EVA Operations Design Considerations

NESC Workshop
Unique Science from the Moon in the Artemis Era

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Purpose

Open a dialogue regarding incorporation of EVA requirements in future vehicles, payloads, and other lunar surface hardware.

- Astronaut Requirements for Assembly and Servicing
  - EVA Basics
  - EVA Gaps & Requirements
  - Human Space Flight infrastructure
  - Robotics interaction
- Lessons Learned
  - Historical Testing
  - Shuttle & Station era construction
- Going Forward

EVA Basics

An EVA or Spacewalk is anytime when a crewmember is no longer protected by their home vehicle and are exposed to the external vacuum environments (Micro-gravity, Lunar, or other).

- An EVA is one of the top 3 highest risk events in Human Spaceflight

EVAs have a limited duration based on both crew and suit system consumable resources.

EVA task operations vary in both time and technique between crew members.

- Crew members interact and manipulate a suit differently due to human variations. Tasks cannot be as structured as a robotic operation.
- Interfaces with the suited crew require intentional thought and planning with EVA experts

A spacesuit is a single person spacecraft which protects the crewmember from the external elements and provides life sustaining needs in a mobile workable volume

- Human-shaped and sized space vehicle
- Requires same key systems as other spacecraft however, it needs to be carried by a person
- Habitable pressure, breathable atmosphere, thermal control, mobility, visibility, communication, and protection from environmental concerns

The benefit of an EVA crewmember is the human ability to react to unexpected failures in real-time.

- Robotics and automation is continually growing but has not surpassed a crewmember in this aspect.

EVAs are performed in buddy pairs

- Pairing crewmembers is to help with contingency responses. This is modeled after scuba diving and other high-risk activities.

EVA operations are planned to be as efficient as possible as time is limited and EVA is a higher risk activity.

- Goal is to reduce overall required EVA time
- Time to effect of potentially catastrophic events can be small therefore, risk increases the further the EVA crew is from a habitable space system asset

EVA Limitations

Although EVA space suits provide a crewmember with protection from the space environment, they also limit their abilities beyond a shirt sleeve environment.

Limited mobility / flexibility

- Pressurized gloves make it difficult to do hand intensive or intricate tasks. Specialized hardware is needed due to space suit dexterity.

Greater mass

- A space suit adds mass to the crewmember's nominal mass which the crewmember needs to account for during operations.

Greater volume

- The volume that the spacesuit takes utilizes more space than a shirt sleeve environment. Tight spaces that restrict movement and body positioning can adversely affect crew health and mission priorities.

Center of gravity differences

- The additional mass and its location on the spacesuit changes the crewmembers typical center of gravity such that many tasks like walking, kneeling, turning, climbing can throw off their balance. Although NASA uses a variety ways to train these differences, they can only simulate part of the equation such that lunar EVAs may still have some learning and real-time adjustments.

Suit Limitations directly affecting payload and science

EVA suits have restrictions with what it can interact with (sharp edges, materials, etc.)

- Hardware hazards near EVA worksites often have KOZs or need inhibits to accommodate EVA suit and crew safety

EVA suits 'off-gas and/or transfer contaminates' to the space around them such that the environment is no longer pure

Additional Lunar Considerations

Extreme Lighting conditions

- Lunar South Pole will have oblique lighting angles casting extreme shadows
- Lunar regolith can be highly reflective
- Permanently Shaded Regions (PSRs) are extremely dark and very cold

Navigation

- Return to vehicle (crew safety)
- Pinpointing scientific locations accurately (EVA efficiency and Science utilization)

Communication and Autonomy

- Task intricacy = additional communication with MCC
- Hardware/software concepts could increase crew autonomy

EVA Gaps

- What technology development is needed for Artemis and beyond?
  - There are more than 100 gaps across the NASA exploration architecture that affect EVA.
- References:
  - Beyond Artemis EVA Gap Overview
    - October 2021 Exploration EVA Technology Workshop (NASA/Chris Nelson)
      - https://www.nasa.gov/sites/default/files/atoms/files/8.0_-_beyond_artemis_iii_eva_gap_update_overview_final_updates-1_-_chris_nelson.pdf
  - https://www.nasa.gov/suitup/reference

- Notable Gaps:
  - Dust Tolerance and Mitigation
  - Lighting
  - Communication
  - Autonomy
  - Navigation
  - Mass reduction

EVA Operations Thinking

Using this Mars Architecture rendering, what do you see?

- What works operationally for EV Crew?
- What does not make for good operations?

- Winch system √
- Fall protection X
- Pressurized Rover √
- Incline ramp with no rails or aids X
- No Handholds or large labels on crates X

EVA Hardware Requirements

The concept for EVA assembly and repair is to keep it simple

- Plan Orbital Replacement Units vs intricate repairs
- Big elements by robotics and intricate or detailed work by EV crew
- Standardization of bolts, connectors across vehicles and payloads

There are a multitude of EVA documents that describe con ops and requirements

- Public info at https://www.nasa.gov/suitup/reference and additional documentation available within NASA
- We are working to make a primer to get hardware developers started
- Early integration with EVA Operations is essential

Exceptions to requirements will be analyzed and tested by NASA EVA

- Potentially granted on a case-by-case basis but not guaranteed

Operations Influencing Design

- All designs start out with a concept to build the best 'x'.
- Requirements may not design hardware that optimizes the operation of the hardware.
- Thus, it becomes very important for the operations teams to play an influential part in the design process.

Injury and Risk Prevention	• Can this design injure or pose significant risk to crew?
Reliable	• Where does this design need to be more robust or redundant to keep crew safe and to prevent design failures?
Efficient	• Does this design increase crew efficiency in operations?
Reduced Workload	• Does this design add to the cognitive or physical workload?
Upgradeable	• If we must live with this design for the next 10, 20, 30, 40 years, can we make easy upgrades?
Maintainable	• Does this design significantly reduce or eliminate the need for corrective maintenance requirements?
Flexible	• Does this design lock in only one ops concept or does it allow for operation flexibility?
Testable	• Does this design have a plan to test and evaluate prelim concepts? How early can the ops community get hands-on?
Compatible	• Is this design compatible with the current and future ops concepts and other existing hardware?
Trainable	• Does this design require new or modified training infrastructure? Is there a plan for early training hardware?

EVA Operations Integration into the Design Process
Flight Operations Directorate (FOD)

During the design phase, FOD EVA is involved in early design reviews to evaluate the crew – hardware interactions.

- FOD EVA will provide the hardware team with assessments of the compatibility of the design to EVA operations. There may be required changes (safety) and desired changes (EVA efficiency and ops ease).

After a tool, payload, or hardware has a preliminary design, FOD EVA and the crew office will test the EVA Operations with it.

- Hardware will be rated: Acceptable, Unacceptable (design changes required), or Inconclusive

EVA is a unique skill and does not always align to defined actions

- The crew office and FOD (Flight Operations Directorate) EVA assess hardware and develop procedures and will incorporate workarounds if required.

Infrastructure Essential for Optimal EVAs

HLS vehicle

Base Camp (Hab)

Home Base
- Crew living area
- Consumables recharge
- Communication relays
- Earth Return

Communication & Navigation Resources

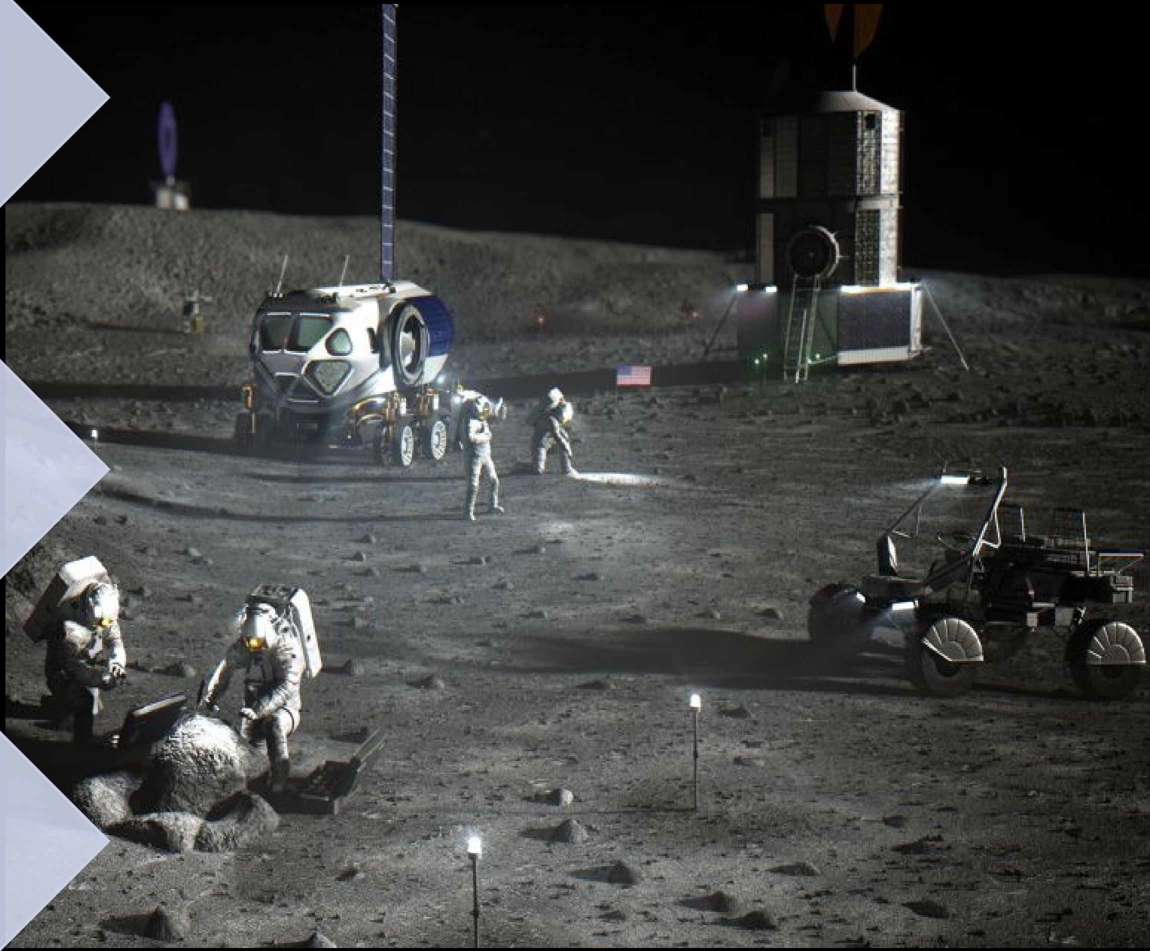
- EVA crew needs constant communication with each other
  - Easy comm with MCC for guidance as needed
- Precise navigation
  - Science & Safety

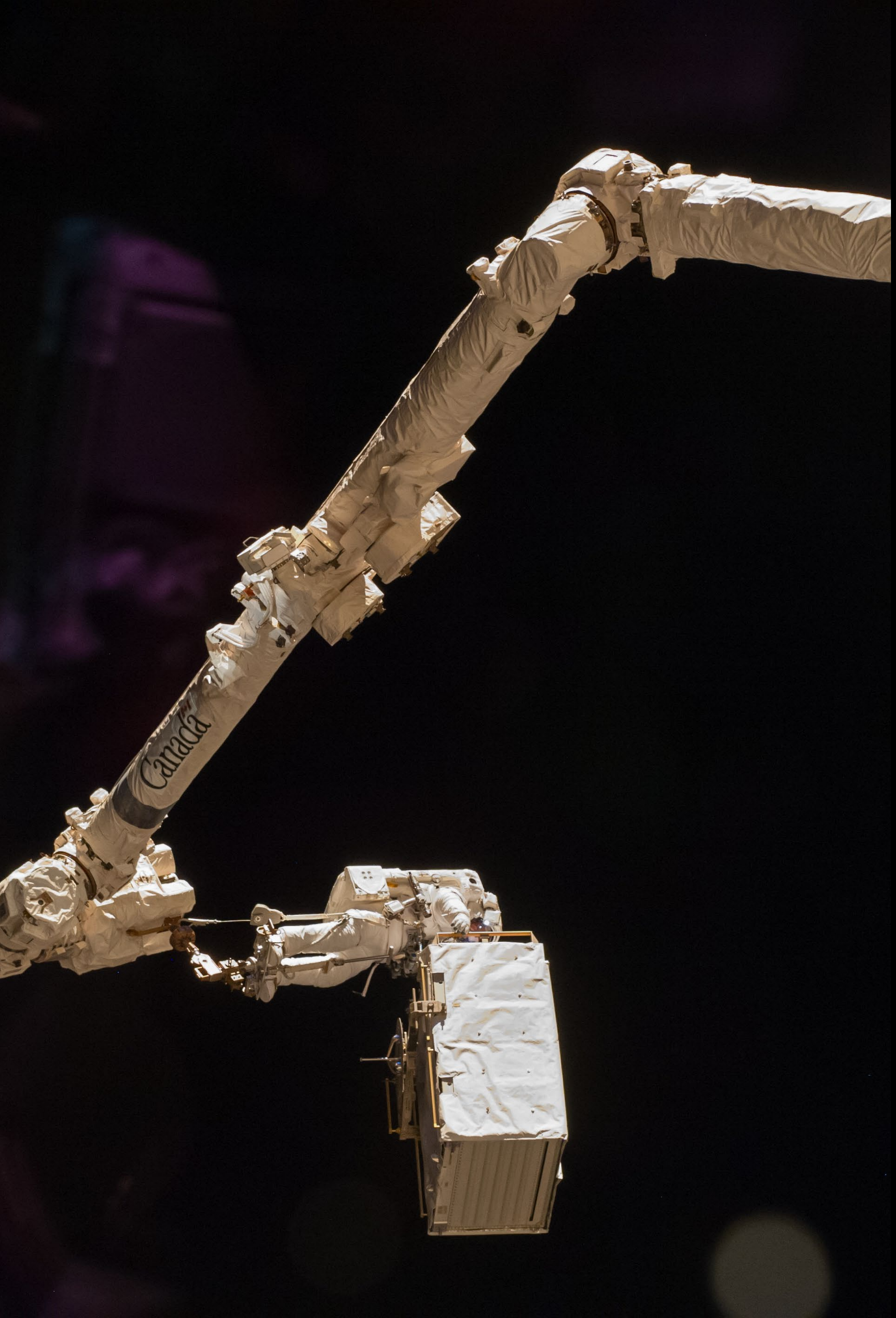
Expanded mobility

- LTV
  - Reduces workload on crew
- Pressurized Rover
  - Take your “safe haven” with you
  - Allows for farthest exploration

Ease of EVA

- Going EVA needs to become easier, less overhead
- “Safe Haven” readily accessible





Robotics Integration

Robotics is typically utilized for EVA in 2 distinct methods

- During EVA
  - Direct interaction between robotic entity and EV crew
    - Current operations are predominately controlled by a local IVA or internal crewmember
    - Very limited work analyzed for remotely controlled (MCC)
    - No experience base with autonomous robotics
  - Typical interactions
    - Utilize robotics as a mobile platform (move crew to worksite in microgravity)
    - Robotics move large hardware and hold in position for EVA crew
- Pre EVA-Setup and Post EVA Cleanup
  - Robotic resource may setup worksites (tools, restraints, hardware) before the EVA to make EVA time more efficient
  - Similar post EVA cleanup and “housekeeping”

Robotics Requirement Considerations for EVA

Planned operation of lunar transport vehicles while crew on or in vicinity is crew operated

Future work to identify “follow along” or “summon” features

Remote operation should be possible while crew is not EVA or a defined safe distance

Ability to have inhibited motion when crew is near

Especially during ingress & egress of a vehicle like the Pressurized Rover

Large uncontrolled robotic maneuvers could cause harm to crewmembers and EVA suits

To enable non-local crew controlled robotic operations, remote sensing to stop robotic operation prior to impact of crew needs to be explored

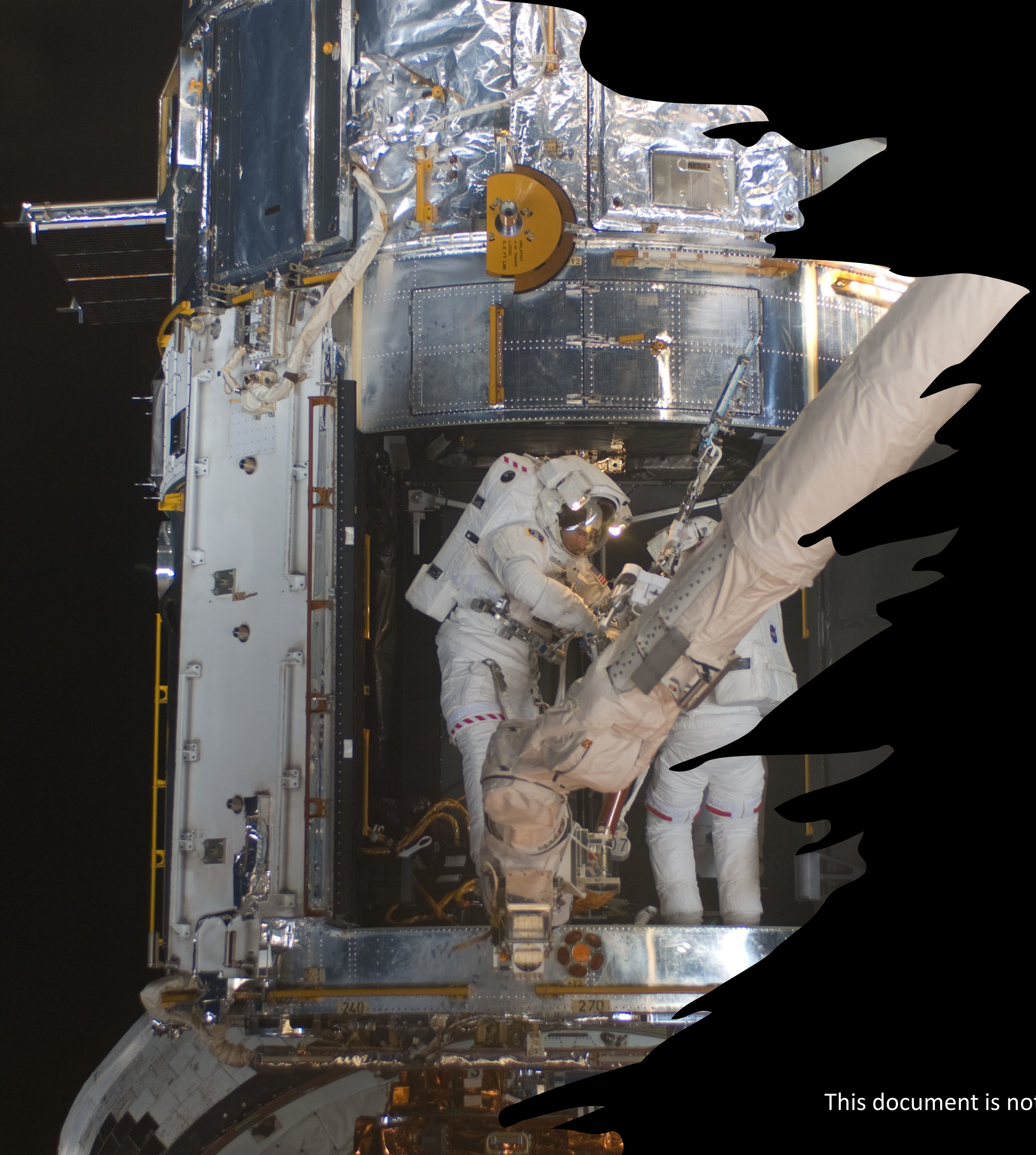
This is not specific to space exploration. Integrate research on human robotic interactions and apply to spaceflight.

Shuttle Era Concept Testing

- STS-61 B EVA 1 & EVA 2
  - Demonstrate assembly techniques for space station
  - ACCESS (Assembly concept for construction of erectable space structures) and EASE (experimental assembly of Structures through EVA)
    - http://www.spacefacts.de/mission/english/sts-61b.htm
  - Successful demonstration of suited capabilities but did show that attempting to build a space station beam by beam and integrating cabling would be time consuming vs launching prefabricated segments for EVA attachment and outfitting
- STS-49 EVA 4
  - Second EASE / ACCESS
  - Updated truss build experiment using proposed ISS-like truss segments (vs smaller segments on 61B)
  - Proved concept not feasible for large construction project (ISS assembly)

Planned Assembly & Servicing

- The International Space Station was designed to be assembled and serviced by EV crew
  - Common parts, captive bolts, hardware that meets the EVA requirements documents
- ISS construction – mating of truss segments and deploy of radiators and solar arrays
- ORUs (Orbital Replacement Units) are best – replace an entire box
  - No splicing wires, non-captive bolts, etc.
- IROSA (ISS Roll Out Solar Array)
  - More intensive EVA construction than mate/bolt but designed specifically for EVA



Unplanned Servicing and Repair

Successful examples of unplanned servicing of hardware not designed for EVA crewmembers. Additional tools or hardware had to be built and operational constraints waived to accommodate new tasks.

- Skylab
  - Heat shield and “parasol” EVA
- Hubble
  - Unique that is had planned and unplanned servicing over its life
- LEE (Latching End Effector) Lubing
  - ISS arm grappling mechanism wear
- AMS (Alpha Magnetic Spectrometer)
  - Cooling pump failures on a scientific experiment with no EVA aids or even sharp edge verification

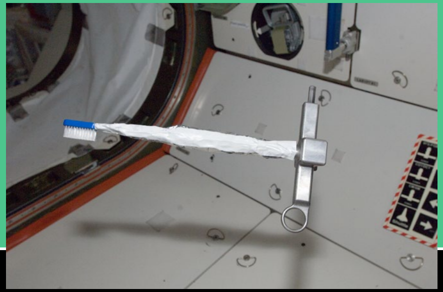
Contingency Workarounds

Spaceflight is not a stranger to needing to address Off Nominal situations real-time during a Mission or EVA.

Apollo 17 Lunar Rover fender fix

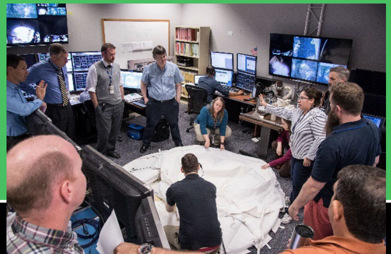
STS-120/10A Solar Array Repair

US EVA 19 MBSU bolt lubing



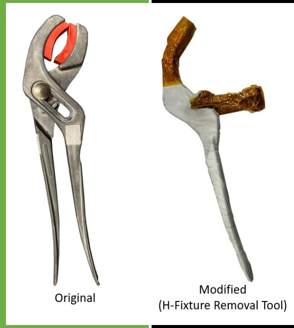
US EVA 41

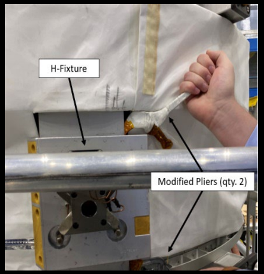
- Axial shield lost overboard and real-time workaround



US EVAs 66/68

- Inability to remove fixture
- IVA channel locks disassembled and modified for EVA





Lessons Learned Summary

- Keep It Simple
  - Standardization
- Design with EVA Requirements from the beginning
  - Although we often can make it work later; it costs significant more money and EVA time thus more risk (to both crew and mission success)
- Integrate EVA experts from the beginning

Going Forward

- Steer future designs to include EVA requirements
  - Don’t focus only on the desired plan of your hardware concept but also on the “what if”
  - Other projects have not included basic EVA requirements which led to significant issues when EVA assistance was needed
- Use EVA expertise to bring EVA capability actualities into concepts

- Questions?
- Additional Resources:
  - https://www.nasa.gov/suitup/reference
    - Links to published EVA documents including gaps
  - https://www.nasa.gov/jsc/procurement/xevas
    - xEVAS RFP, waiting on vendor selection

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