Extra-Vehicular Activity

Human Spaceflight Operations

Zebulon Scoville
Anna Jarvis
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Overview

- What is Extra-Vehicular Activity (EVA)?
  – A crewmember leaves the protective environment of a pressurized spacecraft cabin and ventures into the vacuum of space wearing an extravehicular spacesuit
- Why people and not robots?
  – There is a place for both and mission requirements drive architecture
  – Adaptability
  – Efficiency
  – Judgment
  – Flexible tool and worksite interfaces
  – Human interest

Mission Objectives Drive Design

- A suit designed for 0-g EVAs (like those on ISS), may be significantly different than a suit used on a planetary surface
- Suits must always trade design drivers based on needs of mission. Very difficult to have a suit that does it all.
  - Volume and mass – Rocket upmass, vehicle stowage, system redundancy, human endurance (on surface), mobility, EVA duration
  - Mobility – ability to perform complex tasks, compatible with various crewmember sizes, design complexity, durability, crewmember protection, fatigue, prebreathe requirements
  - Lifetime – maintenance requirements, redundancy, part sparing

EVA Requirements

What do we need to survive in a spacesuit?

- Oxygen to breathe
- Pressure
- Carbon dioxide removal
- Thermal protection
- Micrometeoroid Orbital Debris (MMOD) protection
- Radiation protection

EVA Requirements

What do we need to *work* in a spacesuit?

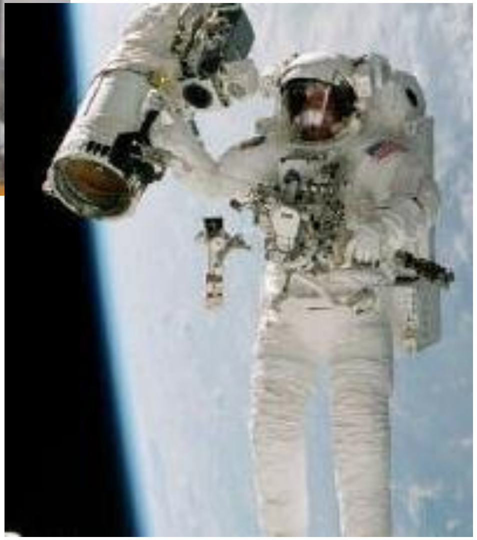
- Dexterity
- Fatigue reduction
- Thermal/ humidity control
- Waist containment
- Communication
- Visibility
- Body restraint
- Tool compatibility
- Suit-friendly interfaces

50 Year Evolution of the Spacewalk

- March 1965: Russian Cosmonaut Alexei Leonov performs 1st Spacewalk , Ed White performs first US Spacewalk three months later
- 1969: US Astronauts Armstrong and Aldrin put 1st human footprints on Lunar Surface
- 1973: US begins EVAs on Skylab
- 1979: Russia conducts 1st Salyut EVA
- 1983: 1st Space Shutte EVA
- 1987: 1st Mir-based EVA for Russia
- 1998: 1st EVA in support of ISS Assembly
- 2001: 1st EVA out of US segment of ISS
- 2008: 1st Chinese EVA
- 2015: Completion of the **184th** EVA in support of ISS

Suit Purpose

- Spacesuits
  - » 2 types of pressurized spacesuits have been constructed to support our space programs



Launch, entry, and abort (LEA) spacesuit

- Used to protect crewmembers from launch, ascent, abort, landing and other dynamic loading.
- Capable of providing protection from loss of cabin pressure and crew rescue following landing.

Extravehicular Activity (EVA) spacesuit

- Used to allow crewmembers to work effectively in the harsh external space environment

Note: Gemini and Apollo used the same suit for launch, entry and EVAs. For Apollo, the crew reconfigured the suit during lunar transit to prepare for excursions on the surface. The same concept has been proposed for Orion asteroid missions.

US Suit Evolution

Mercury Suit

- Purpose: Protect astronaut from space vacuum if cabin pressure lost
- Derived from Navy Mark-IV high altitude aircraft pressure suit
- Designed for unpressurized comfort
- Vehicle provided life support via umbilical

Gemini Suit

- Purpose: First US space suit used both inside and outside the vehicle
- Derived from USAF AP/22 high altitude aircraft pressure suit
- Designed for unpressurized comfort
- Incorporated cooling system
- Vehicle provided life support via umbilical
- 9 EVAs totaling 12 hours 22 minutes

Apollo Suit

- Purpose: Keep astronaut alive during Earth and lunar launch/re-entry, microgravity EVA, and lunar EVA
- Improved mobility features at shoulder, waist, knees, lower arms, and wrists
- First space suit with a portable life support system (PLSS)
- 20 EVAs (surface and 0-g) ~ 170 hours

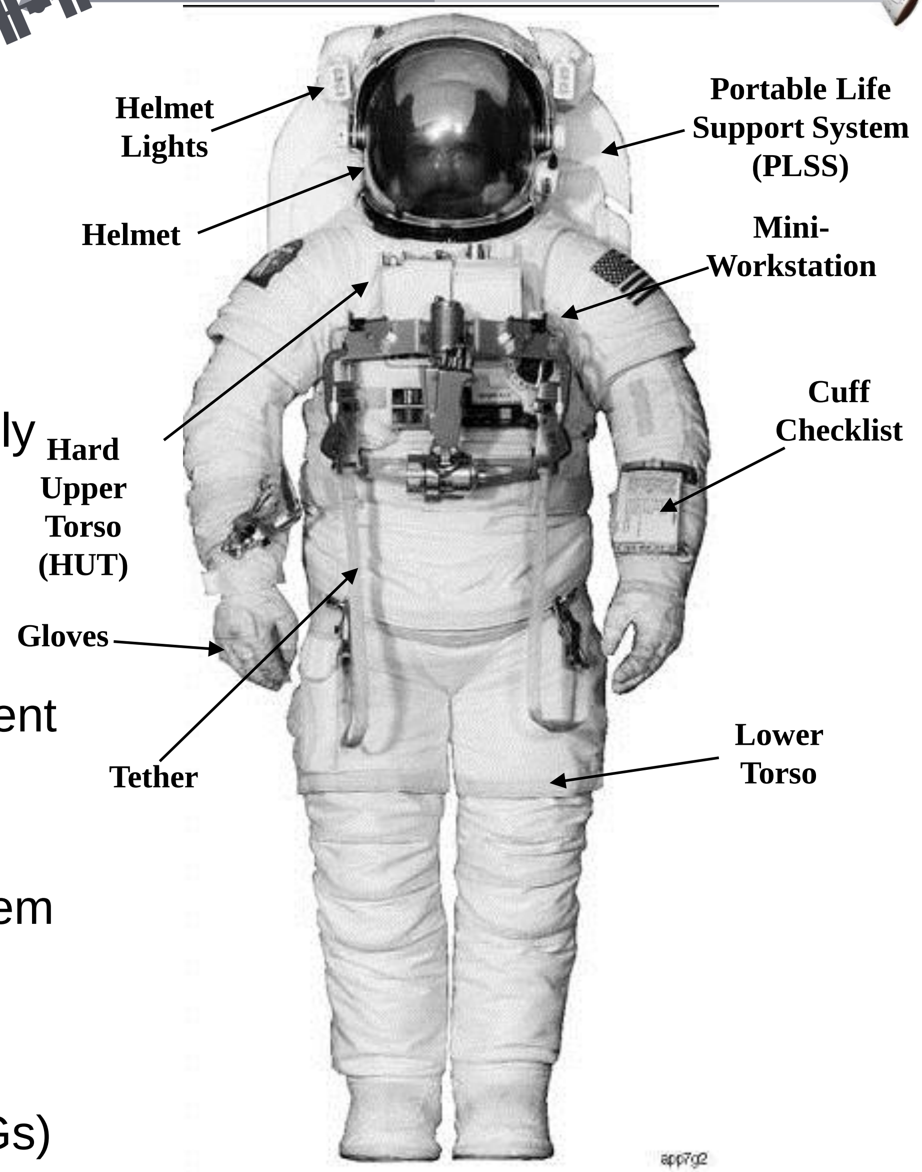
EMU Design Requirement

- NASA's Extravehicular Mobility Unit (EMU)
  - Designed for 6.5 hours of activity with 30 minutes of reserve
  - Zero fault tolerant, plus an abort capability
    - » Some single failures require emergency abort within 30 minutes

- EMU is an integrated system consisting of two subassemblies:
  - Space Suit Assembly (SSA)
  - Portable Life Support System (PLSS)

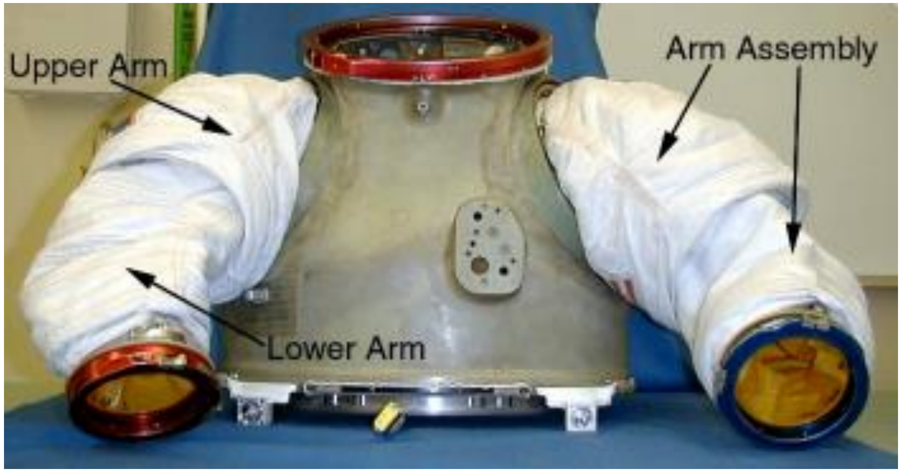
Space Suit Assembly

- Space Suit Assembly Components:
  - »Hard Upper Torso (HUT)/arms
  - »Lower Torso Assembly (LTA)
  - »Extravehicular (EV) gloves
  - »Helmet/Extravehicular Visor Assembly (EVVA)
  - »Communications Carrier Assembly (CCA; Comm Cap)
  - »Liquid Cooling and Ventilation Garment (LCVG) / Thermal Cooling Under-Garment (TCU)
  - »Operational Bioinstrumentation System (EKG)
  - »Disposable In-Suit Drink Bag (DIDB)
  - »Maximum Absorption Garment (MAGs)



Space Suit Assembly Pressure Retention

- Suit pressure selection trades mobility against prebreathe requirements
  - Low pressure suits have less joint torque, but require longer prebreathe protocols to purge nitrogen from blood and prevent decompression sickness
- EMU nominally pressurized to 4.3 psia
  - Russian Orlan operating pressure = 5.8 psia
  - Apollo suit operating pressure = 3.7 psia
- Suit pressure vessels can be rigid or flexible constructions
  - EMU Hard Upper Torso (HUT)
  - EMU urethane coated bladders

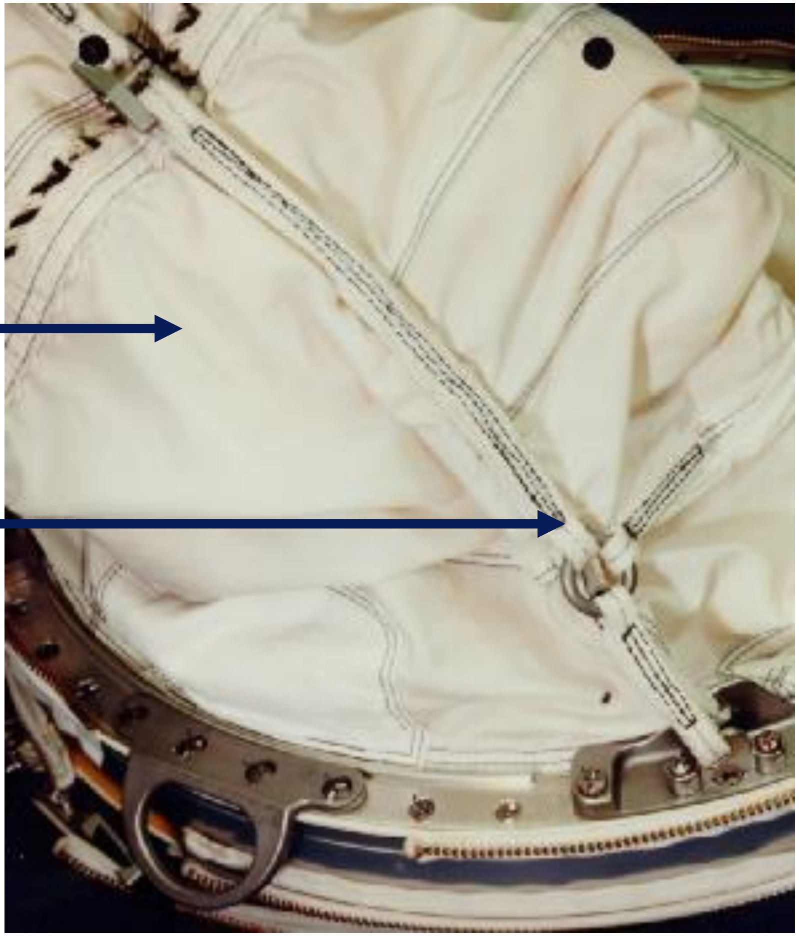


Hard Upper Torso (HUT)

Lower Torso Assembly (LTA)

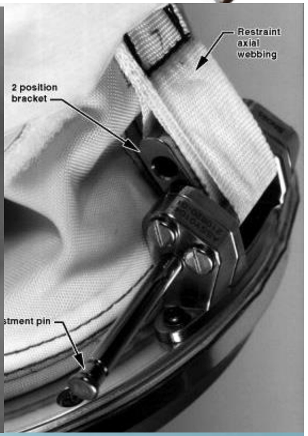
Space Suit Assembly Pressure Retention

- Structural loads for flexible components are carried by restraints
  - Circumferential restraints hold radial suit pressure (prevents bladder ballooning)
  - Axial restraints hold axial suit pressure and crew loads along limbs



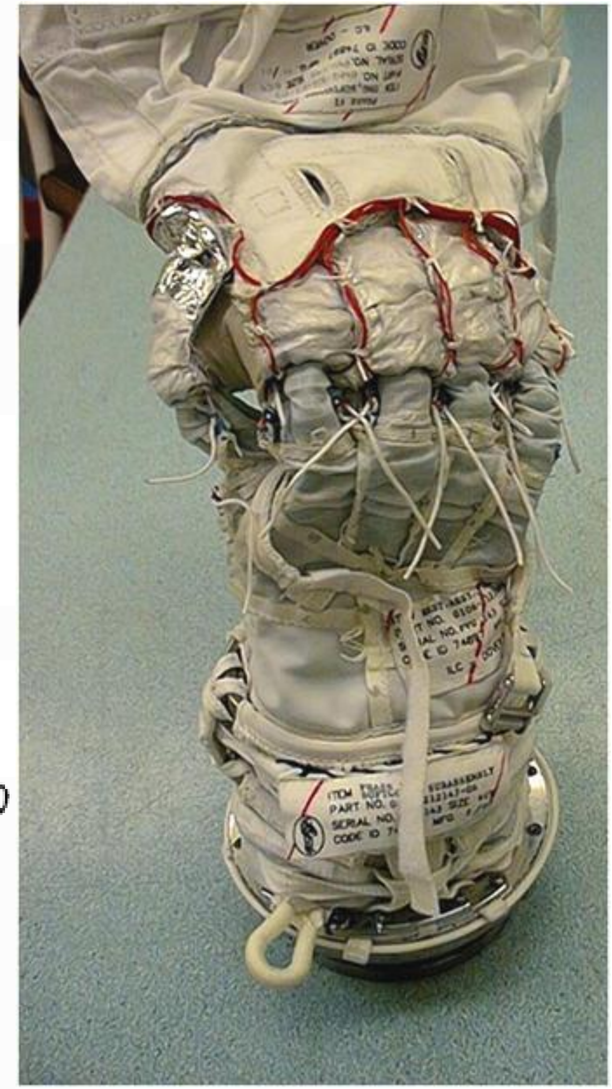
Suit Sizing

- Mercury and Gemini suits were all custom made to fit each astronaut
- Subsequent programs have incorporated resizing capability in suit design
  - 0-g spinal growth can cause astronauts to grow 1”-2” in height
  - EMU has multiple sizes of arms, legs, HUTs, waist/briefs, gloves which can be swapped out
    - » Fine adjustment can also be made with sizing rings, adjustment cams, and padded inserts



Gloves

- Gloves have posed the greatest design challenge for suits
  - Highest mobility requirements
  - Sustains the greatest abuse from wear and abrasion



Abrasion, MMOD, and Leak Prevention

- Loss of pressure integrity is a catastrophic hazard during EVA requiring immediate abort
- Suits have emergency oxygen supplies to feed leaks for ~30 minutes until crew can ingress and repress airlock
  - For EMU, this assumes hole is < ~1/8th inch diameter. Larger holes would likely result in loss of crewmember
- Strict sharp edge requirements were used for ISS design
  - Exposed threads, coder pins, edge radius, pinch points, etc.
  - Extensive swatch tests and inspections performed on ground
- MMOD can directly impact suit and is also creating new sharp edges on ISS all the time

Glove damage during HST service mission

MMOD impact on EVA tool during STS-123 at ISS

Case Study – Sharp Edge Risk

Over the last 50 years of spacewalking, we have modified our processes for controlling the risk of suits pressure integrity breach:

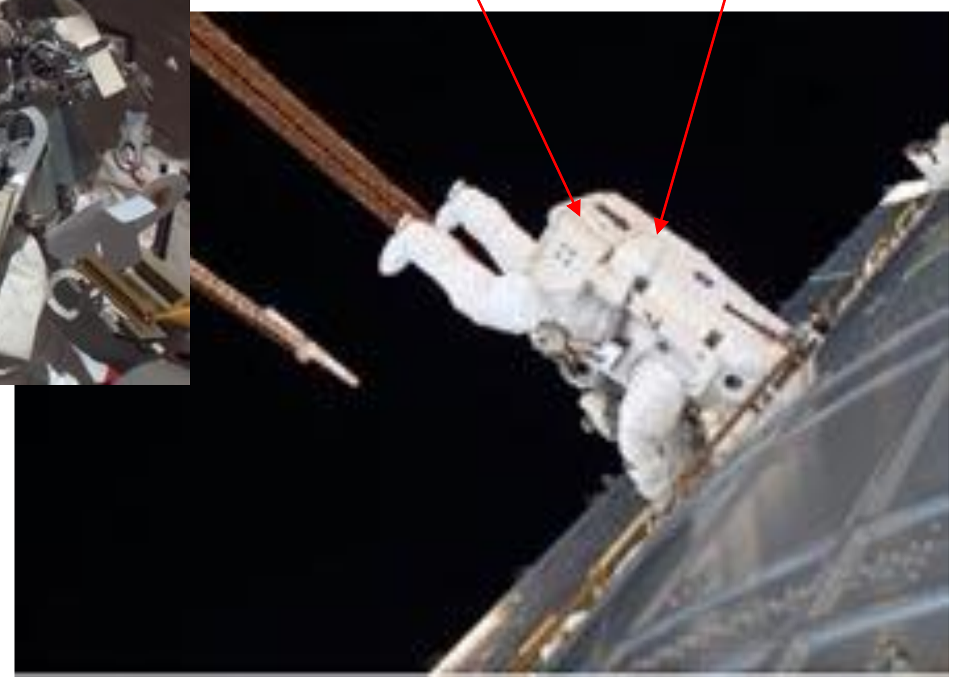
1. Inspect hardware for sharp edges prior flight
2. Inspect suit hardware when it comes home to see if being exposed to sharp edges

1. Made the gloves more resistant to sharp edge damage
2. Inspect gloves during use and established terminate criteria
3. Inspect the ISS for damage when the opportunity arises
4. Protect the crews against known/suspect sharp edge areas by either avoidance of the area or mechanical coverings

How do you determine that the appropriate amount of action has been taken to adequately control this risk?

What alternate approaches would you pursue?

Critical Support Systems



Simplified Aid for EVA Rescue (SAFER)

Secondary Oxygen Package (SOP)

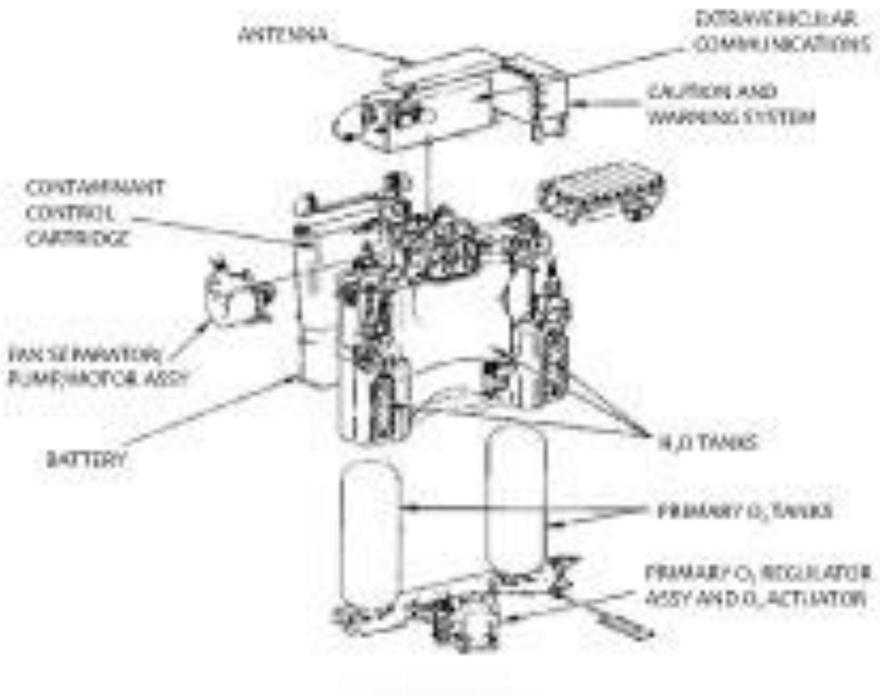
Portable Life Support System (PLSS)

Display and Control Module (DCM)

Life Support System Functions

Primary Life Support Subsystem (PLSS) provides ~7 to 8 hours of:

- Breathing O_2,
- Suit pressure regulation
- Electrical power
- Communications
- Ventilation flow
- CO2, and trace contaminant removal
- Thermal/humidity regulation
- Performance monitoring



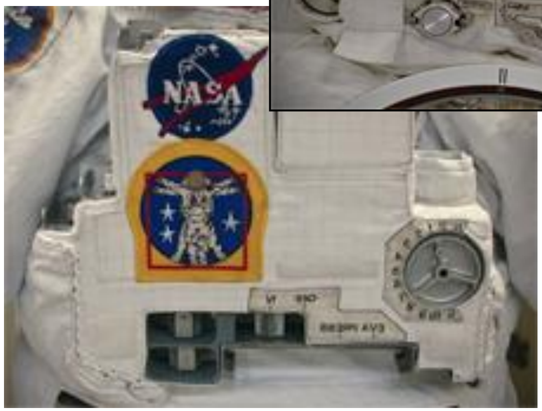
Secondary Oxygen Package (SOP) provides:

- Parachute-mode capability for critical single-string system failures
- Minimum of 30 minutes of emergency O2 in a controlled open-loop purge
- Maintains ventilation flow, CO2 washout, and minimal cooling while regulating to a reduced suit pressure
- Auto-activated based on suit pressure

Supporting Systems

Display and Control Module (DCM) provides:

- Crew member interface for
- Caution & Warning System (CWS) messages
- EMU parameters
- EMU controls to crewmember



Simplified Aid for EVA rescue (SAFER) provides:

- Single String Emergency Return to Vehicle Capability for a separated crewmember
- Inert gas Propellant system with limited delta V capability
- 6 degree of freedom flight maneuverability with automatic attitude hold positioning

Fault Protection Design Strategy Discussion

Fully Redundant Systems

V.S.

Single-string with Autonomous/ Reliable/ Interchangeable Contingency mode

What are the trades of each option?

Why did NASA choose the current design for its EVA suit?

Why is this concept different than the ISS design philosophy?

How would you choose your design approach?

The Danger of Suit Failures is Real

In July 2013, Luca Parmitano was conducting a US EVA on the ISS when he experienced one of the most significant real-time suit failures in the history of US EVAs. Due to a malfunctioning water separator, water began to collect in his helmet, impeding his vision, communication, and encroaching his airways.

His blog gives a chilling first hand description of the event

http://blogs.esa.int/luca-parmitano/2013/08/20/eva-23-exploring-the-frontier/

"…By now, the upper part of the helmet is full of water and I can't even be sure that the next time I breathe I will fill my lungs with air and not liquid. To make matters worse, I realize that I can't even understand which direction I should head in to get back to the airlock. I can't see more than a few centimeters in front of me, not even enough to make out the handles we use to move around the Station…"

"…I try to contact Chris and Shane: I listen as they talk to each other, but their voices are very faint now: I can hardly hear them and they can't hear me. I'm alone. I frantically think of a plan. It's vital that I get inside as quickly as possible…"

Case study – Fan/Pump/Water Failures

In recent years of ISS EVA operations, NASA has experienced four on-orbit system failures of the Fan/Pump/Water Separator component in the EMU. The effects of these failures was significant in many ways:

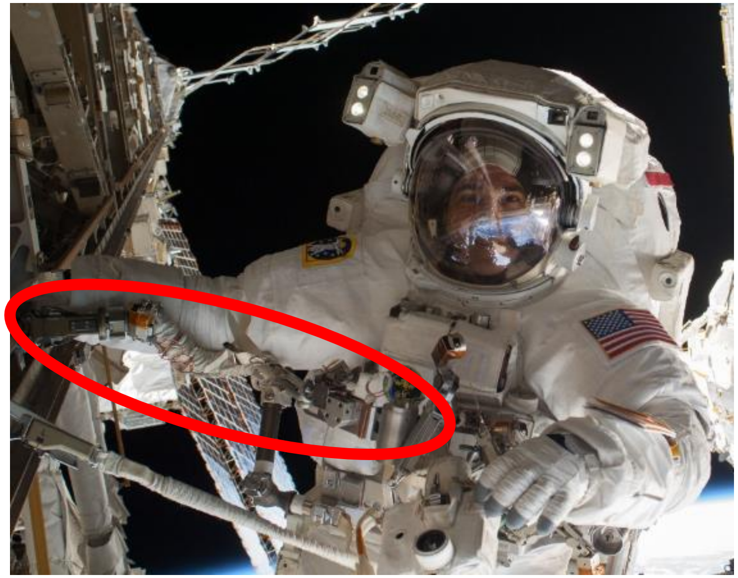
- They confirmed the suits reliance on proper water quality
- They uncovered an understated, under-evaluated, under-mitigated risk to crew in a system that was in operation for over 30 years
- They confirmed the need to enact previously uncertified in-flight repairs of the space suit
- They challenged the NASA team with effectively managing the risk of continued use of a space suit design with a possible systemic issue against the risk of being without US EVA capability on the ISS

Tool and Equipment Interfaces

- Purpose
  - Restrain/stabilize crew
    - » Foot restraints, tethers
  - Restrain hardware
    - » Tethers, bags, caddies
  - Contain trash
  - Improve visibility
    - » Lights, mirrors, cameras
  - Perform tasks
    - » Torque tools, sockets, leverage tools, fluid/electrical actuators
  - Crew procedures
    - » Cuff checklists
- How are tools different for 0-g compared to surface based spacewalks?

Crew Restraint

Flexible tether – fast and easy, low control

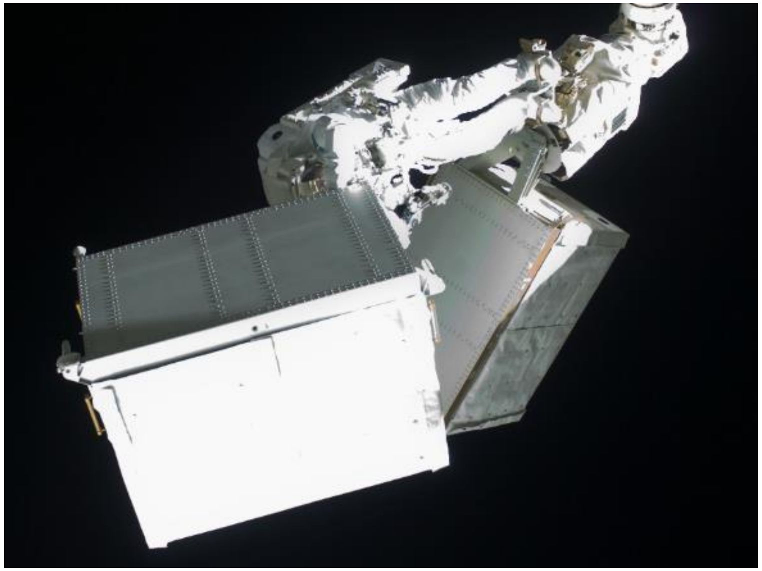


Rigid tether – Requires dogbone, hands free, moderate control

Restraint method often trades stability against overhead to set up.

Allows ability to work with hands, react torque, control large mass

Foot restraint – high overhead, best control



Design for Human in the Loop

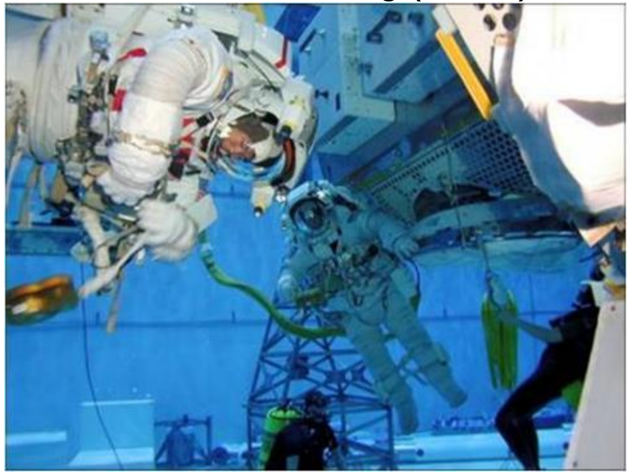
EVA Training and Development Facilities

- Simulating the 0-g EVA environment is impossible with a single facility. Instead we build our understanding based on contributions from several testing environments.
- Facility choice is driven by cost, specific test objectives, and merit/shortcoming of specific facilities
  - Quality of 0-g
  - Thermal
  - Vacuum
  - Vehicle/robotic interfaces
  - Suit and mockup fidelity

Neutral Buoyancy

- Early Gemini flights identified the difficulty with performing EVA tasks.
- Underwater neutral buoyancy training was first adopted for Gemini 12 and has been the primary training environment since

Buzz Aldrin during Gemini12 (above)
ISS NBL training (below)



PROS
- Large work volume (limited by pool size)
- Accommodates vehicle mockups and robotic integration
- Fully pressurized, medium fidelity suit
- Test durations up to ~6 hours

CONS
- Water drag
- Buoyance induces righting moments, and 1-g effects on suit/tools
- Thermal/Vacuum not simulated

Virtual Reality

- 3-D immersive graphical environment
- Easy to update vehicle configuration
- Ground and on-orbit training allows worksite review close to EVA date
- Accurate robotics trajectories (not limited by pool floor)
- Easy to train directional disorientation (no perceived gravity vector relative to vehicle)
- Unpressurized shirt sleeve training
  - No physical challenges of working with suit/tools
  - Less overhead to conduct training

0-G Parabolic Flight

- No drag, suited, 0-g
- Limited to ~20 second parabolas
- Limited volume to size of aircraft cabin
- Due to cost, overhead, and limitations not used for standard training. Has been used for development testing.

Gravity Offload Facilities

- Low drag environment
- Unpressurized shirt sleeve training
- Good for training torque reaction, mass handling in complement with NBL and VR
- Limited work volume constraints
- Body orientation constrained to horizontal (multi-axis gimbal harness in development)

Space Vehicle Mockup Facility (SVMF)

- Used to train intra-vehicular (IV) activities
  - EVA Prep/Post
  - Prebreathe
  - Maintenance
  - Resize

Vacuum Chambers

- Demonstrates vacuum performance of flight suits, life support systems, and airlock components
- No 0-g simulation, suit weight offloaded with suspension device
- Some facilities can control thermal environment as well for best representation of space
- Large vacuum chambers can allow some limited task testing
  - Example: JSCs Human Thermal Vacuum chamber used for testing of Shuttle Thermal Protection repair techniques

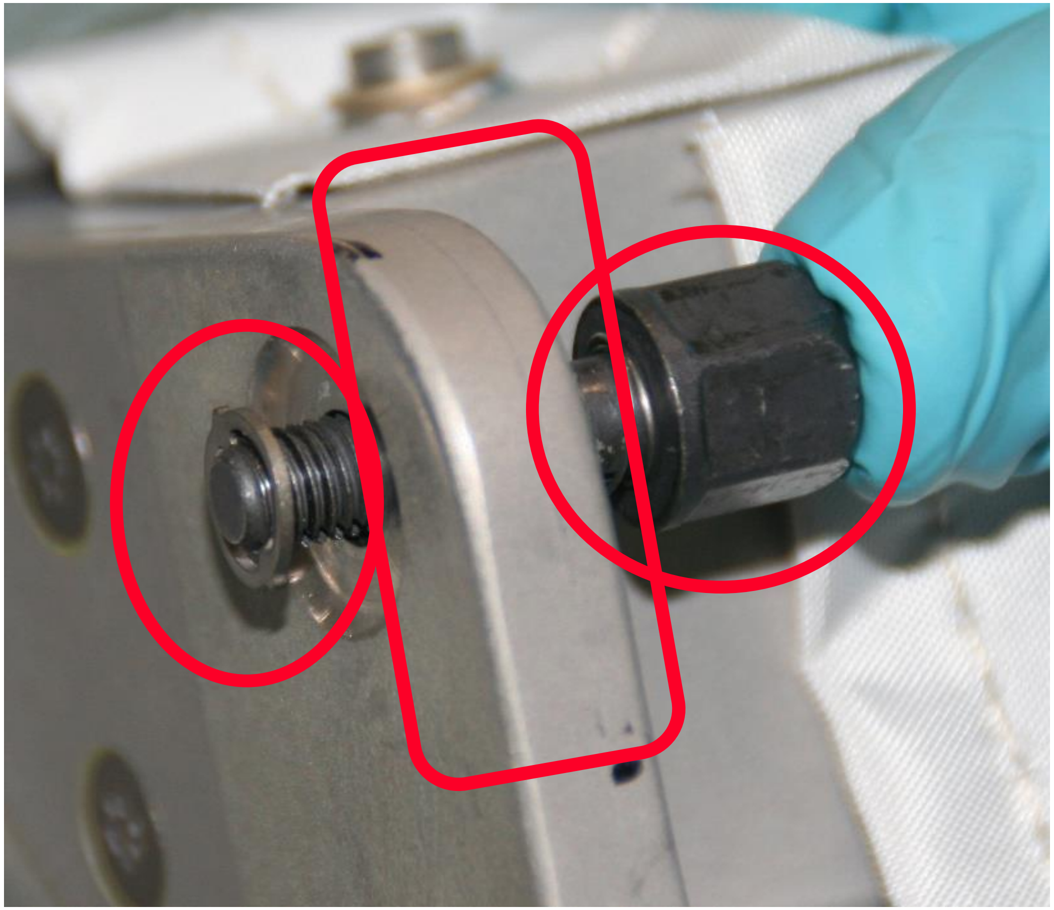
Access to Flight Hardware

The single most important thing that can be done to prepare for EVAs is to have the crew and ground controllers intimately familiar with the flight hardware

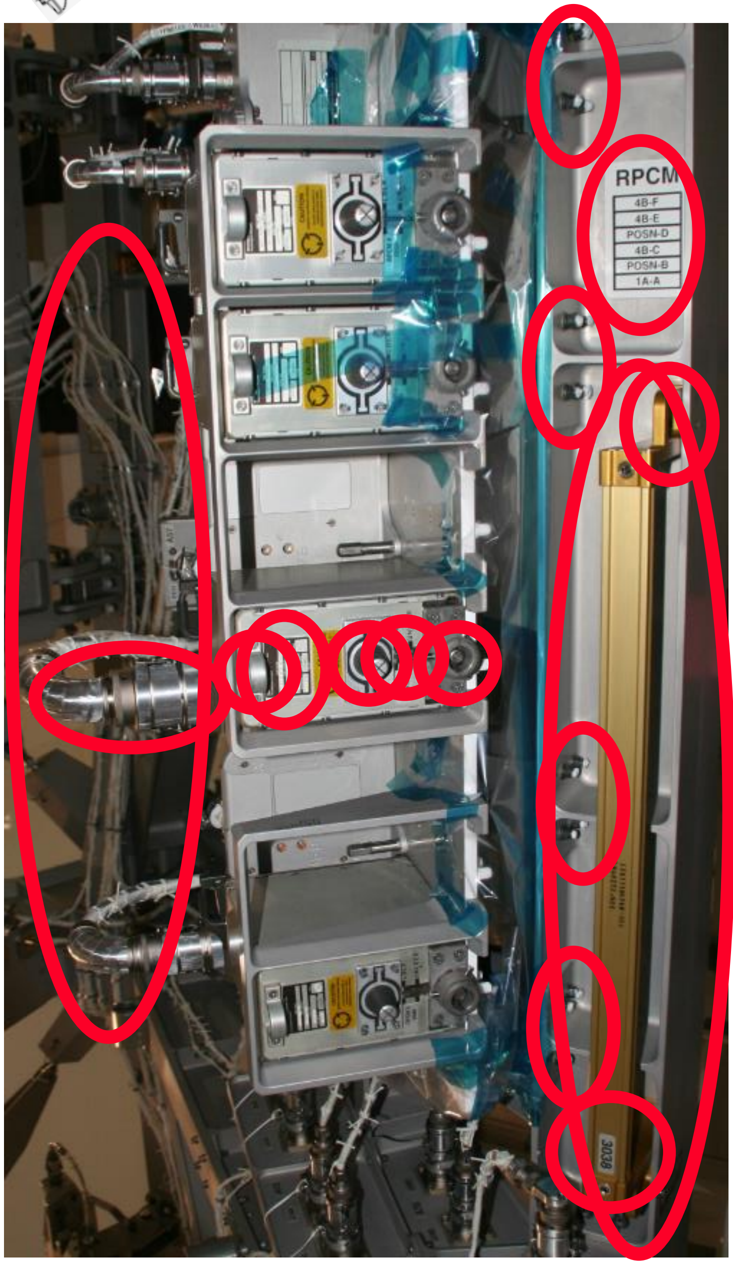
On a vehicle like ISS, all worksites can be designed for EVA compatibility…

Design Interfaces

- Consideration for EVA compatibility must be pervasive through vehicle design
  - Captive washer prevents bolt from flying away
  - Rounded edges to prevent sharp edges
  - Common bolt head size which has been fit-checked to verify compliance



Design Interfaces (Continued)



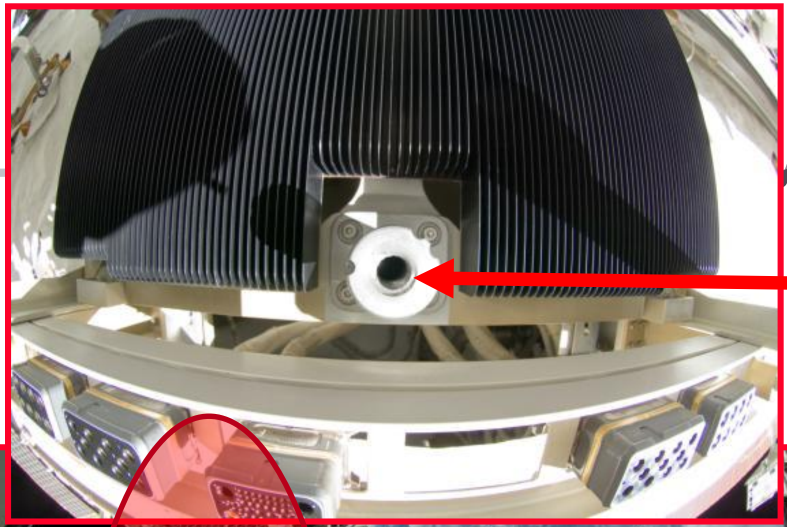
- Labeling
- Tether point
  - Hole size designed to prevent finger entrapment, allow tether hooks
- Robotic interfaces/EVA handling aids
- Visual Lock/Unlock indicator
- Electrical connectors compatible with pressurized, gloved hand. Each plug and jack uniquely labeled
- Handrail
  - Positioned for crew stability at worksite
  - 575 lbf Load certified for safety tether
  - Dog bone shape for rigid tether (BRT) interface
- Cable routing/restraint
- Epoxy covered bolt threads (sharp edge protection)

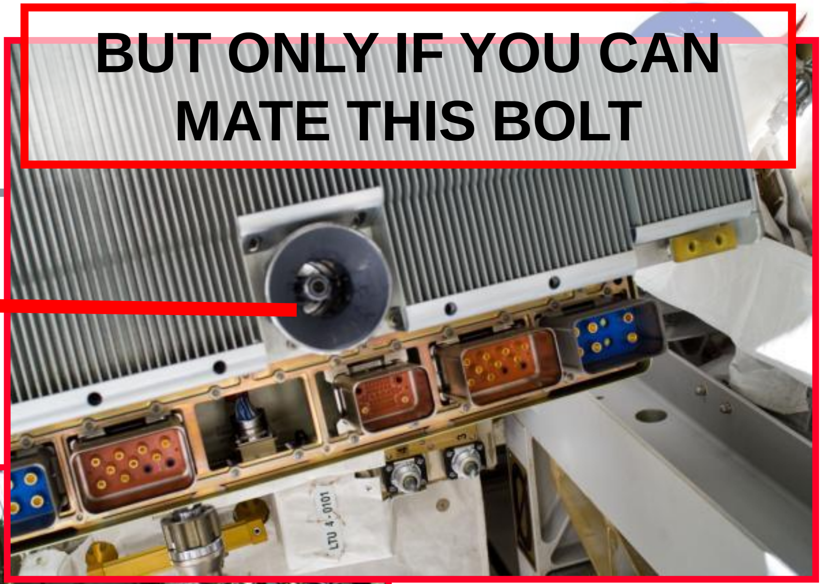
How do the suit and tools need to change to interface with the Moon or Mars?

How about an asteroid?

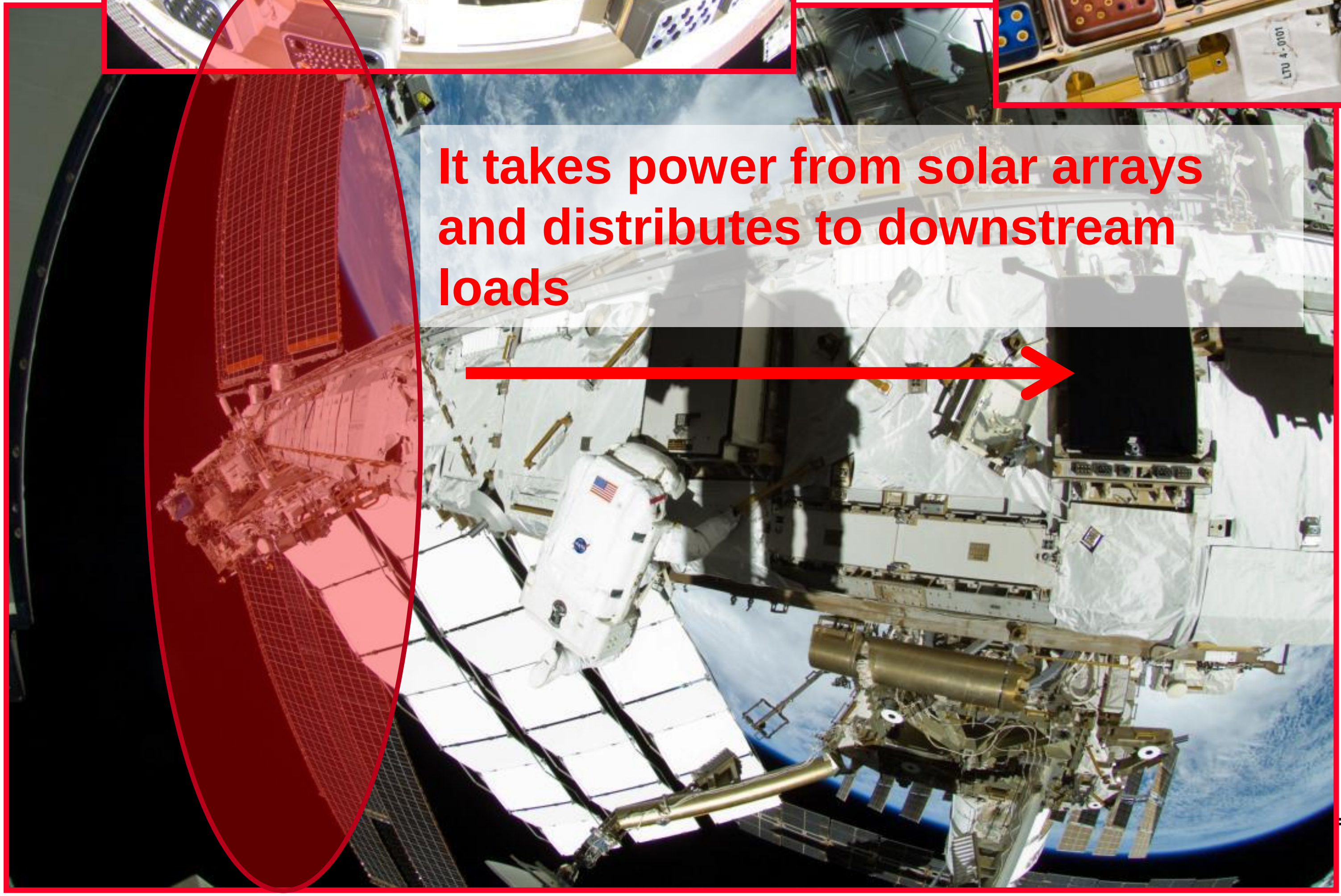
- ~0-gravity
- Unknown rock hardness and cohesion

A Recent Challenge in EVA





BUT ONLY IF YOU CAN MATE THIS BOLT

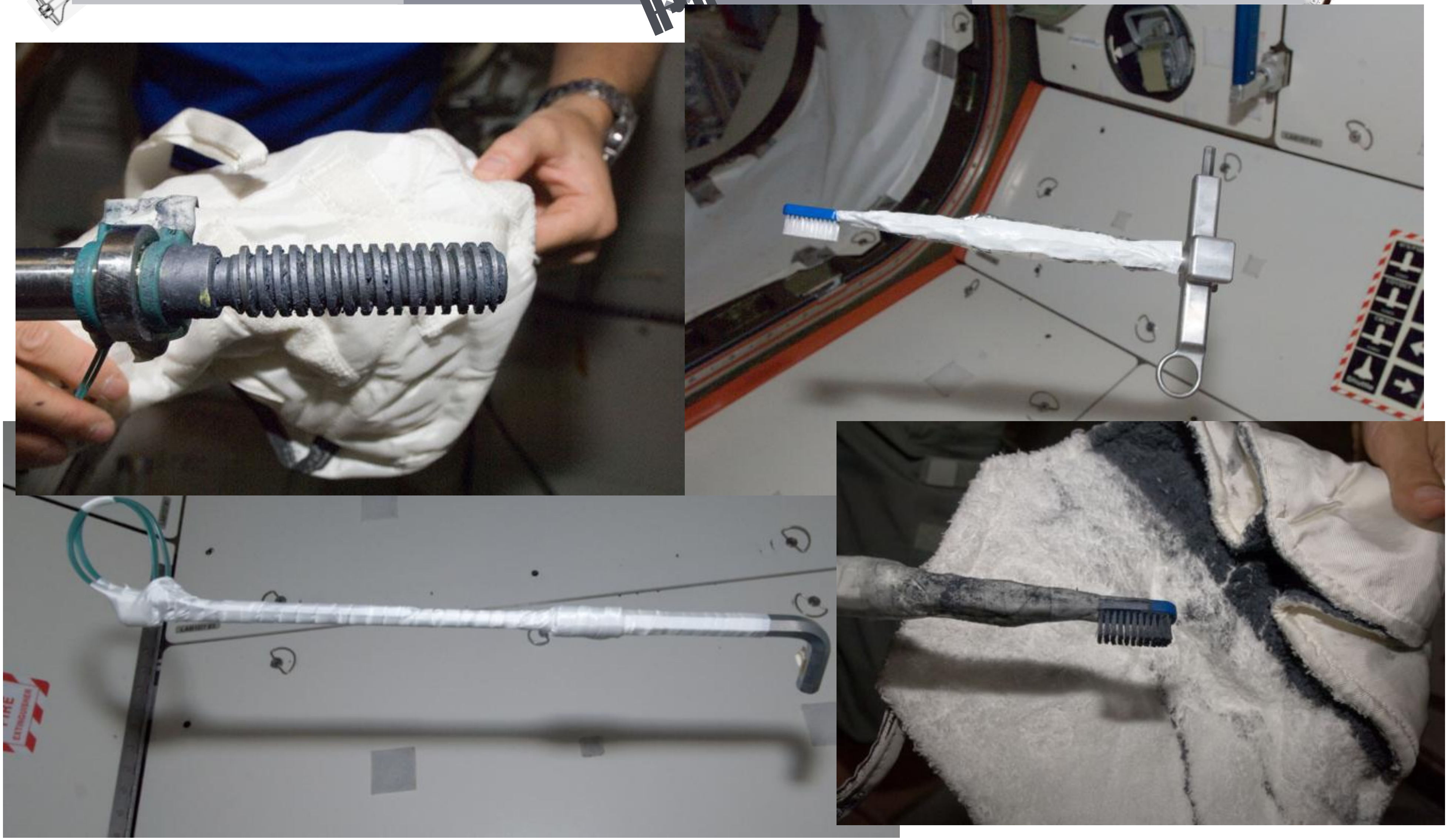


It takes power from solar arrays and distributes to downstream loads

MBSU Bolt Case Study

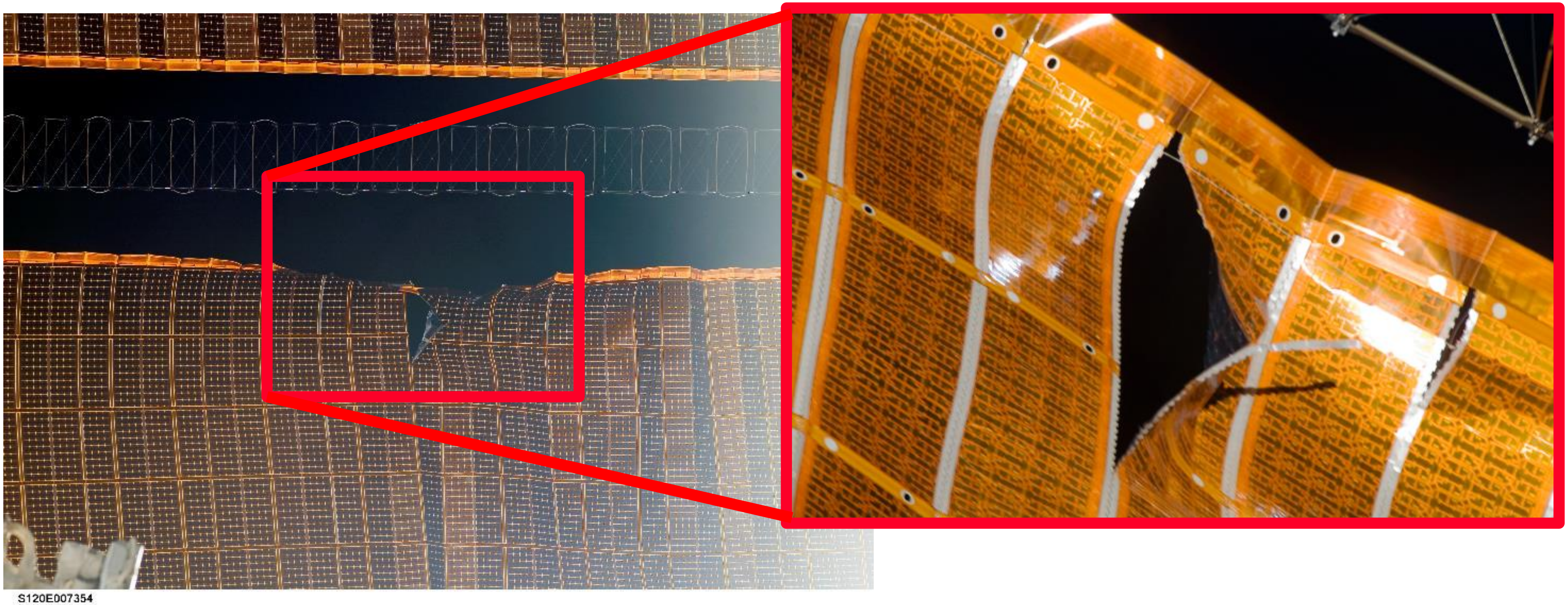
- Halfway through driving bolt, the running torque increases and bolt binds.
- Crew backs out bolt and reattempts
  - Each time it binds at about the same turn count.
- Insufficient turns to create electrical connector contact
- Ground teams recall difficulties installing unit, due to orientation and weight relief system (may have caused side-loading on interface.)
- Spare unit inside ISS has different function, but same bolt design

MBSU Case Study



Solar Array Case Study

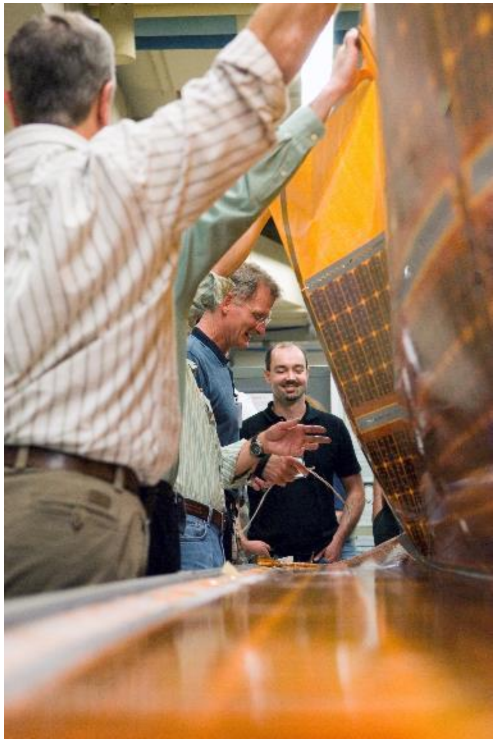
- During ISS assembly a truss segment and solar array had to be relocated. During re-deployment of solar array the following damage was observed.
  - Array was only partially deployed and unable to sustain docking/undocking loads
  - The Space Shuttle is planned to undock within the week

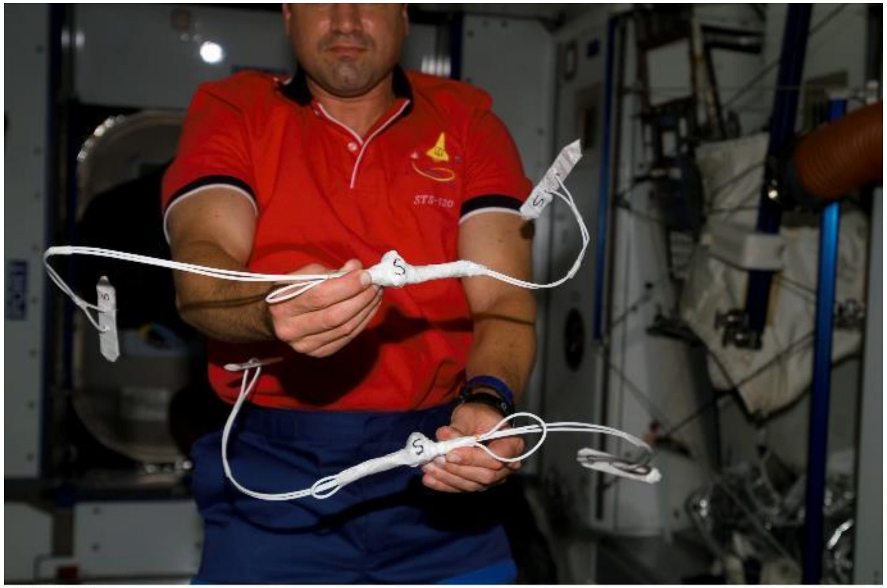


Solar Array Case Study

- Ground teams examined engineering test units and focused on holes in array blankets which were used to secure blankets during launch

- Crew was given procedures to build “cuff links” out of spare electrical wire and sheets of teflon





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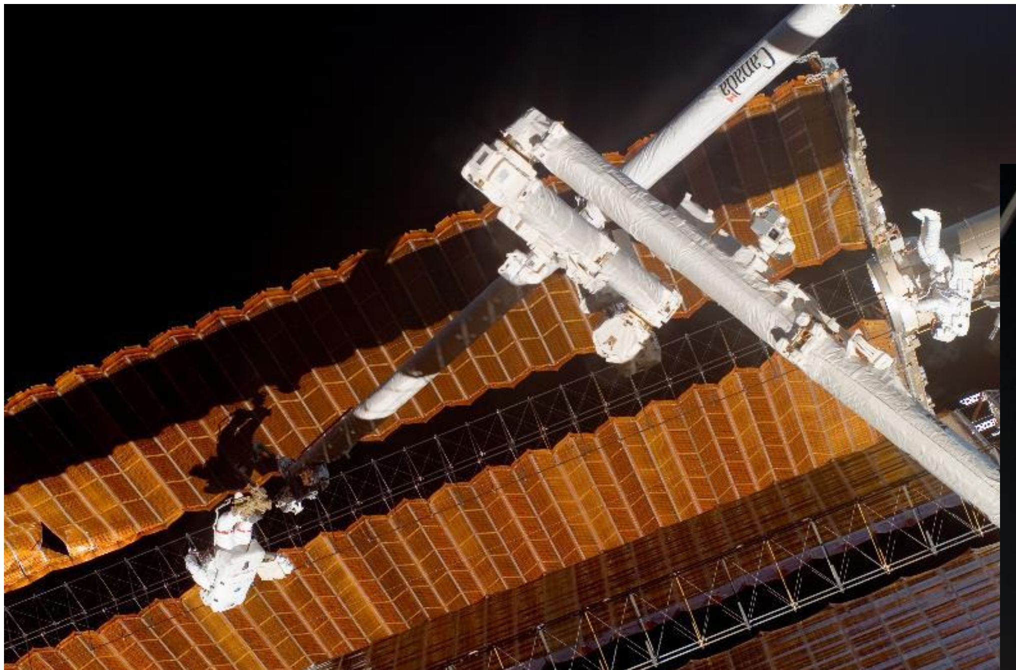
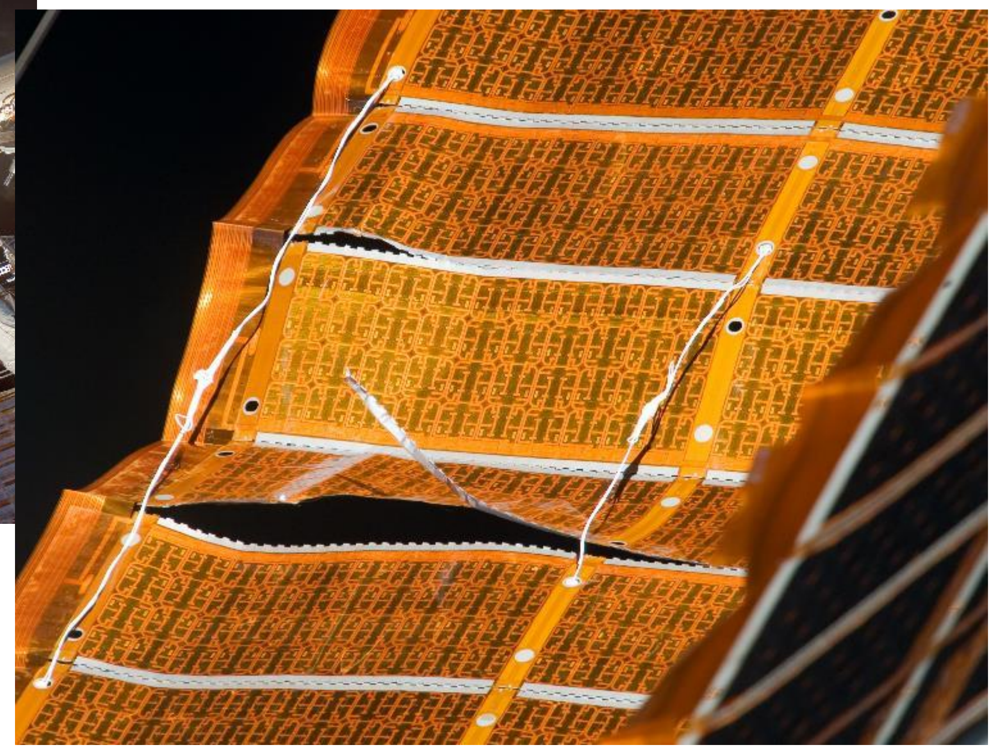
Solar Array Case Study

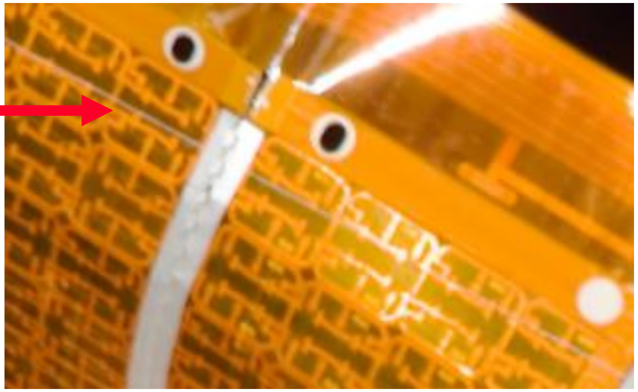
- Within days EVA procedures were written, tools built, robotic trajectories planned, crew trained, and repair implemented





Solar Array Case Study

- Post flight failure analysis determine that an MMOD strike had damaged some strands on a braided guide cable which then snagged on the array during extension.



- Repair solution did not require launch of any unique hardware, but used materials never intended for this purpose
- All crew training for task performed on-orbit
- Shock hazard required all tools be insulated with kapton tape
- Crew access required use of a robotic extension boom used for inspecting shuttle thermal tiles.
- Failure to repair could have collapsed array during Shuttle undock and significantly reduced power availability for life of ISS

Lessons Learned

- **Don't underestimate the challenges of seemingly simple tasks**
- **Design hardware to be as easy to use as possible, it will still be difficult**
- **When you design something, recognize that you won't know how it is really going to be used (build margin/flexibility into your design)**
- **Consider going beyond the current requirements (anticipate what the future *may* bring)**
- **Beware the Unintended Consequences**
  - **More water quality sampling/ conditioning may expose hardware to corrosion**
  - **More neutral buoyancy training can expose crews to unnecessary injury risk**
  - **Untested operations can a uncover unanticipated results**

Lessons Learned

- **Access to/ knowledge of flight hardware is crucial to proper preparation**

- **The environment will affect your hardware over time – expect that things will change**
  - **Bolt torques change due to lube degradation**
  - **New sharp edges are introduced every day**
  - **Connectors and cabling and mechanisms get stiffer over time**
  - **Dust/ Foreign Object Debris must be controlled**
  - **Water quality will vary**

- **Past experience doesn't guarantee you fully understand every susceptibility of your system**
  - **Expect to be surprised, but do everything you can not to be**