

# EVA Console Handbook

Volume 5  
TPS Inspection  
and Repair

EVA, Robotics,  
and Crew Systems  
Operations Division



EVA Group

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

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# **EVA Console Handbook**

## **TPS Inspection and Repair**

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## **PREFACE**

This document has been prepared by the Extravehicular Activity (EVA) Systems Group under the authority of the EVA and Crew Systems Operations Branch, EVA, Robotics, and Crew Systems Operations Division, Lyndon B. Johnson Space Center (JSC), National Aeronautics and Space Administration (NASA).

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## **PURPOSE**

The EVA Console Handbook provides a single authoritative source of primary information for use by EVA flight control personnel. For additional information, the reader should refer to training manuals and other documents referenced in this handbook.

## **SCOPE**

Information in this handbook is not flight specific. It addresses systems and procedures used during nominal space shuttle flights.

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## 1.0 TPS INSPECTION AND REPAIR CAPABILITIES

Thermal Protection System (TPS) inspection and repair platforms for an Extravehicular (EV) crewmember include the following (all assume a foot restraint installed for EV performing the inspection or repair, and these are listed in order of decreasing stability for the EV crewmember):

- A. Space Station Remote Manipulator System (SSRMS)
- B. Shuttle Remote Manipulator System (SRMS)
- C. Boom mid-point
- D. Boom tip
- E. Simplified Aid For EVA Rescue (SAFER) flight (point inspection only - not for repair or 'mapping' a large area for inspection)

If at ISS, a tool stanchion can be installed into an Articulating Portable Foot Restraint (APFR) for a second free-floating crewmember to more easily assist the crewmember performing a repair and to more easily allow for tool transport when many tools are required. Additionally, a Worksite Interface (WIF) extender can be used to extend the reach of the foot restraint platforms, sometimes allowing Extravehicular Activity (EVA) to use a more stable platform (by avoiding the boom, for example). If not at ISS and if EVA inspection/repair tools are manifested, a Portable Foot Restraint (PFR) can be used on the SRMS and/or boom to accomplish the repair.

If non-EVA methods of inspecting the TPS method fail or if the Mission Management Team (MMT) believes that EVA is required for supplemental inspection, inspection options include the following:

- A. Point inspection (inspection of a specific damage site) with an EV crewmember in a foot restraint on the SSRMS/SRMS/boom; inspection hardware can include the digital camera and/or Infrared (IR) camera
- B. Point inspection with an EV crewmember flying SAFER; inspection hardware is the digital camera (IR camera too complicated and bulky for SAFER flight)
- C. Wing Leading Edge (WLE) mapping with an EV crewmember in a foot restraint on the SSRMS/SRMS/boom; inspection hardware can include the digital camera and/or IR camera

If either non-EVA or EVA TPS inspection reveals a potential need to perform a TPS repair, repair options include the following available techniques to be performed from the SSRMS, SRMS, or boom:

- A. Gap filler pulling or cutting
- B. Blanket cutting

- C. Emittance Protective Coating (EPC) application, also known as an Emittance Wash Applicator (EWA) repair
- D. Tile Overlay installation over damaged tile area
- E. Shuttle Tile Ablator 54 lbs/cu. ft. (STA-54) application in damaged tile or door seal area, and subsequent EVA to verify cure
- F. Non Oxide Adhesive eXperimental (NOAX) application over Reinforced Carbon Carbon (RCC) cracks, spalls, and gouges (and possibly very small holes)
- G. Plug installation with NOAX sealant in RCC holes or severe damages (might require drilling to create a hole)

## **2.0 EVA TPS INSPECTION AND REPAIR HISTORY**

Development work for TPS repair was conducted in the 1979-1980 timeframe, focusing on tile repair. Access to the TPS was planned using the Manned Maneuvering Unit (MMU) and ablator materials (pre-cured blocks and materials similar to STA-54) were considered for tile repair. This effort was dropped early in the program for several technical reasons that were deemed too challenging to pursue at the time. Following the Columbia accident in 2003, the EVA community again became engaged in the TPS inspection and repair development effort. This section addresses the rationale behind concepts that were rejected for access to the TPS and the history of the various inspection and repair concepts developed to date.

### **2.1.1 HISTORY OF EVA ACCESS TO TPS**

Several repair platforms were considered in the 2003-2004 timeframe to allow for EVA access to the shuttle TPS for inspection and repair. Prior to the shuttle program selecting the current boom and subsequent scheduling of the EVA boom Detailed Test Objective (DTO) on STS-121, these options included the following (although many other options were considered):

- A. An inflatable boom transported through the airlock and inflated in the payload bay. EVA operations testing was performed on this boom in the Neutral Buoyancy Laboratory (NBL). Limitations of this system included lack of Micrometeoroid Orbital Debris (MMOD) protection and the space required in the airlock for both this rolled-up boom and other repair equipment. This option was eliminated when the current boom was selected by the shuttle program as the future repair platform.
- B. Truss systems built/extended by the EVA crew or launched on the stbd side of the payload bay in Manipulator Positioning Mechanisms (MPMs). Multiple systems were preliminarily designed and subsequently discussed and/or tested by EVA operations. This option was eliminated when the current boom was selected by the shuttle program as the future repair platform.
- C. Use of the ORU Transfer Device (OTD) on the SRMS or SSRMS was considered for inspection operations. This option was eliminated as ground-based testing with the current boom showed promise for light inspection operations and because of instability of the OTD.
- D. Use of the Russian Strela extendable boom. This option proved difficult due to the lack of available engineering data. This option was eliminated when the current boom was selected by the shuttle program as the future repair platform.
- E. SAFER (or an upgraded SAFER) flight to the worksite with adhesive pads to adhere the EV crewmember in a Extravehicular Mobility Unit (EMU) to the TPS in the vicinity of the worksite. Several operational tests were conducted in many facilities for this option, called the SAFER Lander. Weaknesses of this option included lack of crewmember reach when adhered to the worksite and inability to

carry the required tools. This option was eliminated when the current boom was selected by the shuttle program as the future repair platform.

- F. Orbiter Repair Maneuver. For this maneuver, the SRMS grappled an ISS Flight Releasable Grapple Fixture (FRGF) on Pressure Mating Adapter (PMA) 2, the orbiter undocked, and the SRMS maneuvered the orbiter to present the TPS to an EV crewmember on the SSRMS. Many operational tests were performed, procedures were produced, and EVA crews were trained in the Virtual Reality (VR) Lab for the slow-moving orbiter response from performing a repair in this configuration. This was the shuttle program agreed-to repair access method for STS-114 and STS-121, although the boom would have been considered on those flights had a repair been necessary. This option was eliminated when the STS-121 boom DTO, combined with ground testing, showed that this complex and risky maneuver was not required.

Many operational SAFER tests in the VR Lab, on the Precision Air Bearing Facility (PABF), and on the KC-135 zero-g aircraft were conducted for inspection operations, and fairly early in the development effort SAFER flight was deemed viable for point inspection photography only. Mapping of large areas of the TPS was ruled out because the piloting of SAFER and consumables usage during these operations was considered too risky.

After the shuttle program selected the boom as the repair platform, EVA MOD worked with various organizations to develop an operations concept and crew training plan for inspection and repair operations from the boom. At the time, little was understood about how operations from the boom would be performed. Initial (conservative) assessments by the engineering robotics and EVA community indicated that the boom would exhibit large deflections and that many brake slips might occur. These assessments were initially based on EVA loads (forces, moments) from historical data of EVA crewmembers in a foot restraint on a stable platform, such as in a foot restraint in the payload bay. The only existing facility that could mimic the reaction of EVA loads on the SRMS/boom system was the VR Lab, but this facility could not support a suited crewmember performing repairs. This facility showed that cross coupling existed in boom motion and that “counter-intuitive” motion can result from loading inputs. Because the lack of loads information and to a lesser extent the counter-intuitive motion expected, the EVA community did not agree that the boom could be used as a viable work platform right away (especially for repair, since repair causes higher crewmember loads). So, in parallel with boom simulator development, the EVA community worked on worksite stabilization concepts. Concepts included the following:

- A. Use of a covered foam pad that would absorb energy as the boom impacted the TPS. This option did not provide in-out stability and was dropped in favor of adhesive concepts.
- B. Use of pressure sensitive adhesive or hot melt adhesive pads to adhere struts to the tiles or RCC. There were several concepts for strut attachment at the tip and/or mid-point of the boom and at the “feet” that adhered to the TPS. This option was

put on hold until after the boom DTO, and then it was decided not to pursue worksite stabilization.

- C. Use of a mechanism in the External Tank (ET) door cavity to stabilize the boom. This option was put on hold until after the boom DTO, and then it was decided not to pursue worksite stabilization.
- D. Use of a handhold that adhered to the tile or RCC using pressure sensitive adhesive or a hot melt adhesive. This option was put on hold until after the boom DTO, and then it was decided not to pursue worksite stabilization.

EVA operations on the boom were difficult to mimic on the ground because of boom/arm masses and lack of loads information for an EVA crewmember on the unstable SRMS/boom system (prior to the STS-121 boom DTO). Simulation of the boom movement was attempted in several ways:

- A. VR Lab - The high-fidelity SRMS and boom model was used in a closed-loop system on Charlotte (as is currently used) where loads information is fed back into the system and the Charlotte robot reacts accordingly. The uncertainty in this system is how much a crewmember in an EMU will 'absorb' some of the load, since a crewmember in an EMU cannot stand on Charlotte.
- B. NBL - The SRMS/boom system could not be easily mocked up to move in the actual frequency and deflection of the flight system due to water drag and corrosive effects. However, an EMU positioning device can be stretched out to give some flexibility and movement to a worksite interface, allowing a crewmember to stand on a moving platform to perform tasks. This was done on a number of occasions during development and early training events, but it was not considered an exact science. The NBL is also the primary facility for training of boom setup and cleanup activities.
- C. 3 Degree-of-Freedom (3-DOF) - This simulator allowed for suited or unsuited subject testing while lying on their side on the PABF. A boom was built that deflected according to the stiffness of springs in the boom support table. Engineering used this facility as the primary loads-gathering simulator to ensure crew safety and to attempt to predict the EVA loads that would be put into the system. Because movement only occurred in a plane, a number of assumptions had to be made to apply the data and operations to the real 6-DOF movement of the SRMS/boom system.
- D. 6-DOF - This simulator allowed for suited subjects to stand on a moving platform that used the same SRMS/boom model that the VR Lab used. Also a closed loop system based on loads imparted from the suited subject, this simulator moved in 6 degrees of freedom in a manner similar to the SRMS/boom system. Operations used this simulator as the primary facility to verify that TPS inspection and repair (and boom DTO) operations were feasible and that TPS repair hardware was acceptably built. Because an overhead suspension system limited the subject's

movement, assumptions had to be made to apply the operations to a flight-like capability.

After many ground-based tests, the STS-121 crew performed an EVA boom DTO, during which they performed motions to take loads data and mimic inspection and repair operations. After crew return, discussions were held about crew training venues and repair operations. The STS-121 crew felt that the VR Lab (and the NBL, for boom setup and cleanup) allowed for sufficient training because boom motion was only important as the relative movement between the crewmember and worksite. Based on ground testing and STS-121 crew comments, the EVA community has judged the boom to be a viable platform for performing the currently required inspection and repair operations. SAFER flight for point inspection is also still an option.

### **2.1.2 HISTORY OF EVA TPS INSPECTION CAPABILITIES**

Several capabilities were considered to give EVA the ability to perform a TPS inspection in case the primary (non-EVA) method failed. While the program tried to determine what the primary non-EVA method of inspection would be for RCC (the current boom was not selected right away), the Rendezvous Pitch Maneuver (RPM) at ISS approach was developed early in the effort to give 2-dimensional photos of tile damages for the orbiter belly. Also early in the effort, SAFER flight as an EVA option for photography was considered.

From an EVA perspective, the F5 camera was the existing camera at the start of the inspection development effort following Columbia. This camera could not give real-time data to clear the shuttle for landing (modifications to a digital camera were subsequently pursued for EVA use). The Wireless Video System (WVS) helmet camera was considered, but the resolution of the images was not considered good enough for RCC and the coverage was not guaranteed along both wings for upper and lower surfaces. Additionally, 3-dimensional (3-D) images were required to verify tile damages could be cleared for entry, and WVS could not give 3-D data for tile depth.

The Mechanical Contour Gauge (MCG), currently used for STA-54 repairs, was operationally tested and procedures were written to use this gauge to measure tile depth in a scenario where the RPM showed damage and the EVA crew was required to obtain 3-D data. Subsequent to this, photogrammetry information became promising for white tile. Therefore, the MCG option was eliminated because it required contact with the tile which could cause tile damage and/or crewmember stability issues for the boom and SAFER inspection scenarios.

The IR camera was developed later in the program and testing on several shuttle and ISS EVAs surrounding the STS-121 timeframe. Before the development of this EVA camera, the RCC damage experts performed many impact tests to determine what the delamination and backside spalling characteristics are for various RCC impacts. As a result, assumptions could be made about the internal and backside damage for a particular damage site. Therefore, the IR camera was not considered a requirement for either RCC inspection or RCC repair teams. Although supported by the shuttle



program, the IR camera was not considered an alternate to digital photography for RCC, and is considered a supplement for other inspection methods.

### 2.1.3 HISTORY OF TPS REPAIR CONCEPTS

The Columbia investigation board determined that the cause of the Columbia accident was a breach in the TPS on the left WLE RCC panel 8 that resulted from an ET foam impact in the area on ascent. This board recommended the following, as it relates to TPS repair:

- A. For missions to ISS, develop a practicable capability to inspect and effect emergency repairs to the widest possible range of damage to the TPS, including both tile and RCC, taking advantage of the additional capabilities available when near to or docked at the ISS.
- B. For non-ISS missions, develop a comprehensive autonomous (independent of Station) inspection and repair capability to cover the widest possible range of damage scenarios.

Several RCC and tile repair concepts were considered that have since been eliminated from the program (there were several more concepts than are listed below):

- A. RCC repair 'filled wing' concept. In this concept, a bag was inserted into the damaged RCC and filled with insulating foam. The bag was sealed and the hole was then covered with a viscous resin or other material. This option was eliminated due to lack of testing and the quantity of foam required.
- B. RCC repair adhesive patch concept. A patch (more than one type was considered) was rolled onto the damaged area where it adhered to the RCC, and then a heater was applied with slight pressure. Several operational evaluations were performed for this option. This option was eliminated due to the complexity of the heater system, poor entry (arc jet) test results at the time, and uncertainty in the verification in the bond after EVA application.
- C. RCC repair viscous materials (other than NOAX). Glenn Refractory Adhesive Bonding and Exterior Repair (GRABER), Starfire-based, and other materials were considered and tested operationally. These materials were eliminated from the program because they did not perform as well as NOAX in entry (arc jet) conditions and some were toxic to varying degrees.
- D. RCC repair "overwrap" concept. There were two types of overwrap concepts: Intravehicular Activity (IVA)-cured over a template, and overwraps launched in pre-formed RCC shape (rigid shell). Many operational evaluations were performed for this option. Of the two types, the shuttle program preferred the rigid shell, but this option was eliminated due to the issues involved with manifesting 44 rigid shells.
- E. RCC repair Small Area Repair (SAR). This repair method involves drilling a small hole in the RCC and installing a small (~ 3 inch diameter) rigid plate of plug-like

material by threading into the hole like a wood screw. Some research is still on-going for this concept.

- F. RCC Large Area Repair (LAR). This concept involves installation of a larger flexible plate over a large hole in the RCC, with the fastening concept similar to the SAR concept (or using the SARs themselves around the perimeter). Some research is still on-going for this concept.
- G. Tile repair STA-54, stored in and dispensed from the Cure In Place Ablator (CIPA) Applicator (CIPAA). This type of Room Temperature Vulcanizing (RTV) material (at the time it was called MA25S) was selected early on in this development process (it was really the only option considered) because NASA had done some testing with it in the 1979-1980 timeframe. A big challenge in the early 80s was accessing the worksite and getting CIPA to adhere to tile, which are some reasons this effort was dropped at the start of the shuttle program. After Columbia, the effort resumed where it left off, and from an EVA operational standpoint, approximately 35 zero-g KC-135 flights were performed from 2003-2005 to understand methods of EVA application and methods to promote adhesion of STA-54 to tile substrate. EVA application methods on exposed tile cavities included the following methods:
  - 1. Application of an adhesive membrane over the tile cavity, followed by insertion of the nozzle into a cut in the membrane and subsequent CIPA application between the membrane and tile. This resulted in a fill that was flush with the tile Outer Mold Line (OML), and the adhesive was intended to burn off on entry. This option was eliminated when it was determined that the CIPA would swell on entry and would require an underfill.
  - 2. Application of CIPA, followed by installation of a non-adhesive membrane that was rolled over the CIPA to create a smooth flush finish. The non-adhesive membrane would remain on the repair and burn up during entry. This option was eliminated when it was determined that the CIPA would swell on entry and would require an underfill.
  - 3. Installation of pre-cured ablator blocks into the cavity, along with CIPA. There were several methods considered for these blocks (originally looked at in the late 70s/early 80s). Methods included holes in the blocks to fill under them, dispensing CIPA on the blocks before installation, and starting with the blocks attached to an adhesive membrane. The concept of precured blocks was eliminated due to concern about void formation around the blocks (note that this was prior to later CIPA development testing during which bubbles formed anyway).

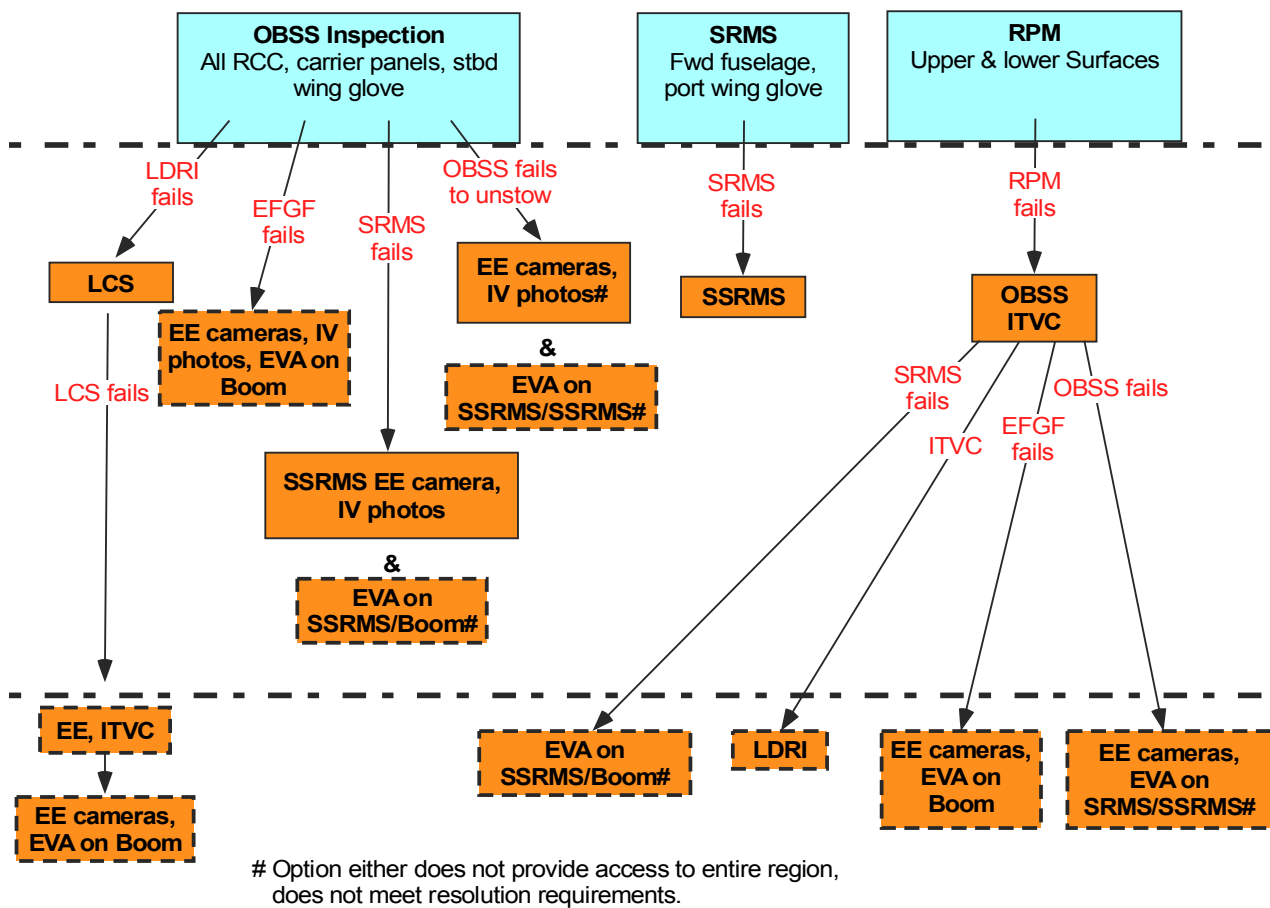
After it was discovered that open-celled foam does not stick to CIPA (discovered by EVA Engineering and MOD personnel), after emittance wash was determined to promote adhesion, and after a down-selection of options, the current underfill method of CIPA application was chosen. The dispenser, CIPAA, flew on STS-114. However, concern about whether CIPA material properties and application, the manifesting of the

large CIPAA (it dispensed about 600 cu. in. of material), and toxicity concerns of CIPA at the time, CIPAA was eliminated in favor of the tile overlay system. STA-54 later made a comeback for STS-121 in a smaller dispenser, Tile Repair Ablator Dispenser (T-RAD). T-RAD was sized much smaller and advertised as a door seal repair capability. T-RAD was acquired by the shuttle program at a time when toxicity appeared to be less of a concern and while the tile overlay system development test program was still immature.

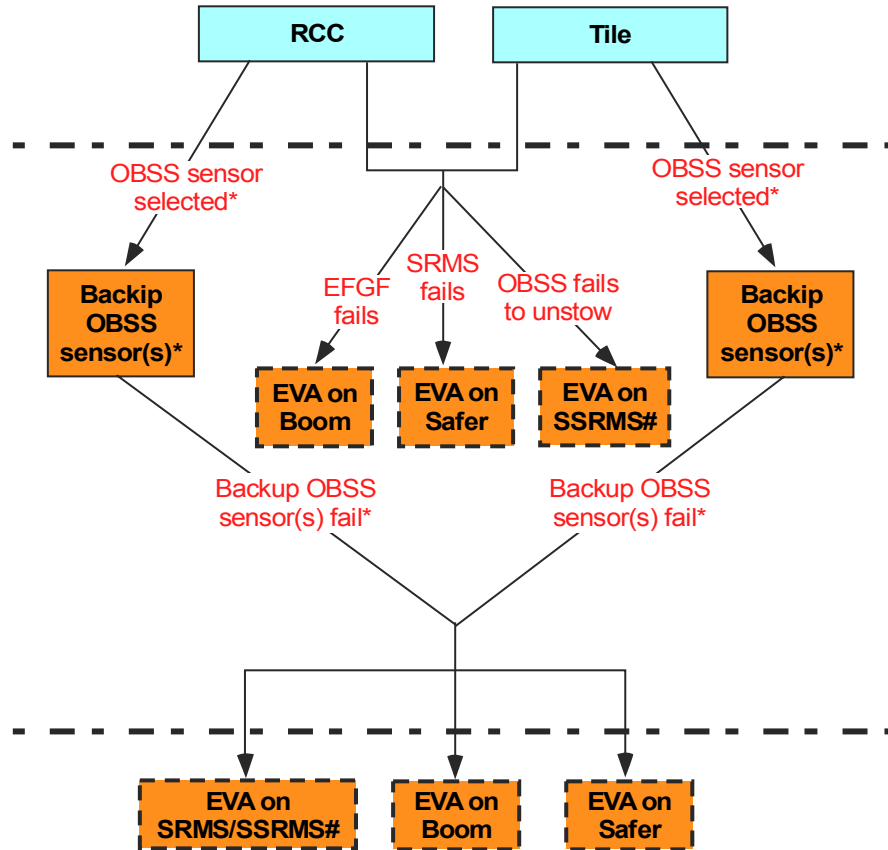
The core repair options (EWA, tile overlay, STA-54, NOAX, and plug) have been undergoing near-continuous hardware and operational testing and development and are at varying degrees of maturity, as of 2006. As Engineering or operational tests have uncovered hardware or application issues, the repair procedures and tools have changed to increase confidence in application and integrity of the repair.

### 3.0 INSPECTION OVERVIEW

The nominal TPS inspection plan includes the review of ascent data and an on-orbit inspection via Orbiter Boom Sensor System (OBSS), Shuttle Remote Manipulator System (SRMS) and handheld cameras. Several types of failures can lead to either partial or complete lack of RCC mapping as well as inadequate 2-D or 3-D tile inspection, which leads to a need for EVA inspection. Figure 3-1 and Figure 3-2 describe the failures that could lead to EVA inspection. EVA has the ability to perform focused inspection of Tile and RCC, as well as RCC WLE mapping. The platforms used for these tasks vary depending upon the damage location and type of inspection being performed. EVA inspection can be based on the SRMS, SSRMS, OBSS, or with SAFER.



**Figure 3-1. Flowchart for nominally planned inspection**



\* Sensor experts will identify the OBSS sensor for focused inspection of an area of interested based upon real-time findings. Backup sensor options will also

**Figure 3-2. Failure flowchart for focused inspection**

### 3.1 HARDWARE

The Kodak DCS 760 still camera with optional flash has been modified to operate in the EVA environment. The camera can be equipped with several lenses depending on the resolution and field of view requirements for a particular site. The 50 mm lens is standard although others could be considered on a case by case basis. All handheld Digital Communications Subsystem (DCS) cameras are hardware Criticality 1R. The camera can be used for 2-D imaging or, with special EV crewmember and ground techniques, can be used to produce 3-D measurements as described below. 3-D measurements are accurate to within +/- 0.05 inches (assumes DCS 760 with 50mm lens at 5 to 10 foot range). At this printing, 3-D measurements with RCC have not been tested or quantified.

## **3.2 SUMMARY OF OPERATIONS**

### **3.2.1 Photogrammetry**

Photogrammetric analysis is used to produce depth measurements from EVA imagery acquired with the digital camera. Photogrammetry is the primary inspection method used for tile acreage damage assessment. With special EV crewmember and ground techniques, it can be used to produce 3-D measurements.

Although only two images are required for analysis, a minimum of 10 photographs are taken per site to ensure that some are usable. The camera must be repositioned between each shot to ensure sufficient change in image perspective which makes the analysis possible. The pictures must be acquired at a range of 5 to 10 feet. Camera repositioning to ensure multiple overlapping views will be accomplished by the crewmember physically moving the camera up/down and left/right within normal reach limits. The camera displacement between exposures should be no more than 2 inches for each foot from the target. Thus, if the camera is held five feet from the damage, it should be moved no more than 10 inches between each exposure. The flash cannot be used for photogrammetry so the damage must be illuminated by sunlight or earthshine. The two photos used for analysis must be captured within 2.5 minutes of each other such that the solar angle of incidence changes less than 10 degrees. The image must contain a known dimensional reference in the field of view so that the dimensions can be scaled appropriately. For tile images, this is typically an undamaged tile in the vicinity. The techniques for RCC photogrammetry have not been fully developed at this printing. Photogrammetry can be used to verify allowable step and pertuberances for the Government Furnished Equipment (GFE) overlay. RCC plug and Non-Oxide Adhesive Experimental (NOAX) repair verification has not been verified at this printing.

Once the EVA is complete, the crew will save the images to the onboard Orbiter Communications Adapter (OCA) network for downlink. The images will then be extracted from the laptop by the OCA Officer via ground control, downlinked using the OCA link, and placed on the OCA server in the Mission Control Center (MCC). The images are retrieved by the Electronic Still Camera (ESC) console operator, renumbered and placed on the Payload Operations Control Center (POCC) server.

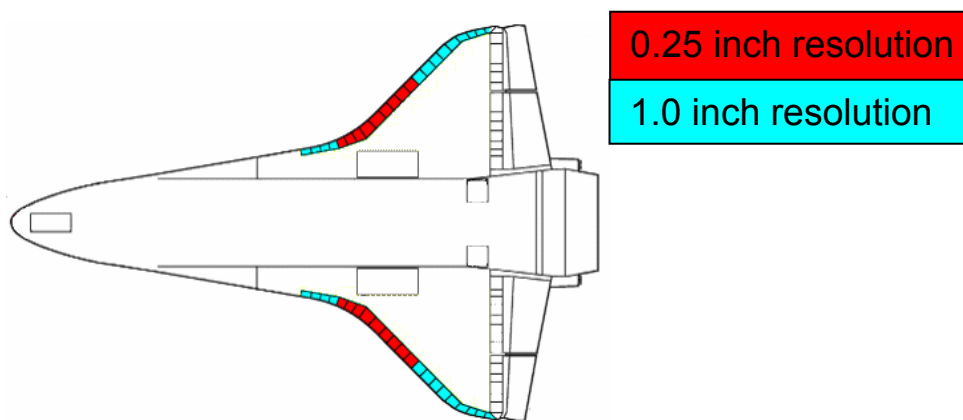
The JSC IIT will retrieve the images from the POCC server and initiate ground processing using the Cardinal Systems software. Measurements in a 3-D point cloud format will be posted to TPS Imagery (TIIMS). Written reports will be generated within TIIMS and posted to the Imagery Ops Integration (OIO) website.

### **3.2.2 WLE Mapping (Robotic/Boom-Based Only)**

In the event of a total OBSS sensor failure, an EVA can be conducted to perform backup mapping of the WLE. Complete RCC coverage requires an EVA crewmember to be positioned on the tip of the boom. In the event that the boom cannot be unberthed from the starboard MPM latches, partial coverage can be achieved from a foot restraint on the SRMS. EVA crewmembers will only map those areas of the RCC that cannot be

inspected by the SRMS/SSRMS end effector cameras, or IV photography from the ISS crew.

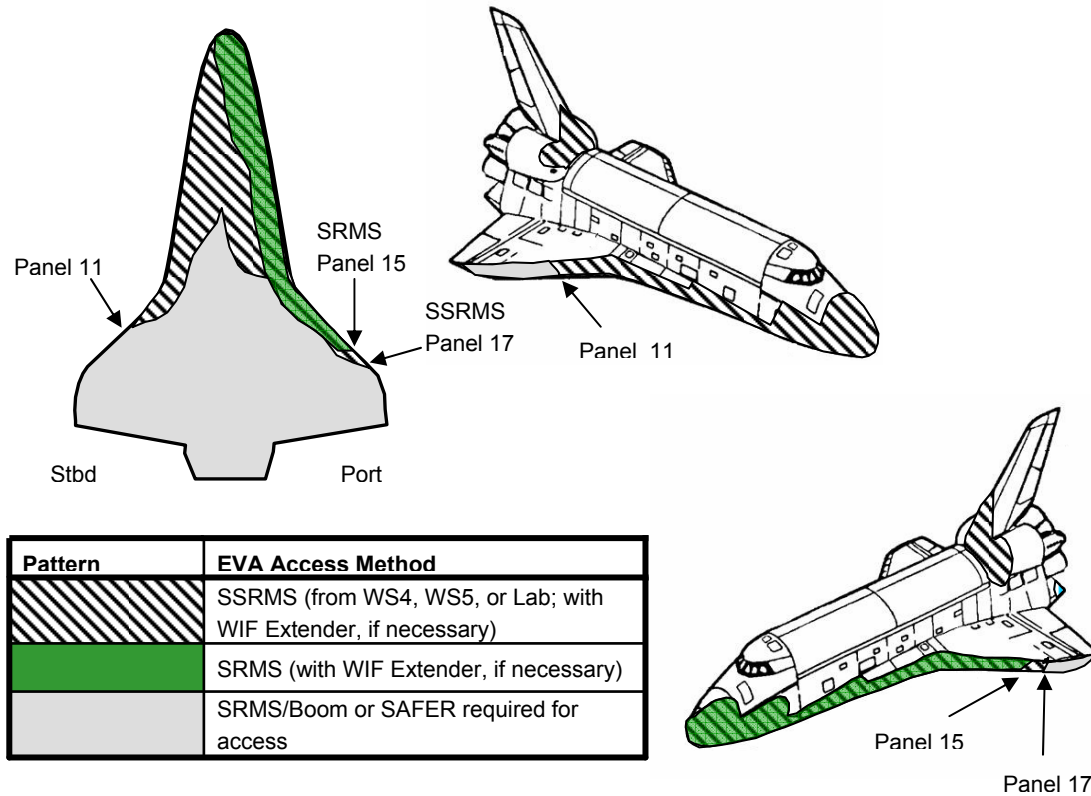
The EVA digital camera with 50 mm lens can obtain 2-D imagery with 0.25 inch to 1.0 inch resolution depending upon the crewmember's distance away from the vehicle (see Figure 3-3). The unknowns associated with boom dynamics, including SRMS brake slips and possible vehicle impacts, as well as the corresponding time required to dampen motion, are contributors to making this EVA very long. In addition, frequent translations to the orbiter sill for foot restraint articulation drive the EVA duration to be approximately 7.5 hours.



**Figure 3-3. EVA WLE mapping resolution capability**

### 3.2.3 Robotic-Based Focused Inspection

Robotic-based EVA focused inspections can be conducted from the SRMS, SSRMS or boom. The platform will be chosen based on the damage location as illustrated in Figure 3-4. An EV crewmember positioned directly on an arm's end effector is preferred because of the added stability, but access to many TPS regions is limited. An EV crew member on the boom tip can access all required TPS inspection areas. The boom grappled by the SSRMS does not allow for complete coverage of the vehicle but does provide some additional access in the event of an SRMS failure. Due to the unknown dynamics associated with the SRMS/boom system, as well as the EVA time and constraints associated with set up, the boom option would be weighed against SAFER inspection.



**Figure 3-4. Robotics-based focused inspection access**

### 3.2.4 SAFER Focused Inspection

For SAFER focused inspection, either the SRMS or SSRMS is used to position two EVA crewmembers as close to the damage location as possible. The SAFER pilot will always remain tethered to the end effector handrail. One EV crew will be fixed in a foot restraint on the end effector to manage safety tether cable slack and provide situational awareness. SAFER flight must happen during orbit day and is limited to 45 minutes of powered operation. This typically allows up to three damage sites to be inspected with the digital camera. The duration of a SAFER inspection EVA is estimated to be 3.5 hours.

### 3.2.5 Reporting

Inspection reports will be processed by the Johnson Space Center (JSC) Integration Inspection Team (IIT) and will require approximately 2.5 hours per site depending upon the size and distribution of measurements required. Written reports will be generated within TIIMS and posted to OIO.



## 4.0 DOUG USE

Several new features have been created in Dynamic Onboard Ubiquitous Graphics (DOUG) to assist in planning inspection or repair of TPS damage. The features include TPS Zones, the Reach and Access models, and Camera Resolution "Painting." The TPS Zones tool identifies regions of tile on the space shuttle vehicle. The zones were created to distinguish the types of tile, location on the vehicle, and critical damage size. Engineering will use these zones in discussions about damage events. The Reach and Access models show an estimate of an EV crewmember's ability to touch the vehicle from various arm configurations. It would be used to determine access for repair activities. It is only an estimate, however, and real-time analysis must be done to confirm access. In general if the program shows access, then the area can be reached. If it does not show access, then the Robotics operators may still be able to determine an arm configuration to reach the region. For Camera Resolution Painting, once the EV crewmember is positioned by the user to image the damage, the tool will "paint" the portion of vehicle surface, which meets specified EVA Digital Camera resolution criteria.

The tools are located in the STS-121 DOUG load. The Tile data support file is required to run the application.

### 4.1 TPS ZONES TOOL

The TPS Zones and Inspection Criteria tool has the zones agreed upon by the engineering and imagery groups. Definition of the zones can be found at the following link: <http://sspweb.jsc.nasa.gov/webdata/iw/>

On the right-hand side, there will be a link to the Zone Definitions Document and to the OIO damage reporting site.

#### To use the TPS Zones and Inspection Criteria Tool:

Turn on the tile model:

#### **Reconfig, Orbiter Tiles, All Tiles On**

Display the dialog box for selecting a vehicle region:

**Options, Tile Groupings** and "**Tile Dialog**" box will appear

The zones for tile and RCC include:

**Temperature** .....

- HRSI tiles
- LRSI tiles
- RCG tiles

**Material** .....

- Li-900 tiles
- FRCI-12 tiles
- Li-2200 tiles
- AETB-8 tiles

**SIP** .....

- SIP 1 tiles
- SIP2 tiles
- SIP3 tiles

**Criteria 3** .....

- 3" inspection criteria
- Upper forward fuselage
- Lower forward fuselage
- Mid-fuselage forward
- Mid-fuselage forward center
- Mid-fuselage aft
- Mid-fuselage aft center
- Glove fairing
- Aft fuselage
- Body Flap
- Vertical Stabilizer
- Right OMS Pod
- Left OMS Pod
- Forward RCS (forward fuselage)
- Right hand wing intermediate section and MLGD
- Right hand torque box
- Wing glove
- Right hand inboard elevon
- Right hand outboard elevon
- Left hand wing intermediate section and MLGD
- Left hand torque box
- Left hand inboard elevon
- Left hand outboard elevon
- Nose cap and chin RCC (not tile)

**Criteria 1** .....

- 1" inspection criteria
- Right hand lower wing carrier panel tiles
- Right hand upper wing carrier panel tiles
- Right hand inboard elevon cove
- Right hand outboard elevon cove
- Left hand lower wing carrier panel tiles
- Left hand upper wing carrier panel tiles
- Left hand inboard elevon cove
- Left hand outboard elevon cove
- Right hand ET umbilical door seal
- Left hand ET umbilical door seal
- Nose landing gear door seals
- Left main landing gear door seal
- Right main landing gear door seal
- .....+numerous numbered zones
- .....+Zone borders (shows the edges of all zones)

Once the TPS zone is selected, the program will highlight all tiles that fall within that classification. Note: if a specific tile number is known, it can be selected under the **Tile**

**Dialog** selection (also under **Options**.) All of the tile's associated zones will be generated in a list. You can also highlight the tile so it is easier to find.

## 4.2 REACH AND ACCESS TOOL

With the Reach and Access tool, the user selects an inspection configuration; then the program will highlight the approximate regions of the vehicle for which the EV crewmember has touch access. The data is approximate since the regions were defined using a relatively small sample of known arm positions, and reach will vary greatly from crewmember to crewmember. However, in the event of real damage at a known tile location, the tool can be used to quickly assess the best possible choices for reach and access. A case-specific assessment must be done to determine the exact hardware configuration needed. **In general, if the tool shows access, then the region can be reached. If the tool does not show access, the Robotics operators may still be able to determine an arm configuration that will allow access.**

### To Use the Reach and Access Tool

Turn on the tile model:

#### **Reconfig, Orbiter Tiles, All Tiles On**

Display the dialog box for selecting an Inspection configuration:

**Options, EVA Touch Access**, then select from:

- **SSRMS-ORM** (orbiter repair maneuver)
- **SSRMS-DOCKED**
- **SRMS**

A dialog box by the same name will appear. From this box select the desired configuration. For example for the SSRMS, select the Mobile Transporter (MT) worksite to be used and the MRS Base System (MBS) Power Data Grapple Fixture (PDGF) on which the SSRMS is based. The darker colors are with the arm alone and the pastel of each color includes the additional reach provided by use of the WIF extender. In general, full extension of the WIF Extender was assumed; if this cannot be accomplished due to exceeding the WIF Extender's load limiting capability, then the reach capability will be less. Note: Some areas on the nose and side hatch appear to be the pastel because the underlying tile is white. The WIF extender highlight is generally on the belly and can be turned on/off independently.

## 4.3 CAMERA RESOLUTION PAINTING TOOL

With the Camera Resolution Painting tool, the user positions the EV crewmember holding an EVA Digital Camera, and then the tool will "paint" the portion of vehicle surface where the specified camera resolution requirements are met. Note: This is NOT touch access. It shows where the camera will get the requested resolution.

Highly curved surfaces (or photos taken at oblique angles) pose challenges for meeting resolution requirements; only a small portion of the surface will be painted.

In the VR Lab, the paint color will change with each shot so the overlap can be determined. However in the Portable Computer (PC) version, the same color is used for each shot. The color used is selectable, but it will change all previously painted areas to whatever new color is selected. Once a new color is selected, click on the “Apply” button for the change to take place.

The program assumes that EV1 has the camera.

To use the Camera Paint option:

### **Options, Sensor Dialog, EVA**

The 50 mm lens information is pre-loaded, although you should verify desired resolution and max focal distance. If using a different lens, use the data from the tables in this write-up to modify the parameters.

#### **√ Show Areas Mapped**

Buttons to “Hide All Mapped” colors or to “Clear Mapped” areas are also present in this dialog box.

Set up the EVA crewmember to the position desired, then select **Sensor ON**, and the snapshot/painting will occur. Deselect **Sensor ON**, reconfigure the crewmember to the next position, select **Sensor ON** for another snapshot, etc.

Reminder example on how to set up the EV1 crewmember:

**Reconfig, SSRMS** pick configuration (worksite and PDGF)  
**Joint Systems,**

- **SSRMS** to set arm joint angles
- **APFR SSRMS** to config APFR
- **WIF Ext** to config the WIF Extender, if used

**Toggles,**

- **APFR\_SSRMS**
- May need to toggle off the **IAPFR**

With the WIF Extender:

**Options, WIFs, SSRMS,** select **LEE1** or **LEE2**  
**Things to Move** button, select **WIF Extender**

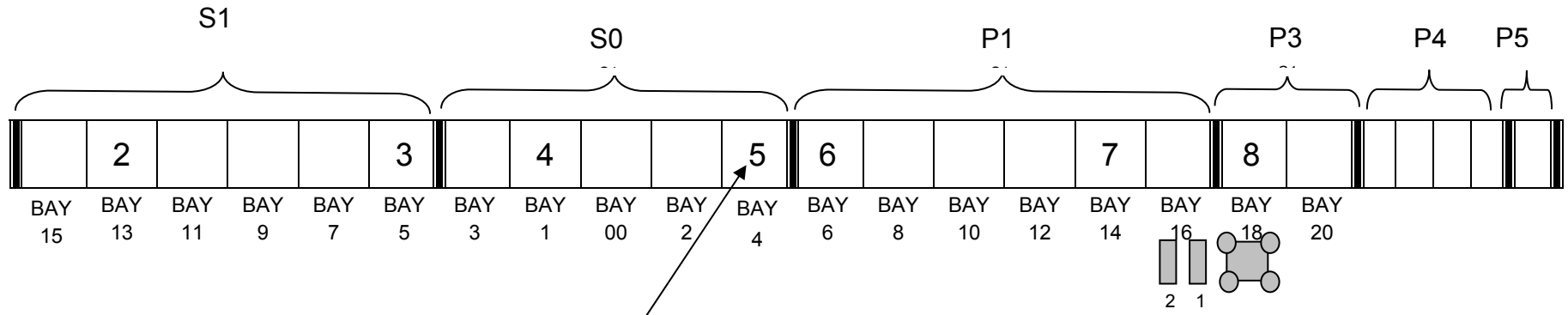
**Options, WIFs, WIF Extender,** select **WIF Extender**  
**Things to Move** button, select **APFR\_SSRMS**

**Reconfig, EV1,** select **EV1→APFR\_SSRMS**

Without the WIF Extender:

**Options, WIFs, SSRMS,** select **LEE1** or **LEE2**  
**Things to Move** button, select **APFR\_SSRMS**

**Reconfig, EV1,** select **EV1→APFR\_SSRMS**



MT shown @ Worksite 8

MT WORKSITE LOCATIONS

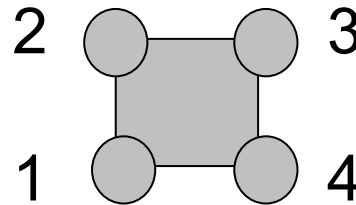


Figure 4-1. PDGF numbering

**Table 4-1. EVA digital camera lens information for DOUG**

Lens	28 mm	35 mm	50 mm	85 mm	105 mm	180 mm	80-200 mm
Degrees off normal			35				
Horizontal FOV (degrees)	53	43	31	19	15	9	20 - 8
Vertical FOV (degrees)	37	30	21	12	10	6	13 - 5
Min Focus Distance (in.)	15	11	18	36	12	60	72
Desired Resolution (in.)↓	Max Focal Distance (inches) per desired resolution ↓						
0.25		53.7	93.9	187.5	204.6	416.7	
0.5		107.1	187.5	375.0	409.2	833.4	
1		214.2	375.0	750.0	818.4	1666.8	
3		642.9	1125.0	2250.0	2455.2	5000.4	

Notes:

- Maximum Focal Distance assumes daylight conditions and analytical resolution
- F-stop for each lens: f-4 is the worst case in focus area, f-8 is the best case (WLE mapping will use f-8)
- The units are those required by the DOUG program
- Additional lens information can be found in the section on the EVA Digital Camera

## **5.0 EVA DIGITAL CAMERA**

### **5.1 DESCRIPTION**

The EVA digital camera shown in Figure 5-1 and Figure 5-2 is the same DCS 760 Commercial Off The Shelf (COTS) camera used for IVA photography that has been modified to operate under EVA conditions.

#### **5.1.1 CAMERA USES**

EVA WLE Mapping: The 50 mm lens obtains imagery with 0.25 inch to 1.0 inch resolution depending upon the crewmember's distance away from the vehicle. The resolution achieved by the EV crewmember with the digital camera does not meet the RCC requirements as specified in NSTS 60517, Shuttle On-Orbit TPS Inspection Program Requirements Document. The flash will be installed and in the ON position during night passes for this scenario, and the crewmember will use the camera to perform standard photography. The crewmember has the option of turning the flash off during day passes to save flash battery power.

EVA Point Inspection: The camera will also be used to document specific damage areas for tile or RCC. As an alternative to standard photography, a technique called Photogrammetry will be used to obtain 3-D depth measurements of tile from EVA imagery acquired with the digital camera. The flash is required to be OFF for Photogrammetry in order to meet the requirement for a stationary light source.

General Photography: The digital camera can be used in a general sense to obtain standard 2-D imagery for documenting potential TPS damage areas. With that said, such photos would provide a more high-level overview of a damage site, and would not necessarily obtain the required resolution.

#### **5.1.2 HARDWARE DESCRIPTION**

There is a new high strength camera mount with bayonet and Retractable Equipment Tether (RET), similar to the existing F5 camera mount.

The entire assembly (both camera and flash) is mounted onto a digital camera bracket that has a dogbone handrail for use with the Body Restraint Tether (BRT). This bracket also has a (camera shoe) dovetail fitting to take another L-shaped bracket with bayonet that is compatible with the MWS receptacle.

The EVA camera components are IVA-reconfigurable such that the high strength camera mount can be used with the camera alone for nominal EVAs, or the entire system can be used when flash capability or BRT mount is desired.

There are thermal blankets installed on the camera, lens, brackets, and flash.

Lens sizes include: 28 mm, 35 mm, 50 mm, 85 mm, 105 mm, 180 mm, and 70-200 mm; the 50 mm lens is standard for all EVA Inspection tasks. For general photography where a wider field of view is needed, the 28mm lens would be the best option.

The camera utilizes the existing Sport DA-30 viewfinder used with the F5. The crew must use this viewfinder to center and take photos. When the thermal blankets are installed, the Liquid Crystal Display (LCD) screen cannot be seen, and, therefore, cannot be used to verify that a good photo has been taken.

There are two shutter release buttons on the camera. The first is a static button that is located in the upper right-hand corner of the camera itself. The second is a remote shutter release located at the end of a 3-foot-long cable. The nominal configuration of the remote shutter release has the cable stowed under Multilayer Insulation (MLI) and the button secured and exposed near the lower left hand corner of the flash bracket. The cable and button can also be deployed, however this requires IV reconfiguration.

The remote shutter release has a slide lock on it. If inadvertently locked, the crew could be misled into believing they are still taking photos. When locked, the button will remain depressed after taking the first photo. The first photo will be recorded; however, subsequent images will not. If the crew does not visually verify that the button is unlocked, they could complete the entire EVA without recording any photos. The lack of tactile feedback in a pressurized suit does not allow them to feel the "click" of each photo. This remote feature is labeled LOCK with an arrow on top of it that points to the locked position. This concern only applies if the remote shutter release is used with the cable fully deployed; when stowed, the lock is inaccessible and, therefore, only needs to be checked IV prior to stowing the remote shutter release button.

### **5.1.3 BATTERIES**

There are a total of three rechargeable batteries in the camera system: one inside the camera, and two in the flash housing.

One battery in the flash housing provides the primary power for the camera (it is configured IV). When it is depleted, the Camera Battery Switch Light Emitting Diode (LED) on the back of the flash housing will illuminate. The crew will need to move the switch from EXTERNAL to INTERNAL, which will enable the internal camera battery to function as the secondary power supply. The second battery in the flash housing is for the flash.

Once the battery is installed into the camera, the camera powers ON and remains in that state. The ON/OFF switch is not EVA accessible because it is covered by the thermal blanket. After a few minutes, the camera automatically goes into a sleep mode to conserve power. When the crew hits the shutter release button, the camera will power on again. The batteries are the limiting consumable of the camera system and their life varies directly with temperature.

It is still undetermined how long each camera battery will last while out EVA. When not constrained in terms of body positioning and worksite requirements (such as SAFER), it is a good idea to bring the flash housing out even if the flash is turned off to have an additional camera battery available.

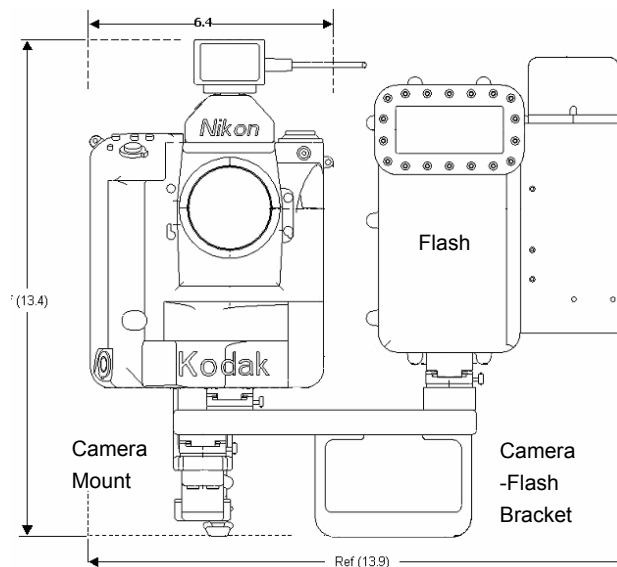


### 5.1.4 Card and Card Busy Light

The camera uses a 1 Gig Simpletech card. The camera can hold two cards. Each card can hold slightly greater than 130 photos in a non-extreme thermal environment. This number can vary based on thermal environment, as well as photo size and type. The EVA requirement was that the camera should take at least 50 photos, with the expectation that it will take more based on battery usage. In a best case thermal environment while out EVA, the card is expected to hold between 112-130 photos as long as there is enough battery power left to allow for more photos to be taken.

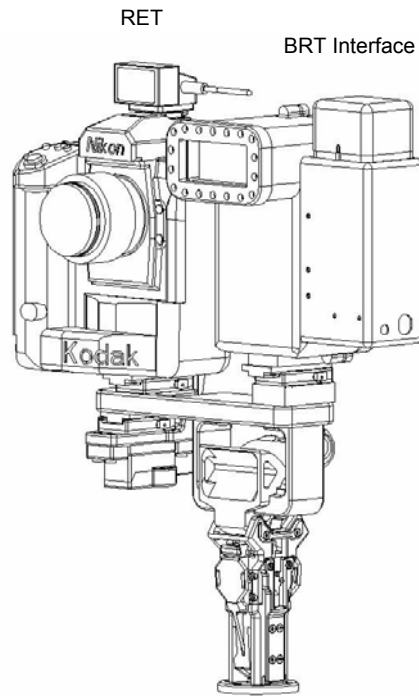
When the camera takes a picture, it stores the file in a buffer and then transfers it to the card. There is a card busy light that blinks while the camera is transferring images from the buffer to the card. Ground testing has shown that the buffer can successfully store up to 18 photos, after which the camera will not fire until there is space available on the buffer. For the WLE Mapping procedures where camera position and the number of photos are so critical, the crew is required to verify that the card busy light blinks momentarily and then stops prior to taking subsequent photos. This is because the only indication that a photo has been taken is when the card busy light blinks. The camera is capable of taking several photos at a time while the card busy light is on, but tracking and verification that each of the individual photos has been acquired is impossible. This is less of a concern during point inspections because extra photos are taken of each damage site.

The card busy light is very difficult to see in a well-lit environment, or from off-normal viewing positions. It blinks very quickly for a short duration. Thus, it could be missed entirely if not checked immediately after taking the photograph. The card busy light is actually the exit side of a fiber-optic cable and is barely visible near the lower left corner of the view finder.

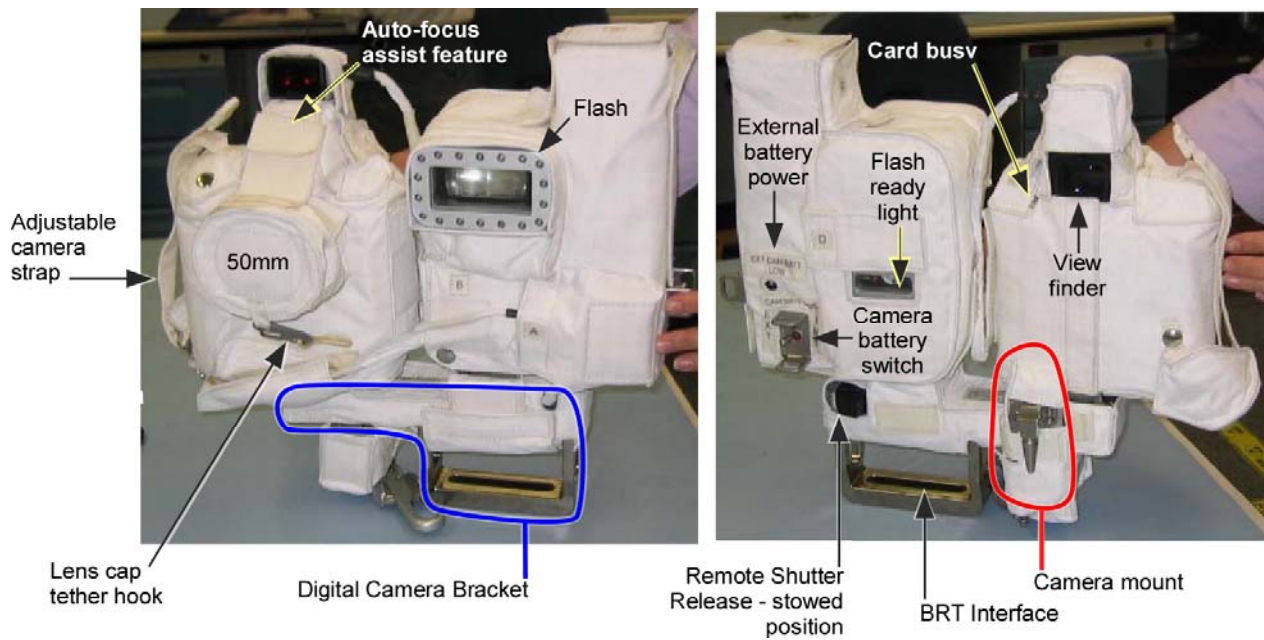


**Figure 5-1. EVA digital camera and flash bracket**

(MLI not shown)



**Figure 5-2. Camera on BRT**



**Figure 5-3. EVA digital camera and flash bracket photo**

### 5.1.5 LENS OPTIONS

The digital camera has the ability to support up to seven different lens sizes. The standard lens used for EVA WLE Mapping and Point Inspection (boom and SAFER) is 50mm. The table below shows the lens types and their corresponding focus distances, analytical resolution (inches) at various distances away from vehicle, and max angles:

**Table 5-1. Types of lenses**

Lens	FOV (degrees)			min focus dist (ft)	Resolution (daylight)			Horiz photo size (ft)			Vert photo size (ft)		
	horiz	vert	diag		5ft	10ft	20ft	5 ft	10 ft	20 ft	5 ft	10 ft	20 ft
50 mm	31	21	37	1.5	0.16	0.28	0.6	2.77	5.55	11.09	1.85	3.71	7.41
85 mm	19	12	22	3	0.08	0.2	0.36	1.67	3.35	6.694	1.05	2.1	4.2
105 mm	15	10	18	1	0.08	0.16	0.28	1.32	2.63	5.266	0.87	1.75	3.5
180 mm	9	6	11	5	0.04	0.16	0.16	0.79	1.57	3.148	0.52	1.05	2.1

**Table 5-2. Digital camera specs with oblique angles**

Lens	Day Res at 35 deg			Day Res at 50 deg			Day Res at 60 deg			Day Res at 80 deg		
	5ft	10ft	20ft	5ft	10ft	20ft	5ft	10ft	20ft	5ft	10ft	20ft
50 mm	0.195	0.342	0.73	0.249	0.436	0.933	0.320	0.560	1.200	0.921	1.612	3.455
85 mm	0.098	0.244	0.44	0.124	0.311	0.560	0.160	0.400	0.720	0.461	1.152	2.073
105 mm	0.098	0.195	0.34	0.124	0.249	0.436	0.160	0.320	0.560	0.461	0.921	1.612
180 mm	0.049	0.195	0.2	0.062	0.249	0.249	0.080	0.320	0.320	0.230	0.921	0.921

### 5.1.6 Technique

The digital camera and flash bracket assembly are flexible enough to allow for multiple configurations based on user requirements. For the different types of EVA inspection, the crew will carry the digital camera and flash in different ways. Factors that drive different configurations include worksite stability, crew dexterity, tile and RCC resolution requirements, and lighting environment. The following paragraphs will identify EVA Inspection methods and digital camera user techniques.

When not in use, the lens cap should always be installed to protect the lens and to preclude camera misfires from happening. With the lens cap installed, the camera cannot focus and, therefore, cannot take a photo. This saves both card space and battery power.

### 5.1.7 WLE Mapping

The camera configuration for WLE Mapping includes the entire assembly of both camera and flash, configured together on the camera/flash bracket. The Auto-Focus Assist feature of the flash only operates in low-light situations. In these conditions, the flash is required to be ON to ensure the camera can focus on the RCC panels and T-seals. Because the EVA Mapping procedure is very long, there is not enough time to complete the required number of photos during orbit day only. In addition, the camera cannot focus on the low contrast of RCC panels during daylight. To aid in focusing, the edge of a T-seal is required to be in the field of view. During the day, the flash should be turned OFF to save the flash battery.

Standard photography is used to map the required RCC panels. The 50 mm lens obtains 2-D imagery with 0.25 inch to 1.0 inch resolution depending upon the crewmember's distance away from the vehicle.

To assure necessary coverage and resolution, every photograph taken for WLE Mapping is critical. The crewmember is required to ensure two things prior to taking every photo.

1. Verify the card busy light is OFF. If the crew tries to depress the shutter release button when the card busy light is still on, the photo will be captured. However, the crew will not get visual verification to distinguish the recording of each photo for tracking purposes.
2. Verify the flash ready light is ON (for low light situations). If the flash ready light is not ON and the crew tries to take a photo, the flash can still fire but the exposure may not be correct. This is based on how much energy is used to light up a very dark area.

The crewmember in the Articulating Portable Foot Restraint (APFR) on the boom will nominally wear two digital cameras. One will be carried on the BRT, and one will be carried on the MWS T-Bar bayonet receptacle. By carrying two cameras and leaving one spare on the orbiter sill, potential extra SRMS translations back and forth from the TPS worksite and sill are reduced.

The crew will hold the camera (originally stowed on the T-Bar) with both hands, center each RCC T-seal within the viewfinder alignment markings per the procedure details, and then depress either of the two shutter release buttons. The second camera will remain on the BRT as a spare

### 5.1.8 Boom/Robotics-Based Point Inspection

Photogrammetry is the primary inspection method used for tile acreage damage assessment. With special EV crewmember and ground techniques, it can be used to produce 3-D measurements on tile that are accurate to within +/- 0.05 inches (assumes DCS 760 with 50mm lens at 5- to 10-foot range.)

The camera configuration for Boom Point Inspection includes the entire assembly of both camera and flash, configured together on the camera/flash bracket, with the flash OFF. The flash must be off because Photogrammetry requires a fixed light source. As the crewmember moves the camera to take photos, the flash also moves. Although the flash is not used, it was decided to leave it installed for the Boom Inspection EVAs to reserve the option of taking standard 2-D photographs, as well as having a spare battery to increase the performance duration of the camera.

Only one camera is nominally carried to a worksite, since only a few photos are required for each damage site to acquire enough information to get the necessary resolution.

If possible, the crew should attempt to aim the camera by holding it in two hands and looking through viewfinder. Some crew prefer to nominally use the remote shutter release button stowed on the bracket as opposed to the standard button in the upper right-hand section of the camera.

The required camera motion of 10 to 20 inches can be achieved by leaning to the side. This is easier than moving the robotic arm, and provides better aim than moving the camera and not looking through viewfinder (though either of these other techniques would also work.)

Due to the high contrast of RCG and tile substrate, it may be necessary to adjust the camera exposure prior to EVA in order to capture the required detail in the image. This is likely not required for RCC or overlay inspection. Precoordination with Photo/TV will verify if this is necessary.

### **5.1.9 SAFER Point Inspection**

The camera configuration for SAFER Point Inspection includes the camera/flash bracket with only the camera installed. The flash assembly is left inside because it is not required for Photogrammetry and it adds more bulk for a SAFER crewmember to manage with only one hand available. In this configuration, one hand is always available to fly SAFER while the other hand can reposition and operate the camera. The remote shutter release is preferred for one handed operation.

Crew may find it easier to move the camera between shots by putting it in a fixed location where they can see through the viewfinder and then initiating a small SAFER translation followed by repeated photographs. However, it is imperative that photography does not distract the crew from maintaining positive flight control. This technique will probably provide better aiming than if crew were to maintain a stabilized hover and move the camera on the BRT.

Expect aiming to be less precise on SAFER. More images should be captured to be conservative.

## 6.0 PHOTOGRAMMETRY

This image analysis technique has significant background in industry over the past 100 years. It is used for many applications from geographical mapping to manufacturing verification of as-built parts. Because of its pedigree, there are many industrial software applications that are used to automate much of the analysis. There are two different types of photogram metric analysis, industrial and topographical. Industrial photogrammetry uses many images taken from highly convergent angles. This type has been used by NASA in the past and was considered for tile inspection. However, after a detailed comparison of techniques it was decided to use topographical photogrammetry. This is the same technique that the US Geological Survey uses for developing topographical maps of the earth. A pair of images is taken at slightly different times by a plane flying over the landscape. The camera orientation remains normal to the earth and causes no convergence in the camera aiming. In a similar way the EV crew will use the digital DCS 760 camera to capture a pair of images on the damaged TPS surface. Some terminology must be defined to better understand some of the factors that affect the accuracy of photogrammetry.

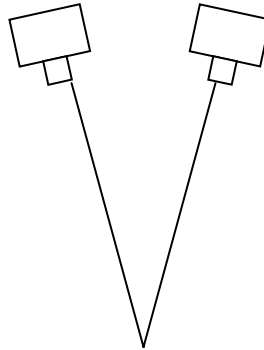
**Optical distortion:** This is an effect that is the result of light passing through the optics of the lens and camera. This is what makes pictures taken with a wide angle lens appear to have a 'fish-eye' appearance. The image is slightly distorted, which affects the accuracy of the measurement. The optical distortion is different for each serial number lens and camera body. To reduce the effect, a ground calibration is performed with each lens and camera flown. With the distortion known, it can be accounted for in the analysis which increases the analytical accuracy. Because of this however, it is not recommended to use a lens or camera that was previously on the ISS and has not been analyzed on the ground. It should also be noted that the optical distortion increases with smaller lenses.

**Range:** Distance from camera to the target. For EVA focused inspection of tile the target range is between 5 and 10 feet. At closer ranges, the field of view is less. At farther ranges the image resolution, and thus the measurement accuracy, decreases.

**Camera Displacement or Base:** This is the amount that the camera moves between exposures of the two images that are used for analysis. For EVA focused inspection, the camera displacement should be 2 inches for each foot of range. Therefore, at a range of 5 feet the base is 10 inches.

**Convergence:** This is the angle between the camera aiming on successive shots. If the camera were aimed perpendicular to the surface for all shots the convergence would be zero. If the camera is aimed such that the target is always in the center of the field of view, the convergence will increase the more the camera is displaced. Ideally for topographical photogrammetry the convergence should be zero with a 60 percent to 80 percent overlap in the field of view. However, in adapting this technique for EVA it was recognized that this would complicate the operation. Aiming the camera is difficult enough, and there was a strong desire to keep this as simple as possible by allowing the crew to aim the camera directly at the target. If the zero convergence were to be

achieved the crew would have to aim slightly to the side of the damage and try to keep track of overlap between images. As a compromise, testing has shown that sufficient accuracy can be achieved provided the convergence is kept to a minimum. If the guidelines discussed under “camera displacement” are adhered to, then the convergence will be acceptable.



**Figure 6-1. Convergence angle**

**Field of View:** Area that is seen through the viewfinder and captured in an image. A high zoom lens or close range results in a smaller field of view.

**Dimensional Reference:** This is an object in the field of view that has a known dimension to a high precision. The accuracy of photogrammetry is directly proportional to the known accuracy of the dimensions in the reference. The same dimensional reference must be in both images that are used for analysis. Typically an undamaged tile is a sufficient dimension reference. However, if the tile has significant ground repairs, its dimensions may have changed from its original installation. The lack of a dimensional reference is one of the major obstacles in using photogrammetry on RCC. Although ground testing has not been completed it is believed that the carrier panels are the best option for a reference in RCC. The dimensional reference is used in the image analysis to scale the pictures to the same size. This means that the range can change between pictures without affecting the analysis. It should also be noted that the accuracy increases if the reference is large. Therefore, something like a carrier panel plug would not be a good choice.

**Exposure Compensation:** The DCS 760 camera is set up for automatic exposure. Therefore, the shutter speed and aperture is set automatically based on the lighting conditions at the time. The proper exposure is determined by looking at the light and dark areas and setting an exposure that produces a “middle gray.” For tile, the dark Reaction Cured Glass (RCG) can cause the white substrate to be overexposed and washed out. This causes detail to be lost and image analysis is less effective. Because of this the Photo/TV group has determined that the exposure should be stepped down, or slightly underexposed. The criticality of this is less so with flown tile because the RCG gets closer to middle gray.

## 6.1 PHOTOGRAMMETRY ON-ORBIT TECHNIQUES

Because the flash is not used photographs must be taken during the day. Earthshine and direct sunlight both provide sufficient lighting. To ensure that one of these two lighting conditions exist, during the EVA planning phase, the Pointers (Flight Activities Officer (FAO) backroom) should be contacted to understand the lighting at the damage location for various times of the orbit.

Lens selection will be determined based on the expected range from the target. For SAFER, the 50 mm lens should always be used. A larger zoom lens could become difficult to manage while flying SAFER and would also require more precise aiming. However, if based on the arm, there is greater flexibility in lens selection. Make sure that the range (based on RMS positioning) provides a large enough field of view to include a couple undamaged tiles in addition to the damage.

If flying SAFER the camera should be transported to the damage area on the BRT. This allows one-handed SAFER flight. At the damage area, a stable hover should be maintained while the camera is aimed. If possible, try to verify that the damage is visible in the viewfinder. While taking pictures, input a very slight translation parallel to the plane of the TPS surface.

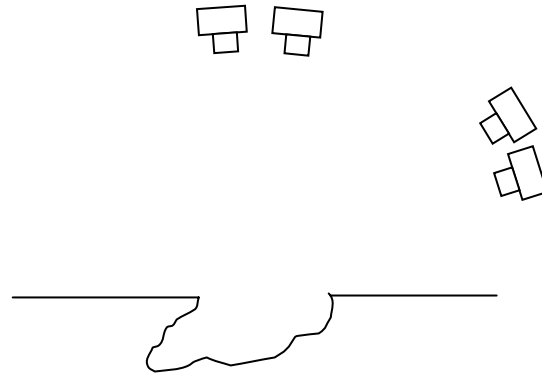
If based on the SRMS, SSRMS or boom, the crewmember should hold camera with two hands at the damage area. This provides much greater control and assures more precise aiming. The crewmember should be able to see through the viewfinder for all pictures. Camera displacement is achieved by leaning in the APFR. Robotic arm translation to achieve camera displacement should not be required.

At least 10 pictures should be taken of each damage area to ensure that at least 2 are usable for analysis. Suited testing has shown that worst case aiming techniques produce about 50 percent of the pictures with acceptable field of view. The worst case technique was with the camera on the BRT and not looking through the viewfinder. If the camera is held in two hands, accuracy increases to about 90 percent.

No operational scenarios have been identified that would call for the remote shutter release to be deployed; it should remain stowed and used on the camera bracket. This reduces snags.

Photogrammetric analysis provides the capability to analyze damage under an overhang. Some damage may be blocked from an overhead view by an overhang. This type of damage is referred to as tunneling or undercut. To measure this damage, additional series of photographs can be taken from more acute side angles. The same guidelines apply about range, camera displacement, convergence, and dimensional references.





***Figure 6-2. Example of camera positioning for tunnel damage inspection***

## **6.2 GROUND ANALYSIS**

Digital pictures are downlinked by OCA after the EVA. The TPS Imagery Coordinator (TIC) will ensure that the photos are delivered to the analysis lab in building 36. Images will be screened and the best pairs will be selected for analysis. A member of the Damage Assessment Team (DAT) will be present in building 36 during the analysis to help focus the results on critical areas. There are several different ways that the data can be presented.

- a. Text file with X, Y, Z dimensions for various spots. This will be the format that is used by the DAT to build the “shoebox” for their thermal analysis.
- b. Topographical maps with contour lines.
- c. 3-D Images - This requires the use of the Cardinal Systems software and high refresh rate monitor that is in building 36. While it is possible to move the computer to an alternate location on site, it is preferable to have required personnel view the images in building 36. The 3-D image is viewed by donning a special pair of glasses that are synchronized with the monitor’s refresh rate. This causes one image to be seen with the left eye and the second image to be seen with the right. Because the refresh rate is so fast, the brain perceives this as 3-D.
- d. Rapid Prototype - Although this has not been demonstrated, it is believed that a rapid prototype of the damage could be built from the data by using a Computer-Aided Drawing (CAD) model of the damage surface.

**7.0 SAFER INSPECTION**

**TBD**

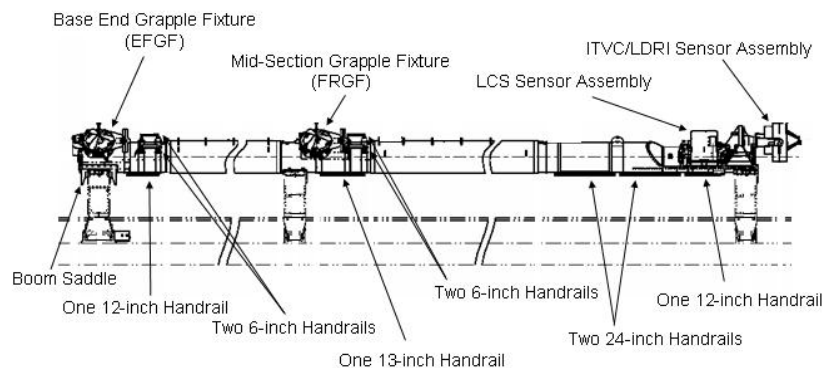
## 8.0 BOOM HARDWARE AND OPERATIONS

The boom launches on the starboard sill cradled in three MPMs. Unlike the SRMS, the boom does not have joints. The three boom striker bars are latched in place with the MPM Manipulator Retention Latches (Marls)

The boom impinges into the shuttle payload clearance envelope. As a result, some future payloads (ISS elements) will have to be modified to accommodate the boom, the boom must be stowed on ISS, or another method of inspection and access will be required.

The boom is designed to be grappled at the base end (forward end) by the SRMS, which provides power and data interfaces for the sensor assemblies via a modified Electrical Flight Grapple Fixture (EFGF). If the orbiter is docked to the ISS, the SRMS cannot reach the base end grapple fixture due to PMA and Lab interference. In this case, the SSRMS must grapple the boom at the mid-section FRGF, lift the boom out of its MPMs, and hand off the base end of the boom to the SRMS.

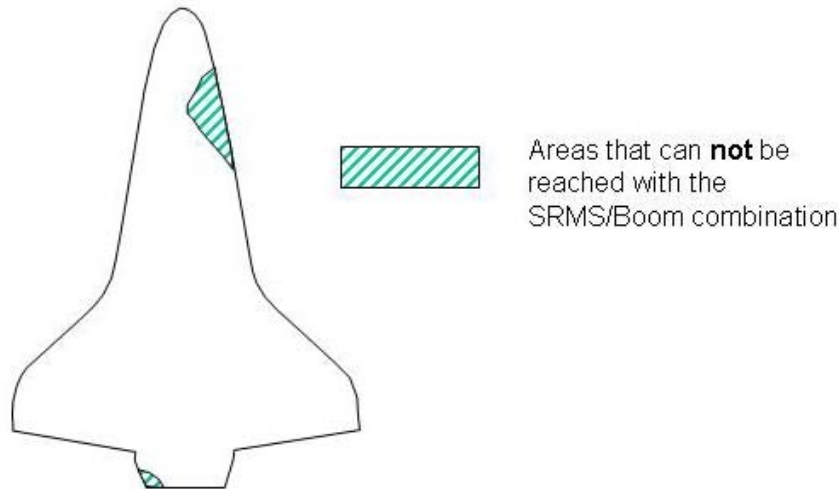
In the event of a boom sensor failure, an EV crewmember can perform an inspection of various points on the shuttle TPS using the boom. There are two types of inspection for which EVA will serve as a backup: WLE Mapping of the RCC WLE and Point Inspection of either Tile or RCC. EVA WLE Mapping will attempt to map the remaining required areas of the WLE that either the boom sensors could not obtain on FD2, or areas that either the SRMS or SSRMS end effector cameras could not obtain to the required resolution using simple 2-D photography. In contrast, Point Inspection will allow for a crewmember to perform photography or photogrammetry in the event that a more detailed tile or RCC Inspection is required that could not be obtained by the boom sensors themselves. A PFR Adapter Device (PAD) can be installed on the striker bars at the mid-section or tip to allow for foot restraint installation. Handrails near the tip and mid-section striker bars can be used to stabilize the boom during PAD installation, APFR ingress/egress, APFR reconfiguration, as well as various boom contingencies.



**Figure 8-1. Boom hardware overview**

In general, a crewmember on the tip of the boom can access the majority of orbiter TPS. There are only two areas that cannot be accessed by a crewmember on the

boom tip per the nominal plan: the starboard most tip of the body flap, and the small swath of lower surface TPS on the port side. If a WIF extender is used, the crew is able to access the starboard tip of the body flap. However, due to boom clearances with the port payload bay door, the crew cannot access the port area region from the boom. See Figure 8-2 for boom access regions:



**Figure 8-2. Boom access regions**

## 8.1 HARDWARE OVERVIEW

The boom is comprised of two composite sections (similar in composition to the SRMS boom sections) with aluminum sections at the base end (forward), mid-section (center), and tip (aft) locations. Unlike the SRMS, the base end of the boom is not fixed to the orbiter since it is designed to be removed from the payload bay. See Figure 8-1 for high-level drawing of the boom.

The boom is approximately 50 feet and 10 inches long from the forward-most point on the base end EFGF to the aft-most point on the Intensified Television Camera (ITVC)/Laser Dynamic Range Imager (LDRI) sensor assembly. The boom is approximately 48 feet long from the center of the base end striker bar to the center of the tip striker bar.

A wiring harness runs the length of the boom to the sensors, underneath thermal blankets that cover the entire boom. The composite sections have two electrical lines running down the lengths of them. The composite sections have metal strips that run along the length for grounding

There are currently two booms in inventory. They are also referred to as “OBSS” (On-orbit Boom Sensor System) and/or “IBA” (Integrated Boom Assembly).

The major components that are mounted to the boom are:

- A. Base end grapple fixture (a modified EFGF)
- B. Mid-section grapple fixture (a modified FRGF)
- C. Nine EVA handrails
- D. Laser Camera System (LCS)
- E. ITVC and LDRI sensor assembly mounted on a Pan/Tilt Unit (PTU)
- f. ISIS Digital Camera (IDC)

## **8.2 EVA INTERFACES**

### **8.2.1 Starboard MPM System**

The starboard MPMs that cradle the boom are each located on the mirror image  $X_o$  locations of the port SRMS shoulder, elbow, and end effector MPMs. Alignment markings are provided on the boom and the MPMs to accommodate berthing cues.

From an EVA perspective, the starboard MPMs operate like the port MPMs. An EVA may be performed to stow or deploy the MPMs.

The base end MPM and the base end of the boom have a slightly different construction than the other two MPMs and striker bar interfaces. The base end MPM upper pedestal is a modified design with a larger base structure to accommodate forward/aft loads for launch and landing. Additionally, automatically mating keep-alive power contacts have been added to the base end MPM and the boom. The boom has an integrated saddle to accommodate berthing and the electrical interfaces.

### **8.2.2 Base-End Grapple Fixture (Modified) EFGF**

The base end grapple fixture is an EFGF that has been modified to accommodate unique boom stowage and operation conditions, including the tight fit of the boom into the payload bay clearance envelope as it rests on the sill. The generic EFGF design has been modified with the following EVA-related changes:

- A. Reduced profile abutment plate
- B. Shortened target plate
- C. Remove and replace capability, including six additional 7/16-inch EVA bolts and two tether points for EFGF removal (no scenario is currently envisioned for this capability)
- D. EFGF connector linkage housing design
- E. A braided grounding path (would require cutting two wires if the EFGF were removed via EVA)

The base end grapple fixture is not compatible with the SSRMS due to interference between the SSRMS latching end effector curvic coupling and the electrical connector on the grapple fixture.

### **8.2.3 Mid-Section Grapple Fixture (Modified FRGF)**

The mid-section grapple fixture is intended to be grappled by the SSRMS. The SRMS can physically grapple this location, but the grapple fixture does not have power or data interfaces. The two grapple shaft release bolts on the forward and aft parts of the grapple fixture are EVA accessible with either the SRMS or SSRMS grappled to the mid-section grapple fixture.

EVA contingency operation of the boom mid-section grapple fixture is similar to a generic FRGF. Changes that were made to the FRGF design to accommodate boom stowage and operation include:

- A. Reduced profile abutment plate
- B. Shortened target plate
- C. Remove and replace capability, including six additional 7/16-inch EVA bolts, two tether points and keying and soft-dock features, grounding wires (2)
- D. EVA release rod changes, including different clocking of bolts, 7/16- inch bolt heads (rather than 1/2-inch bolt heads), and new rod housings
- E. Two braided grounding wires

### **8.2.4 Laser Camera System**

The LCS is a 3-D imaging system that can be configured to scan both small and large target areas and provide depth information on damaged TPS surfaces. With a translating boom, the LCS operates in a line scanner mode.

The LCS is mounted on an interface plate, and this interface plate is designed to accommodate EVA removal and replacement of the LCS. Currently, EVA removal and replacement of the LCS interface plate is not a certified capability. The interface plate can be removed via six 7/16-inch bolts. There are also soft dock detents. Two handling aids and four tether points accommodate EVA capability. Notches in the plate align with V-guides on the boom, and these keying features ensure correct orientation during LCS installation. One EVA wing tab connector would have to be mated or demated between the sensor package and the boom during change out. There is also a specific bolt order required.

### **8.2.5 ITVC/LDRI**

The sensor assembly at the tip of the boom is a combination ITVC and LDRI assembly mounted on a PTU. The LDRI is both a laser (3-D) and black and white TV camera (2-D) inspection tool and is configured with a 50 mm lens with a 15 by 20 degree field of view.

The combination ITVC/LDRI/PTU is secured to the boom tip on a triangular bracket that is tilted 10 degrees with respect to the flat boom section. This bracket is designed to be removed and replaced via six 7/16-inch EVA bolts to accommodate sensor removal. Currently, EVA removal and replacement of this bracket and the sensors is not a certified capability. A tether point is provided to accommodate EVA handling. A notch in the plate aligns with a V-guide on the boom, and this keying feature ensures correct orientation during installation. One EVA wing tab connector would have to be mated or demated between the sensor package and the boom during change out. There are soft dock detents to support this Remove and Replace (R&R). A specific bolt order is required.

### **8.3 SAFETY TETHER CONFIGURATION**

The 85-ft safety tether is required to be used for crewmembers working off the boom for two reasons. The first reason ensures that the crewmember operating off of the boom can egress the APFR and translate back to the airlock without performing a safety tether swap in the event of a suit malfunction that requires an emergency airlock ingress. The second reason ensures that the crewmember simply has enough safety tether length to allow him/her to work from an APFR on the boom tip in multiple APFR configurations. In addition, if a WIF extender is required for access to certain TPS regions, the 55-ft safety tether will not reach.

### **8.4 EVA BOOM OPERATIONS AND DTO CONCLUSIONS**

The potentially dynamic environment of a 50-ft rigid boom attached to the SRMS can cause difficulty in performing inspection and repair operations, and in a worse case can cause safety concerns if EV crewmembers impart too much load (force, moment) into the SRMS/boom system. EV crewmembers are trained to be conservative while working off of the boom to prevent unwanted motion from EVA loads through glove/tool contact with structure or through foot restraints, which could cause SRMS brake slips or vehicle impacts.

A DTO was performed on STS-121 by EVA crewmembers Piers Sellers and Mike Fossum to subjectively evaluate inspection and repair scenarios, and to gather loads data for analysis correlation for EVA crewmember forces and moments. The STS-121 boom DTO, combined with ground tests and analyses, verified that the crew can likely perform TPS repair from the boom, with the following caveats:

- A. Conclusions were based on a single crew performing the repair tasks; the STS-121 crew was well informed and trained on RMS/boom system dynamics, able to adapt

well to the system on-orbit, and were able to control their body movements very well.

- B. The DTO used a force gauge to mimic repairs; an actual repair might be more or less difficult.
- C. The DTO did not evaluate all the possible worst-case SRMS conditions for repair.
  - 1. Crew reports that they did not notice a significant difference between different repair positions, APFR positions or mass at the tip provides confidence that we will not see a problem at the other positions.
- D. Conclusions were based on a single arm in a specific thermal environment, and there are variations in the SRMS brake and joint stiffness (between different SRMS units and dependent on thermal environment).
  - 1. Belief is that the STS-121 SRMS response was representative of SRMS dynamic response.

Risks associated with boom EVA operations include the following:

- A. Slightly increased risk (over SRMS/SSRMS alone) of boom or EMU impact with TPS or structure
  - 1. Crew's awareness of the platform instability and proximity to fragile, critical structure does mitigate this risk (STS-121 crew debrief comments)
- B. Slight risk that crew might damage TPS while stabilizing the system with their hands on the TPS during a repair
  - 1. However, the crew must be allowed to put hands on TPS for most repair scenarios in order to be stable enough to apply the repair (STS-121 crew debrief comments)
- C. Inadvertent APFR egress as a result of boom motion may result in EV quickly grabbing ingress aid (high load) or requiring safety tether rescue
  - 1. This did not happen during the DTO, although this is always a risk with the boots in a foot restraint
- D. Inadvertent end effector release could result in catastrophic EMU or TPS damage
  - 1. There are pros and cons of safety tethering to the SRMS end effector versus the tip of the boom, but safety tethering to the end effector with a local tether at the foot restraint is the approved method
  - 2. There is a need to prevent the safety tether from getting tangled in the mid-boom grapple fixture to allow for case of boom release and safety tether rescue



3. In the case of an inadvertent end effector release, the crew must kick out of the free floating boot plate and release the secondary (local) tether on boom tip
4. EV crewmember loading cases should not result in inadvertent end effector release (although loads used in these analyses assume all EVA loads are enveloped by repair loads)

E. Slightly elevated risk to structure during boom setup with APFR and tool stanchion

Some additional information related to the STS-121 boom DTO:

- A. Reconfiguring the APFR when in free space (i.e. away from the sill), including ingressing and egressing it, is an acceptable operation for inspection and repair scenarios that require it.
- B. For the crew, there was not a noticeable difference between the system response at different SRMS positions, APFR positions, or the mass at the tip (1 vs. 2 crew).
- C. Actual repair from the boom should include time for an on-orbit familiarization sequence.
- D. A high load can be applied, but must be done quickly (impulse).
- E. A free-float EV on the tool stanchion would not adversely affect the repair work being done by the EV in the foot restraint (only noticed the free float EV during intentional moving around).
- F. Passing small tools between crewmembers could possibly be done at the worksite without backing the boom away from the TPS, although the crew must gauge their comfort level with this at the worksite and larger items require backing out the boom.
- G. The VR Lab should be used for procedural development and training when possible. If a suited evaluation is required, the 3-DOF simulator with springs set to an appropriate approximation of the SRMS configuration is more conservative (flight-like) for large loading events than the 6-DOF simulator, which is limited by the overhead suspension system.
- H. The STS-121 crew recommends that the tool stanchion be installed into the APFR without the repair equipment on it, and then the repair equipment can be installed on the tool stanchion with EV2 stabilizing the boom near structure or the bags can be installed away from structure if required.
- I. Inspection operations using a camera can be done with the boom in motion, if required.

## 8.5 BOOM HAZARDS, INHIBITS, AND EVA KEEP OUT ZONES

There are several EVA notes, cautions, and warnings associated with the various boom interfaces. This information can be broken into five separate categories, each pertaining to specific areas of the boom as well as their respective level of criticality. The five parts include sensor no-touch areas, EFGF/Special Purpose End Effector (SPEE) Hazards, Boom Keep-Alive Contacts Hazards, MPM Keep-Alive Contact Hazards, and Laser Inhibits. Reference the latest Generic Inhibit Pad for specific inhibit steps.

### 8.5.1 Sensor No-Touch Areas

- A. In general, do not touch any parts of the sensors. The only designated EVA touch areas are the triangular bracket for the LDRI and ITVC, and the two T-shaped handles for the LCS and IDC.
- B. Do not touch LDRI baffles. They pose both a sharp edge and entrapment hazard. The baffles are located inside a ~ 1-inch square box on the LDRI. This is where the light enters the camera. A swatch test found that the baffles do indeed cut the glove material. A gloved finger can fit inside the aperture opening of the LDRI baffle and trap the gloved finger, possibly causing damage upon removal.
- C. Do not touch the LDRI diffuser. This is next to the baffle area and is where the light exits the camera.
- D. Avoid contact with the LDRI and LCS. They are covered with a silver Teflon radiative coating.
- E. Avoid contact with the gold metal foil covering the ITVC. It can easily tear or crumble.
- F. Avoid contact with the IDC mounted to the side of the LCS.
- G. Do not touch the window on top of the LCS; this is where the laser enters and exits.
- H. Do not touch any of the lenses; scratches will degrade sensor performance.

### 8.5.2 EFGF/SPEE Hazards

The SPEE connector is uncovered and powered while cradled in the starboard MPMs. When the boom is berthed in the MPMs it nominally receives 28 V keep-alive power for both the OBSS sensors and the internal OBSS avionics heaters. This power is received through the forward MPM. This 28 V power also "appears" at the connector on the EFGF. The EFGF connector is therefore both exposed (in the sense that it has no cover during flight) and "hot" at 28 V (or up to 32 V max). This voltage level does not constitute a shock hazard but if a conductive object were to enter the connector cavity and short the 28 V pins (the EFGF connector has pins, not sockets) then an arc could be produced, resulting in the production of molten debris

EV crew gets close to the SPEE connector in the following cases: SRMS safety tether swap (but is covered by the SRMS in this case), EFGF pin release, and during general translation.

There will be a Warning Label (although ironically, the crew should never nominally get close enough to read it) alerting the crew of the EFGF connector hazard.

The SPEE connector is located on the EFGF abutment plate and the cutout is about the size of a credit card. Hot pins are recessed inside cutout about 1.25 inches.

The Keep-Out Zone (KOZ) is 2 feet. There is concern about tools inadvertently floating into the connector. The crew should exercise caution with the tools on their MWS when they get close to the connector.

When a crewmember gets within the 2-ft KOZ of the SPEE connector, such as prior to an EFGF grapple shaft release procedure, and the SRMS is still grappled, power from the SRMS must be removed from both sensor packages. The inhibits turn off power coming from the SRMS and ensure that power is removed from both the LDRI/ITVC (SPEE PWR) and the LCS (Assembly Power Converter Unit (APCU)).

When a crewmember gets within the 2-ft KOZ to the SPEE connector when it is berthed in the MPMs, separate inhibits must be in place to remove power from the shoulder MPM. The current inhibits provide a single level control with no direct verification of removal of power (there are indirect methods).

### **8.5.3 Boom Keep Alive Contact Hazards**

This area is located on the bottom side of the EFGF and will sit in the shoulder MPM saddle when berthed.

The keep-alive contacts have built-in diode protection that allow the flow of current into the boom, but not out. The diodes have a maximum 5 mA leakage current that could flow out the 28 V contacts if the contacts were shorted. This is not a hazard to the EMU or crewmember. The return line contacts are not diode-protected, but these operate at low voltage and are not a hazard.

If procedures are followed, there is no voltage present on these contacts when the boom is not berthed.

There is no KOZ for the crew in this area. There is a Caution in the procedures to avoid contact with the boom contacts to protect the hardware.

### **8.5.4 MPM Keep Alive Contacts**

Power to the MPM is removed just prior to SRMS grapple of the EFGF; therefore, power is nominally turned off when the boom is not cradled. These current inhibits provide a single level of control with no direct verification of power removal (there are indirect methods).

The indirect method is only applicable when the boom is berthed. If heater power is removed, the temperature sensors in the sensor package will indicate decreasing temperatures. There is no direct or indirect method that applies to the boom unberthed.

Although power to the MPM should be off while the boom is removed, there will be a 2-ft KOZ around the stbd fwd MPM contacts due to the inability to verify power has actually been removed.

### **8.5.5 Laser Inhibits**

The boom only has keep alive/heater power when in the MPMs (as opposed to when it is uncradled and operational (lasers ON)), with one caveat: unlike the LCS, the keep-alive power to the LDRI has the ability to power the laser if there were a failure. Normally, this cannot happen since there is no way to command it on, but the power is there.

The conditions that would cause spurious activation of the laser on LDRI while in the MPMs are not considered credible.

Current Laser inhibits (for EVA) and thermal clocks are discussed below. The concept is that these would be verified whenever the SRMS has grappled the boom. If the crew is not in the area, or is outside the defined KOZ of the lasers, then the inhibits may not apply. Reference current flight rules for the laser KOZ distances. If the crew is not in the laser footprint while out EVA, inhibits may not be required. When heater power is removed, a flight specific thermal clock is started for the PTU. There is a minor concern for LCS use if its laser has not been on. LCS may require a 15-minute delay to warm it up before it is used operationally. LDRI has a more serious concern and may require soaking in a warm environment before the laser is taken out of standby mode. Laser inhibits are not required to release an RMS stuck on the FRGF at the center of the boom; the LCS KOZ is fixed and pointing away, and the LDRI KOZ is not long enough to reach the crew even if pointing directly at them. The laser inhibits are also not required if the boom is stowed in the MPMs. The LCS laser lacks power for activation, and LDRI laser activation is not considered credible.

## 9.0 BOOM WLE MAPPING

### 9.1 DESCRIPTION

In the event of a total sensor failure on FD2, and neither of the sensor packages can support nominal boom WLE mapping, an EVA can be conducted to perform a backup mapping of the WLE. There are currently two scenarios that employ the use of EVA; one involves a crewmember in a foot restraint at the end of the SRMS, and the other involves a crewmember in a foot restraint on either the mid or tip striker bar of the boom. A crewmember being on the SSRMS was not looked at in detail since it does not provide much more access than the SRMS.

The WLE Mapping strategy essentially involves the use of an EVA digital camera with 50 mm lens and flash that are used to photograph RCC panels from an APFR on the boom. The crewmember is required to locate a specific RCC panel, center the camera on the required area, and photograph the panel. This process is performed over several iterations of SRMS positions in order to map the required areas.

### 9.2 EVA WLE MAPPING AREAS AND RESOLUTION

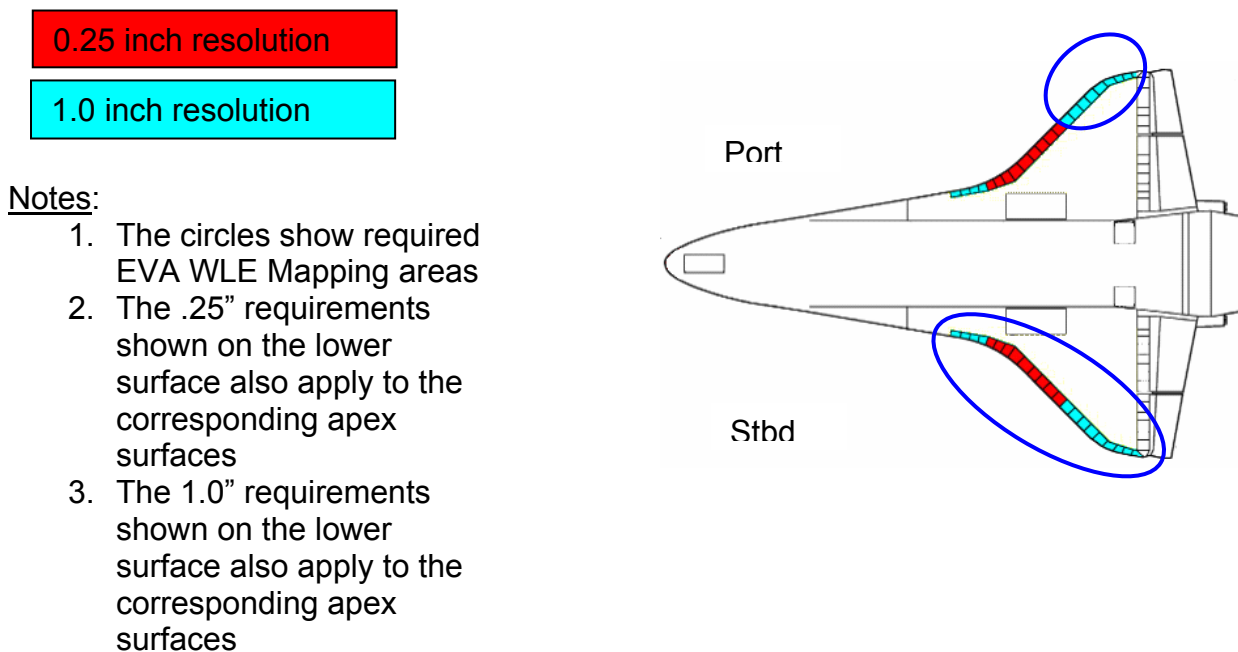
Both of the above scenarios are limited in that they do not provide entire coverage of the port and starboard wings, and they do not provide access to the nose. The regions that EVA is required to access are based on areas the SRMS and SSRMS end effector cameras cannot resolve. Thus, EVA is not needed to perform an entire mapping of panels 1-22 for upper, apex, and lower surfaces for both wings. EVA will only access the remaining panels that cannot be resolved adequately by both RMS cameras. In addition, EVA mapping of the upper surfaces of RCC has been removed from the procedures because these areas can be reached using digital photography by the ISS crew. Table 9-1 shows the required regions for EVA access:

**Table 9-1. Required areas for EVA WLE mapping**

	<b>Task</b>	<b>Location</b>
1.	Stbd Apex RCC (5-13)	Boom mid
2.	Stbd Lower RCC (1-22)	Boom tip
3.	Stbd Apex RCC (1-4, 14-22)	Boom tip
4.	Port Apex RCC (17-22)	Boom tip
5.	Port Lower RCC (17-22)	Boom tip

In order to map all of the required areas for EVA, the boom must be used. The extra length is needed to access the aft most panels of RCC, especially on the starboard side. In the event of a boom failure such that it cannot be released from the starboard MPM latches, a crewmember can work off of the SRMS to access some RCC, but not all of the required panels can be reached.

A significant limitation of this EVA backup capability is that the areas to be mapped are only recorded in 2-D using the EVA digital camera. Photogrammetry is currently not a certified technique for achieving 3-D information from RCC panels. In addition, the resolution achieved by the EV crewmember with the digital camera does not meet the current RCC requirements. The EVA digital camera with 50 mm lens can obtain .25 inch and 1.0 inch resolution based on the crewmember's distance away from the vehicle. In order to achieve this, the crew takes many photos across the span of the WLE, and must continually count panels to ensure the camera is both centered on the exact panel that needs to be photographed, as well as to meet the required overlap in between panels to avoid any gaps in data. See Figure 9-1 for WLE Mapping areas and resolution requirements:



**Figure 9-1. Resolution map for EVA WLE mapping areas**

### **9.3 WLE MAPPING SCENARIO**

#### **9.3.1 Procedure Development and Requirements**

The mapping procedures were developed and tested in the VR Lab using the digital camera specifications for the 50 mm lens. The VR Lab DOUG program also incorporated the resolution requirements of respective RCC panels. SRMS procedures were developed to place the crewmember on either the boom mid or tip at the correct location away from the orbiter that would allow the 50 mm lens to take a photograph to the required resolution. Because the RCC panel requirements are so strict, each RMS position was carefully developed to allow a sufficient amount of overlap in between each photo. The crewmember is trained to both count respective panels and to center each

photo accordingly on an RCC T-seal to allow the camera to focus. Photographing a blank RCC panel without a T-seal centered in the field of view is ineffective based on its featureless, solid-color surface, and the camera cannot focus on that.

To ensure that the proper resolution of either 0.25 inch or 1.0 inch is met, the crewmember is flown to an exact predetermined position that is based on a precise distance away from the vehicle as well as a precise body orientation. Each photograph taken by a crewmember must be centered to the best of their ability and should be taken as normal to the surface as possible. The nature of the curved RCC surface and wing leading edge adds complexity to ensuring a photo has been taken that meets the required resolution. Photos taken at oblique angles lose most of the resolution that is required. These limitations are included in the VR Lab models, so that if a crewmember points the camera too far off from normal, he/she will not meet the required resolution and overlap of a set of panels.

### **9.3.2 WLE Mapping Technique**

In order to cover the five required RCC areas listed in Table 9-1, and to meet the required resolution for each of their varying geometries, the SRMS must make five separate passes to and from the orbiter sill. Each RCC pass requires a different APFR setting to ensure the crewmember is positioned at the correct distance and body orientation with respect to each set of panels being photographed.

The potentially dynamic environment of a 50-foot rigid boom attached to the SRMS has driven the requirement to have several operational constraints regarding crewmember activity while on the end of the boom. To protect for boom loads unknowns, and possible SRMS brake slips, the crew is trained to be conservative while working off of the boom. In addition, they are currently prohibited from performing what are normally considered to be standard EVA tasks while on the boom. The majority of actions performed by EV1 on the boom tip or mid striker bar require the assistance of EV2. Boom constraints are listed in Section 6.4.

Every time a foot restraint setting is changed, another crewmember is required to help react loads. This ultimately drives the SRMS/boom system back to the orbiter sill over several iterations so EV2 can adequately react EV1's loads into the boom for foot restraint setting changes and ingresses. These SRMS passes, coupled with potentially long SRMS/boom maneuvering times, drive the EVA WLE Mapping procedure to be approximately 7:40. If the upper surface passes were added back into the timeline, the procedure grows to be approximately 8:30. Realizing this significantly exceeds nominal EVA length, individual passes of this procedure may be used as stand-alone if, based on real-time mission requirements and decisions, EVA is only required to look at one or two areas. Constraint of boom loads will be reevaluated after the DTO on STS-121.

## **10.0 BOOM/RMS POINT INSPECTION**

### **10.1 DESCRIPTION**

Robotic based point EVA inspections can be conducted from the SRMS, the SSRMS or the boom. An EV crewmember on the SRMS or SSRMS will have access to the forward lower surface, port, and starboard wing glove regions, and a portion of the RCC panels. An EV crew member on the boom tip grappled by the SRMS is required for access to most aft and lower orbiter tiles and RCC; however, the boom grappled by the SSRMS does not allow for complete coverage of the vehicle. In general, the simplest method for inspection will be selected. Based on location of suspected damage site, either the SRMS or SSRMS would be used prior to pulling out the boom, as long as either of the arms could reach the area of concern. Conversely, if there are multiple hits spread across the vehicle, or the hit is on an aft lower surface, the MMT may decide to pull the boom out instead of relying on two different setups for both arms in order to reach the required areas. Due to the unknown dynamics associated with the SRMS/boom system, as well as the EVA time and constraints associated with setting it up and putting a crewmember on the end of it, the boom option will be one of the last efforts used to achieve a focused inspection. Areas that are currently not required for EVA inspection include the base heat shield, rudder, Orbital Maneuvering System (OMS) stinger, and aft compartment. In addition, the inspection of white tiles will be based on MCC call only; there is no nominal plan to inspect those. After Node 2 is installed, access is further reduced.

### **10.2 INSPECTION METHOD**

Similar to WLE Mapping, Boom Point Inspection requires that the same types of precautions be exercised by the EV crewmembers while working off of the boom. The majority of actions performed by EV1 on the boom tip or mid striker bar require the assistance of EV2. A complete list of boom constraints can be found in Section 6.

Every time a foot restraint setting is changed, another crewmember is required to help react loads. This ultimately drives the SRMS/boom system back to the orbiter sill over several iterations so EV2 can adequately react EV1s loads inputted into the boom for foot restraint setting changes and ingresses. Based on the requirements for EV2 to react EV1's loads, and the slower RMS times associated with maneuvering the boom, the EVA Point Inspection procedure is constrained to inspecting up to three TPS damage areas. If the damage areas are close together, there is potential to inspect more than three sites. Conversely, if the damage is spread much further apart, it may be difficult to access all three areas.

EVA point inspection allows for the collection of 3-D TPS data via Photogrammetry. See Section 4.0 for details on photogrammetry techniques.



## 11.0 TPS REPAIR REAL-TIME CONSIDERATIONS

If a repair is being considered, several factors will determine whether the repair is feasible, when it should be performed, what the repair platform should be, how much ground facility support is required, and which various disciplines require involvement. Some of these factors are listed below to aid the EVA team in more quickly integrating the effort.

- A. Work with DX robotics to understand access, understand maneuver times, and ensure crew has most stable configuration, good ingress location/orientation, good orientation for repair
- B. Early in the process if a repair seems likely, information should be sent to the crew regarding the damage location/size, along with current thoughts on repair technique, EVA timeframe, and access
- C. Determine whether any contingency tools are required that could be brought inside on an EVA prior to the repair (e.g., from the TSA or ISS toolboxes)
- D. TPS repair is an evolving technology, and the current status of the repair procedures should be assessed with the repair team (submit CHIT as required)
- E. Facilities, suits and tools should be called up through the Spacecraft Analysis (SPAN) and the ISS Management Center (IMC) (use SPAN and IMC distribution lists in addition to contacting them over the loops) as required to perform any evaluations:
  - 1. Building 9 (1G evaluations can be performed in a more private area of building 9 than the TPS area, if desired)
  - 2. PABF
  - 3. Dual Glove Box, considering repair temperatures
  - 4. VR Lab
  - 5. Blue Room in building 7
  - 6. NBL, including still camera support
  - 7. Flight Crew Equipment (FCE) and Environmental Chamber (EC) (class 1/2) tools
  - 8. EC suits, if suited event required in building 9 or the Blue Room
  - 9. 3-DOF or 6-DOF Boom Simulators
  - 10. Building 8 video and still camera support

Note: Primary contacts are as follows, although in all cases, ensure that the entire EVA Team is aware of any Team 4 activities:

- For the NBL - Contact the SPAN
- For Building 9 - contact the SPAN. SPAN can call the OCC Desk during normal business hours or the mission support pager at other times.
- For EC suits - contact the EVA IMC (XA)
- For EVA tools (for non-NBL runs) - Contact the EVA IMC (XA)

F. Ensure evaluation areas have the appropriate equipment available:

1. Locked cabinet for tools
2. Tables/chairs
3. Safety glasses
4. Towels
5. HEPA Vacuum

G. Materials for evaluations should be acquired or fabricated, with quantities accounting for whether two or more types of repair are being considered:

1. The DX TPS area, building 9 storage, and building 9 loose equipment have some materials for DX and ES use
2. The TPS experts in the DAT area or the shuttle Mission Evaluation Room (MER) should be contacted regarding acquisition of necessary TPS materials to perform 1G evaluations. Materials could be located at JSC or KSC may have to fabricate them
3. Building 9 techs might be able to fabricate a mockup from the materials or KSC might have to supply to the entire mockup
4. Boeing and EV&CS can assist in integrating a mockup fabrication effort
5. Foam versus tile and fiberglass versus RCC should be considered
6. High fidelity applicators should be filled by EC/tools as required; simulants supplied by EC or building 9 should be considered

H. DX procedure work for a specific damage configuration should be paired with MER fabrication of samples for arc jet, wind tunnel, or radiant heat testing when possible; determine whether repair should be done on orbit and then replicated on the ground or if sample should be made before on-orbit repair using DX procedures to perform procedure verification prior to the crew performing repair

- I. A thermal analysis should be requested, with the EVA-desired thermal profiles of the repair specified (submit CHIT as required):
  - 1. Environment for EMU
  - 2. EMU touch temperatures in the area
  - 3. Thermal analysis for the tools or applicators in those environments
  - 4. Thermal analysis for the TPS with respect to day / night cycles, with start of ODAY and ONITE specified on the plots
  - 5. Thermal analysis for repair cure (if required)
- J. Work with shuttle and ISS control teams and MER to ensure shuttle or stack attitude selected will maximize repair application and then repair curing success
- K. If WIF extender or APFR will be used, determine what analysis, if any, is required for those tools in the configuration they will be used including shuttle or stack attitude control (submit CHIT as required)
- L. Determine whether two crewmembers are required/desired for the repair and whether the tool stanchion will be required (ensure DX robotics gets this information)
- M. Determine whether a comm (and WVS) coverage analysis is required and where the second crewmember should be staged if not at the repair worksite (submit CHIT as required)
- N. Work with Integrated Communications Officer (INCO) to build KU protect box if near stbd wing
- O. Discuss emergency ingress scenario and time to get to airlock if emergency occurs along the repair trajectory or at the repair worksite
- P. Ensure team accepts ISS, EMU, and shuttle exterior (cameras, etc.) and interior (toxicity) contamination risks of repair
- Q. Change the EVA LiOH/Metox plan as required
- R. Consider lighting for repair and possibly photogrammetry in EVA timeline/egress times (get lighting analysis from pointers or submit CHIT as required)
- S. Verify TPS and generic EVA inhibit pads cover applicable repair- and flight-specific scenario, including boom inhibits with a specific APFR configuration
- T. Work with Mechanical, Maintenance, Arm and Crew Systems (MMACS), as required, to park elevons (circ pump) or body flap (APU) if required for TPS stability or to ensure boom/crewmember will not contact

- U. Determine whether FRGF grapple pin requires removal to avoid TPS damage (this is a risk tradeoff, since FRGF grapple pin might not go back in)
- V. A payload bay door might need to be partially closed if repair is required on the top of the wing - robotics needs to consider tool stanchion ops (stbd Payload Bay Door (PLBD) closure means no shuttle KU)
- W. Determine whether Teflon squares/Kapton tape is require over WVS (not desirable from a viewing standpoint) and whether O2 actuator cover is required
- X. Determine whether the boom/non-EVA cameras are satisfactory for verification or whether a second EVA is required
- Y. Late messages for the crew can be expected to include the detailed and summary timelines, tool config, any IFMs required for tools, reminders about tool use or tool OCADs, video or photos of ground-simulated repair, expected comm coverage, and expected boom motion notes
- Z. Consider a voice-only or video tag up with the crew to discuss the details of a specific repair
- AA. Consult Tile Repair or RCC Repair Real-time Considerations sections for additional considerations.

### **11.1 TILE REPAIR REALTIME CONSIDERATIONS**

The following additional factors should be considered for a tile repair:

#### General

- A. If the tile damage has a gap filler, team should determine whether gap filler should be cut or if a pull should be attempted to remove it prior to a repair
- B. Determine whether some parts of the cavity are more critical than others
- C. Agree on off-nominal plans with the MER (e.g., auger that doesn't go in fully)
- D. Get information on the type of tile that is damaged to understand deltas from crew training and in procedures
- E. Determine whether we are covering an antenna and how it will affect antenna performance

#### EWA Repair

- A. Determine the percentage coverage that is required
- B. Verify acceptable quantity of residual foam that can remain in the cavity (probably not much of a factor except with respect to percentage EPC coverage)

- C. Determine how much EPC coverage can be expected with the applicators and environment in the expected temperature range

#### Tile Overlay Repair

- A. Robotics development should take into account that the EVA crewmember reach is best with the long axis of the overlay horizontal in front of the crewmember
- B. The bag fill procedure should be agreed on with the MER, including the number of acceptable pins in the cavity and taking into account that stuffing the cavity is more difficult with a pressurized gloved hand
- C. Auger installation sequence should be determined for procedure
- D. Ensure tools available to pull out a hanging auger
- E. If overlay includes an adhesive soft dock, obtain thermal predictions and restrictions for application

#### STA-54 Repair

- A. Determine the underfill requirement
- B. Ensure repair team understands limitations of EVA application:
  - 1. Edges and some areas might not meet the underfill requirement exactly; this affects entry swell model correlation
  - 2. Foam may be present in EPC-to-STA-54 interface or in/on STA-54
  - 3. Bubbling/on-orbit swell might be difficult for the EVA to keep under control (this console handbook section published without Detailed Test Objective having been completed)
  - 4. The entry swell model will assume a specific density range (void distribution); EVA cannot verify that this density range is correct, especially considering varying depths of damage
- C. Determine whether some parts of the cavity are more critical than others for adhesion and update procedure accordingly (freshest material out of the gun is expected to adhere the best)
- D. Obtain purge predictions, working life predictions and bubbling/swell predictions for EVA application for inclusion in procedure
- E. Update procedures with contour gauge underfill requirements
- F. Warmer STA-54 is desirable, shuttle/stack attitude and egress time should ensure warmest STA-54 at dispense
- G. Determine whether the IR camera can be used to verify the repair configuration

- H. Verify durometer harness requirement for a specific cure profile (i.e., is the expected hardness a shore A of 40)
- I. If applied to aluminum structure or other non-tile substrate, determine if we need to take a temperature measurement of the structure before application

## **11.2 RCC REPAIR REALTIME CONSIDERATIONS**

The following additional factors should be considered for an RCC repair:

### General

- A. Verify there are not OML changes that the crew needs to make (e.g., pulling off a piece of hanging coating)
- B. Agree on off-nominal plans with the MER (e.g., plug gap not matching gap map, temperature sensor not reading the same as the thermal analysis predicted, etc.)
- C. Consider using any extra EVA time after the repair to watch the NOAX in order to be ready to re-smooth the repair
- D. Ensure EVA procedures and crew reminders include any new information that the MER can provide based on the latest testing and analysis (e.g., arc jet failures as a result of surface roughness, void characteristics, overall protuberance)

### NOAX Repair

- A. For NOAX repair, the location for NOAX paletting on the wing needs to be determined based on downstream effects, thermal plots (paletting location should have similar temperatures as the repair site), and crewmember hand location
- B. Repair should take place between 140 and 40 degrees Fahrenheit (higher temperatures are better) during a day cycle, with decreasing temperature slope as a goal; temperature profiles should be understood on all parts of the RCC (apex, upper, lower)
- C. Determine the number of expected layers and any other techniques for that specific damage
- D. Determine whether some parts of the damage are more critical than others for NOAX coverage

### Plug Repair

- A. The best fit plug needs to be determined by the MER, along with approximately two backup plugs that have similar curvature; verify accuracy of inspection data to accommodate this selection adequately or whether an EVA measurement to a T-seal or carrier panel is required prior to installation of the plug

- B. Determine whether backside insulation is a factor to give crew hints and develop procedures considering which areas might contact plug hardware or drill bit
- C. Determine safest transportation method for plugs to worksite
- D. Procedures should specify direction of 12 o'clock marking during install
- E. Update IVA procedures as required to ensure stowage locations, Velcro installation, tether point installation, plug T-bar assembly, and plug patches call outs have correct details
- F. Verify whether T-bar will be installed spanwise and update procedures as required
- G. Determine best RCC marking method for the specific damage, taking into consideration the amount of uncertainty in the inspection location:
  - 1. Eye-ball
  - 2. Piece of FDF cover placed near T-seal
  - 3. Piece(s) of FDF cover with damages drawn on them and/or cut out
  - 4. IFM tape measure or marked string
- H. Acquire expected turn count and gap map - perform procedure verification on real RCC if possible
- I. Discuss with the repair team the expected uncertainties in on-orbit EVA installation to ensure team ready for an unexpected fit:
  - 1. RCC marking
  - 2. Rotational misalignment
  - 3. Translational misalignment
  - 4. Outer Mold Line and Inner Mold Line variations from vehicle to vehicle and as a result of damage
  - 5. Use of feeler gauge (technique and gauge accuracy)
  - 6. Delaminations
  - 7. Patch variability (pinholes, thickness specs)
  - 8. Size/irregularity of hole
  - 9. Turn counting (crew/PGT error)
- J. If a hole is present that is greater than 1.1 inches in diameter, determine whether the plug should be biased in the hole away from center (for example, towards the windward side or towards a best fit area)

## 12.0 EMERGENCY INGRESS SCENARIOS

Generic flight rules require that EV crewmembers can abort an EVA at any time, ingress the airlock, and repress to 8 psia within 30 minutes.

EMU Secondary Oxygen Pack (SOP) Go/No-Go pressure is set at 5410 psi which, combined with 150 psi in the primary tanks, provides 30 minutes of purge flow through the DCM purge valve.

Some EVA inspection and repair tasks will require more than 30 minutes to get from the worksite to the airlock, and repressed to 8 psi.

### SAFER Inspection

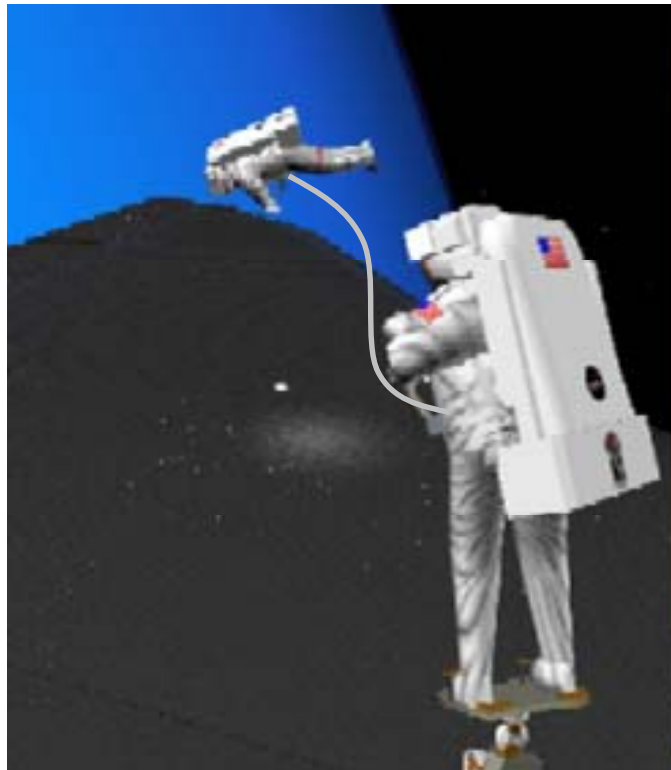
Rescue Scenario Timeline (Shuttle or Joint Airlock):

0:00-0:13 Fly back to SSRMS/SRMS

0:13-0:23 SSRMS/SRMS maneuver to airlock

0:23-0:28 Egress SSRMS/SRMS, translate to airlock

0:28-0:33 Ingress airlock, close hatch, repress



**Figure 12-1. Safer inspection**



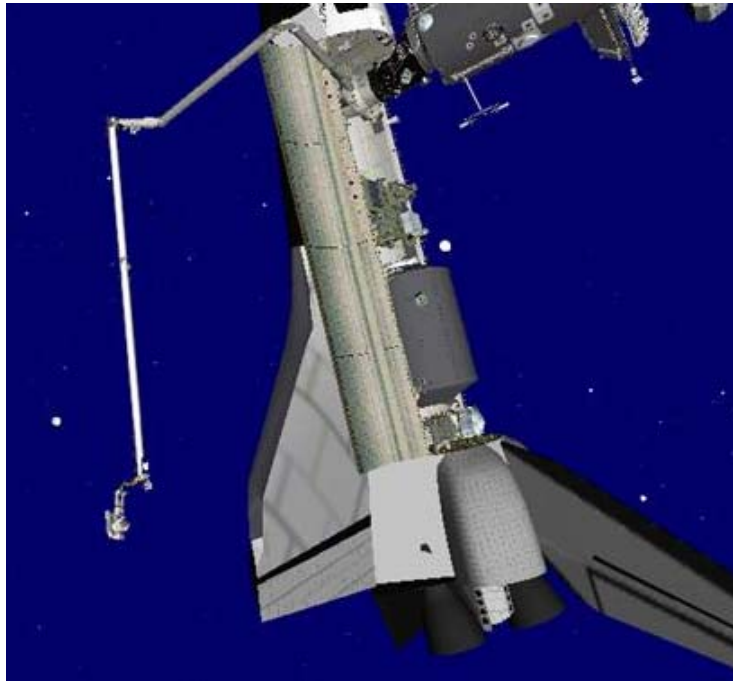
### Boom Inspection

#### Rescue Scenario Timeline (Joint Airlock):

0:00-0:20 Maneuver boom tip to sill  
0:20-0:25 Egress, translate to forward Lab  
0:25-0:27 Perform safety tether swap  
0:27-0:35 Translate to Joint Airlock  
0:35-0:40 Ingress Airlock, close hatch, repress

#### Rescue Scenario Timeline (Shuttle airlock):

0:00-0:20 Maneuver boom tip to sill  
0:20-0:25 Egress, translate to shuttle airlock  
0:25-0:30 Ingress Airlock, close hatch, repress



**Figure 12-2. Boom inspection**

The exposure window during which ingress will require more than 30 minutes is as follows for each of the EVA inspection scenarios.

#### AFER Inspection:

- SAFER inspection flight is limited to 45 minutes. During the rest of the EVA an abort can be executed in 30 minutes.

Boom Point Inspection:

- No more than 3 hours would be spent on the boom. During the rest of the EVA, an abort can be executed in 30 minutes

Wing Leading Edge Mapping:

- Up to 3.5 hours spent on boom in locations that prevent a 30 minutes ingress. During the rest of the EVA, an abort can be executed in 30 minutes

There are two types of EMU failure scenarios that are affected by the increased translation time to the airlock.

- A. Loss of EMU cooling: crewmembers will need to open the DCM purge valve during translation
- B. EMU leak due to component failure, MMOD strike, cut/tear: Suit leaks at a rate equivalent to DCM purge valve (5 lbs/hr)

All other EMU malfunctions can be supported with the helmet purge valve which has a lower flow rate (2.5 lbs/hr). At this flow rate, there is adequate gas in the Secondary Oxygen Pack (SOP) to support the longer translation time.

For the situation where EMU cooling is lost, the following response will allow support of the increased translation time. During robotic arm translations, the EV crew should close the DCM purge valve and open the helmet purge valve. Once the crew is dropped off at structure, the helmet valve can be closed so that the DCM valve can be opened.

During arm translations the EV crew will have a low metabolic rate which will reduce heat generation. This is why the helmet purge valve is deemed acceptable for use during part of the retreat. For every 2 minutes that the helmet purge valve is open instead of the DCM valve, the 30 minute limit can be increased by 1 minute. Retreat from all TPS inspection and repair worksites during a cooling failure can be accomplished under this guideline.

Note: DCM Purge Valve flow = 5 lbs/hr

Helmet Purge Valve flow = 2.5 lbs/hr

Worst case TPS case is on OBSS, and includes 20 minutes of arm translation. Helmet purge during this time will allow additional 10 minutes so that the required 40 minute retreat can be accommodated.

Assumes 500 BTU/hr met rate on arm (this includes an additional 100 BTU/hr load above resting met rates to account for crew stress). 1200 BTU/hr met rate during translation on structure. This met rate has been accepted previously during Metox certification. Thermal analysis indicates that this will not exceed the heat storage limit for the crewperson.

MOD, EC, and Hamilton Sundstrand Windsor Locks (HSWL) agree on the acceptability of this operational solution.

It is not possible to protect for a 5 lb/hr leak out of the EMU during all TPS inspection and repair scenarios:

- A. MMOD – With ISS and shuttle providing shadowing, probability of any penetration is 1 in 7,100 over a 6.5 hour EVA. Probability of catastrophic penetration requiring more than 30 minutes for abort is 1 in 20,000. With longer required translation, likelihood of catastrophic penetration increases for TPS EVAs. Quantitative analysis has not been performed to determine added MMOD risk for 40 minute abort cases, but it is between these two values. Without ISS and shuttle shadowing, the probability of any penetration drops to 1 in 3,400. Likewise, the probability of catastrophic penetration is 1 in 10,000.
- B. There is added risk that suit failures will generate an unsupportable leak. Some components are sized based on 30 minute requirement. Design margin is unknown. Quantification of this added risk is not planned.

Additional buybacks are available to increase sustainable leak time:

- A. Minimum Go/No-Go SOP pressure is 5410 psi at ambient temperature. If SOP pressure is  $\geq 6000$  psi, the additional gas would provide 3 extra minutes of flow.
- B. The SOP Go/No-Go pressure also assumes there is only 150 psi in the primary tanks. Forty minutes of flow time can be achieved with 6000 psi in the SOP and 530 psi in the primary tanks.

Priority must be given to preserving abort capability. For situations in which the crew is unable to abort within 30 minutes, SOP and primary oxygen shall be optimized to extend purge duration. This may include selection of EMUs with higher SOP pressures. Additionally, EVA task priority must be set such that inspection and repairs from the boom or SAFER are performed early in the EVA, or after an O<sub>2</sub> recharge when additional primary oxygen is available. It is recognized that the duration of some inspection and repair tasks prohibit preservation of oxygen to protect for the extended translation time. This zero fault tolerant risk has been accepted only because the safety of the orbiter depends on completion of the tasks. Consideration will be given to preparing the shuttle airlock as a rapid ingress option for inspection and repair EVAs in which the primary and secondary oxygen will not support translation back to the Joint Airlock.

## **13.0 EVA COMM**

### **13.1 SSOR COMM ANALYSIS**

SSOR communication analysis was performed to determine communication capability between an EV crewmember under the orbiter and the IV. For all the plots in this section, recognize that communication may become marginal or lost at 0 to 5 dB link margin.

#### **13.1.1 ORBITER EVA/UHF ANTENNA BACKGROUND AND ASSUMPTIONS**

Realistic RF parameters were used in this EVA voice/data communications coverage analysis. The EMU to Space Shuttle Orbiter (SSO) link has a weaker link than the SSO-to-EMU link. The weaker link is used in the analysis. To be conservative, calculations assume a -10 dB EMU antenna gain and -7 dB polarizations loss, for greater than 60 percent of the sphere of space surrounding the EV astronaut. The signal levels on the orbiter starboard side are higher than the port side due to the SSOR UHF antenna location in the payload bay. The lowest signal levels are in the regions near the tail, due to significant signal blockage by the wing in those areas. The signal levels improve with increasing separation distance between the EV astronaut and the orbiter underside. Coverage plots for the EMU to SSO links at 1, 2, and 3 meters separation distance from the orbiter surface are given in Figure 13-1 and Figure 13-2. The link margins given in these figures are at the underside of the orbiter.

EMU-SSO Link margin (dB) at 1 m Underneath of Space Shuttle

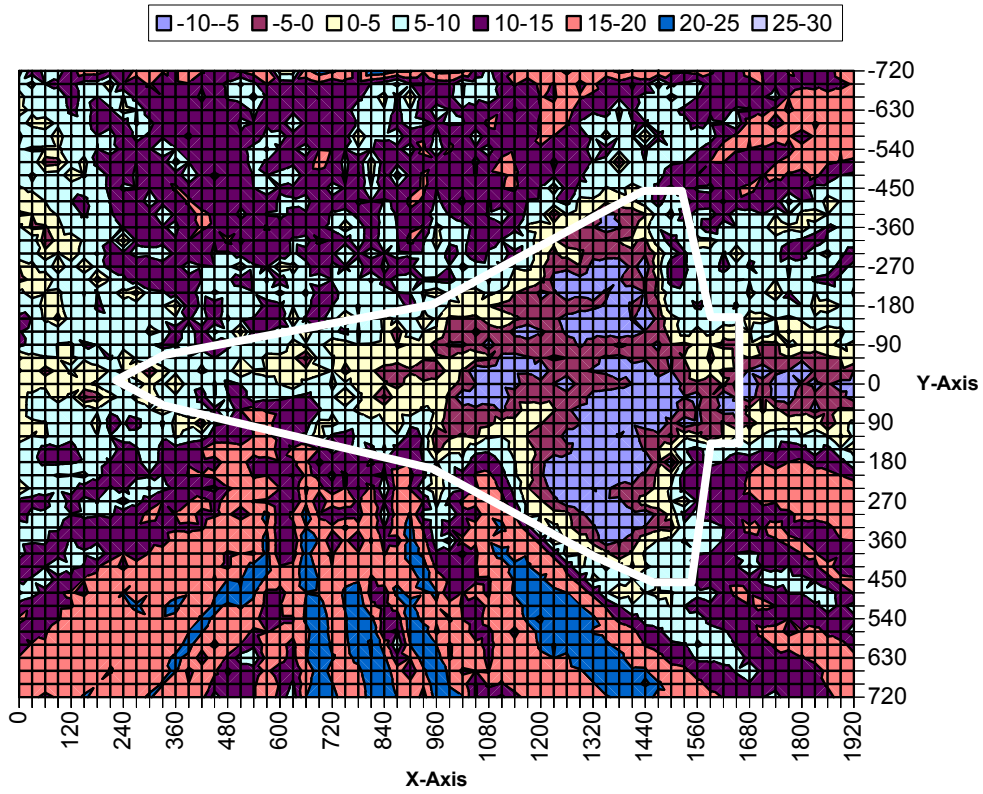


Figure 13-1. EMU SSO link margin (dB) at 1 m. underneath shuttle

EMU-SSO Link margin (dB) at 2 m Underneath of Space Shuttle

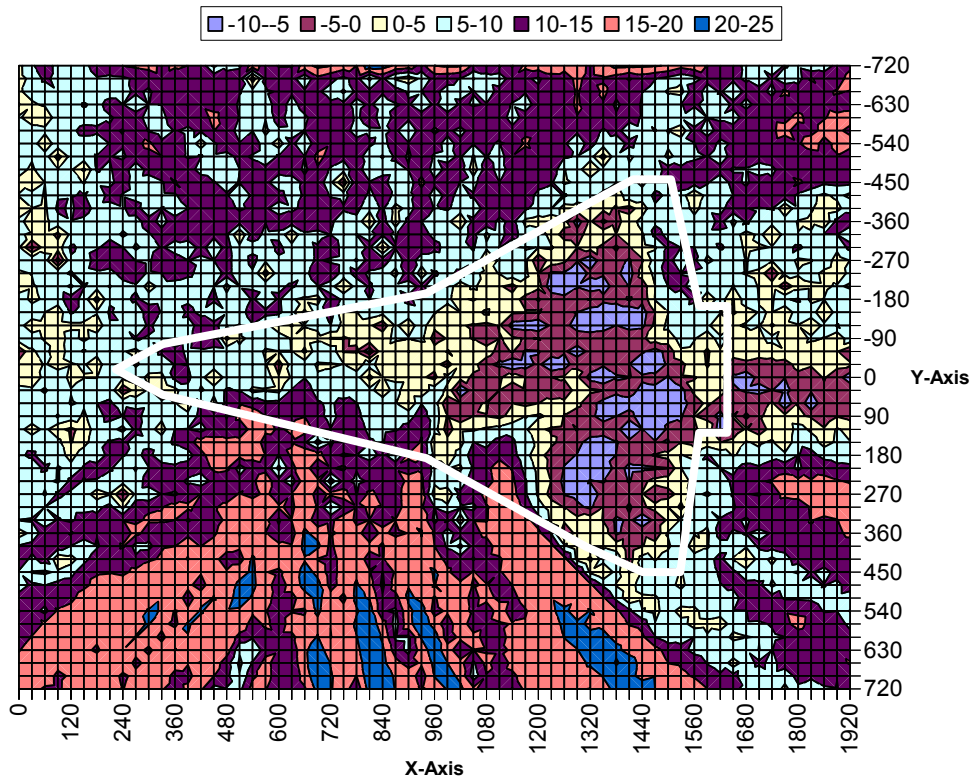
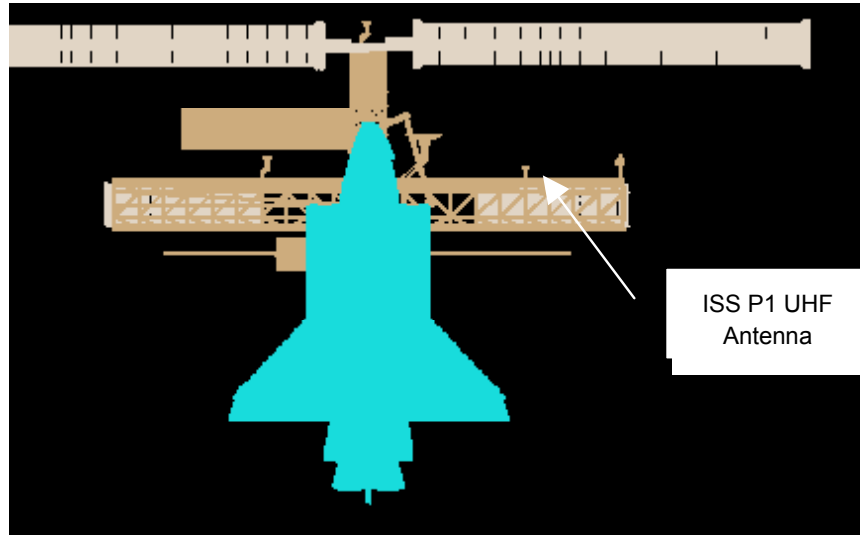


Figure 13-2. EMU SSO link margin (dB) at 2 m. underneath shuttle

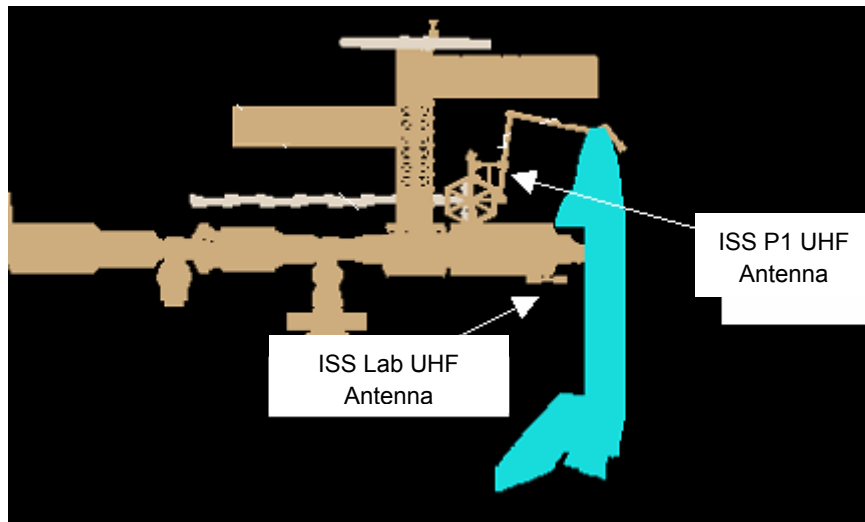
## 13.2 SSSR COMM ANALYSIS

### 13.2.1 ISS LAB UHF ANTENNA BACKGROUND AND ASSUMPTIONS

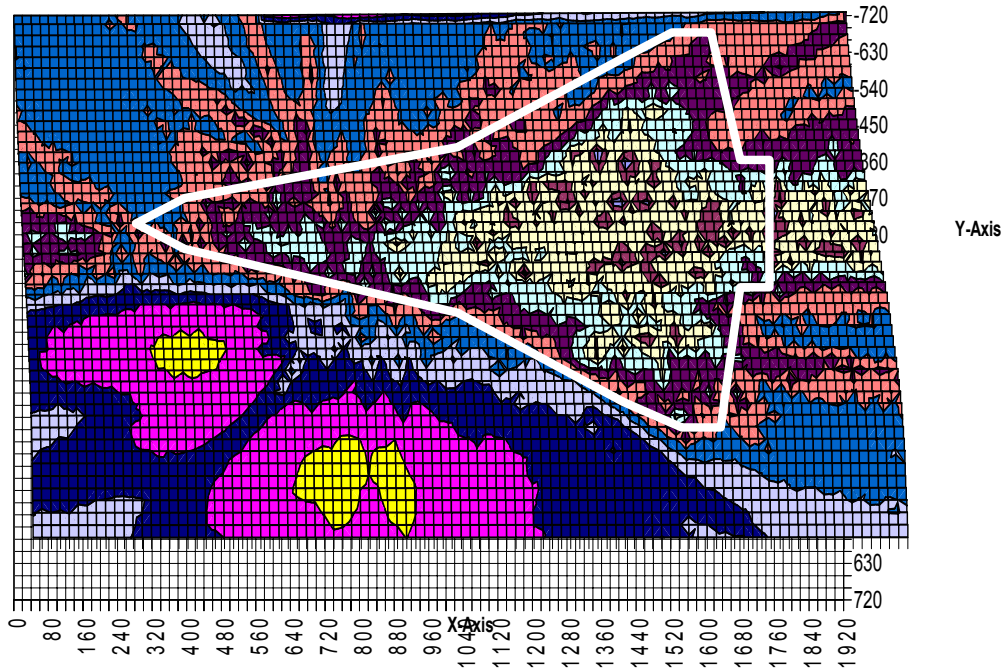
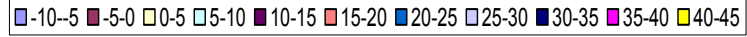
Analysis for ISS communications uses the same conditions specified in 10.1, as well as some additional ones. Reflection from ISS structure was not included in the Anechoic Chamber near-field measurements. The analysis uses only the signals from the ISS P1 and Lab UHF antennas pointing in the +X direction (away from the ISS structure). Any signals received by the -X antennas are ignored. Only the antenna back lobes see ISS structures. The ISS structure effects on the ISS UHF antennas for the SSO underside communications are not significant. The EMU to ISS link is the weaker link compared with ISS to EMU link. The weaker link is used in the analysis. The signal level on the starboard side is much higher due to the ISS UHF Lab antenna location. The signal level is in general better for the ISS Lab UHF antenna than for the SSOR antenna. The ISS Lab UHF antenna is a good candidate for EVA communications underneath the orbiter. Figure 13-3 and Figure 13-4 below identify the locations of the ISS P1 and Lab UHF antennas. Communications coverage plots for the EMU-to-ISS Lab UHF antenna are shown in Figure 13-5 and Figure 13-6. These plots are based on the EV astronaut position at 1 and 2 meters separation distance from the orbiter surface.



**Figure 13-3. ISS P1 UHF antenna**

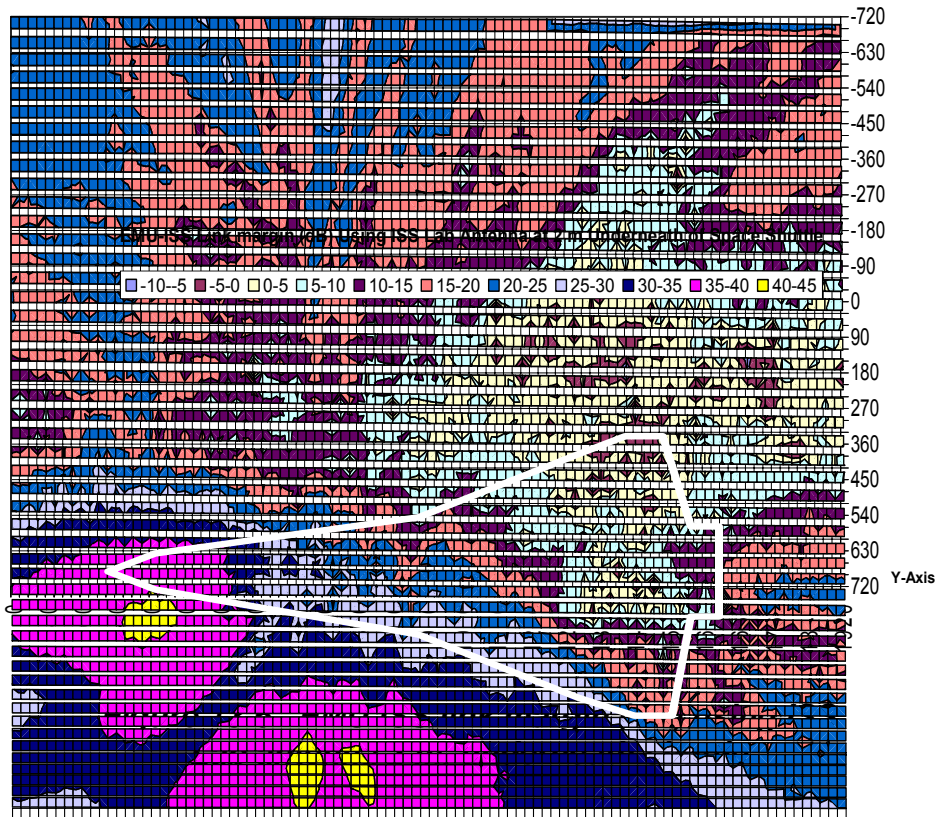


**Figure 13-4. ISS Lab UHF and P1 UHF antennas**



**Figure 13-5. EMU ISS link margin (dB) Lab antenna 1 m. underneath shuttle**

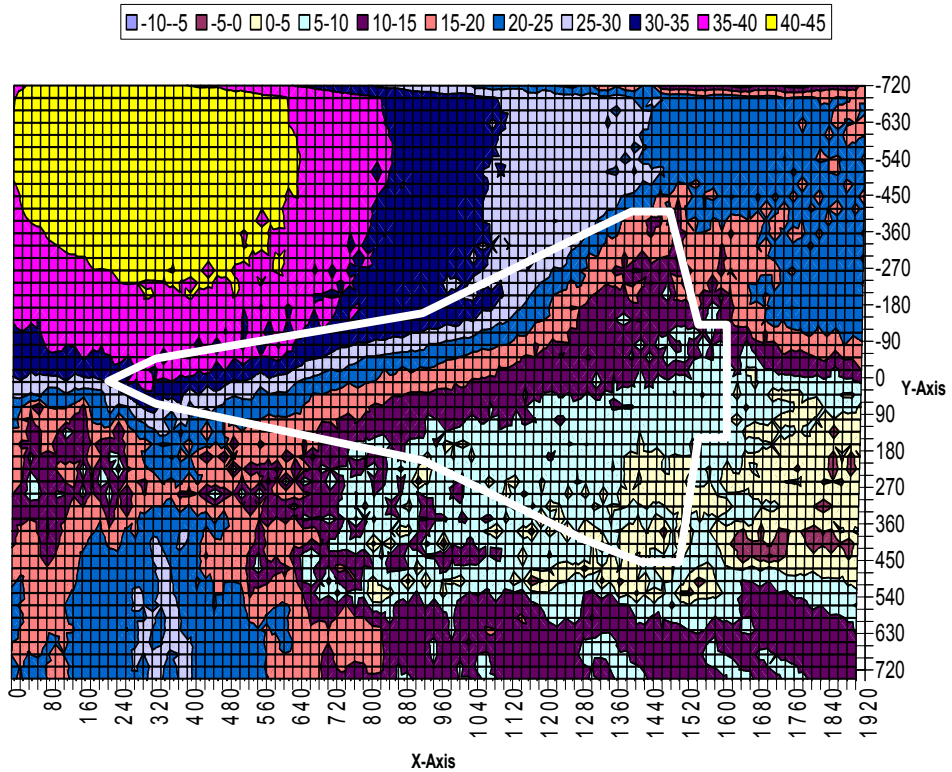




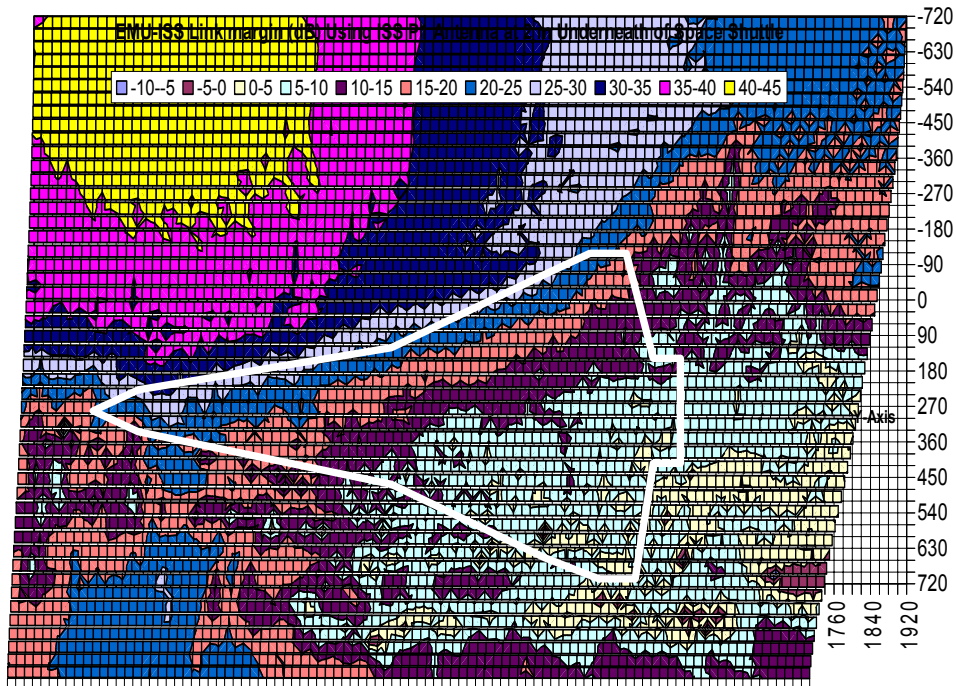
**13.2.2 ISS P1 UHF Antenna Background and Assumptions**

Analysis for ISS communications uses <sup>X-Axis</sup> the same conditions specified in 10.1, with some minor differences, as well as some additional ones. The signal level on the shuttle port side is much higher due to the ISS P1 UHF antenna location. The signal level is in general better for the ISS P1 UHF antenna than for the SSO Space-to-Space Communication System (SSCS) antenna. The ISS P1 UHF antenna is a good candidate as the primary antenna for EVA communications underneath the shuttle. Coverage plots for the EMU-to-ISS P1 UHF antenna links at 1 and 2 meters separation distance from the orbiter surface are given in the figures below. Coverage plots for the EMU to ISS P1 UHF antenna links at 1 and 2 meters separation distance from the orbiter surface, respectively, are given in Figure 13-7 and Figure 13-8 below.

EMU-ISS Link margin (dB) Using ISS P1 Antenna at 1 m Underneath of Space Shuttle



**Figure 13-7. EMU ISS link margin (dB) ISS P1 antenna at 1 m. underneath shuttle**



**Figure 13-8. EMU ISS link margin (dB) using ISS P1 antenna at 2 meters underneath shuttle**

### 13.3 SINGLE VEHICLE ANTENNA ASSESSMENT

The ISS UHF antennas are better than the orbiter EVA/UHF antenna due to the ISS-P1/Lab antenna location and pointing directions. The ISS-P1 antenna provides better signals on the shuttle port side and the ISS-Lab antenna provides better signals on the shuttle starboard side. Generally, the ISS-P1 truss antenna provides better coverage than the ISS-Lab and the orbiter EVA/UHF antennas. The orbiter EVA/UHF antenna provides worse coverage than the ISS-P1/Lab antennas.

### 13.4 COMPOSITION COVERAGE PLOTS

Two composite plots were made using the maximum link margin for each of the following of antennas: ISS P1 and orbiter EVA/UHF Antennas, and ISS LAB and orbiter EVA/UHF Antennas. For Coverage and link margin data on the combined ISS-P1 and orbiter EVA/UHF Antennas, at 1 and 2 meters, refer to Figure 13-9 and Figure 13-10, respectively.

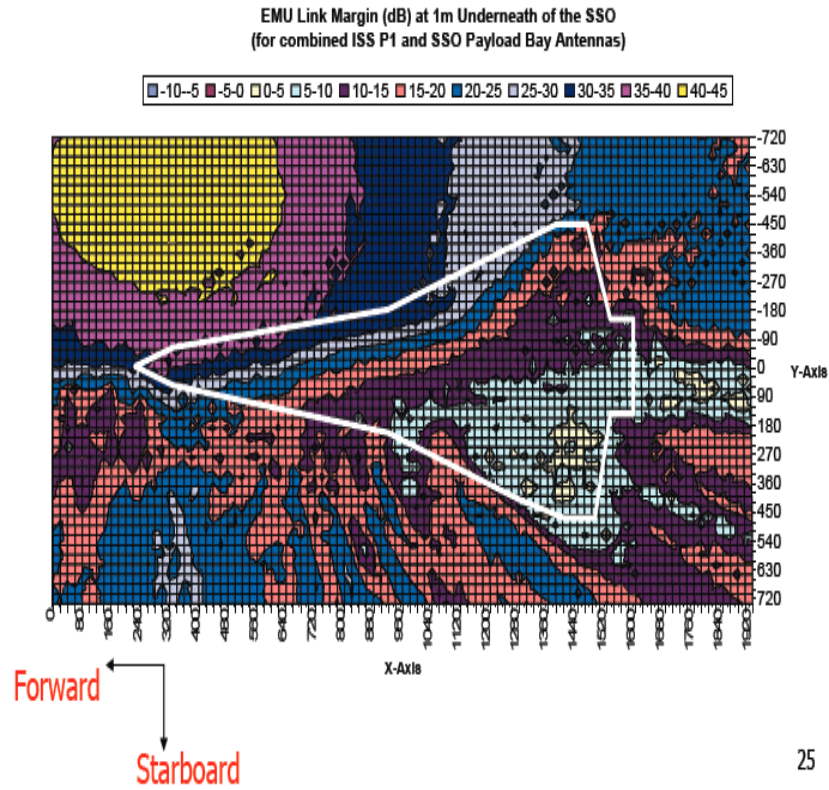


Figure 13-9. EMU link margin (dB) at 1 m. underneath SSO

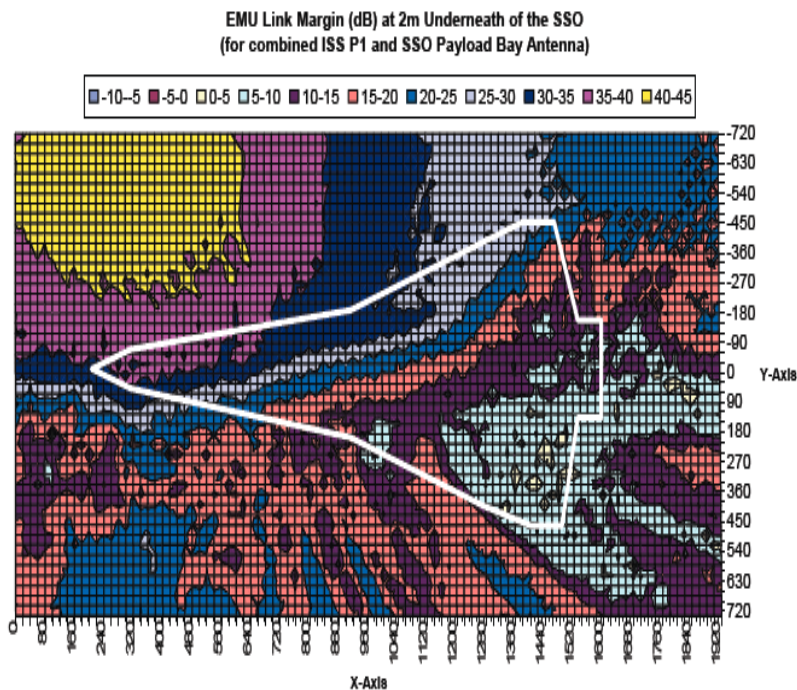


Figure 13-10. EMU link margin (dB) at 2 m. underneath SSO



For communications coverage and link margin data on the combined ISS Lab and orbiter EVA/UHF Antennas, at 1 and 2 meters, refer to Figure 13-11 and Figure 13-12, respectively.

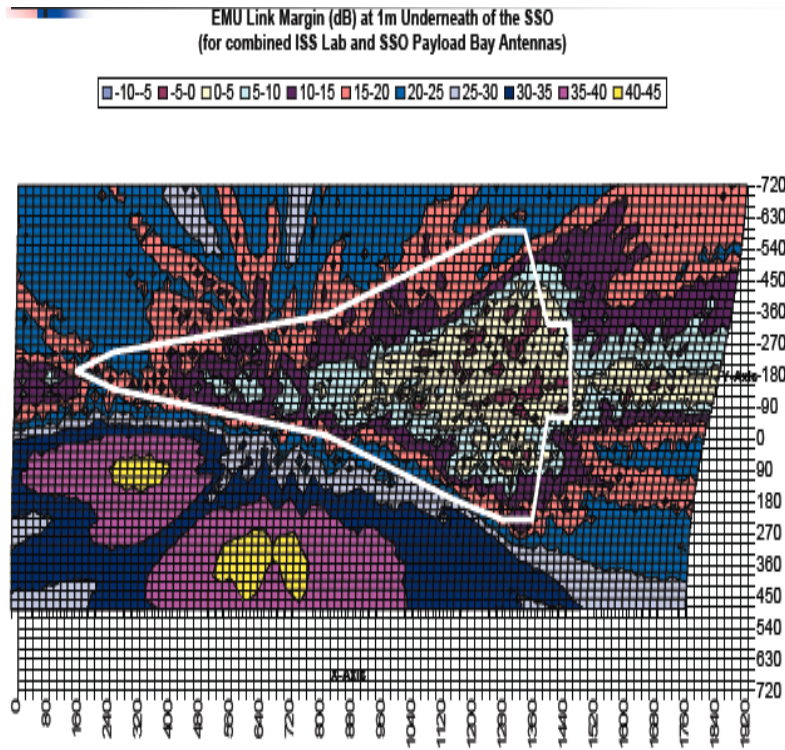


Figure 13-11. EMU link margin (dB) at 1 m. underneath SSO

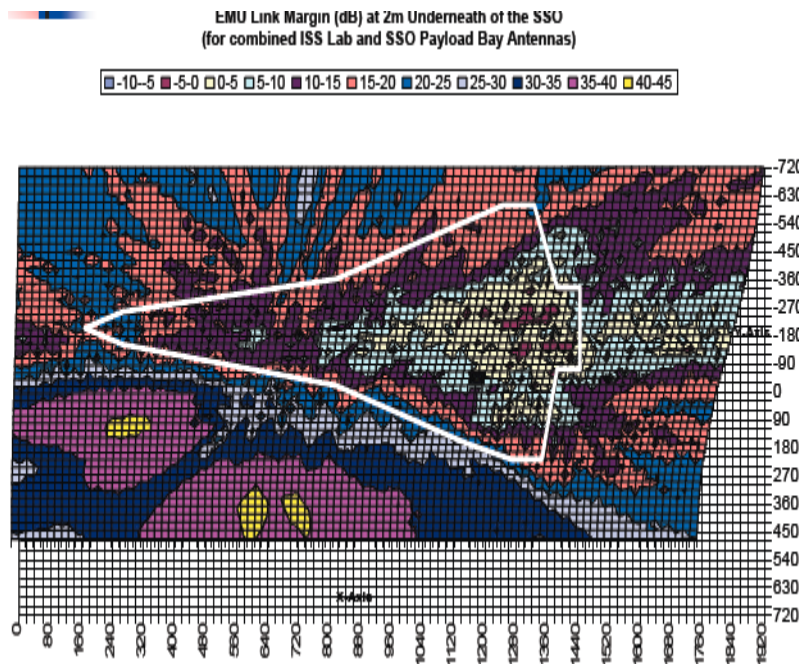


Figure 13-12. EMU link margin (dB) at 2 m. underneath SSO

### 13.5 CONCLUSIONS

Good underside EVA communication coverage can be achieved by using the ISS P1 +X UHF (UHF 1) antenna as the primary antenna, and switching to the ISS Lab +X (UHF 2) antenna when necessary for alternate coverage. Even though the composite plots show good coverage, the following factors must be considered:

- A. EVA may not be able to communicate with both ISS and orbiter crewmembers. (i.e., link from EVA to SSOR may be bad while link from EVA to SSSR is good. Therefore ISS IV would need to relay to Orbiter IV).
- B. EVA gain is -10 dB with a polarization loss of -7 dB. These values are based on 60 percent coverage for the EMU.
- C. The signal levels improve with increasing separation distance between the EV crewmembers and the orbiter underside.
- D. The lowest signal levels are in the regions near the tail due to the significant wing blockage in those areas.
- E. The ISS antennas are better than the orbiter EVA/UHF antenna due to the ISS P1/Lab antenna locations and pointing directions.
- F. The ISS Lab antenna provides better signals on the starboard side and the ISS P1 antenna provides better signals on the orbiter port side.
- G. Underneath shuttle EVA communications is possible for many places except for areas in deep shadow regions.
- H. The deep shadow region underneath of the shuttle can be improved by using the composite antennas (ISS P1, ISS Lab, and orbiter EVA/UHF antennas).
- I. The composite antennas provides better signal than using a single ISS or orbiter EVA/UHF antenna.
- J. This analysis assumes a normal docked, tail down to PMA-2 on ISS forward scenario. Other configuration scenarios must be reevaluated.
- k. EVA may improve link margin by changing orientation (antenna gain ranges between -2 dB to -20 dB).
- l. EVA reorientation and EVA relay scenario using a second crewmember to relay messages can also improve coverage area.

## 14.0 WVS

### 14.1 ANALYSIS OF WVS COVERAGE AT ORBITER BELLY

Analysis applies to the WVS Video and Command links coverage, and is based on orbiter docked to ISS, Orbiter Repair Maneuver (ORM), as well as in orbiter stand alone configurations.

### 14.2 WVS VIDEO COVERAGE FOR DOCKED CONFIGURATION

Assuming that the orbiter is docked to ISS PMA 2 and using the ISS WVS video link (WVS External Transceiver Assembly (WETA) on Camera Port (CP) 8) there will be no coverage for starboard side of fuselage, starboard wing and part of port wing (see Figure 11.1). ISS WVS Command Link Coverage is available for most of the Belly area, however no coverage is available at the starboard aft area (see Figure 14-2).

WVS Video (S-band) Coverage for Docked Configuration

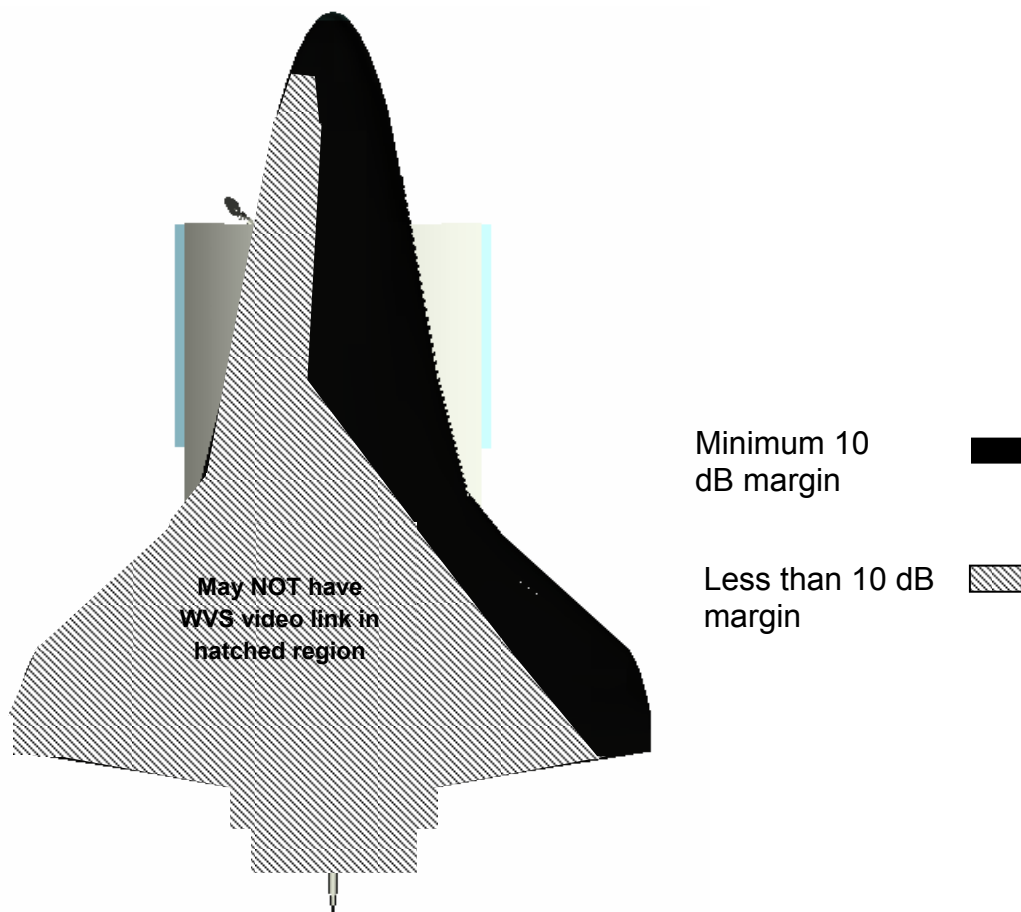
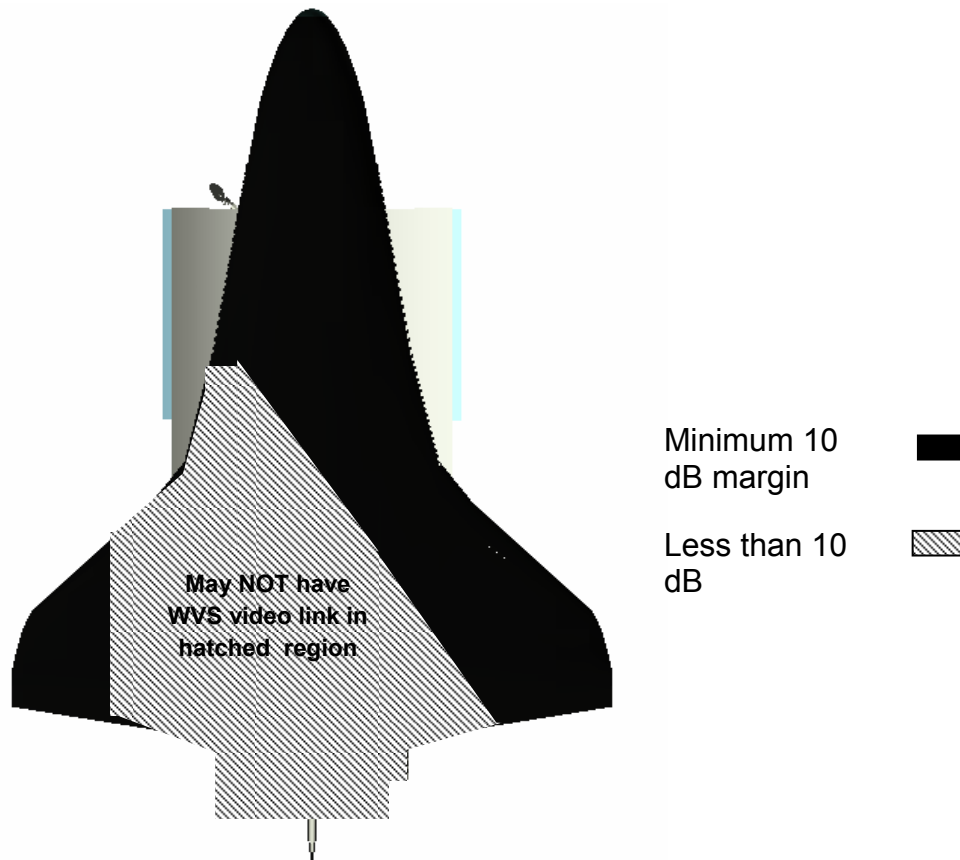


Figure 14-1. WVS video coverage area for orbiter docked to ISS at PMA2

**WVS Command Link (UHF) Coverage for Orbiter Docked to ISS**



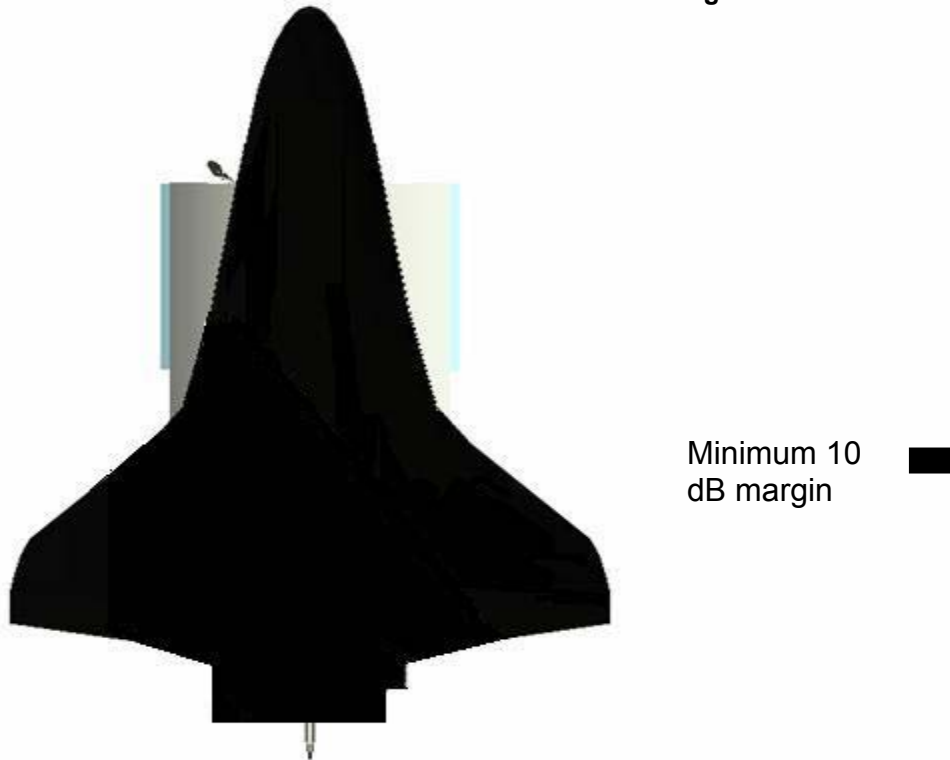
**Figure 14-2. WVS Command Link coverage area for orbiter docked to ISS PMA 2**

**14.3 WVS VIDEO AND COMMAND LINK COVERAGE FOR ORBITER REPAIR MANEUVER (ORM) CONFIGURATION**

SRMS grapples PMA2 and rotates the orbiter underside such that the underside surface is presented to the ISS US Lab segment (Figure 14-3).



**WVS Video (S-band) and Command Link (UHF) Coverage  
for Orbiter in ORM Configuration**

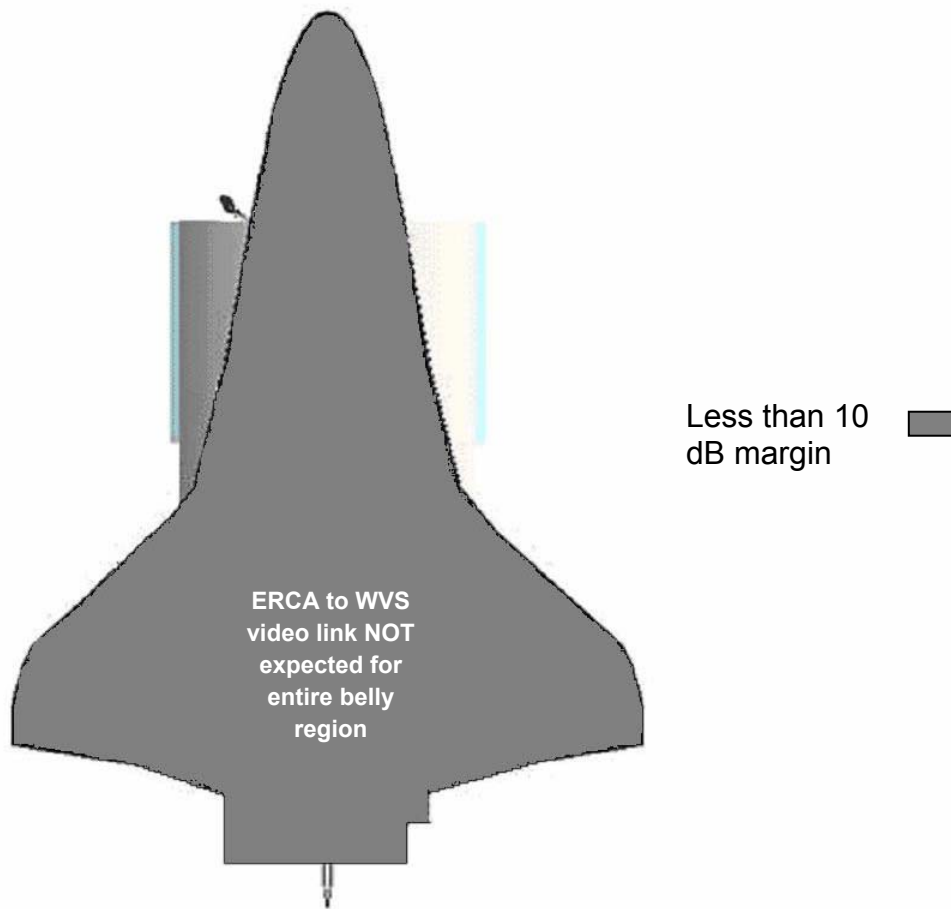


***Figure 14-3. WVS video and command link coverage for orbiter  
in ORM configuration***

Good coverage ( $\geq 10$  dB margin) is predicated for the EMU Remote Camera Assemblies (ERCA) to ISS WVS Video and Command links for essentially the entire underside of the orbiter, using the P1 or Lab WETA.

**14.4 WVS COVERAGE FOR ORBITER STAND ALONE CONFIGURATION**

This analysis is for WVS coverage for the orbiter standalone configuration. This also assumes using orbiter systems only (no WETA transceivers). Video coverage is predicted only in the lower leading edge of the wing (near aft bulkhead S-band quad antenna), but no coverage in the belly area.



**Figure 14-4. WVS video coverage for stand alone orbiter configuration**

#### 14.5 CONCLUSIONS

For the ERCA to orbiter WVS video (S-band), only the ORM configuration provides complete WVS video coverage (via ISS WETA assets). In the docked configuration, there is no video coverage for starboard side of fuselage, starboard wing, and part of port wing. Also, for the orbiter stand alone scenario, no coverage is predicated for essentially the entire underside of the orbiter.

## **15.0 EVA INFRARED CAMERA**

### **15.1 DESCRIPTION**

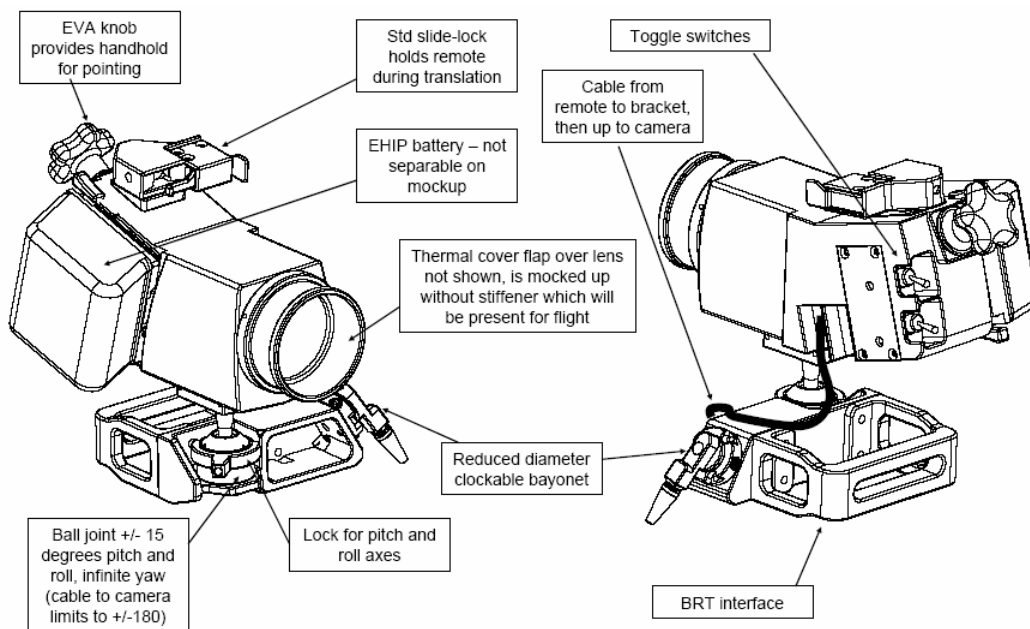
The EVA IR Camera, shown in Figure 15-1, is a modified version of the COTS FLIR S65 handheld IR camera. Modifications include simplification of user functions and controls, EVA-environment compatible housing, thermal management, upgraded firmware, use of a space-qualified battery (EVA Helmet Interchangeable Portable Light (EHIP)), and inclusion of a laser pointer. The EVA IR Camera can be used to measure thermal gradients across the Reinforced Carbon-Carbon (RCC) wing leading edge and nose cone surfaces to potentially detect both external and internal cracks, coating loss, and delamination.

### **15.2 COMPONENTS**

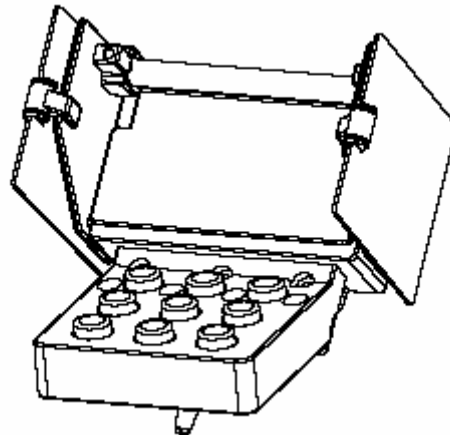
- A. Camera Body: The camera body houses the lens and detector, EHIP battery, laser, data recorder, and heating elements (for temperature stabilization).
- B. Remote Control Unit: The remote control unit houses the camera control buttons and backlit-LCD display. The display is protected by a flip-down visor and side, pull-up sun-shades. The buttons provide control of the camera's focus, laser pointer, data recording, and data transfer as well as other camera functions. The RCU is connected to the camera body by a sheath-protected cable. The RCU has a bayonet probe for attachment to the camera body (during translation) or the EMU mini-workstation (during operation).
- C. Camera Bracket: The camera bracket is attached to the camera body by a ball-swivel joint which allows for pivoting of ~ 15° and rotation of 360°. The camera bracket has a dog bone-shaped handle, tether points, and a rotating bayonet probe. The bracket allows for the camera to be mounted on the EMU MWS T-bar or swing arm or grappled by the BRT.

### 15.3 CAPABILITIES

Feature	Parameter Value
Spectral Range	7.5 – 13 $\mu\text{m}$
Detector type	Uncooled microbolometer
Field of View	24 x 18 degrees
Instantaneous Field of View	1.3 mrad
Focus	Adjustable, 0.3 m to infinity
Accuracy	+/- 20°C or +/-2%
Image Temperature Range	- 400°C to + 1200°C
Image Frame Rate	Adjustable, < 30Hz
Image Acquisition	Single snapshot or time-series (movie)
Image Storage – Internal Memory	600 calibrated, digital, radiometric images (20 seconds at 30Hz frame rate)
Image Storage – Removable Storage	Removable (IVA) Compact Flash Card
Display	External, backlit 4-in LCD



**Figure 15-1. Camera body and bracket**



*Figure 15-2. Remote control unit*

#### **15.4 OPERATION**

The EVA IR camera may be carried to the EVA worksite either stowed in a bag, attached to the crewmember's BRT, or the MWS swing arm. It is not advisable to translate with it attached to the MWS T-bar since it blocks the crewmember's vision. Internal thermal control is activated IVA by a switch on the camera body.

Once at the worksite, the camera bracket can be mounted to the BRT and the RCU attached to the MWS T-bar. The camera lens cover must be removed before turning on camera power. Once power is on, the camera goes through a warm-up/activation cycle lasting up to 5 minutes. The laser can be turned on to align the camera with the target. The crewmember estimates the focal distance and uses the preset focal distances (3, 6, 9, 12, or  $\infty$ ). The crewmember uses the image in the display and the fine focus buttons to sharpen the image. Once the image is adjusted, the crewmember begins recording data. Several movies can be recorded on internal memory before being transferred to the Compact Flash memory. Once all images have been transferred, the camera is turned off, the lens cover replaced, and the camera stowed for translation.

The images stored on the Compact Flash memory card can be downloaded IVA for downlink.

## 16.0 MCC OPERATIONS

Several upgrades have been made to the EVA MPSR to support EVA inspection and repair capability. It was recognized that EVA would need access to the highest quality imagery in order to determine if a particular damage was repairable. Without this capability fine details about the TPS material condition and damage geometry may go unnoticed which could affect the crew's ability to perform a repair.

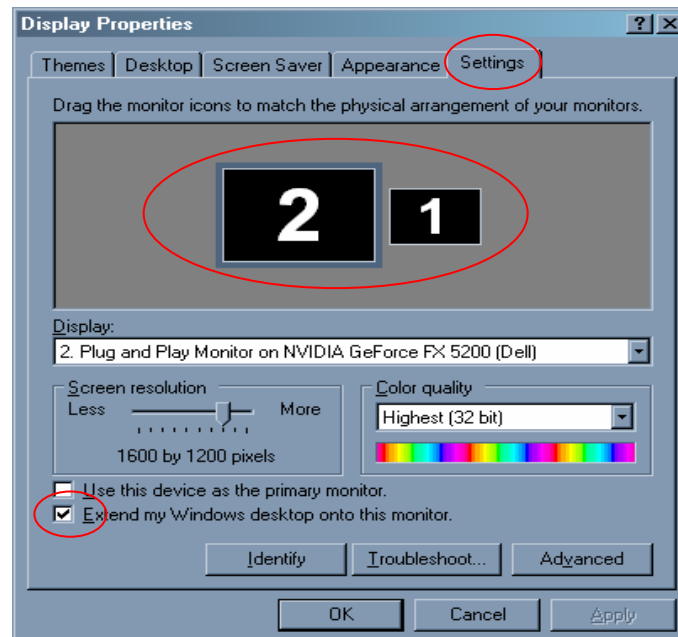
### 16.1 STILL PHOTOGRAPHY

Although LCD flat panel monitors make efficient use of space, the image resolution is fundamentally limited. For this reason the Dec A Cathode Ray Tube (CRT) monitors were connected to the MPSR PCs as a secondary monitor. Using these monitors for viewing still images will provide the best image quality available in the MPSR. Note, the EMU and TEAM four consoles do not have connectivity to the Dec A monitors and, therefore, should not be used for detailed image analysis. The following steps describe how to reconfigure PC and Dec A monitors.

Signal A/B (1/2) button on DEC Alpha monitor toggles display between DEC Alpha and PC.

To make fixes to any display problems:

1. Right click anywhere on the desktop
2. Select "Properties"
3. Click on the "Settings" tab



**Figure 16-1. Display setting window**

If the display does not extend to the DEC Alpha monitor:

1. Verify PC monitor cables are connected
2. Select the monitor (1 or 2) that needs to be added to the display
3. Check "Extend my Windows desktop onto this monitor"
4. Click Apply
5. Click OK

To return to single display use:

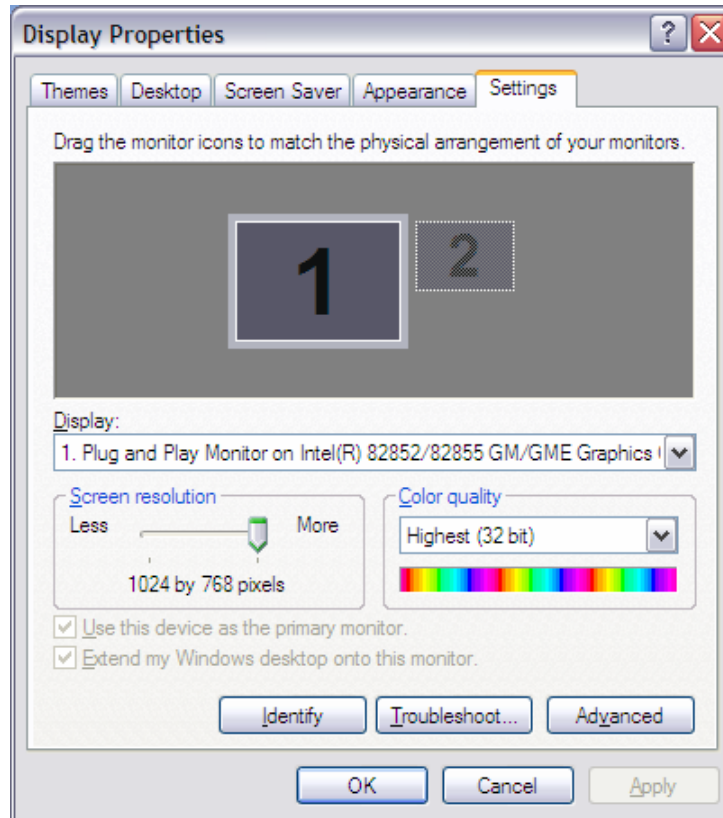
1. Select the monitor you wish to remove from the display (1 or 2)
2. Uncheck "Extend my Windows desktop onto this monitor"
3. Click Apply
4. Click OK

If mouse will not jump to other monitor:

1. Drag monitors to mimic the arrangement in front of you because they are probably in the wrong order
2. Click Apply
3. Click OK

To adjust the monitor resolution:

1. Right click anywhere on the desktop
2. Select "Properties"
3. Click on the "Settings" tab
4. Select the monitor that needs to be adjusted
5. Drag the slide bar all the way to the right for maximum resolution
6. Drag the slide bar to the left as necessary to increase magnification of display (Note: this decreases resolution)
7. **Hint for non-LCD monitors:** To avoid eye-strain, choose resolutions that enable >60 Hz refresh rate. Refresh rate is found by clicking the "Advanced" button and looking under the "Monitor" tab once resolution is selected.



**Figure 16-2. Monitor resolution adjustment**

## 16.2 VIDEO

ISS has the capability to downlink four analog video signals. The shuttle has the capability to downlink two analog signals or one digital signal. If the digital signal is routed through the standard Video Switch Matrix and viewed on the regular MCC TV stations, some image quality is lost in the digital to analog conversion. To retain the digital signal quality cabling has been routed from the Digital Video Switch Matrix (DVSM) to the large LCD flat panel display in the MPSR. To view the digital image the TV input must be set to 'Component 1'. Although the MPSR is equipped for analog recording and playback, EVA does not have this capability for the digital signal in the MPSR. If playback is required, a request would need to be submitted through GC.

Use ASPECT to cycle between display options. Normal or Zoom are preferred due to the lack of image distortion.

- Normal: No distortion, entire image
- Just: Some distortion
- Zoom: No distortion, partial image
- Full: Some distortion

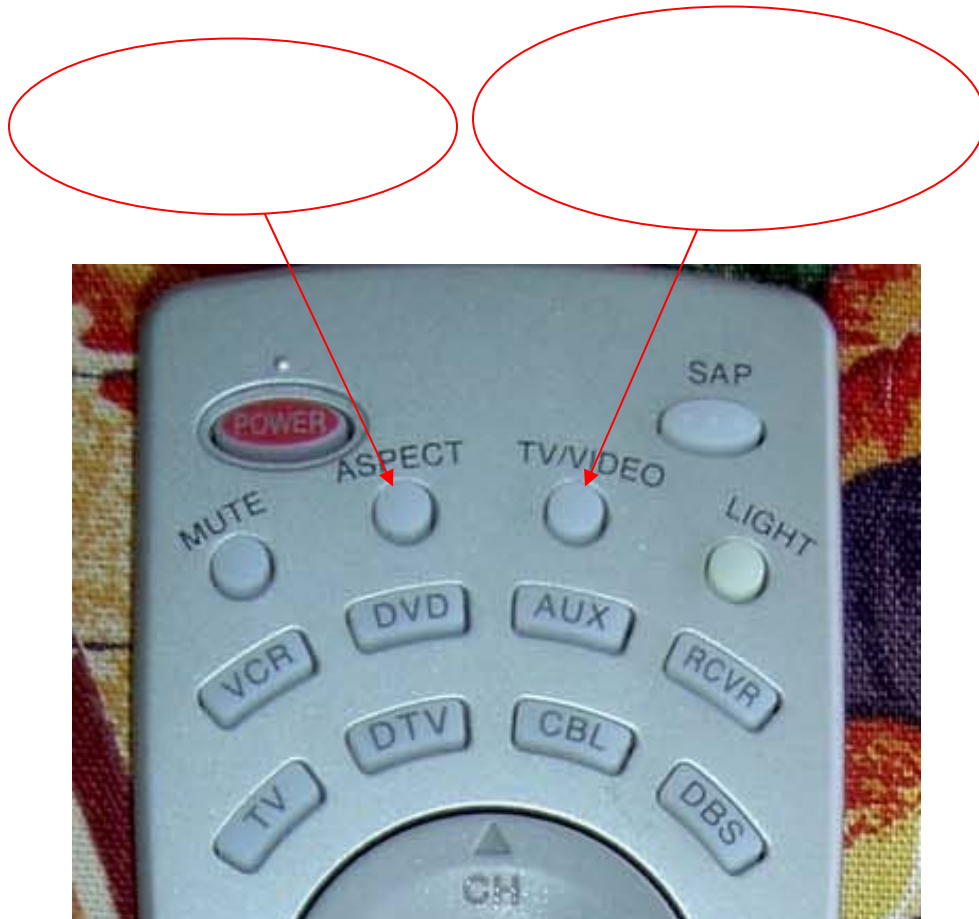


Use TV/VIDEO to change input

- Channels (National Television Standards Committee (NTSC))
- Component 1 digital feed from DVSM

Ch  $\uparrow\downarrow$  switches between channels and defaults to the NTSC signal (even if you are watching digital feed on Component 1).

Note: The user's manual is located on the table with the TV in a plastic bag. The remote *should be* in the black cabinet to the right of the bulletin board.



**Figure 16-3. LCD flat panel remote**

Digital Video Recorders (DVRs) provide real-time record and playback of NTSC analog video. The video files can be archived to DVD using the integrated DVD burners. Upgrades are in work at time of print to allow a signal from any DVR in the MPSR to be routed to the analog video switch matrix. This will enable any flight controller to view video by selecting the appropriate channel on their television or picture in picture.

**APPENDIX A    ACRONYMS**

A/D	Analog to Digital
A/G	Air to Ground
A/L	Airlock
AAP	Airlock Adapter Plate
<i>AC</i>	<i>Alternate Current</i>
acfm	actual cubic feet per minute
<i>ACO</i>	<i>Assembly Activation and Checkout</i>
ACP	Auxiliary Charge Port
<i>ADCO</i>	<i>Attitude Determination and Control Officer</i>
AH	Amp Hour
AFD	Assistant Flight Director
ALCLR	Airlock Cooling <i>Loop</i> Recovery
ALARA	As Low As Reasonably Achievable
ALPS	Airlock Power Supply
AM	Amplitude Modulation
AMPEV	Airlock Manual Pressure Equalization Valve
APCL	Ascent Pocket Checklist
APCU	Assembly Power Converter Unit
APDS	Androgynous Peripheral Docking System
APFR	Articulating PFR
APM	Attached Pressure Module
APU	Auxiliary Power Unit
AR	Anomaly Report
ARS	Air Revitalization System
ASC	Aisle Stowage Container
ATC	Air Traffic Control
ATCO	Ambient Temperature Catalytic Converter
ATU	Audio Terminal Unit
<i>AutoCAR</i>	<i>Automated Computer Access Request System</i>
B/U	Backup
BC	Battery Charger
BCA	Battery Charger Assembly
BCM	Battery Charger Module
BFO	Blood Forming Organ
BITE	Built-In Test Equipment
<i>BM</i>	<i>Book Manager</i>
BME	Biomedical Engineer
BRA	Bends Recovery Adapter
BRT	Body Restraint Tether
BSA	Battery Stowage Assembly

BTA	Bends Treatment Adapter
BTPS	Body Temperature and Pressure, Saturated with water
BTU	British Thermal Unit
C&C	Command and Control
C/L	Checklist
C/O	Checkout
C/W	Caution and Warning
CAD	Computer-Aided Drawing
CAPCOM	Capsule Communicator
<i>CAR</i>	<i>Computer Access Request</i>
CATO	Communications and Tracking Officer
CBSA	Cargo Bay Stowage Assembly
CC	Constant Current
CCA	Communications Carrier Assembly
CCAA	Common Cabin Air Assembly
CCC	Contaminant Control Cartridge
<i>CCC Ops</i>	<i>Control Center Complex Operations</i>
CCS	Command Control Software
CCT	Crew Compartment Trainer
CCTV	Closed Circuit Television
<i>CDDT</i>	<i>Common Display Development Team</i>
CEIT	Crew Equipment Interface Test
CFU	Colony Forming Unit
CIL	Critical Items List
<i>CIO</i>	<i>Cargo and Integration Officer</i>
CIPA	Cure In Place Ablator
CIPPA	CIPA Application
<i>C/L</i>	<i>Checklist</i>
<i>CLDB</i>	<i>Console Log Database</i>
<i>CORE</i>	<i>Control Operations Room for EVA</i>
COTS	Commercial Off The Shelf
CP	Constant Potential
CR	Change Request
CRANS	Configurable Real-Time Analysis System
CRT	Cathode Ray Tube
CSC	Contingency Waste Container
CSR	Customer Support Room
CTSD	Crew and Thermal Systems Division
<i>CWC</i>	<i>Contingency Water Container</i>
CWS	Caution and Warning System
D-CCTV	Delta Closed-Circuit Television
DAT	Data Assessment Team
DC	Direct Current
DCM	Display and Control Module

DCS	Decompression Sickness
DFE	Data Flow Engineer
<i>DIMS</i>	<i>Digital Imagery Management System</i>
DIS	Document Index System
DMM	Digital Multimeter
DNAV	Display Navigation
DOF	Degree Of Freedom
<i>DPS</i>	<i>Data Processing Systems</i>
DRTS	Discrepancy Report and Tracking System
DSC	Dedicated Signal Conditioner
DTE	Data Terminal Equipment
DTO	Detailed Test Objective
DVIS	<i>Digital Voice Integration System</i>
	Digital Voice Intercommunication Subsystem
DVR	Digital Video Recorder
DVSM	Digital Video Switch Matrix
EAR	Equivalent Activity Rate
EC	Environmental Chamber
ECC	Electronic Cuff Checklist
ECG	Electrocardiogram
ECLSS	Environmental Control and Life Support System
EDD	Extended Data Dump
EDDA	EMU Don/Doff Assembly
EDFT	Engineering Development Flight Test
EDP	Electronic Data Project
EE	End Effector
EECOM	Emergency, Environmental, and Consumables Management
EGIL	Electrical Generation and Illumination Engineer
EFGF	Electrical Flight Grapple Fixture
EHIP	EVA Helmet Interchangeable Portable Light
EL	Equipment Lock
<i>ELI</i>	<i>EMU Logistics Integrators</i>
ELOG	Event Logger
EMU	Extravehicular Mobility Unit
EOL	End of Life
EOM	End Of Mission
EOR	EVA Operations Room
EPC	Emittance Protective Coating
EPCL	Entry Pocket Checklist
EPROM	Erasable Programmable Read-Only Memory
<i>EPS</i>	<i>Electrical Power System</i>
ERCA	EMU Remote Camera Assembly
<i>ESCG</i>	<i>Engineering and Science Contract Group</i>
ESEL	EVA Support Equipment List
<i>ETCA</i>	<i>EVA Tools and Crew Aids</i>

EVA	Extravehicular Activity
EVC	Extravehicular Communicator
EWA	Emittance Wash Applicator
FAO	Flight Activity Officer
FC	Flight Controller <i>Firmware Controller</i>
FCE	Flight Crew Equipment
FCOH	Flight Control Operations Handbook
FCR	Flight Control Room
FCT	Flight Control Team
FD	Flight Day Flight Director
FDF	Flight Data File
FDS	Flight Data System
FEP	Front-End Processor
FEPC	Flight Equipment Processing Contractor
FGS	Fine Guidance Sensor
FIW	Failure/Impact/Workaround
<i>FM</i>	<i>File Manager</i>
FMEA	Failure Mode and Effects Analysis
<i>FN</i>	<i>Flight Note</i>
FPU	Fluid Pumping Unit
FRGF	Flight Releasable Grapple Fixture
FSE	Flight Support Equipment
FSM	Flight Software Manager
FSS	Flight Support Station
G T/R	Guard Transmit/Receive
GA	Group Administrator
GC	Ground Controller
GCR	Galactic Cosmic Radiation
GG	Gravity Gradient
<i>GGR&amp;C</i>	<i>Guidelines, Groundrules and Constraints</i>
GIRA	Galley Iodine Removal Assembly
GMT	Greenwich Mean Time
<i>GP</i>	<i>Gas Pressure</i>
GRABER	Glenn Refractory Adhesive Bonding and Exterior Repair
GRO	Gamma Ray Observatory
GSE	Ground Support Equipment
HHF	Helmet Holding Fixture
HL	Helmet Light
HM	High Monitor
<i>HS</i>	<i>Hamilton Sustrand</i>
HSMS	Hamilton Standard Management Services

HSSSI	Hamilton Standard Space Systems International
HST	Hubble Space Telescope
HSWL	Hamilton Sundstrand Windsor Locks
HUT	Hard Upper Torso
HX	Heat Exchanger
I/O	Input/Output
IATCS	International Active Thermal Control System
IATT	ISS Command and Telemetry Team
IBA	Integrated Boom Assembly
<i>IC</i>	<i>Initial Condition</i>
ICB	Increased Capacity Battery
<i>ID</i>	<i>Identification</i>
IDC	ISS Digital Camera
<i>IDRD</i>	<i>Increment Definitions and Requirements Document</i>
<i>IEPC</i>	<i>International Execution Planning Center</i>
<i>IFI</i>	<i>In-Flight Investigations</i>
	<i>Items For Investigation</i>
<i>IFA</i>	<i>In-Flight Anomaly</i>
IFM	In-Flight Maintenance
IIT	Integration Inspection Team
ILC	International Latex Corporation
IMC	ISS Management Center
<i>IMCOH</i>	<i>IMC Operational Handbook</i>
<i>IMMT</i>	<i>ISS Mission Management Team</i>
<i>IMS</i>	<i>Inventory Management System</i>
IMV	Intermodule Ventilation Valve
INCO	Integrated Communications Officer
<i>IPS</i>	<i>Integrated Planning System</i>
<i>IPT</i>	<i>Integrated Product Team</i>
<i>IPV</i>	<i>International Procedures Viewer</i>
IR	Infrared
IRU	In-Flight Refill Unit
ISIS	Integrated Sensor Inspection System
<i>ISO</i>	<i>Inventory Stowage Officer</i>
ISS	International Space Station
ITCS	Integrated Thermal Control System
ITVC	Intensified Television Camera
IUS	Inertial Upper Stage
IV	Intravehicular
IVA	Intravehicular Activity
<i>JEDI</i>	<i>Joint Execute Package Development and Integration</i>
JSC	Johnson Space Center
KSC	Kennedy Space Center

LAN	Local Area Network
LAR	Large Area Repair
LCD	Liquid Crystal Display
LCG	Liquid Cooling Garment
LCS	Laser Camera System
LCVG	Liquid Cooling Ventilation Garment
LDRI	Laser Dynamic Ranger Imager
LED	Light Emitting Diode
LES	Launch Entry Suit
LiCO <sub>3</sub>	Lithium Carbonate
LiOH	Lithium Hydroxide
LiOH H <sub>2</sub> O	Lithium Hydroxide Monohydrate
LOEP	List Of Effective Pages
<i>LOS</i>	<i>Loss of Signal</i>
<i>LRP</i>	<i>Long Range Planner</i>
LSS	Life Support Systems
LST	Life Support Thermal
LTA	Lower Torso Assembly
LTL	Low Temperature Loop
LVLH	Local Vertical/Local Horizontal
M	Monitor
Marl	Manipulator Retention Latch
<i>MARS</i>	<i>MOD Access Request System</i>
<i>MAS</i>	<i>MCC Automation System</i>
MBS	MRS Base System
MCC	Mission Control Center
MCC-H	Mission Control Center-Houston
MCG	Mechanical Contour Gauge
MDM	Multiplexer/Demultiplexer
MER	Mission Evaluation Room
MET	Mission Elapsed Time
Metox	Metal Oxide
MEWS	Mission Evaluation Workstation System
MFR	Manipulator Foot Restraint
MIA	Multiplexer Interface Adapter
MIS	Mission Information System
MLI	Multilayer Insulation
MMACS	Mechanical, Maintenance, Arm, and Crew Systems
MMOD	Micrometeoroid Orbital Debris
MMT	Mission Management Team
MMU	Manned Maneuvering Unit
MOCR	Mission Operations Control Room
<i>MOD</i>	<i>Mission Operations Directorate</i>
MOIR	Mission Operations Integration Room
MOU	Memorandum Of Understanding

MPLM	Multipurpose Logistics Module
MPM	Manipulator Positioning Mechanism
MPSR	Multipurpose Support Room
MR	Metabolic Rate
MRL	Manipulator Retention Latch
MSID	Measurement Stimulation Identification
MSIS	Measurement Simulation Identification
MSK	Manual Select Keyboard
<i>MSS</i>	<i>Mobile Servicing System</i>
MT	Mobile Transporter
MTL	Moderate Temperature Loop
MWC	Multiple Water Connector
MWS	Miniworkstation
N <sub>2</sub> H <sub>4</sub>	Hydrazine
NAND	Not AND
NASA	National Aeronautics and Space Administration
NBL	Neutral Buoyancy Lab
NDD	Normal Data Dump
NOAX	Non Oxide Adhesive eXperimental
NSP	Network Signal Processor
NTSC	National Television Standards Committee
NVRAM	Non-Volatile RAM
OBS	Operational Bioinstrumentation System
OBSS	On-orbit Boom Sensor System
OCA	Orbiter Communication Adapter
<i>OCAD</i>	<i>Operational Control Agreement Database/Document</i>
OCC	Operations Control Center
OCV	Open Circuit Voltages
<i>ODF</i>	<i>Operations Data File</i>
ODIN	Onboard Data Interfaces and Network
ODRC	Orbiter Data Reduction Complex
ODS	Orbiter Docking System
<i>OEM</i>	<i>Original Equipment Manufacturer</i>
<i>OFS</i>	<i>Onboard Fault Summary</i>
OI	Operational Instrumentation
OIO	Operations Integration Office
OJT	On-the-Job Training
OML	Outer Mold Line
OMS	Orbital Maneuvering System
OPCL	Orbit Pocket Checklist
<i>OPS</i>	<i>Operations</i>
ORCA	Oxygen Recharge Compressor Assembly
ORM	Orbiter Repair Maneuver
ORS	Orbital Refueling System



ORU	Orbital Replacement Unit
OSO	Operations Support Officer
<i>OSS</i>	<i>Oceaneering Space Systems</i>
OSTP	Onboard Short Term Plan
OTD	ORU Transfer Device
OV	Orbiter Vehicle
P/N	Part Number
PA	Power Amplifier
PABF	Precision Air Bearing Facility
PABX	Private Automatic Branch Exchange
PC	Portable Computer
PCA	Pressure Control Assembly
PCMMU	Pulse-Code Modulation Master Unit
PCN	Page Change Notice
PCS	Portable Computer System
PDGF	Power Data Grapple Fixture
PDRS	Payload Deployment and Retrieval System
<i>PEEP</i>	<i>Post EVA Entry Prep</i>
PET	Phase Elapsed Time
PFR	Portable Foot Restraint
PGT	Pistol Grip Tool
<i>PHALCON</i>	<i>Power Heating Articulation Lighting Control</i>
<i>PIA</i>	<i>Pre-Installation Acceptance</i>
<i>PIDS</i>	<i>Prime Item Development Specification</i>
PLB	Payload Bay
PLBD	Payload Bay Door
PLS	Primary Landing Site
PLSS	Portable Life Support System <i>Primary Life Support System</i>
<i>PLUTO</i>	<i>Plug-in Plan Logistics and Utilization Officer</i>
PMA	Pressure Mating Adapter
<i>POC</i>	<i>Point of Contact</i>
POCC	Payload Operations Control Center
<i>POI</i>	<i>Product of Interest</i>
POP	Perpendicular to Orbital Plane
POR	Power-On Restart
POS	Portable Oxygen System
PPO <sub>2</sub>	Partial Pressure of Carbon Dioxide
<i>PPCR</i>	<i>Planning Period Change Requests</i>
PPL	Pre-Positioned Load
ppm	parts per million
PPO <sub>2</sub>	Partial Pressure of Oxygen
PPRV	Positive Pressure Relief Valve
PR	Problem Report
<i>PRACA</i>	<i>Problem Reporting and Corrective Action</i>

<i>PRCB</i>	<i>Program Requirements Control Board</i>
PRLA	Payload Retention Latch Assembly
PSA	Provisions Stowage Assembly
	<i>Power Supply Assembly</i>
PTC	Passive Thermal Control
PTT	Press To Talk
PTU	Pan Tilt Unit
PUI	Program Unique Identifier
PWP	Portable Work Platform
PWR	Payload Water Reservoir
QDM	Quick Disconnect Mechanism
	<i>Quick Don Mask</i>
R	Ratio
R&R	Remove and Replace
RAD	Radiation Absorbed Dose
RAM	Random Access Memory
<i>RAVEN</i>	<i>Resource Avionics Engineer</i>
RCC	Reinforced Carbon Carbon
RCG	Reaction Cured Glass
RCS	Reaction Control System
RCV	Receive
RDM	Robotics Desktop Manager
RDF	Requirements Definition File
REBA	Rechargeable EVA Battery Assembly
RF	Radio Frequency
<i>RIO</i>	<i>Russian Integration Officer</i>
<i>RISS</i>	<i>Russian Inventory Specialist</i>
RMS	Remote Manipulator System
<i>ROBO</i>	<i>Robotics Officer</i>
RPCM	Remote Power Control Module
RPM	Rendezvous Pitch Maneuver
RPS	RMS Planning System
RQ	Respiratory Quotient
RSR	Resupply Storage Rack
RTDS	Real-Time Data System
<i>RT FRCR</i>	<i>Real-Time Flight Rule Change Request</i>
RTPLOT	Real-Time Plot
RTV	Room Temperature Vulcanizing
S/AD	Specifications/Assembly Drawing
<i>S/G</i>	<i>Space to Ground</i>
S/N	Serial Number
SAA	South Atlantic Anomaly

SAFER	Simplified Aid For EVA Rescue
SCP	Shuttle Control Procedure
	Standard Console Procedure
SCU	Service and Cooling Umbilical
<i>SEMU</i>	<i>Short Extravehicular Mobility Unit</i>
<i>SEO</i>	<i>Space Environment Officer</i>
SGLS	Space Ground Link System
<i>SGMT</i>	<i>Sims Greenwich Mean Time</i>
SMS	Shuttle Mission Simulator
SODB	Shuttle Operations Data Book
SODF	Systems Operations Data File
SOP	Secondary Oxygen Pack
SORG	Shuttle Orbiter Repackage Galley
SOW	Statement Of Work
SPAN	Spacecraft Analysis
SPAS	Shuttle Pallet Satellite
SPCE	Servicing and Performance Checkout Equipment
SPCU	Service and Performance Checkout Unit
SPEE	Special Purpose End Effector
SPLX	Simplex
SPLX+G RCV	Simplex Plus Guard Receive
SR	Support Request
SRAG	Space Radiation Group
SRMS	Shuttle Remote Manipulator System
SRV-K	Russian Water Processor
SSA	Space Suit Assembly
SSATA	Space Station Airlock Test Article
<i>SSC</i>	<i>Space Station Computer</i>
SSCS	Space-to-Space Communications System
SSER	Space-to-Space EMU Radio
SSM	Subsystem Manager
SSO	Space Shuttle Orbiter
SSOR	Space-to-Space Orbiter Radio
<i>SSP</i>	<i>Space Shuttle Program</i>
SSRMS	Space Station Remote Manipulator System
SSSH	Space Shuttle Systems Handbook
STDN	Space Tracking and Data Network
STIC	Scientific and Technical Information Center
<i>STP</i>	<i>Short Term Plan</i>
T&O	Test and Operation
TAA	Tunnel Adapter Assembly
tb	Talkback
TCO	Temperature Cut-Off
<i>TCON</i>	<i>Thermal Control</i>
TCV	Temperature Control Valve

<i>TDRS</i>	<i>Tracking and Data Relay Satellite</i>
TERA	Temporary Equipment Restraint Aid
TFL	Telemetry Format Load
<i>THOR</i>	<i>Thermal Operations and Resources</i>
TIC	TPS Imagery Coordinator
TIIMS	Texas Institute of Intelligent Bio-Nano Materials and Structures
TIPS	Thermal Impulse Printer System
TLM	Talk, Listen, Monitor Telemetry
TMG	Thermal Micrometeoroid Garment
TPS	Thermal Protection System <i>Trajectory Profile Support</i>
TR	Tissue Ratio
TSA	Tools Stowage Assembly
TUC	Time of Useful Consciousness
UCD	Urine Collection Device
UF	Utility Flight
UHF	Ultrahigh Frequency
UIA	Umbilical Interface Assembly
ULF	Utilization Logistics Flight
<i>U.S.</i>	<i>United States</i>
USA	United Space Alliance
USOS	United States Operational Segment
VAJ	Vacuum Access Jumper
VAP	Vacuum Access Port
VGE	Venous Gas Embolism
VMDB	Vehicle Master Database
VR	Virtual Reality
VRA	Vent and Relief Assembly
VRAM	Volatile RAM
<i>VVO</i>	<i>Visiting Vehicle Officer</i>
WCS	Waste Collection System
<i>WET</i>	<i>Water Evaluation Team</i>
WETA	WVS External Tranceiver Assembly
WFCR	White Flight Control Room
WIF	Worksite Interface
<i>WLP</i>	<i>Weekly Look-ahead Plan</i>
<i>WP</i>	<i>Water Pressure</i>
WPA	Water Processing Assembly
<i>WPR</i>	<i>Weekly Planning Review</i>

WSS	Workstation Software Support
WVS	Wireless Video System
<i>XA</i>	<i>Extended Architecture</i>
XCVR	Transceiver

TITLE: EVA Console Handbook Volume 5 TPS Inspection and Repair

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