown	1		
3370	FF	translate to NT	Bay 5 & 6 NOBL Retrieval	Yes	move about worksite	Motion	1		
3371	FF	retrieve NOBL plug stringer	Bay 5 & 6 NOBL Retrieval	Yes	stow/retrieve plug stringer	delicate pinch	1		
3372	FF	transfer NOBL plug stringer	Bay 5 & 6 NOBL Retrieval	Yes	transfer stringer	delicate pinch	1	delicate pinch	1
3373	RMS	receive NOBL plug stringer from FF EV	Bay 5 & 6 NOBL Retrieval	No		delicate pinch	1		
3374	FF	open NT	Bay 5 & 6 NOBL Retrieval	Yes	open/close NT	Small handrail	1		
3375	FF	retrieve NOBL 5 & 6	Bay 5 & 6 NOBL Retrieval	Yes	retrieve NOBL	delicate pinch	2		
3376	FF	transfer NOBL 5 & 6	Bay 5 & 6 NOBL Retrieval	Yes	transfer NOBL	delicate pinch	2	delicate pinch	2
3377	RMS	receive NOBL 5 & 6 from FF EV	Bay 5 & 6 NOBL Retrieval	No		delicate pinch	2		
3378	FF	close NT	Bay 5 & 6 NOBL Retrieval	Yes	open/close NT	Small handrail	1		
3379	FF	engage NT latches (3)	Bay 5 & 6 NOBL Retrieval	Yes	engage/disengage NT latch	Pinch	3		

3|20		**Bay 5 & 6 NOBL Installation**							
3381	FF	translate to Bay 5	Bay 5 & 6 NOBL Installation	Yes	move about worksite	Motion	1		
3382	RMS	mnvr to Bay 6	Bay 5 & 6 NOBL Installation	Yes	move about worksite	Motion	1		
3383	RMS	transfer Bay 5 NOBL	Bay 5 & 6 NOBL Installation	Yes	transfer NOBL	delicate pinch	1	delicate pinch	1
3384	FF	receive Bay 5 NOBL from RMS EV	Bay 5 & 6 NOBL Installation	No		delicate pinch	1		
3385	RMS	attach door clips to door stop (bay 6 NOBL)	Bay 5 & 6 NOBL Installation	Yes	attach door clips to door stop	Unknown	1		
3386	RMS	secure door handle attachment to door handle	Bay 5 & 6 NOBL Installation	Yes	secure door handle attachment to door handle	Unknown	1		
3387	RMS	mnvr to Bay 5	Bay 5 & 6 NOBL Installation	Yes	move about worksite	Motion	1		
3388	FF	transfer Bay 5 NOBL	Bay 5 & 6 NOBL Installation	Yes	transfer NOBL	delicate pinch	1	delicate pinch	1
3389	RMS	receive Bay 5 NOBL from FF EV	Bay 5 & 6 NOBL Installation	No		delicate pinch	1		
3390	RMS	install Bay 5 NOBL	Bay 5 & 6 NOBL Installation	Yes	install NOBL	Unknown	1		
3391	RMS	install NOBL plugs	Bay 5 & 6 NOBL Installation	Yes	install NOBL plugs	Pinch	1		
3392	RMS	connect NOBL ground cap to j-bolt	Bay 5 & 6 NOBL Installation	Yes	connect ground cap to j-bolt	Unknown	1		
3393	RMS	stow plug stringer in trash bag	Bay 5 & 6 NOBL Installation	Yes	stow/retrieve plug stringer	delicate pinch	1		
		DAY 4							
4|1		**MFR Setup**							
4002	RMS	transfer MFR handle	MFR Setup	No		Small handrail	1		

		to FF EV							
4003	RMS	egress airlock	MFR Setup	No		Motion	1		
4004	RMS	attach MWS tether to boot plate lanyard	MFR Setup	No		Tether tool	1		
4005	RMS	ingress MFR	MFR Setup	No		Large handrail	1		
4006	RMS	receive MFR handle from FF EV	MFR Setup	No		Small handrail	1		
4007	RMS	install MFR handle	MFR Setup	No		Small handrail	1	Small handrail	
4008	RMS	rotate tool interface 180 deg	MFR Setup	No		Unknown	1		
4|2		**BAPS Post Setup**							
4010	FF	install PIP pins (2) (BAPS Center)	BAPS Post Setup	unk	install/remove PIP	PIP	2		
4|3		**Translation Aid Setup**							
4012	FF	remove PIP pin from mini-TA (if necessary)	Translation Aid Setup	No		PIP	1		
4013	FF	rotate handle 140 deg (mini-TA)	Translation Aid Setup	No		Small handrail	1		
4014	FF	install PIP pin (mini-TA)	Translation Aid Setup	No		PIP	1		
4015	FF	install hitch pin (mini-TA)	Translation Aid Setup	No		Hitch	1		
4016	FF	extend TA tube (stbd) (if necessary)	Translation Aid Setup	No		Small handrail	1	Small handrail	
4017	FF	rotate TA joint (stbd)	Translation Aid Setup	No		Small handrail	1		
4018	FF	extend TA tube (port) (if necessary)	Translation Aid Setup	No		Small handrail	1	Small handrail	
4019	FF	rotate TA joint (port)	Translation Aid Setup	No		Small handrail	1		
4|4		**Aft Fixture Setup**							

4021	FF	remove hitch pins (2) from aft fixture	Aft Fixture Setup	Yes	install/remove hitch pin	Hitch	2		
4022	FF	stow hitch pins (aft fixture)	Aft Fixture Setup	Yes	install/remove hitch pin	Hitch	2		
4023	FF	remove PIP pins (2) from aft fixture	Aft Fixture Setup	Yes	install/remove PIP	PIP	2		
4024	FF	stow PIP pins (aft fixture)	Aft Fixture Setup	Yes	install/remove PIP	PIP	2		
4025	FF	deploy aft fixture	Aft Fixture Setup	Yes	stow/deploy aft fixture	Unknown	1		
4026	FF	engage locking PIP pins (2)	Aft Fixture Setup	Yes	install/remove PIP	PIP	2		
4027	FF	check top fork PIP pin in proper orientation	Aft Fixture Setup	Yes	inspect worksite	Camera	1		
4|5		**Y-Harness Retrieval**							
4029	FF	translate to port ATM	Y-Harness Retrieval	Yes	move about worksite	Motion	1		
4030	FF	open ATM (port)	Y-Harness Retrieval	Yes	open/close ATM	Small handrail	1		
4031	FF	retrieve COSTAR Y-harness with small hook of retr tether	Y-Harness Retrieval	Yes	stow/retrieve harness	Tether tool	1		
4032	FF	close ATM (port)	Y-Harness Retrieval	Yes	open/close ATM	Small handrail	1		
4033	FF	engage ATM latches (4)	Y-Harness Retrieval	Yes	engage/disengage ATM latch	Unknown	4		
4034	FF	translate to -V2 aft shroud	Y-Harness Retrieval	Yes	move about worksite	Motion	1		
4|6		**Open -V2 Doors**							
4036	RMS	Mnvr to -V2 aft shroud	Open -V2 Doors	Yes	move about worksite	Motion	1		
4037	RMS	stanchion 180 deg	Open -V2 Doors	No		Unknown	1		
4038	RMS	stow 80-in adj tether on right -V2 door handrail (temp)	Open -V2 Doors	unk	stow/retrieve tether	delicate pinch	1		

4039	RMS	Apply lubricant to latch bolts (4)	Open -V2 Doors	Yes	apply lubricant	Lubricant tool	4		
4040	RMS	PGT: A4, CCW 3, 23.5 short adj	Open -V2 Doors	Yes	set bolt drive	COMPUTER	1		
4041	RMS	drive latch bolts (3) 7 turns (disengage)	Open -V2 Doors	Yes	drive bolt	Bolt drive	3		
4042	RMS	drive handle bolt 7 turns (disengage)	Open -V2 Doors	Yes	drive bolt	Bolt drive	1		
4043	RMS	Maintain pressure on doors	Open -V2 Doors	Yes	maintain pressure on doors	Small handrail	1		
4044	RMS	Remove PIP pin	Open -V2 Doors	Yes	install/remove PIP	PIP	1		
4045	RMS	drive handle latch (release)	Open -V2 Doors	Yes	release latch	Pinch	1		
4046	RMS	Install PIP pin	Open -V2 Doors	Yes	install/remove PIP	PIP	1		
4047	RMS	Open doors	Open -V2 Doors	Yes	open/close V2 door	Small handrail	1	Small handrail	1
4048	RMS	stow PGT	Open -V2 Doors	No		COMPUTER	1		
4049	RMS	stow lube applicator	Open -V2 Doors	No		Unknown	1		
4050	RMS	Config PRT controller A1	Open -V2 Doors	Yes	set bolt drive	COMPUTER	1		
4|7		**FOC Removal**							
4052	RMS	stabilize FF EV (if necessary)	FOC Removal	No		Unknown	1		
4053	FF	tether right aft shroud door open	FOC Removal	unk	tether shroud door	Tether tool	1		
4054	FF	stow Y-harness (lower left)	FOC Removal	Yes	stow/retrieve harness	delicate pinch	1		
4055	FF	check MCC GO for FOC connector demate	FOC Removal	Yes	check GO	COMPUTER	1		
4056	FF	tether connectors (4)	FOC Removal	No		Tether tool	4	Pinch	4
4057	FF	demate connectors (4)	FOC Removal	Yes	mate/demate connector	Pinch	4		

4058	FF	disconnect purge line	FOC Removal	Yes	disconnect purge line	Pinch	1		
4059	FF	stow purge line	FOC Removal	Yes	stow purge line	Unknown	1		
4060	FF	PGT: A3, CCW 3, 10.5, 6-in wobble	FOC Removal	Yes	set bolt drive	COMPUTER	1		
4061	FF	drive groundstrap 4-6 turns (disconnect)	FOC Removal	Yes	drive bolt	Bolt drive	1		
4062	FF	stow groundstrap	FOC Removal	Yes	stow/retrieve groundstrap	delicate pinch	1	delicate pinch	1
4063	RMS	mnvr for FOC removal	FOC Removal	Yes	move about worksite	Motion	1		
4064	FF	remove "B" latch cover	FOC Removal	Yes	install/remove latch cover	delicate pinch	1		
4065	FF	check indicator lights off (4)	FOC Removal	Yes	inspect worksite	Camera	4		
4066	FF	note alignment and position of FOC	FOC Removal	Yes	inspect worksite	Camera	1		
4067	RMS	check "A" LATCHED lights off (2)	FOC Removal	Yes	inspect worksite	Camera	2		
4068	RMS	PRT: RCCW, 38 or EVA Ratchet: CCW, MTL 38	FOC Removal	Yes	set bolt drive	COMPUTER	1		
4069	RMS	drive "A" latch 1/2 turn (manual disengage)	FOC Removal	Yes	drive bolt	Bolt drive	1		
4070	FF	PRT: A1, CCW, 5 (stall) or PGT: B2, CCW 3, 5.5	FOC Removal	Yes	set bolt drive	COMPUTER	1		
4071	FF	drive "A" latch 11.5-15.5 turns to hardstop (disengage)	FOC Removal	Yes	drive bolt	Bolt drive	1	Camera	1
4072	RMS	check "A" LATCHED lights on (1-2 turns)	FOC Removal	No		Bolt drive	1	Camera	1

4073	RMS	note alignment and position of FOC	FOC Removal	No		Camera	1		
4074	RMS	maintain downward force	FOC Removal	No		Small handrail	1		
4075	RMS	check GO for "B" latch disengage	FOC Removal	Yes	check GO	COMPUTER	1		
4076	FF	PGT: A3, CCW 2, 10.5	FOC Removal	Yes	set bolt drive	COMPUTER	1		
4077	FF	drive "B" latch 1/2 turn (disengage) while maintain downward force	FOC Removal	Yes	drive bolt	Bolt drive	1	Small handrail	1
4078	FF	PGT: B5, CCW 2, 5.5 MTL	FOC Removal	Yes	set bolt drive	COMPUTER	1		
4079	FF	drive "B" latch 9.5-13.5 turns to hardstop (disengage) while maintain downward force	FOC Removal	Yes	drive bolt	Bolt drive	1	Small handrail	1
4080	FF	check "A" SEATED lights on	FOC Removal	Yes	inspect worksite	Camera	1		
4081	FF	check "B" SEATED lights on	FOC Removal	Yes	inspect worksite	Camera	1		
4082	RMS	remove FOC	FOC Removal	Yes	install/remove FOC	Small handrail	1	Small handrail	1
4083	FF	inform RMS EV when "B" READY lights on	FOC Removal	Yes	notify MCC	COMPUTER	1		
4084	FF	inspect bay (latches and all MLI)	FOC Removal	Yes	inspect worksite	Camera	1		
4085	RMS	mnvr to aft fixture	FOC Removal	Yes	move about worksite	Motion	1		
4086	RMS	stow FOC on aft fixture (connectors fwd)	FOC Removal	Yes	stow/retrieve FOC	Small handrail	1	Small handrail	1
4087	RMS	install PIP pin	FOC Removal	Yes	install/remove	PIP	1		

					PIP				
4|8		**CASH Installation**							
4089	RMS	mnvr to SAC UPS	CASH Installation	Yes	move about worksite	Motion	1		
4090	RMS	stow PRT	CASH Installation	No		COMPUTER	1		
4091	FF	translate to SAC UPS	CASH Installation	Yes	move about worksite	Motion	1		
4092	FF	release UPS latches (4)	CASH Installation	Yes	engage/disengage UPS latch	Unknown	4		
4093	FF	open UPS	CASH Installation	Yes	open/close UPS	Unknown	1		
4094	FF	release CASH restraint straps (2)	CASH Installation	Yes	release/secure restraint strap	delicate pinch	2		
4095	FF	open contamination cover	CASH Installation	Yes	open/close contamination cover	delicate pinch	1		
4096	FF	retrieve primary CASH (lower)	CASH Installation	Yes	retrieve CASH	Unknown	1		
4097	FF	transfer primary CASH	CASH Installation	Yes	transfer CASH	Unknown	1	Unknown	1
4098	RMS	receive CASH from FF EV	CASH Installation	No		Unknown	1		
4099	FF	close contamination cover	CASH Installation	Yes	open/close contamination cover	delicate pinch	1		
4100	FF	secure restraint straps (2)	CASH Installation	Yes	release/secure restraint strap	delicate pinch	2		
4101	FF	close UPS	CASH Installation	Yes	open/close UPS	Unknown	1		
4102	FF	engage UPS latches (4)	CASH Installation	Yes	engage/disengage UPS latch	Unknown	4		
4103	RMS	mnvr to -V2	CASH Installation	Yes	move about worksite	Motion	1		
4104	FF	translate to -V2 aft shroud	CASH Installation	Yes	move about worksite	Motion	1		
4105	FF	position for CASH install	CASH Installation	Yes	move about worksite	Motion	1		

4106	RMS	stabilize FF EV during CASH installation	CASH Installation	No		Unknown	1		
4107	FF	install CASH (+V2/-V3 vertical handrails--bottom of uppermost section)	CASH Installation	Yes	install CASH	Unknown	1		
4|9		**ACS Retrieval**							
4109	RMS	Mnvr to ASIPE	ACS Retrieval	Yes	move about worksite	Motion	1		
4110	RMS	retrieve PRT	ACS Retrieval	No		COMPUTER	1		
4111	RMS	PRT: A1	ACS Retrieval	Yes	set bolt drive	COMPUTER	1		
4112	FF	Config HST PFR (aft ASIPE) (AS: Y=90R, P=1; PFR: Y=12, R=A, P=9.5) (if required)	ACS Retrieval	No		Unknown	1		
4113	RMS	PRT: RCCW, 38 or EVA Ratchet: CCW, MTL 38	ACS Retrieval	Yes	set bolt drive	COMPUTER	1		
4114	RMS	ASIPE "A" latch-disengage 1/2 turn	ACS Retrieval	Yes	drive bolt	Bolt drive	1		
4115	RMS	PRT: A1, CCW, 5 (stall) or PGT: B2, CCW 3, 5.5	ACS Retrieval	Yes	set bolt drive	COMPUTER	1		
4116	RMS	ASIPE "A" latch-diesngage 13-13.5 turns to hardstop	ACS Retrieval	Yes	drive bolt	Bolt drive	1		
4117	RMS	Check "A" LATCHED lghts on (1-2 turns) (use PRT or PGT)	ACS Retrieval	Yes	inspect worksite	Bolt drive	1	Camera	1
4118	FF	Open ASIPE	ACS Retrieval	Yes	open/close ASIPE	Small handrail	1		
4119	FF	Preposition groundstrap tether	ACS Retrieval	unk	position groundstrap	delicate pinch	1	Tether tool	1

		(box end on handrail)			tether				
4120	RMS	PRT: A3, CW, 10 or PGT: A3, CW 2, 10.5	ACS Retrieval	Yes	set bolt drive	COMPUTER	1		
4121	FF	Ingress PFR	ACS Retrieval	No		Large handrail	1		
4122	FF	PGT: A3, CCW 3, 10.5	ACS Retrieval	Yes	set bolt drive	COMPUTER	1		
4123	FF	drive groundstrap bolt 6 (4-6) turns (disconnect)	ACS Retrieval	Yes	drive bolt	Bolt drive	1		
4124	FF	drive alignment aid stowage lock 6-8 turns (disengage)	ACS Retrieval	Yes	disengage alignment aid stowage lock	Pinch	1		
4125	FF	drive alignment aid deployment lock 1/2 turn (disengage)	ACS Retrieval	Yes	engage/disegage deployment lock	Pinch	1		
4126	FF	Deploly alignment aid 90 deg	ACS Retrieval	Yes	stow/deploy alignment aid	Pinch	1		
4127	FF	drive deployment lock 1/2 turn (re-engage)	ACS Retrieval	Yes	engage/disengage deployment lock	Pinch	1		
4128	FF	PGT: A3, CCW 2, 10.5	ACS Retrieval	Yes	set bolt drive	COMPUTER	1		
4129	FF	drive "B" latch 1/2 turn (disengage)	ACS Retrieval	Yes	drive bolt	Bolt drive	1		
4130	RMS	Maintain aftward force	ACS Retrieval	Yes	maintain pressure on doors	Small handrail	1		
4131	FF	check GO for "B" latch release	ACS Retrieval	Yes	check GO	COMPUTER	1		
4132	FF	PGT: B5, CCW 2, 5.5 MTL	ACS Retrieval	Yes	set bolt drive	COMPUTER	1		
4133	FF	drive "B" latch 9.5-13.5 turns to hardstop (disengage)	ACS Retrieval	Yes	drive bolt	Bolt drive	1		
4134	FF	Check "B" latch	ACS Retrieval	Yes	inspect worksite	Camera	1		

		disengaged							
4135	FF	Check "A" SEATED lights on	ACS Retrieval	Yes	inspect worksite	Camera	1		
4136	FF	Check "B" READY lights off	ACS Retrieval	Yes	inspect worksite	Camera	1		
4137	RMS	Remove ACS	ACS Retrieval	Yes	install/remove ACS	Small handrail	1	Small handrail	1
4138	FF	Remove ACS (assist RMS EV)	ACS Retrieval	No		Small handrail	1	Small handrail	1
4139	FF	Inform RMS EV when "B" READY lights on	ACS Retrieval	Yes	notify MCC	COMPUTER	1		
4140	FF	Inspect ASIPE interior	ACS Retrieval	Yes	inspect worksite	Camera	1		
4141	FF	Inspect ASIPE "A", "B", and "C" latches	ACS Retrieval	Yes	inspect worksite	Camera	3		
4142	FF	Close ASIPE	ACS Retrieval	Yes	open/close ASIPE	Small handrail	1		
4143	FF	ASIPE latch-engage	ACS Retrieval	Yes	engage/disengage ASIPE latch	Small handrail	1		
4|10		**ACS Installation**							
4145	RMS	Mnvr to -V2 aft shroud	ACS Installation	Yes	move about worksite	Motion	1		
4146	FF	Translate to -V2 aft shroud	ACS Installation	Yes	move about worksite	Motion	1		
4147	FF	PGT: A3, CW 1, 10.5	ACS Installation	Yes	set bolt drive	COMPUTER	1		
4148	FF	Insert ACS (assist RMS EV)	ACS Installation	No		Small handrail	1	Small handrail	1
4149	RMS	Insert ACS until front face clears center guide rail	ACS Installation	Yes	install/remove ACS	Small handrail	1	Small handrail	1
4150	RMS	Insert ACS until "B" READY lights off	ACS Installation	Yes	install/remove ACS	Small handrail	1	Small handrail	1
4151	FF	drive alignment aid deployment lock 1/2	ACS Installation	Yes	engage/disengage deployment lock	Pinch	1		

		turn (disengage)							
4152	FF	Deploy alignment aid arm	ACS Installation	Yes	stow/deploy alignment aid	Pinch	1		
4153	FF	drive deployment lock 1/2 turn (re-engage)	ACS Installation	Yes	engage/disengage deployment lock	Pinch	1		
4154	FF	Inform RMS EV when "B" READY lights off	ACS Installation	Yes	notify MCC	COMPUTER	1		
4155	FF	Check "B" READY lights off	ACS Installation	Yes	inspect worksite	Camera	1		
4156	RMS	Maintain downward force	ACS Installation	No		Small handrail	1		
4157	FF	PGT: A3, CW 1, 10.5	ACS Installation	Yes	set bolt drive	COMPUTER	1		
4158	FF	drive "B" latch 2 turns (engage) while maintain downward force	ACS Installation	Yes	drive bolt	Bolt drive	1	Small handrail	1
4159	FF	Check no ACS vertical movement	ACS Installation	Yes	inspect worksite	Camera	1	Small handrail	1
4160	RMS	Check no ACS vertical movement	ACS Installation	No		Camera	1		
4161	FF	drive "B" latch 8-12 turns (engage)	ACS Installation	Yes	drive bolt	Bolt drive	1		
4162	FF	Check "A" SEATED lights off	ACS Installation	Yes	inspect worksite	Camera	1		
4163	RMS	PRT: A3, CW, 10 or PGT: A3, CW 3, 10.5	ACS Installation	Yes	set bolt drive	COMPUTER	1		
4164	RMS	Check GO for "A" latch engage	ACS Installation	Yes	check GO	COMPUTER	1		
4165	RMS	drive "A" latch 11.5-15.5 turns (engage)	ACS Installation	Yes	drive bolt	Bolt drive	1		
4166	RMS	PRT: RCW, 38 or EVA Ratchet CW, 38	ACS Installation	Yes	set bolt drive	COMPUTER	1		

4167	RMS	drive "A" latch 1/2 turn until MTL slips (engage)	ACS Installation	Yes	drive bolt	Bolt drive	1		
4168	RMS	Check "A" LATCHED lights off	ACS Installation	Yes	inspect worksite	Camera	1		
4169	RMS	Mnvr to stabilize FF EV if required	ACS Installation	No		Motion	1		
4170	FF	Replace "B" latch cover	ACS Installation	Yes	install/remove latch cover	delicate pinch	1		
4171	FF	Stow alignment aid	ACS Installation	Yes	stow/deploy alignment aid	Pinch	1		
4172	FF	Engage stowage lock zip nut hand tight	ACS Installation	Yes	engage zip nut	Pinch	1		
4173	FF	Engage deployment lock hand tight (1/2 turn)	ACS Installation	Yes	engage/disengage deployment lock	Pinch	1		
4174	FF	PGT: B6, CW2, 10.5	ACS Installation	Yes	set bolt drive	COMPUTER	1		
4175	FF	drive groundstrap bolt 4-6 turns (re-install)	ACS Installation	Yes	drive bolt	Pinch	1	Bolt drive	1
4176	FF	Inspect connector (ACS) P1	ACS Installation	Yes	inspect worksite	Pinch	1	Camera	1
4177	FF	Mate connector (ACS) P1	ACS Installation	Yes	mate/demate connector	Pinch	1		
4178	FF	Inspect connector (ACS) P2	ACS Installation	Yes	inspect worksite	Pinch	1	Camera	1
4179	FF	Mate connector (ACS) P2	ACS Installation	Yes	mate/demate connector	Pinch	1		
4180	FF	Inspect connector (ACS) P3	ACS Installation	Yes	inspect worksite	Pinch	1	Camera	1
4181	FF	Mate connector (ACS) P3	ACS Installation	Yes	mate/demate connector	Pinch	1		
4182	FF	Inspect connector (ACS) P4	ACS Installation	Yes	inspect worksite	Pinch	1	Camera	1
4183	FF	Mate connector (ACS) P4	ACS Installation	Yes	mate/demate connector	Pinch	1		

4184	FF	secure Velcro strap to restrain CASH connectors	ACS Installation	Yes	secure/remove Velcro	delicate pinch	1		
4|11		**FOC Installation**							
4186	RMS	mnvr to aft fixture	FOC Installation	Yes	move about worksite	Motion	1		
4187	FF	ingress PFR	FOC Installation	No		Large handrail	1		
4188	FF	drive ASIPE latch (disengage)	FOC Installation	Yes	engage/disengage ASIPE latch	Small handrail	1		
4189	FF	open ASIPE	FOC Installation	Yes	open/close ASIPE	Small handrail	1		
4190	RMS	retrieve FOC	FOC Installation	Yes	stow/retrieve FOC	Small handrail	1	Small handrail	1
4191	RMS	mnvr to ASIPE	FOC Installation	Yes	move about worksite	Motion	1		
4192	FF	stow aft fixture	FOC Installation	Yes	stow/deploy aft fixture	Unknown	1		
4193	FF	engage PIP pins (2)	FOC Installation	Yes	install/remove PIP	PIP	2		
4194	FF	ingress PFR (aft ASIPE)	FOC Installation	No		Large handrail	1		
4195	RMS	insert FOC until "B" READY lights off	FOC Installation	Yes	install/remove FOC	Small handrail	1	Small handrail	1
4196	RMS	check fwd and aft alignment marks visible	FOC Installation	Yes	inspect worksite	Camera	1		
4197	FF	inform RMS EV when "B" READY lights off	FOC Installation	Yes	notify MCC	COMPUTER	1		
4198	FF	check "B" ready lights OFF	FOC Installation	Yes	inspect worksite	Camera	1		
4199	RMS	install FOC into "A" and "C" latches	FOC Installation	Yes	install/remove FOC	Small handrail	1	Small handrail	1
4200	RMS	maintain fwd force (orbiter +X)	FOC Installation	No		Small handrail	1		

4201	FF	PGT: B6, CW 1, 10.5	FOC Installation	Yes	set bolt drive	COMPUTER	1		
4202	FF	drive "B" latch 5 turns (engage) while maintain forward force	FOC Installation	Yes	drive bolt	Bolt drive	1	Small handrail	1
4203	FF	check "B" latch engages into FOC	FOC Installation	Yes	inspect worksite	Camera	1		
4204	FF	drive "B" latch 5-9 turns (engage) while maintain forward force	FOC Installation	Yes	drive bolt	Bolt drive	1	Small handrail	1
4205	FF	report number of "B" turns	FOC Installation	Yes	notify MCC	COMPUTER	1		
4206	FF	check "A" SEATED lights off	FOC Installation	Yes	inspect worksite	Camera	1		
4207	RMS	check GO for "A" latch engage	FOC Installation	Yes	check GO	COMPUTER	1		
4208	RMS	PRT: A3, CW, 10 or PGT: A3, CW 3, 10.5	FOC Installation	Yes	set bolt drive	COMPUTER	1		
4209	RMS	drive "A" latch 13-13.5 turns (engage) on FF EV GO	FOC Installation	Yes	drive bolt	Bolt drive	1		
4210	RMS	PRT: RCW, 38 or EVA Ratchet CW, 38	FOC Installation	Yes	set bolt drive	COMPUTER	1		
4211	RMS	drive "A" latch 1/2 turn until MTL slips (engage)	FOC Installation	Yes	drive bolt	Bolt drive	1		
4212	RMS	report number of "A" turns (TORQUE CRITICAL)	FOC Installation	Yes	report turn count	COMPUTER	1		
4213	RMS	check "A" LATCHED lights off	FOC Installation	Yes	inspect worksite	Camera	1		
4214	FF	PGT: A3, CCW 3, 10.5	FOC Installation	Yes	set bolt drive	COMPUTER	1		

4215	FF	drive groundstrap bolt (FOC) 4-6 turns (disengage)	FOC Installation	Yes	drive bolt	Bolt drive	1		
4216	FF	PGT: A3, CW 2, 10.5	FOC Installation	Yes	set bolt drive	COMPUTER	1		
4217	FF	drive groundstrap bolt (FOC) 4-6 turns (engage)	FOC Installation	Yes	drive bolt	Bolt drive	1		
4218	FF	report number of groundstrap turns	FOC Installation	Yes	report turn count	COMPUTER	1		
4219	FF	Close ASIPE	FOC Installation	Yes	open/close ASIPE	Small handrail	1		
4220	FF	drive ASIPE latches (5-engage)	FOC Installation	Yes	engage/disengae ASIPE latch	Small handrail	5		
4|12		**MFR Swap**							
4222	RMS	stow PGT	MFR Swap	No		COMPUTER	1		
4223	FF	translate to MFR	MFR Swap	No		Motion	1		
4224	FF	Daisy chain extra waist tether to RMS EV	MFR Swap	No		Unknown	1		
4225	RMS	Daisy chain extra waist tether to FF EV	MFR Swap	No		Unknown	1		
4226	FF	Disconnect RMS EV's safety tether from EMU D-ring	MFR Swap	No		Tether tool	1		
4227	RMS	Disconnect FF EV's safety tether from EMU D-ring	MFR Swap	No		Tether tool	1		
4228	FF	Mate RMS EV's safety tether to FF EV EMU D-ring	MFR Swap	No		Tether tool	1		
4229	RMS	Mate FF EV's safety tether to RMS EV EMU D-ring	MFR Swap	No		Tether tool	1		
4230	FF	Check safety tether gate closed	MFR Swap	No		Camera	1		

4231	RMS	Check safety tether gate closed	MFR Swap	No		Camera	1		
4232	FF	Disconnect RMS EV's prime waist tether from EMU D-ring	MFR Swap	No		Tether tool	1		
4233	RMS	Disconnect FF EV's prime waist tether from EMU D-ring	MFR Swap	No		Tether tool	1		
4234	FF	Mate RMS EV's prime waist tether to FF EV EMU D-ring	MFR Swap	No		Tether tool	1		
4235	RMS	Mate FF EV's prime waist tether to RMS EV EMU D-ring	MFR Swap	No		Tether tool	1		
4236	FF	Disconnect extra waist tether daisy chain	MFR Swap	No		Unknown	1		
4237	RMS	Disconnect extra waist tether daisy chain	MFR Swap	No		Unknown	1		
4238	FF	PGT swap (if required)	MFR Swap	No		Large handrail	1		
4239	RMS	PGT swap (if required)	MFR Swap	No		Large handrail	1		
4240	FF	retrieve sm trash bag	MFR Swap	No		delicate pinch	1		
4|13		**ESM Retrieval**							
4242	FF	translate to MULE	ESM Retrieval	Yes	move about worksite	Motion	1		
4243	RMS	mnvr to MULE	ESM Retrieval	Yes	move about worksite	Motion	1		
4244	RMS	Boot plate 90L	ESM Retrieval	No		Unknown	1		
4245	RMS	Stanchion 135R	ESM Retrieval	No		Unknown	1		
4246	RMS	stow PRT	ESM Retrieval	No		COMPUTER	1		
4247	FF	open ESM contamination cover	ESM Retrieval	Yes	open/close contamination	delicate pinch	1		

					cover				
4248	FF	PGT: B7, CCW 3, 15.5, 6-in wobble	ESM Retrieval	Yes	set bolt drive	COMPUTER	1		
4249	FF	drive keyway bolts (ESM) 6-8 turns (4-disengage)	ESM Retrieval	Yes	drive bolt	Bolt drive	4		
4250	FF	remove ESM	ESM Retrieval	Yes	install/remove ESM	Small handrail	1	Small handrail	1
4251	FF	transfer ESM	ESM Retrieval	Yes	transfer ESM	Small handrail	1	Small handrail	1
4252	RMS	receive ESM from FF EV	ESM Retrieval	No		Small handrail	1		
4253	FF	close thermal cover (ESM)	ESM Retrieval	Yes	open/close thermal cover	delicate pinch	1		
4|14		**ESM Installation**							
4255	FF	translate to -V2 aft shroud	ESM Installation	Yes	move about worksite	Motion	1		
4256	RMS	mnvr to -V2 aft shroud	ESM Installation	Yes	move about worksite	Motion	1		
4257	RMS	Boot plate 0 deg	ESM Installation	No		Unknown	1		
4258	RMS	Stanchion 180 deg	ESM Installation	No		Unknown	1		
4259	RMS	inspect connectors	ESM Installation	Yes	inspect worksite	Camera	1	Pinch	1
4260	RMS	install ESM	ESM Installation	Yes	install/remove ESM	Small handrail	1	Small handrail	1
4261	RMS	PGT: A2, CW 2, 5.5, short adj	ESM Installation	Yes	set bolt drive	COMPUTER	1		
4262	RMS	drive handrail latch 7-9 turns (engage)	ESM Installation	Yes	drive bolt	Bolt drive	1		
4263	FF	flip center guide control lever	ESM Installation	Yes	flip lever	Bolt drive	1		
4264	FF	extend center guide latch plunger (no preload)	ESM Installation	Yes	extend latch plunger	Pinch	1		
4265	FF	check plunger nose cone centered in	ESM Installation	Yes	inspect worksite	Camera	1		

		middle of hole							
4266	FF	preload center guide latch plunger until hardstop	ESM Installation	Yes	preload latch plunger	Pinch	1		
4267	FF	check 1/8-in white band visible on plunger shaft	ESM Installation	Yes	inspect worksite	Camera	1		
4268	FF	PGT: A2, CW 2, 2.5 MTL	ESM Installation	Yes	set bolt drive	COMPUTER	1		
4269	FF	drive inboard lockdown bolt .75-1.25 turn (engage)	ESM Installation	Yes	drive bolt	Bolt drive	1		
4270	FF	PGT: A2, CW 2, 5.5	ESM Installation	Yes	set bolt drive	COMPUTER	1		
4271	FF	drive outboard bolt .75-1.25 turn (engage)	ESM Installation	Yes	drive bolt	Bolt drive	1		
4272	RMS	PGT: B6, CW 2, 10.5	ESM Installation	Yes	set bolt drive	COMPUTER	1		
4273	RMS	install groundstrap (ACS ESM) on ESM	ESM Installation	Yes	install groundstrap	Bolt drive	1	Pinch	1
4274	RMS	drive groundstrap bolt 2-4 turns (engage)	ESM Installation	Yes	drive bolt	Bolt drive	1		
4275	FF	retrieve y-harness from temp stow	ESM Installation	Yes	stow/retrieve harness	delicate pinch	1		
4276	FF	remove Velcro from y-harness	ESM Installation	Yes	secure/remove Velcro	delicate pinch	1	Small handrail	1
4277	FF	check MCC GO for COSTAR connector demate	ESM Installation	Yes	check GO	COMPUTER	1		
4278	FF	demate connectors (COSTAR) (4)	ESM Installation	Yes	mate/demate connector	Pinch	4		
4279	RMS	stabilize FF EV during connector mate	ESM Installation	No		Small handrail	1		
4280	FF	mate connectors (Y-harness) to COSTAR	ESM Installation	Yes	mate/demate connector	Pinch	4	Pinch	4

		harness (4)							
4281	FF	mate connectors (Y-harness) to COSTAR (4)	ESM Installation	Yes	mate/demate connector	Pinch	4		
4282	FF	route Y-harness across aft shroud	ESM Installation	Yes	route harness	delicate pinch	1	delicate pinch	1
4283	FF	transfer Y-harness to	ESM Installation	Yes	transfer harness	delicate pinch	1	delicate pinch	1
4284	RMS	receive Y-harness from FF EV	ESM Installation	No		delicate pinch	1	delicate pinch	1
4285	RMS	route Y-harness to ESM	ESM Installation	Yes	route harness	delicate pinch	1	delicate pinch	1
4286	FF	secure Velcro strap to secure Y-harness to bulkhead rail (4-in slack)	ESM Installation	Yes	secure/remove Velcro	delicate pinch	1	delicate pinch	1
4287	RMS	stabilize FF EV during connector mate	ESM Installation	No		Small handrail	1		
4288	FF	mate connector (Y-harness) P1 to ESM	ESM Installation	Yes	mate/demate connector	Pinch	1		
4289	FF	mate connector (Y-harness) P2 to ESM	ESM Installation	Yes	mate/demate connector	Pinch	1		
4290	FF	mate connector (Y-harness) P3 to ESM	ESM Installation	Yes	mate/demate connector	Pinch	1		
4291	FF	mate connector (Y-harness) P4 to ESM	ESM Installation	Yes	mate/demate connector	Pinch	1		
4292	FF	release tether securing CASH connectors	ESM Installation	unk	release/secure tether	Pinch	1	Tether tool	1
4293	RMS	transfer tether hook to FF EV for connector caps	ESM Installation	unk	transfer tether hook	Pinch	1	Pinch	1
4294	FF	receive tether hook from RMS EV	ESM Installation	No		Pinch	1		

4295	FF	tether connector caps	ESM Installation	unk	release/secure tether	Pinch	1	Tether tool	1
4296	FF	remove connector cap P7 from CASH	ESM Installation	Yes	install/remove connector cap	Pinch	1		
4297	FF	remove connector cap P9 from CASH	ESM Installation	Yes	install/remove connector cap	Pinch	1		
4298	FF	inspect connector P6 (CASH)	ESM Installation	Yes	inspect worksite	Pinch	1	Camera	1
4299	FF	Mate connector P6 (CASH) to ESM	ESM Installation	Yes	mate/demate connector	Pinch	1		
4300	FF	inspect connector P7 (CASH)	ESM Installation	Yes	inspect worksite	Pinch	1	Camera	1
4301	FF	mate connector P7 (CASH) to ESM	ESM Installation	Yes	mate/demate connector	Pinch	1		
4302	FF	inspect connector P9 (CASH)	ESM Installation	Yes	inspect worksite	Pinch	1	Camera	1
4303	FF	mate connector P9 (CASH) to ESM	ESM Installation	Yes	mate/demate connector	Pinch	1		
4304	FF	inspect connector P10 (CASH)	ESM Installation	Yes	inspect worksite	Pinch	1	Camera	1
4305	FF	mate connector P10 (CASH) to ESM	ESM Installation	Yes	mate/demate connector	Pinch	1		
4306	RMS	stow connector caps (2) in trash bag	ESM Installation	Yes	stow connector cap	Pinch	2		
4307	FF	notify MCC CASH and COSTAR Y-harness mated	ESM Installation	Yes	notify MCC	COMPUTER	1		
4308	FF	check CASH "hook" engaged	ESM Installation	Yes	inspect worksite	Camera	1		
4309	FF	secure Velcro of CASH integral black/white onto self	ESM Installation	Yes	secure/remove Velcro	delicate pinch	1	delicate pinch	1
4310	FF	transfer tether from Y-harness temp stow to RMS EV	ESM Installation	unk	transfer tether	Pinch	1	Pinch	1

4311	RMS	receive tether from FF EV	ESM Installation	No		Pinch	1		
4|15		**Close -V2 Doors**							
4313	FF	close doors (-V2)	Close -V2 Doors	No		Small handrail	1		
4314	RMS	Close doors (-V2)	Close -V2 Doors	Yes	open/close V2 door	Small handrail	1	Small handrail	1
4315	RMS	install PIP pin on handle	Close -V2 Doors	Yes	install/remove PIP	PIP	1		
4316	RMS	PGT: B4, CW 3, 23.5 or PRT: B4, CW, 23 (stall)	Close -V2 Doors	Yes	set bolt drive	COMPUTER	1		
4317	RMS	drive handle bolt 6 turns (engage)	Close -V2 Doors	Yes	drive bolt	Bolt drive	1		
4318	RMS	Report peak running torque for handle bolt	Close -V2 Doors	Yes	report running torque	COMPUTER	1		
4319	FF	Transfer 80-in tether to center handrail for RMS EV	Close -V2 Doors	unk	transfer tether	Pinch	1		
4320	RMS	drive latch bolts (3) 6 turns (engage)	Close -V2 Doors	Yes	drive bolt	Bolt drive	3		
4321	RMS	Report peak running torque for latch bolts	Close -V2 Doors	Yes	report running torque	COMPUTER	3		
4322	RMS	Check door seals	Close -V2 Doors	Yes	inspect worksite	Camera	1		
4323	RMS	Retrieve 80-in tether	Close -V2 Doors	unk	stow/retrieve tether	Pinch	1		
4324	RMS	Stow 80-in tether in trash bag (temp)	Close -V2 Doors	unk	stow/retrieve tether	Pinch	1		
4|16		**Bay Door Bolt Engage**							
4326	RMS	Stanchion 135R	Bay Door Bolt Engage	No		Unknown	1		
4327	RMS	Boot plate 90L	Bay Door Bolt Engage	No		Unknown	1		
4328	RMS	Mnvr to Bay 2	Bay Door Bolt Engage	Yes	move about worksite	Motion	1		

4329	RMS	PGT: A3, CW 3, 10.5	Bay Door Bolt Engage	Yes	set bolt drive	COMPUTER	1		
4330	RMS	drive J-bolts (5) 4-6 turns (engage)	Bay Door Bolt Engage	Yes	drive bolt	Bolt drive	5		
4331	RMS	Mnvr to Bay 3	Bay Door Bolt Engage	Yes	move about worksite	Motion	1		
4332	RMS	PGT: A3, CW 3, 10.5	Bay Door Bolt Engage	Yes	set bolt drive	COMPUTER	1		
4333	RMS	drive J-bolts (5) 4-6 turns (engage)	Bay Door Bolt Engage	Yes	drive bolt	Bolt drive	5		
4334	RMS	Mnvr to Bay 4	Bay Door Bolt Engage	Yes	move about worksite	Motion	1		
4335	RMS	PGT: A3, CW 3, 10.5, short adj or 6-in wobble	Bay Door Bolt Engage	Yes	set bolt drive	COMPUTER	1		
4336	RMS	drive J-bolts (5) 4-6 turns (engage)	Bay Door Bolt Engage	Yes	drive bolt	Bolt drive	5		
4|17		**Thermal Cover Removal**							
4338	FF	translate to Bay 10	Thermal Cover Removal	Yes	move about worksite	Motion	1		
4339	FF	check DBA thermal cover secure	Thermal Cover Removal	Yes	inspect worksite	Camera	1		
4340	FF	remove thermal cover (bay 10)	Thermal Cover Removal	Yes	install/remove thermal cover	delicate pinch	1		
4341	FF	translate to ASIPE	Thermal Cover Removal	Yes	move about worksite	Motion	1		
4342	FF	stow thermal cover (bay 10)	Thermal Cover Removal	Yes	stow/retrieve thermal cover	delicate pinch	1	delicate pinch	1
4343	FF	secure Velcro for bay 10 thermal cover	Thermal Cover Removal	Yes	secure/remove Velcro	delicate pinch	1	delicate pinch	1
4344	FF	translate to Bay 5	Thermal Cover Removal	Yes	move about worksite	Motion	1		
4345	FF	check DBA thermal cover secure	Thermal Cover Removal	Yes	inspect worksite	Camera	1		

4346	FF	remove thermal cover (bay 5)	Thermal Cover Removal	Yes	install/remove thermal cover	delicate pinch	1		
4347	FF	install vent plugs (2)	Thermal Cover Removal	Yes	install vent plug	Pinch	2		
4348	FF	translate to ASIPE	Thermal Cover Removal	Yes	move about worksite	Motion	1		
4349	FF	stow thermal cover (bay 5)	Thermal Cover Removal	Yes	stow/retrieve thermal cover	delicate pinch	1	delicate pinch	1
4350	FF	secure Velcro for bay 5 thermal cover	Thermal Cover Removal	Yes	secure/remove Velcro	delicate pinch	1	delicate pinch	1
4351	FF	config HST PFR (aft ASIPE) for NCS	Thermal Cover Removal	No		Unknown	1		
4|18		**FHST & WF/PC Cover Removal**							
4353	FF	Remove WF/PC (assist RMS EV as required)	FHST & WF/PC Cover Removal	No		delicate pinch	1	Small handrail	1
4354	FF	Remove FHST covers (assist RMS EV as required)	FHST & WF/PC Cover Removal	No		delicate pinch	3		
4355	RMS	Mnvr to FHST covers	FHST & WF/PC Cover Removal	Yes	move about worksite	Motion	1		
4356	RMS	Remove FHST covers	FHST & WF/PC Cover Removal	Yes	install/remove FHST cover	Unknown	3	Unknown	3
4357	RMS	Slide FHST covers together	FHST & WF/PC Cover Removal	Yes	slide FHST covers together	delicate pinch	3	delicate pinch	3
4358	RMS	secure Velcro restraint to FHST covers	FHST & WF/PC Cover Removal	Yes	secure/remove Velcro	delicate pinch	1	delicate pinch	1
4359	RMS	Mnvr to WF/PC cover	FHST & WF/PC Cover Removal	Yes	move about worksite	Motion	1		
4360	RMS	Remove WF/PC cover	FHST & WF/PC Cover Removal	Yes	install/remove WF/PC cover	delicate pinch	1	Small handrail	1

4361	RMS	Tighten WF/PC cover zip nuts (2)	FHST & WF/PC Cover Removal	Yes	engage zip nut	Pinch	2		
4362	RMS	Mnvr to SAC	FHST & WF/PC Cover Removal	Yes	move about worksite	Motion	1		
4363	RMS	Transfer FHST covers	FHST & WF/PC Cover Removal	Yes	transfer FHST covers	delicate pinch	1	delicate pinch	1
4364	FF	Receive FHST covers from RMS EV	FHST & WF/PC Cover Removal	No		Small handrail	1		
4365	FF	Stow FHST covers	FHST & WF/PC Cover Removal	Yes	stow/retrieve FHST cover	Small handrail	1	delicate pinch	1
4366	FF	secure Velcro (grounding) on FHST cover	FHST & WF/PC Cover Removal	Yes	secure/remove Velcro	delicate pinch	1	delicate pinch	1
4367	RMS	Transfer WF/PC cover	FHST & WF/PC Cover Removal	Yes	transfer WF/PC cover	Small handrail	1	Small handrail	1
4368	FF	Receive WF/PC cover from RMS EV	FHST & WF/PC Cover Removal	No		Unknown	1		
4369	FF	Stow WF/PC cover	FHST & WF/PC Cover Removal	Yes	stow/retrieve WF/PC cover	Small handrail	1		
4370	FF	Secure Velcro (grounding) on WF/PC cover	FHST & WF/PC Cover Removal	Yes	secure/remove Velcro	Pinch	1	Pinch	1
		DAY 5							
5|1		**MFR Setup**							
5002	RMS	transfer MFR handle to FF EV	MFR Setup	No		Small handrail	1		
5003	RMS	egress airlock	MFR Setup	No		Motion	1		
5004	RMS	attach MWS tether to boot plate lanyard	MFR Setup	No		Tether tool	1		
5005	RMS	ingress MFR	MFR Setup	No		Large handrail	1		
5006	RMS	receive MFR handle from FF EV	MFR Setup	No		Small handrail	1		
5007	RMS	install MFR handle	MFR Setup	No		Small handrail	1		
5008	RMS	retrieve 80-in tether	MFR Setup	unk	stow/retrieve	Pinch	1		

		from MFR			tether				
5009	RMS	retrieve lube applicator	MFR Setup	No		Lube applicator	1		
5|2		**BAPS Post Setup**							
5011	FF	install PIP pins (2) (BAPS Center)	BAPS Post Setup	unk	install/remove PIP	PIP	2		
5|3		**Translation Aid Setup**							
5013	FF	remove PIP pin from mini-TA (if necessary)	Translation Aid Setup	No		PIP	1		
5014	FF	rotate handle 140 deg (mini-TA)	Translation Aid Setup	No		Small handrail	1		
5015	FF	install PIP pin (mini-TA)	Translation Aid Setup	No		PIP	1		
5016	FF	install hitch pin (mini-TA)	Translation Aid Setup	No		Hitch	1		
5017	FF	extend TA tube (stbd)	Translation Aid Setup	No		Small handrail	1	Small handrail	
5018	FF	rotate TA joint (stbd)	Translation Aid Setup	No		Small handrail	1		
5019	FF	extend TA tube (port)	Translation Aid Setup	No		Small handrail	1	Small handrail	
5020	FF	rotate TA joint (port)	Translation Aid Setup	No		Small handrail	1		
5|4		**Tool Setup**							
5022	FF	translate to port ATM	Tool Setup	Yes	move about worksite	Motion	1		
5023	FF	open ATM (port)	Tool Setup	Yes	open/close ATM	Small handrail	1		
5024	FF	retrieve CVL bag	Tool Setup	Yes	stow/retrieve CVL bag	delicate pinch	1		
5025	FF	retrieve NCS sock bag	Tool Setup	Yes	stow/retrieve NCS sock bag	delicate pinch	1		
5026	FF	close ATM (port)	Tool Setup	Yes	open/close ATM	Small handrail	1		

5027	FF	engage ATM latches (4-port)	Tool Setup	Yes	engage/disengage ATM latch	Unknown	4		
5028	FF	retrieve door stop extensions (2)	Tool Setup	Yes	retrieve door stop extension	Unknown	2		
5029	FF	translate to +V2 aft shroud	Tool Setup	Yes	move about worksite	Motion	1		
5030	FF	stow CVL bag on stanchion (temp)	Tool Setup	Yes	stow/retrieve CVL bag	delicate pinch	1		
5031	FF	stow NCS sock bag on aft shroud handrail (temp)	Tool Setup	Yes	stow/retrieve NCS sock bag	delicate pinch	1		
5032	FF	install door stop extensions (2)	Tool Setup	Yes	install door stop extension	Unknown	2		
5033	FF	translate to stbd ATM	Tool Setup	Yes	move about worksite	Motion	1		
5034	FF	open ATM (stbd)	Tool Setup	Yes	open/close ATM	Small handrail	1		
5035	FF	retrieve NCC groundstrap	Tool Setup	Yes	stow/retrieve groundstrap	delicate pinch	1		
5036	FF	retrieve cryo vent insert	Tool Setup	Yes	stow/retrieve cryo vent insert	Unknown	1		
5037	FF	retrieve P600 harness	Tool Setup	Yes	stow/retrieve harness	delicate pinch	1		
5038	FF	close ATM (stbd)	Tool Setup	Yes	open/close ATM	Small handrail	1		
5039	FF	engage ATM latches (2-stbd)	Tool Setup	Yes	engage/disengage ATM latch	Unknown	2		
5040	FF	translate to +V2 aft shroud	Tool Setup	Yes	move about worksite	Motion	1		
5041	FF	stow cryo vent insert on stanchion (temp)	Tool Setup	Yes	stow/retrieve cryo vent insert	Unknown	1		
5042	FF	open door (assist RMS EV)	Tool Setup	No		Small handrail	1		
5043	FF	rotate tool interface 180 deg	Tool Setup	No		Unknown	1		

5044	FF	retrieve fish stringer from stanchion	Tool Setup	Yes	stow/retrieve fish stringer	delicate pinch	1		
5|5		**Open +V2 Doors**							
5046	RMS	mnvr to +V2 aft shroud	Open +V2 Doors	Yes	move about worksite	Motion	1		
5047	RMS	stanchion 180 deg	Open +V2 Doors	No		Unknown	1		
5048	RMS	stow 80-in adj tether on left door lower handrail	Open +V2 Doors	unk	stow/retrieve tether	Pinch	1		
5049	RMS	apply lubricant to latch bolts (4)	Open +V2 Doors	Yes	apply lubricant	Lubricant tool	4		
5050	RMS	PGT: A4, CCW 3, 23.5 short adj or PRT: A4, CCW, 23 short adj	Open +V2 Doors	Yes	set bolt drive	COMPUTER	1		
5051	RMS	drive latch bolts 7 turns (3-disengage)	Open +V2 Doors	Yes	drive bolt	Bolt drive	3		
5052	RMS	drive handle bolt 7 turns (disengage)	Open +V2 Doors	Yes	drive bolt	Bolt drive	1		
5053	RMS	maintain pressure on doors	Open +V2 Doors	Yes	maintain pressure on doors	Small handrail	1		
5054	RMS	remove PIP pin	Open +V2 Doors	Yes	install/remove PIP	PIP	1		
5055	RMS	release handle latch	Open +V2 Doors	Yes	release latch	Small handrail	1		
5056	RMS	install PIP pin	Open +V2 Doors	Yes	install/remove PIP	PIP	1		
5057	RMS	open doors	Open +V2 Doors	Yes	open/close V2 door	Small handrail	1	Small handrail	1
5|6		**NICMOS Prep**							
5059	FF	transfer CVL bag	NICMOS Prep	Yes	transfer CVL bag	delicate pinch	1	delicate pinch	1
5060	RMS	receive CVL bag from FF EV	NICMOS Prep	No		delicate pinch	1		
5061	RMS	stow CVL bag on MWS	NICMOS Prep	Yes	stow/retrieve CVL bag	delicate pinch	1		

5062	FF	stow NCS sock bag on right bulkhead HR	NICMOS Prep	Yes	stow/retrieve NCS sock bag	delicate pinch	1		
5063	FF	stow NCC goundstrap on NICMOS short HR	NICMOS Prep	Yes	stow/retrieve groundstrap	delicate pinch	1		
5064	FF	stow fish stringer	NICMOS Prep	Yes	stow/retrieve fish stringer	delicate pinch	1		
5065	FF	release CVL tie-down from aft bulkhead handrail	NICMOS Prep	Yes	release CVL tie-down	delicate pinch	1		
5066	FF	PGT: A3, CCW 3, 10.5, 6-in wobble	NICMOS Prep	Yes	set bolt drive	COMPUTER	1		
5067	FF	drive keyway bolts (NICMOS CVL) 5-6 turns (3-disengage)	NICMOS Prep	Yes	drive bolt	Bolt drive	3		
5068	RMS	PGT: A3, CCW 3, 10.5	NICMOS Prep	Yes	set bolt drive	COMPUTER	1		
5069	RMS	drive keyway bolts (bulkhead CVL) 4-7 turns (3-disengage)	NICMOS Prep	Yes	drive bolt	Bolt drive	3		
5070	RMS	remove CVL mounting flange from bulkhead	NICMOS Prep	Yes	remove CVL mounting flange	Unknown	1		
5071	FF	remove NICMOS CVL mounting flange	NICMOS Prep	Yes	remove CVL mounting flange	Unknown	1		
5072	RMS	release CVL tie-down strap from center handrail	NICMOS Prep	Yes	release CVL tie-down	delicate pinch	1		
5073	RMS	remove CVL	NICMOS Prep	Yes	remove CVL	Small handrail	1		
5074	RMS	back out of aft shroud	NICMOS Prep	Yes	move about worksite	Motion	1		
5075	RMS	stow CVL in CVL bag using integral tether	NICMOS Prep	Yes	stow CVL	delicate pinch	1		
5076	RMS	stow CVL bag on	NICMOS Prep	Yes	stow/retrieve	delicate pinch	1		

		stanchion			CVL bag				
5077	RMS	retrieve cryo vent insert	NICMOS Prep	Yes	stow/retrieve cryo vent insert	Unknown	1		
5078	FF	check MCC GO for NICMOS groundstrap removal and NCC install	NICMOS Prep	Yes	check GO	COMPUTER	1		
5079	FF	PGT: A3, CCW 2, 10.5	NICMOS Prep	Yes	set bolt drive	COMPUTER	1		
5080	FF	drive groundstrap bolt (NICMOS) 4-6 turns (disengage)	NICMOS Prep	Yes	drive bolt	Bolt drive	1		
5081	RMS	PGT: A3, CW 3, 10.5	NICMOS Prep	Yes	set bolt drive	COMPUTER	1		
5082	RMS	drive cryo vent insert (install) handle at 1 o'-clock	NICMOS Prep	Yes	drive bolt	Bolt drive	1		
5083	RMS	rotate cryo vent insert CW	NICMOS Prep	Yes	rotate cryo vent insert	Unknown	1		
5084	RMS	drive keyway bolts 4-6 turns (3-engage)	NICMOS Prep	Yes	drive bolt	Bolt drive	3		
5085	RMS	retract latches (3)	NICMOS Prep	Yes	release latch	Unknown	3		
5086	RMS	stabilize FF EV (if necessary)	NICMOS Prep	No		Unknown			
5087	FF	PGT: B6, CW 2, 10.5	NICMOS Prep	Yes	set bolt drive	COMPUTER	1		
5088	FF	drive groundstrap adapter bolt (NCC) on NICMOS 4-6 turns (engage)	NICMOS Prep	Yes	drive bolt	Bolt drive	1		
5089	FF	install NICMOS groundstrap on NCC adapter, engage bolt 4-6 turns	NICMOS Prep	Yes	install groundstrap	Bolt drive	1	Pinch	1
5090	FF	check free end of NCC groundstrap tethered to NICMOS	NICMOS Prep	unk	inspect worksite	Camera	1		

		handrail							
5091	FF	retrieve fish stringer	NICMOS Prep	Yes	stow/retrieve fish stringer	delicate pinch	1		
5092	FF	tether CASH connectors to +V2 upper door handrail to clear NCC worksite	NICMOS Prep	unk	tether connector	Tether tool	1		
5|7		**P600 Retrieval**							
5094	FF	translate to stbd ATM	P600 Retrieval	Yes	move about worksite	Motion	1		
5095	FF	open ATM (stbd)	P600 Retrieval	Yes	open/close ATM	Small handrail	1		
5096	FF	retrieve P600 harness	P600 Retrieval	Yes	stow/retrieve harness	delicate pinch	1		
5097	FF	close ATM (stbd)	P600 Retrieval	Yes	open/close ATM	Small handrail	1		
5098	FF	engage ATM latches (2-stbd)	P600 Retrieval	Yes	engage/disengage ATM latch	Unknown	2		
5099	FF	translate over ASIPE	P600 Retrieval	Yes	move about worksite	Motion	1		
5100	FF	stow P600 harness on MFR handle	P600 Retrieval	unk	stow/retrieve harness	delicate pinch	1		
5101	FF	close NCC contamination cover	P600 Retrieval	Yes	open/close contamination cover	delicate pinch	1		
5|8		**NCC Retreival**							
5103	RMS	mnvr to SAC	NCC Retrieval	Yes	move about worksite	Motion	1		
5104	RMS	open NCC contamination cover	NCC Retrieval	Yes	open/close contamination cover	delicate pinch	1		
5105	RMS	PGT: A4, CCW 3, 23.5 fully extended	NCC Retrieval	Yes	set bolt drive	COMPUTER	1		

5106	RMS	drive keyway bolts (NCC) 5-7 turns (4-disengage)	NCC Retrieval	Yes	drive bolt	Bolt drive	4		
5107	RMS	PGT: A2, CW 2, 5.5	NCC Retrieval	Yes	set bolt drive	COMPUTER	1		
5108	RMS	remove NCC	NCC Retrieval	Yes	install/remove NCC	Small handrail	1		
5109	RMS	open neon bypass valves ~130 deg up (2)	NCC Retrieval	Yes	open neon bypass valve	Unknown	2		
5|9		**NCC Installation**							
5111	FF	translate to +V2 aft shroud	NCC Installation	Yes	move about worksite	Motion	1		
5112	RMS	mnvr to +V2 aft shroud	NCC Installation	Yes	move about worksite	Motion	1		
5113	RMS	install NCC	NCC Installation	Yes	install/remove NCC	Small handrail	1		
5114	RMS	drive handrail latch 7-9 turns (engage)	NCC Installation	Yes	drive bolt	Bolt drive	1		
5115	FF	extend center guide latch plunger (no preload)	NCC Installation	Yes	extend latch plunger	Pinch	1		
5116	FF	stabilize NCC	NCC Installation	Yes	stabilize ORU	Small handrail	1		
5117	FF	check plunger nose cone centered in middle of hole	NCC Installation	Yes	inspect worksite	Camera	1		
5118	FF	preload center guide latch plunger until hardstop	NCC Installation	Yes	preload latch plunger	Pinch	1		
5119	FF	check 1/8-in white band visible on plunger shaft	NCC Installation	Yes	inspect worksite	Camera	1		
5120	FF	PGT: A2, CW 2, 2.5 MTL	NCC Installation	Yes	set bolt drive	COMPUTER	1		
5121	FF	drive lockdown bolt (inboard) .75-1.25 turns (engage)	NCC Installation	Yes	drive bolt	Bolt drive	1		

5122	FF	PGT: A2, CW 2, 5.5	NCC Installation	Yes	set bolt drive	COMPUTER	1		
5123	FF	drive lockdown bolt (outboard) .75-1.25 turns (engage)	NCC Installation	Yes	drive bolt	Bolt drive	1		
5124	RMS	PGT: B6, CW 2, 10.5	NCC Installation	Yes	set bolt drive	COMPUTER	1		
5125	RMS	drive groundstrap bolt (NCC) (install)	NCC Installation	Yes	drive bolt	Bolt drive	1	Pinch	1
5126	RMS	drive groundstrap bolt 2-4 turns (engage)	NCC Installation	Yes	drive bolt	Bolt drive	1		
5127	RMS	retrieve groundstrap tether	NCC Installation	Yes	stow/retrieve tether	delicate pinch	1		
5128	RMS	remove connector cap J7 from NCC	NCC Installation	Yes	install/remove connector cap	Pinch	1		
5129	RMS	remove connector cap J8 from NCC	NCC Installation	Yes	install/remove connector cap	Pinch	1		
5130	RMS	release CASH restraint tether	NCC Installation	No		Tether tool	1		
5131	RMS	remove turn-around plug	NCC Installation	Yes	install/remove turn-around plug	Pinch	1		
5132	RMS	stow turn-around plug on fish stringer	NCC Installation	Yes	stow turn-around plug	Pinch	1	Pinch	1
5133	RMS	inspect connector (CASH)	NCC Installation	Yes	inspect worksite	Pinch	1	Camera	1
5134	RMS	mate connector (CASH)	NCC Installation	Yes	mate/demate connector	Pinch	1		
5135	RMS	transfer stringer to stanchion	NCC Installation	unk	transfer stringer	delicate pinch	1		
5136	RMS	transfer retractable tether to stanchion	NCC Installation	unk	transfer tether	Unknown	1		
5137	RMS	stow caps (J7 & J8) in trash bag	NCC Installation	Yes	stow connector cap	Pinch	2	Pinch	2
5138	FF	translate to MULE	NCC Installation	Yes	move about worksite	Motion	1		
5139	FF	release MULE latch (lower port)	NCC Installation	Yes	release latch	Unknown	1		

5140	FF	release shear ties CCW, 52 deg (2)	NCC Installation	Yes	engage/disengage shear tie	Unknown	2		
5141	FF	PGT: A6, CCW 4, 30.5, 19 ft-lb	NCC Installation	Yes	set bolt drive	COMPUTER	1		
5142	FF	drive latch bolts (center) 15 turns (3-disengage)	NCC Installation	Yes	drive bolt	Bolt drive	3		
5143	FF	release MULE latch (lower stbd)	NCC Installation	Yes	release latch	Unknown	1		
5144	FF	translate to +V2 aft shroud	NCC Installation	Yes	move about worksite	Motion	1		
5|10		**MFR Swap**							
5146	RMS	stow PGT	MFR Swap	No		COMPUTER	1		
5147	FF	translate to MFR	MFR Swap	No		Motion	1		
5148	FF	Daisy chain extra waist tether to RMS EV	MFR Swap	No		Unknown	1		
5149	RMS	Daisy chain extra waist tether to FF EV	MFR Swap	No		Unknown	1		
5150	FF	Disconnect RMS EV's safety tether from EMU D-ring	MFR Swap	No		Tether tool	1		
5151	RMS	Disconnect FF EV's safety tether from EMU D-ring	MFR Swap	No		Tether tool	1		
5152	FF	Mate RMS EV's safety tether to FF EV EMU D-ring	MFR Swap	No		Tether tool	1		
5153	RMS	Mate FF EV's safety tether to RMS EV EMU D-ring	MFR Swap	No		Tether tool	1		
5154	FF	Check safety tether gate closed	MFR Swap	No		Camera	1		
5155	RMS	Check safety tether gate closed	MFR Swap	No		Camera	1		

5156	FF	Disconnect RMS EV's prime waist tether from EMU D-ring	MFR Swap	No		Tether tool	1		
5157	RMS	Disconnect FF EV's prime waist tether from EMU D-ring	MFR Swap	No		Tether tool	1		
5158	FF	Mate RMS EV's prime waist tether to FF EV EMU D-ring	MFR Swap	No		Tether tool	1		
5159	RMS	Mate FF EV's prime waist tether to RMS EV EMU D-ring	MFR Swap	No		Tether tool	1		
5160	FF	Disconnect extra waist tether daisy chain	MFR Swap	No		Unknown	1		
5161	RMS	Disconnect extra waist tether daisy chain	MFR Swap	No		Unknown	1		
5162	FF	PGT swap (if required)	MFR Swap	No		Large handrail	1		
5163	RMS	PGT swap (if required)	MFR Swap	No		Large handrail	1		
5|11		**Radiator Retrieval**							
5165	RMS	mnvr to MULE	Radiator Retrieval	Yes	move about worksite	Motion	1		
5166	RMS	boot plate 90L	Radiator Retrieval	No		Unknown	1		
5167	RMS	stanchion 135R	Radiator Retrieval	No		Unknown	1		
5168	FF	close aft shroud door (left) (partially)	Radiator Retrieval	Yes	open/close shroud door	Small handrail	1		
5169	FF	tether aft shroud door (left)	Radiator Retrieval	unk	tether shroud door	Tether tool	1		
5170	FF	translate to MULE	Radiator Retrieval	Yes	move about worksite	Motion	1		
5171	FF	release MULE latch (upper stbd)	Radiator Retrieval	Yes	release latch	Unknown	1		

5172	RMS	release MULE latch (upper port)	Radiator Retrieval	Yes	release latch	Unknown	1		
5173	FF	remove NCS radiator from MULE	Radiator Retrieval	Yes	install/remove NCS radiator	Small handrail	1	Small handrail	1
5174	RMS	remove NCS radiator from MULE	Radiator Retrieval	No		Small handrail	1	Small handrail	1
5175	FF	open handrail (N3) latch (NCS radiator)	Radiator Retrieval	Yes	engage/disengage handrail latch	Small handrail	1		
5176	RMS	stabilize radiator	Radiator Retrieval	Yes	stabilize ORU	Small handrail	1		
5177	FF	transfer NCS radiator	Radiator Retrieval	Yes	transfer NCS radiator	Small handrail	1	Small handrail	1
5178	RMS	receive NCS radiator from FF EV	Radiator Retrieval	No		Unknown	1		
5|12		**Radiator Installation**							
5180	FF	translate to +V2 aft shroud	Radiator Installation	Yes	move about worksite	Motion	1		
5181	RMS	mnvr to +V2/-V3 aft shroud	Radiator Installation	Yes	move about worksite	Motion	1		
5182	RMS	boot plate 30R	Radiator Installation	No		Unknown	1		
5183	RMS	open handrail (N1, N2) latches (2) (NCS radiator)	Radiator Installation	Yes	engage/disengage handrail latch	Small handrail	2		
5184	RMS	install radiator over HST handrails	Radiator Installation	Yes	install/remove NCS radiator	Small handrail	1	Small handrail	1
5185	RMS	check alignment arrows on radiator and FR26	Radiator Installation	Yes	inspect worksite	Camera	1		
5186	RMS	engage radiator handrail (N1, N2) latches (2)	Radiator Installation	Yes	engage/disengage handrail latch	Small handrail	2		
5187	FF	check alignment	Radiator Installation	Yes	inspect worksite	Camera	1		
5188	FF	engage radiator handrail (N3) latch	Radiator Installation	Yes	engage/disengage handrail latch	Small handrail	1		

5189	RMS	engage shear ties CW 52 deg (2)	Radiator Installation	Yes	engage/disengage shear tie	Unknown	2		
5190	FF	check alignment of radiator skirt	Radiator Installation	Yes	inspect worksite	Camera	1		
5191	RMS	check alignment of radiator skirt	Radiator Installation	Yes	inspect worksite	Camera	1		
5192	FF	check MULE latches in detents (2) facing upward	Radiator Installation	Yes	inspect worksite	Camera	2		
5193	RMS	check MULE latches in detents (2) facing downward	Radiator Installation	Yes	inspect worksite	Camera	2		
5|13		**NCC Power Cable Installation**							
5195	RMS	retrieve P600 harness from stanchion	NCC Power Cable Installation	unk	stow/retrieve harness	delicate pinch	1		
5196	RMS	retrieve 90 deg connector tool from stanchion	NCC Power Cable Installation	unk	stow/retrieve connector tool	Small handrail	1		
5197	RMS	remove connector cap (J1 diode box)	NCC Power Cable Installation	Yes	install/remove connector cap	Pinch	1		
5198	RMS	stow connector cap J1 in trash bag	NCC Power Cable Installation	Yes	stow connector cap	Pinch	1	Pinch	1
5199	RMS	inspect diode box J1	NCC Power Cable Installation	Yes	inspect worksite	Pinch	1	Camera	1
5200	RMS	mate P600 harness P1 to diode box J1	NCC Power Cable Installation	Yes	mate/demate connector	Pinch	1		
5201	RMS	mnvr to EPS test panel at +V2 trunnion	NCC Power Cable Installation	Yes	move about worksite	Motion	1		
5202	RMS	open MLI tent	NCC Power Cable Installation	Yes	open MLI tent	delicate pinch	1		
5203	RMS	remove connector cap (EPS P600)	NCC Power Cable Installation	Yes	install/remove connector cap	Pinch	1		

5204	RMS	remove connector cap (P600 harness P600A)	NCC Power Cable Installation	Yes	install/remove connector cap	Pinch	1		
5205	RMS	inspect P600	NCC Power Cable Installation	Yes	inspect worksite	Pinch	1	Camera	1
5206	RMS	mate P600 to EPS P600	NCC Power Cable Installation	Yes	mate/demate connector	Pinch	1		
5207	RMS	stow connector caps (2) in trash bag	NCC Power Cable Installation	Yes	stow connector cap	Pinch	2		
5208	RMS	install MLI tent	NCC Power Cable Installation	Yes	install MLI tent	delicate pinch	1		
5209	RMS	mnvr to radiator diode box	NCC Power Cable Installation	Yes	move about worksite	Motion	1		
5210	RMS	secure Velcro for P600 harness on to radiator handrail	NCC Power Cable Installation	Yes	secure/remove Velcro	delicate pinch	1		
5211	RMS	open diode box cover	NCC Power Cable Installation	Yes	open/close diode box cover	Unknown	1		
5212	RMS	check NCS-A and NCS-B LEDs illuminated	NCC Power Cable Installation	Yes	inspect worksite	Camera	1		
5213	RMS	stow 90 deg connector tool	NCC Power Cable Installation	unk	stow/retrieve connector tool	Small handrail	1		
5214	RMS	stanchion 180 deg	NCC Power Cable Installation	No		Unknown	1		
5|14		**NCC Prep**							
5216	FF	open aft shroud door (partially)	NCC Prep	Yes	open/close aft shroud door	Small handrail	1		
5217	FF	install COOLANT IN cryo valve heater (outboard)	NCC Prep	Yes	install cryo valve heater	Unknown	1		
5218	FF	install COOLANT OUT cryo valve heater (inboard)	NCC Prep	Yes	install cryo valve heater	Unknown	1		

5219	FF	inspect o-rings (prior to neon line installation)	NCC Prep	Yes	inspect worksite	Camera	1		
5220	FF	install COOLANT IN neon line (outboard)	NCC Prep	Yes	install neon line	Unknown	1		
5221	FF	tighten wing nut CW 3-5 turns	NCC Prep	Yes	engage wing nut	Pinch	1		
5222	FF	install COOLANT OUT neon line (inboard)	NCC Prep	Yes	install neon line	Unknown	1		
5223	FF	tighten wing nut CW 3-5 turns	NCC Prep	Yes	engage wing nut	Pinch	1		
5224	FF	attach CASH integral black/white tether to long NCC handrail	NCC Prep	Yes	release/secure tether	Tether tool	1		
5|15		**Conduit Installation**							
5226	RMS	GCA to primary sock restraints	Conduit Installation	Yes	move about worksite	Motion	1		
5227	FF	config HST PFR (aft ASIPE)	Conduit Installation	No		Unknown	1		
5228	RMS	release upper primary sock restraint	Conduit Installation	Yes	release sock restraint	delicate pinch	1		
5229	RMS	Release upper conduit latch 90 deg CCW	Conduit Installation	Yes	release latch	Small handrail	1		
5230	RMS	release remaining sock restraints	Conduit Installation	Yes	release sock restraint	delicate pinch	1		
5231	RMS	secure fixed restraint under sock	Conduit Installation	Yes	release/secure restraint strap	delicate pinch	1		
5232	RMS	release lower conduit latch (1) 90 deg CCW	Conduit Installation	Yes	release latch	Small handrail	1		
5233	RMS	pivot conduit	Conduit Installation	Yes	pivot conduit	Unknown	1		
5234	FF	ingress PFR	Conduit Installation	No		Large handrail	1		
5235	FF	release secondary sock restraint	Conduit Installation	Yes	release sock restraint	delicate pinch	1		

5236	RMS	mnvr to aft shroud	Conduit Installation	Yes	move about worksite	Motion	1		
5237	RMS	boot plate 0 deg	Conduit Installation	No		Unknown	1		
5238	RMS	open aft shroud door (left)	Conduit Installation	Yes	open/close shroud door	Small handrail	1		
5239	RMS	retrieve 80-in tether	Conduit Installation	unk	stow/retrieve tether	Pinch	1		
5240	RMS	pass adj equip tether through cryo vent insert	Conduit Installation	unk	transfer tether	delicate pinch	1		
5241	FF	receive adj equip tether	Conduit Installation	No		delicate pinch	1		
5242	FF	attach to sock tether loop	Conduit Installation	unk	secure tether to loop	Unknown	1		
5243	RMS	check cryo vent insert latches retracted	Conduit Installation	Yes	inspect worksite	Camera	1		
5244	FF	feed conduit into cryo vent insert	Conduit Installation	Yes	feed conduit	delicate pinch	1		
5245	FF	route CPL sock	Conduit Installation	Yes	route CPL sock	delicate pinch	1		
5246	RMS	egress MFR	Conduit Installation	No		Large handrail	1		
5247	RMS	tether CPL to STIS L-handle	Conduit Installation	unk	tether CPL sock	Tether tool	1		
5248	RMS	ingress MFR	Conduit Installation	No		Large handrail	1		
5249	RMS	engage cryo vent insert latches (3)	Conduit Installation	Yes	engage cryo vent insert latch	Small handrail	3		
5250	FF	egress PFR	Conduit Installation	No		Large handrail	1		
5251	RMS	PGT: A3, CW 2, 10.5	Conduit Installation	Yes	set bolt drive	COMPUTER	1		
5252	RMS	drive locking bolts (cryo vent insert) 4-6 turns (2-engage)	Conduit Installation	Yes	drive bolt	Bolt drive	2		
5|16		**Radiator Harness Mate**							
5254	RMS	check MCC GO for NCC connector mates	Radiator Harness Mate	Yes	check GO	COMPUTER	1		
5255	FF	fairlead to mini-TA	Radiator Harness	No		Unknown	1		

			Mate						
5256	FF	release Velcro (sock)	Radiator Harness Mate	Yes	secure/remove Velcro	delicate pinch	1		
5257	FF	retrieve harnesses (NCS radiator) P4 and P3 (2)	Radiator Harness Mate	Yes	stow/retrieve harness	delicate pinch	2		
5258	FF	transfer harnesses (radiator) P4 and P3	Radiator Harness Mate	Yes	transfer harness	delicate pinch	2	delicate pinch	2
5259	RMS	receive harnesses (radiator) P4 and P3	Radiator Harness Mate	No		delicate pinch	2		
5260	RMS	inspect harnesses (NCS radiator) P4 and P3	Radiator Harness Mate	Yes	inspect worksite	Pinch	2	Camera	2
5261	RMS	mate harness (NCS radiator) P4	Radiator Harness Mate	Yes	mate/demate connector	Pinch	1		
5262	RMS	mate harness (NCS radiator) P3	Radiator Harness Mate	Yes	mate/demate connector	Pinch	1		
5263	RMS	open NCC saddle thermal cover	Radiator Harness Mate	Yes	open/close thermal cover	delicate pinch	1		
5264	FF	retrieve harnesses (NCS radiator) P2 and P1 (2)	Radiator Harness Mate	Yes	stow/retrieve harness	delicate pinch	2		
5265	FF	transfer harnesses (radiator) P2 and P1 to RMS EV	Radiator Harness Mate	Yes	transfer harness	delicate pinch	2	delicate pinch	2
5266	RMS	receive harnesses (NCS radiator) P2 and P1	Radiator Harness Mate	No		delicate pinch	2		
5267	RMS	inspect harness (NCS radiator) P1	Radiator Harness Mate	Yes	inspect worksite	Pinch	1	Camera	1
5268	RMS	mate harness (NCS radiator) P2	Radiator Harness Mate	Yes	mate/demate connector	Pinch	1		
5269	RMS	mate harness (NCS radiator) P1	Radiator Harness Mate	Yes	mate/demate connector	Pinch	1		
5270	RMS	mnvr to NCS diode box	Radiator Harness Mate	Yes	move about worksite	Motion	1		

5271	RMS	boot plate 30R	Radiator Harness Mate	No		Unknown	1		
5272	FF	route integral tether from P4 around electrical harnesses (4)	Radiator Harness Mate	unk	route tether	delicate pinch	1		
5273	FF	secure integral tether to center guiderail	Radiator Harness Mate	unk	release/secure tether	Tether tool	1		
5274	RMS	A sw - ENABLE	Radiator Harness Mate	Yes	flip switch	Bolt drive	1		
5275	RMS	B sw - ENABLE	Radiator Harness Mate	Yes	flip switch	Bolt drive	1		
5276	RMS	A sw - ENABLE (NCS)	Radiator Harness Mate	Yes	flip switch	Bolt drive	1		
5277	RMS	B sw - ENABLE (NCS)	Radiator Harness Mate	Yes	flip switch	Bolt drive	1		
5278	RMS	A sw - DISABLE	Radiator Harness Mate	Yes	flip switch	Bolt drive	1		
5279	RMS	B sw - DISABLE	Radiator Harness Mate	Yes	flip switch	Bolt drive	1		
5280	RMS	close diode box cover	Radiator Harness Mate	Yes	open/close diode box cover	Unknown	1		
5281	RMS	notify MCC NCS diode box Pwr ON	Radiator Harness Mate	Yes	notify MCC	COMPUTER	1		
5282	RMS	mnvr to +V2 aft shroud	Radiator Harness Mate	Yes	move about worksite	Motion	1		
5283	RMS	boot plate 0 deg	Radiator Harness Mate	No		Unknown	1		
5284	RMS	PGT: B1, CCW 3, 23.5	Radiator Harness Mate	Yes	set bolt drive	COMPUTER	1		
5285	RMS	drive saddle bolts (center) 7-8 turns (2-disengage)	Radiator Harness Mate	Yes	drive bolt	Bolt drive	2		
5286	FF	remove CPL evaporator from sock	Radiator Harness Mate	Yes	install/remove CPL evaporator	Unknown	1		

5287	FF	transfer CPL evaporator	Radiator Harness Mate	Yes	transfer CPL evaporator	Unknown	1	Unknown	1
5288	RMS	remove saddle cover	Radiator Harness Mate	Yes	remove saddle cover	delicate pinch	1		
5289	RMS	stow saddle cover (temp)	Radiator Harness Mate	Yes	stow saddle cover	delicate pinch	1		
5290	RMS	receive CPL evaporator	Radiator Harness Mate	No		Unknown	1		
5291	RMS	install CPL evaporator in saddle	Radiator Harness Mate	Yes	install/remove CPL evaporator	Unknown	1		
5292	RMS	PGT: B1, CW 2, 23.5	Radiator Harness Mate	Yes	set bolt drive	COMPUTER	1		
5293	RMS	drive bolts (center) 7-9 turns (2-engage) to install saddle cover	Radiator Harness Mate	Yes	drive bolt	Bolt drive	2		
5294	RMS	drive bolts (retorque)	Radiator Harness Mate	Yes	drive bolt	Bolt drive	2		
5295	RMS	close thermal cover (NCC saddle)	Radiator Harness Mate	Yes	open/close thermal cover	delicate pinch	1		
5296	FF	bundle CPL and electrical harnesses (4) w/CPL integral tether	Radiator Harness Mate	unk	bundle harnesses with tether	Unknown	1	Unknown	1
5297	FF	attach bundle to center guide bulkhead standoff bolt	Radiator Harness Mate	Yes	attach bundle to bulkhead bolt	delicate pinch	1	delicate pinch	1
5298	FF	secure Velcro on pull-thru strap to CPL sock	Radiator Harness Mate	Yes	secure/remove Velcro	delicate pinch	1		
5299	FF	attach NCS sock bag to MWS	Radiator Harness Mate	Yes	attach NCS sock bag to MWS	delicate pinch	1		
5300	FF	stow NCS sock in bag	Radiator Harness Mate	Yes	stow NCS sock	delicate pinch	1		
5|17		**Close +V2 Doors**							
5302	FF	close doors (assist RMS EV)	Close +V2 Doors	No		Small handrail	1		

5303	RMS	mnvr for door closure	Close +V2 Doors	Yes	move about worksite	Motion	1		
5304	RMS	close doors	Close +V2 Doors	Yes	open/close V2 door	Small handrail	1	Small handrail	1
5305	RMS	engage handle	Close +V2 Doors	Yes	engage V2 door handle	Small handrail	1		
5306	RMS	install PIP pin (handle)	Close +V2 Doors	Yes	install/remove PIP	PIP	1		
5307	RMS	PGT: B4, CW 3, 23.5 or PRT: B4, CW, 23 stall	Close +V2 Doors	Yes	set bolt drive	COMPUTER	1		
5308	RMS	drive handle bolt 6 turns (engage)	Close +V2 Doors	Yes	drive bolt	Bolt drive	1		
5309	RMS	report peak running torque	Close +V2 Doors	Yes	report running torque	COMPUTER	1		
5310	RMS	drive latch bolts 6 turns (3-engage)	Close +V2 Doors	Yes	drive bolt	Bolt drive	3		
5311	RMS	report peak running torque	Close +V2 Doors	Yes	report running torque	COMPUTER	3		
5312	RMS	PGT: to retorque bolt if nec	Close +V2 Doors	Yes	set bolt drive	COMPUTER	3		
5313	RMS	check door seals	Close +V2 Doors	Yes	inspect worksite	Camera	1		
5314	RMS	retrieve 80-in tether	Close +V2 Doors	unk	stow/retrieve tether	Pinch	1		
5315	RMS	Stow 80-in tether in trash bag (temp)	Close +V2 Doors	unk	stow/retrieve tether	Pinch	1		
5316	RMS	check door seals	Close +V2 Doors	Yes	inspect worksite	Camera	1		
5|18		**Sortie Cleanup**							
5318	FF	translate to port ATM	Sortie Cleanup	Yes	move about worksite	Motion	1		
5319	FF	open ATM (port)	Sortie Cleanup	Yes	open/close ATM	Small handrail	1		
5320	RMS	mnvr to port RAC ATM	Sortie Cleanup	Yes	move about worksite	Motion	1		
5321	RMS	stow PGT	Sortie Cleanup	No		COMPUTER	1		

5322	FF	stow NCS sock bag	Sortie Cleanup	Yes	stow/retrieve NCS sock bag	delicate pinch	1		
5323	RMS	transfer CVL bag	Sortie Cleanup	Yes	transfer CVL bag	delicate pinch	1	delicate pinch	1
5324	FF	receive CVL bag from RMS EV	Sortie Cleanup	No		delicate pinch	1		
5325	FF	stow CVL bag	Sortie Cleanup	Yes	stow/retrieve CVL bag	delicate pinch	1		
5326	FF	close ATM (port)	Sortie Cleanup	Yes	open/close ATM	Small handrail	1		
5327	FF	engage ATM latches (port)	Sortie Cleanup	Yes	engage/disengage ATM latch	Unknown	1		
5|19		**PLB Cleanup**							
5329	FF	translate to FSS	PLB Cleanup	Yes	move about worksite	Motion	1		
5330	RMS	mnvr to airlock	PLB Cleanup	Yes	move about worksite	Motion	1		
5331	FF	inspect main umbilical mechanism	PLB Cleanup	Yes	inspect worksite	Camera	1		
5332	RMS	transfer F5 camera to MFR handle	PLB Cleanup	Yes	transfer F5 camera	Unknown	1		
5333	FF	remove PIP pins (2-BAPS center)	PLB Cleanup	unk	install/remove PIP	PIP	2		
5334	FF	stow PIP pins (BAPS)	PLB Cleanup	unk	install/remove PIP	PIP	2		
5335	FF	retract mini-TA (ASIPE) if nec	PLB Cleanup	No		Unknown	1		
5336	FF	retract TA (stbd) if nec	PLB Cleanup	No		Unknown	1		
5337	FF	retract TA (port) if nec	PLB Cleanup	No		Unknown	1		
5338	FF	perform tool inventory	PLB Cleanup	No		Unknown	1		
5339	RMS	perform tool inventory	PLB Cleanup	No		Unknown	1		
5340	RMS	stanchion 0 deg	PLB Cleanup	No		Unknown	1		
5341	RMS	boot plate 0 deg	PLB Cleanup	No		Unknown	1		

5342	RMS	config tool interface 0 deg	PLB Cleanup	No		Unknown	1		
5343	FF	translate to airlock	PLB Cleanup	No		Motion	1		
5344	FF	open thermal cover	PLB Cleanup	No		delicate pinch	1		
5345	RMS	remove MFR handle	PLB Cleanup	No		Small handrail	1		
5346	RMS	transfer MFR handle to FF EV	PLB Cleanup	No		Small handrail	1		
5347	FF	receive MFR handle from RMS EV	PLB Cleanup	No		Small handrail	1		
5348	RMS	egress MFR	PLB Cleanup	No		Large handrail	1		
5|20		**Final PLB Cleanup**							
5350	FF	translate to airlock	Final PLB Cleanup	No		Motion	1		
5351	RMS	mnvr to airlock	Final PLB Cleanup	No		Motion	1		
5352	RMS	transfer F5 camera	Final PLB Cleanup	Yes	transfer F5 camera	Unknown	1		
5353	RMS	perform tool inventory	Final PLB Cleanup	No		Unknown	1		
5354	RMS	config tool interface 0 deg	Final PLB Cleanup	No		Unknown	1		
5355	RMS	remove MFR handle	Final PLB Cleanup	No		Small handrail	1		
5356	RMS	transfer MFR handle to FF EV	Final PLB Cleanup	No		Small handrail	1		
5357	FF	receive MFR handle from RMS EV	Final PLB Cleanup	No		Small handrail	1		
5358	FF	stow MFR handle in airlock	Final PLB Cleanup	No		Small handrail	1		
5359	FF	close thermal cover	Final PLB Cleanup	No		delicate pinch	1		
5360	FF	translate to mini-TA	Final PLB Cleanup	No		Motion	1		
5361	FF	stow mini-TA	Final PLB Cleanup	No		Unknown	1		
5362	FF	retract TA for landing (stbd) if nec	Final PLB Cleanup	No		Unknown	1		
5363	FF	retract TA for landing (port) if nec	Final PLB Cleanup	No		Unknown	1		
5364	FF	translate to Orbiter	Final PLB Cleanup	Yes	move about	Motion	1		

		Bay 10			worksite				
5365	FF	stow MFR (assist RMS EV)	Final PLB Cleanup	No		Unknown	1		
5366	FF	inspect P105 and P106 cover	Final PLB Cleanup	Yes	inspect worksite	Camera	2		
5367	FF	inspect main umbilical mechanism	Final PLB Cleanup	Yes	inspect worksite	Camera	1		
5368	FF	remove PIP pins (2-BAPS center)	Final PLB Cleanup	unk	install/remove PIP	PIP	2		
5369	FF	stow PIP pins (center BAPS)	Final PLB Cleanup	unk	install/remove PIP	PIP	2		
5|21		**MFR Stow**							
5371	RMS	ride RMS to Orbiter bay 10	MFR Stow	No		Motion	1		
5372	RMS	stanchion 0 deg	MFR Stow	No		Unknown	1		
5373	RMS	boot plate 0 deg	MFR Stow	No		Unknown	1		
5374	RMS	boot plate D-ring 0 deg	MFR Stow	No		Unknown	1		
5375	RMS	attach boot plate tether to stanchion	MFR Stow	No		Tether tool	1		
5376	RMS	stow MFR stanchion	MFR Stow	No		Unknown	1		
5377	RMS	check stanchion latched	MFR Stow	No		Camera	1		
5378	RMS	tether MFR to APC	MFR Stow	No		Tether tool	1		
5379	RMS	release MFR/RMS tether	MFR Stow	No		Tether tool	1		
5380	RMS	stow MFR/RMS tether	MFR Stow	No		delicate pinch	1		
5381	RMS	hold MFR while RMS ungrapples	MFR Stow	No		Large handrail	1		
5382	RMS	give IV GO to release MFR	MFR Stow	No		COMPUTER	1		
5383	RMS	latch MFR to APC	MFR Stow	No		Unknown	1		
5384	RMS	check MFR latched	MFR Stow	No		Camera	1		

5385	RMS	install PIP pin	MFR Stow	No		PIP	1		
5386	RMS	remove tether from MFR and APC	MFR Stow	No		Tether tool	1		
5387	RMS	translate to LGA	MFR Stow	Yes	move about worksite	Motion	1		
5388	RMS	remove LGAP cover	MFR Stow	Yes	remove LGAP cover	Unknown	1		
5389	RMS	translate to FSS	MFR Stow	Yes	move about worksite	Motion	1		
5390	RMS	stow LGAP cover	MFR Stow	Yes	stow LGAP cover	Unknown	1		

Appendix B: Comparison of Broad Primitives and End-Effectors

Broad Primitive	**First EE**	**# Instanes**	**Second EE**	**# Instances**
Apply lubricant	Lubricant Applicator	8		
Attach bundle to bulkhead bolt	Delicate Pinch	1	Delicate Pinch	1
Attach door clips to door stop	Unknown	1		
Attach NCS sock bag to MWS	Delicate Pinch	1		
Bundle harnesses with tether	Unknown	1	Unknown	1
Check GO	COMPUTER	14		
Connect ground cap to j-bolt	Unknown	1		
Cut MLI groundstraps	Unknown	2		
Deploy mast	Unknown	2		
Deploy MLI	Delicate Pinch	2		
Deploy SA panel	Unknown	4		
Deploy/retract FHST cover	Delicate Pinch	6		
Disconnect purge line	Pinch	1		
Disengage alignment aid stowage lock	Pinch	1		
Drive bolt	Bolt Drive	307		
Drive bolt	Bolt Drive	9	Small Handrail	9
Drive bolt	Bolt Drive	1	Camera	1
Drive bolt	Bolt Drive	2	Pinch	2
Engage cryo vent insert latch	Small Handrail	3		
Engage V2 door handle	Small Handrail	1		
Engage wing nut	Pinch	2		
Engage zip nut	Pinch	5		
Engage/disengage ASIPE latch	Small Handrail	7		
Engage/disengage ATM latch	Unknown	13		
Engage/disengage deployment lock	Pinch	5		
Engage/disengage handrail latch	Small Handrail	6		
Engage/disengage NT latch	Pinch	3		
Engage/disengage SADA clamp spindle lock	Unknown	4		
Engage/disengage shear tie	Unknown	4		
Engage/disengage UPS latch	Unknown	8		
Evaluate mass handling	COMPUTER	2		
Exchange DBA	Small Handrail	2	Small Handrail	2
Exchange PCU	Small Handrail	1	Small Handrail	1
Exchange RWA	Small Handrail	1	Small Handrail	1
Extend BAPS post	Small Handrail	1	Small Handrail	1
Extend latch plunger	Pinch	2		
Feed conduit	Delicate Pinch	1		

Flip lever/switch	Bolt Drive	7		
Fold MLI	Delicate Pinch	1	Delicate Pinch	1
Grasp SA handrail	Small Handrail	4		
Guide SA into SADA clamp	Small Handrail	2	Small Handrail	2
Inspect worksite	Camera	1	Bolt Drive	1
Inspect worksite	Camera	92		
Inspect worksite	Camera	32	Pinch	32
Inspect worksite	Camera	1	Small Handrail	1
Install BAPS end	Unknown	2		
Install CASH	Unknown	1		
Install cross strap harness clip	Unknown	1		
Install cryo valve heater	Unknown	2		
Install door stop extension	Unknown	2		
Install groundstrap	Bolt Drive	2	Pinch	2
Install handrail covers	Unknown	1		
Install MLI tent	Delicate Pinch	2		
Install neon line	Unknown	2		
Install NOBL	Unknown	1		
Install NOBL plugs	Pinch	1		
Install PCU handhold	Small Handrail	1	Small Handrail	1
Install vent plug	Pinch	4		
Install/remove ACS	Small Handrail	3	Small Handrail	3
Install/remove connector cap	Pinch	12		
Install/remove connector cap	Pinch	1	Delicate Pinch	1
Install/remove connector cap	Pinch	12	Pinch	12
Install/remove connector strap	Delicate Pinch	2	Delicate Pinch	2
Install/remove CPL evaporator	Unknown	2		
Install/remove DBA	Small Handrail	6		
Install/remove door stay	Small Handrail	14		
Install/remove ESM	Small Handrail	2	Small Handrail	2
Install/remove FHST cover	Unknown	8		
Install/remove FOC	Small Handrail	3	Small Handrail	3
Install/remove fuse plug	Pinch	2		
Install/remove hitch pin	Hitch	6		
Install/remove HRD	Small Handrail	2		
Install/remove latch cover	Delicate Pinch	2		
Install/remove NCC	Small Handrail	2		
Install/remove NCS radiator	Small Handrail	2	Small Handrail	2
Install/remove PDU fuse plug caddy	Pinch	2	Pinch	2
Install/remove PIP	PIP	50		
Install/remove PIP	PIP	2	Small Handrail	2
Install/remove SA	Small Handrail	2		
Install/remove SA	Small Handrail	6	Small Handrail	6
Install/remove stringer cap	Unknown	2		
Install/remove thermal cover	Delicate Pinch	7		
Install/remove thermal cover	Delicate Pinch	1	Small Handrail	1
Install/remove turn-around plug	Pinch	4		
Install/remove WF/PC cover	Delicate Pinch	3	Small Handrail	3

Maintain pressure on doors	Small Handrail	3		
Maintain SA slew	Bolt Drive	1	Small Handrail	1
Maintain SADA clearance	Unknown	2		
Mate/demate connector	Pinch	7	Delicate Pinch	7
Mate/demate connector	Pinch	61		
Mate/demate connector	Pinch	16	Pinch	16
Mate/demate PCU connector	HT Pinch	28		
Mate/demate PCU connector	HT Pinch	44	Pinch	44
Move about worksite	Motion	160		
Notify MCC	COMPUTER	14		
Open MLI tent	Delicate Pinch	1		
Open neon bypass valve	Unknown	2		
Open/close aft shroud door	Small Handrail	1		
Open/close ASIPE	Small Handrail	4		
Open/close ATM	Small Handrail	12		
Open/close bay door	Small Handrail	12		
Open/close contamination cover	Delicate Pinch	5		
Open/close diode box cover	Unknown	2		
Open/close LOPE	Small Handrail	2		
Open/close NT	Small Handrail	2		
Open/close PDU fuse plug caddy cover	Delicate Pinch	3		
Open/close shroud door	Small Handrail	2		
Open/close thermal cover	Delicate Pinch	11		
Open/close UPS	Unknown	2		
Open/close V2 door	Small Handrail	4	Small Handrail	4
Perform translation adaption	Unknown	2		
Pivot conduit	Unknown	1		
Pivot latch	Small Handrail	4		
Position connector	Pinch	2		
Position groundstrap tether	Delicate Pinch	1	Tether Tool	1
Position SADM	Unknown	2		
Preload latch plunger	Pinch	2		
Pull LGAP cover latch assy knob	Unknown	1		
Push/pull tee handle	Small Handrail	2		
Release BAPS post mechanism	Unknown	1		
Release CVL tie-down	Delicate Pinch	2		
Release groundstrap	Delicate Pinch	2		
Release latch	Pinch	1		
Release latch	Small Handrail	3		
Release latch	Unknown	7		
Release sock restraint	Delicate Pinch	3		
Release/secure cross strap	Delicate Pinch	2		
Release/secure restraint strap	Delicate Pinch	5		
Release/secure tether	Tether Tool	2	Pinch	2
Release/secure tether	Tether Tool	2		
Release/set door opening	Pinch	10		
Remove BAPS post	Small Handrail	1		
Remove CVL	Small Handrail	1		

Remove CVL mounting flange	Unknown	2		
Remove EPS panel	MWS EE	1		
Remove LGAP cover	Unknown	1		
Remove palm wheel	Unknown	2		
Remove PCU	Small Handrail	2		
Remove RWA	Small Handrail	2	Small Handrail	2
Remove saddle cover	Delicate Pinch	1		
Report running torque	COMPUTER	8		
Report turn count	COMPUTER	8		
Retrieve ASLR	Unknown	4		
Retrieve CASH	Unknown	1		
Retrieve cross strap	Delicate Pinch	2		
Retrieve door stop extension	Unknown	2		
Retrieve handrail covers	Unknown	1		
Retrieve inspection mirror	Pinch	1		
Retrieve NOBL	Delicate Pinch	2		
Retrieve vent plug	Pinch	4		
Rotate cryo vent insert	Unknown	1		
Rotate LGAP cover dome	Unknown	1		
Rotate SA	Small Handrail	4	Small Handrail	4
Rotate tee handle	Small Handrail	2		
Route CPL sock	Delicate Pinch	1		
Route cross strap	Delicate Pinch	4		
Route harness	Delicate Pinch	2	Delicate Pinch	2
Route tether	Delicate Pinch	1		
Secure door handle attachment to door handle	Unknown	1		
Secure harness to handrail	Delicate Pinch	2	Small Handrail	2
Secure harness to SADA soft-dock	Delicate Pinch	2	Small Handrail	2
Secure tether to loop	Unknown	1		
Secure/remove Velcro	Delicate Pinch	25		
Seure/remove Velcro	Delicate Pinch	10	Delicate Pinch	10
Secure/remove Velcro	Delicate Pinch	1	Small Handrail	1
Secure/remove Velcro	Pinch	1	Pinch	1
Secure/remove Velcro to connector	Delicate Pinch	4	Pinch	4
Set bolt drive	COMPUTER	149		
Slide bracket against SA	Small Handrail	2		
Slide FHST covers together	Delicate Pinch	6	Delicate Pinch	6
Stabilize ORU	Small Handrail	2		
Stow ASLR	Unknown	4		
Stow connector bracket on connector strap	Unknown	4		
Stow connector cap	Pinch	4	Pinch	4
Stow connector cap	Pinch	9		
Stow connector on connector stowage bracket	Pinch	9		
Stow CVL	Delicate Pinch	1		
Stow DBC	Unknown	1		

Stow fuse plug	Pinch	1		
Stow LGAP cover	Unknown	1		
Stow MLI	Delicate Pinch	1		
Stow NCS sock	Delicate Pinch	1		
Stow palm wheel	Unknown	2		
Stow PCU	Small Handrail	1	Small Handrail	1
Stow PCU caddy	Unknown	2		
Stow PCU connector	HT Pinch	28	Pinch	28
Stow purge line	Unknown	1		
Stow RWA	Small Handrail	1	Small Handrail	1
Stow saddle cover	Delicate Pinch	1		
Stow tang	Bolt Drive	2	Small Handrail	2
Stow turn-around plug	Pinch	2		
Stow turn-around plug	Pinch	1	Pinch	1
Stow/deploy aft fixture	Unknown	2		
Stow/deploy alignment aid	Pinch	3		
Stow/remove connector	Delicate Pinch	2	Delicate Pinch	2
Stow/remove connector	Pinch	11	Delicate Pinch	11
Stow/remove connector	Pinch	2		
Stow/remove SA panel restraint strap	Delicate Pinch	2	Small Handrail	2
Stow/remove SA panel restraint strap	Delicate Pinch	2		
Stow/retrieve connector tool	Small Handrail	2		
Stow/retrieve cryo vent insert	Unknown	3		
Stow/retrieve CVL bag	Delicate Pinch	5		
Stow/retrieve door stay	Small Handrail	2		
Stow/retrieve door stay	Unknown	2		
Stow/retrieve FHST cover	Delicate Pinch	3		
Stow/retrieve FHST cover	Small Handrail	1	Delicate Pinch	1
Stow/retrieve fish stringer	Delicate Pinch	3		
Stow/retrieve FOC	Small Handrail	2	Small Handrail	2
Stow/retrieve groundstrap	Delicate Pinch	4		
Stow/retrieve groundstrap	Delicate Pinch	1	Delicate Pinch	1
Stow/retrieve harness	Delicate Pinch	10		
Stow/retrieve harness	Tether Tool	1		
Stow/retrieve HRD	Small Handrail	4		
Stow/retrieve MLI recovery bag	Delicate Pinch	2		
Stow/retrieve MLI tent	Delicate Pinch	3		
Stow/retrieve NCS sock bag	Delicate Pinch	4		
Stow/retrieve PCU handhold	Small Handrail	2		
Stow/retrieve PDU fuse plug caddy	Pinch	2		
Stow/retrieve plug stringer	Delicate Pinch	2		
Stow/retrieve tether	Delicate Pinch	2		
Stow/retrieve tether	Pinch	7		
Stow/retrieve thermal cover	Delicate Pinch	8		
Stow/retrieve thermal cover	Delicate Pinch	2	Delicate Pinch	2
Stow/retrieve WF/PC cover	Small Handrail	3		

Tether connector	Tether Tool	1		
Tether CPL sock	Tether Tool	1		
Tether shroud door	Tether Tool	2		
Tighten wing bolt	Pinch	2		
Tighten/release EVA knob	Pinch	28		
Transfer CASH	Unknown	1	Unknown	1
Transfer CPL evaporator	Unknown	1	Unknown	1
Transfer CVL bag	Delicate Pinch	2	Delicate Pinch	2
Transfer ESM	Small Handrail	1	Small Handrail	1
Transfer F5 camera	Unknown	2		
Transfer FHST covers	Delicate Pinch	2	Delicate Pinch	2
Transfer harness	Delicate Pinch	5	Delicate Pinch	5
Transfer HRD	Small Handrail	2	Small Handrail	2
Transfer MLI recovery bag	Delicate Pinch	2	Delicate Pinch	2
Transfer NCS radiator	Small Handrail	1	Small Handrail	1
Transfer NOBL	Delicate Pinch	4	Delicate Pinch	4
Transfer PCU handhold	Small Handrail	2	Small Handrail	2
Transfer stringer	Delicate Pinch	1	Delicate Pinch	1
Transfer stringer	Delicate Pinch	1		
Transfer tether	Delicate Pinch	1		
Transfer tether	Pinch	1	Pinch	1
Transfer tether	Pinch	1		
Transfer tether	Unknown	1		
Transfer tether hook	Pinch	1	Pinch	1
Transfer WF/PC cover	Small Handrail	2	Small Handrail	2

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