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Extravehicular Activity Development of Unforeseen International Space Station Maintenance

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What is the NASA Flight Operations Directorate (FOD)?

- Mission: To select and protect our astronauts and to plan, train and fly human space flight and aviation missions.
  - Includes the astronaut trainers and the Mission Control flight controllers.

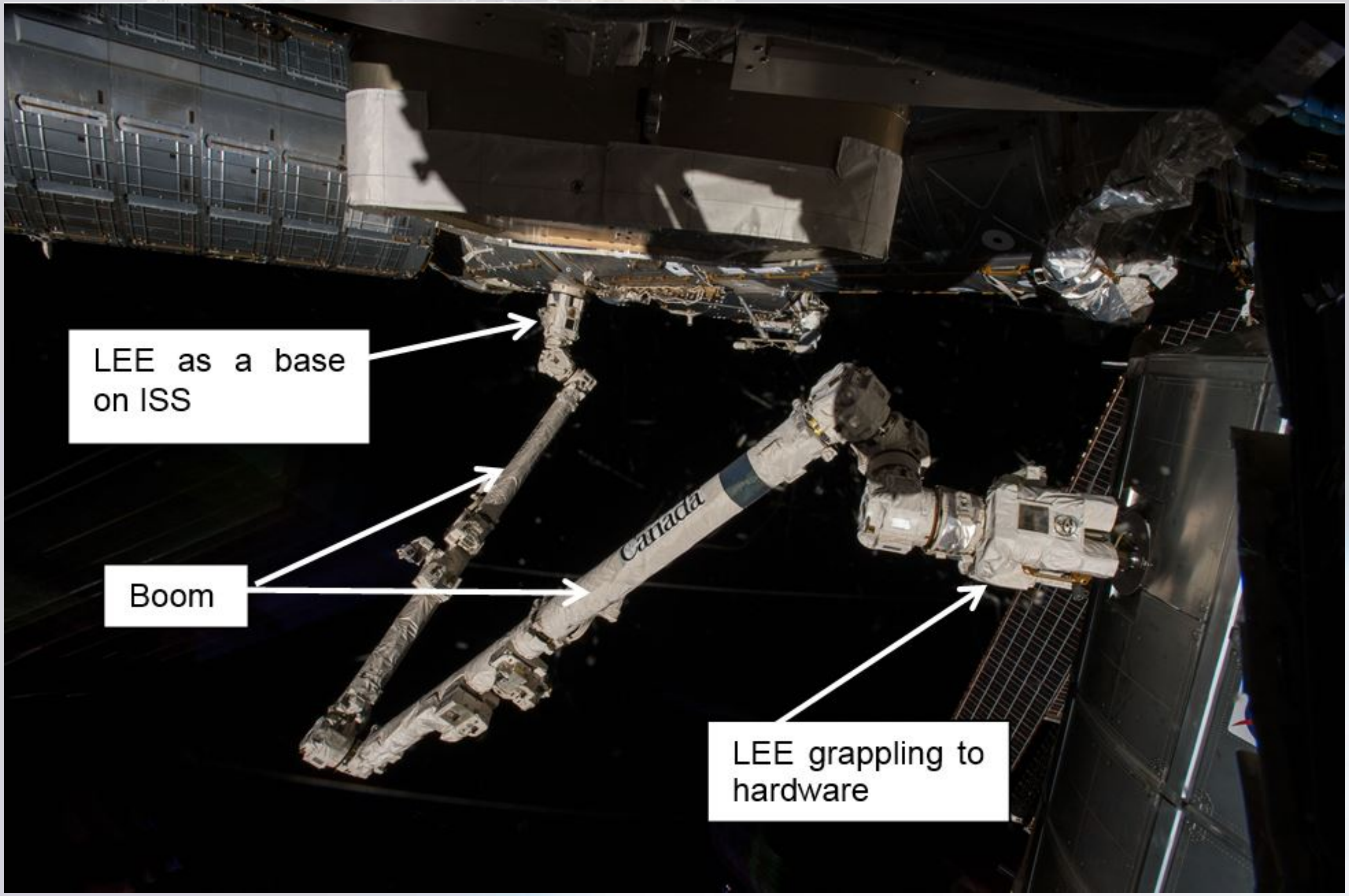
Plan, Train, Fly

- Plan - Builds the strategy of how to accomplish the given assignment.
- Train - Includes preparing both the team on the ground and the astronauts.
- Fly - To execute the mission.

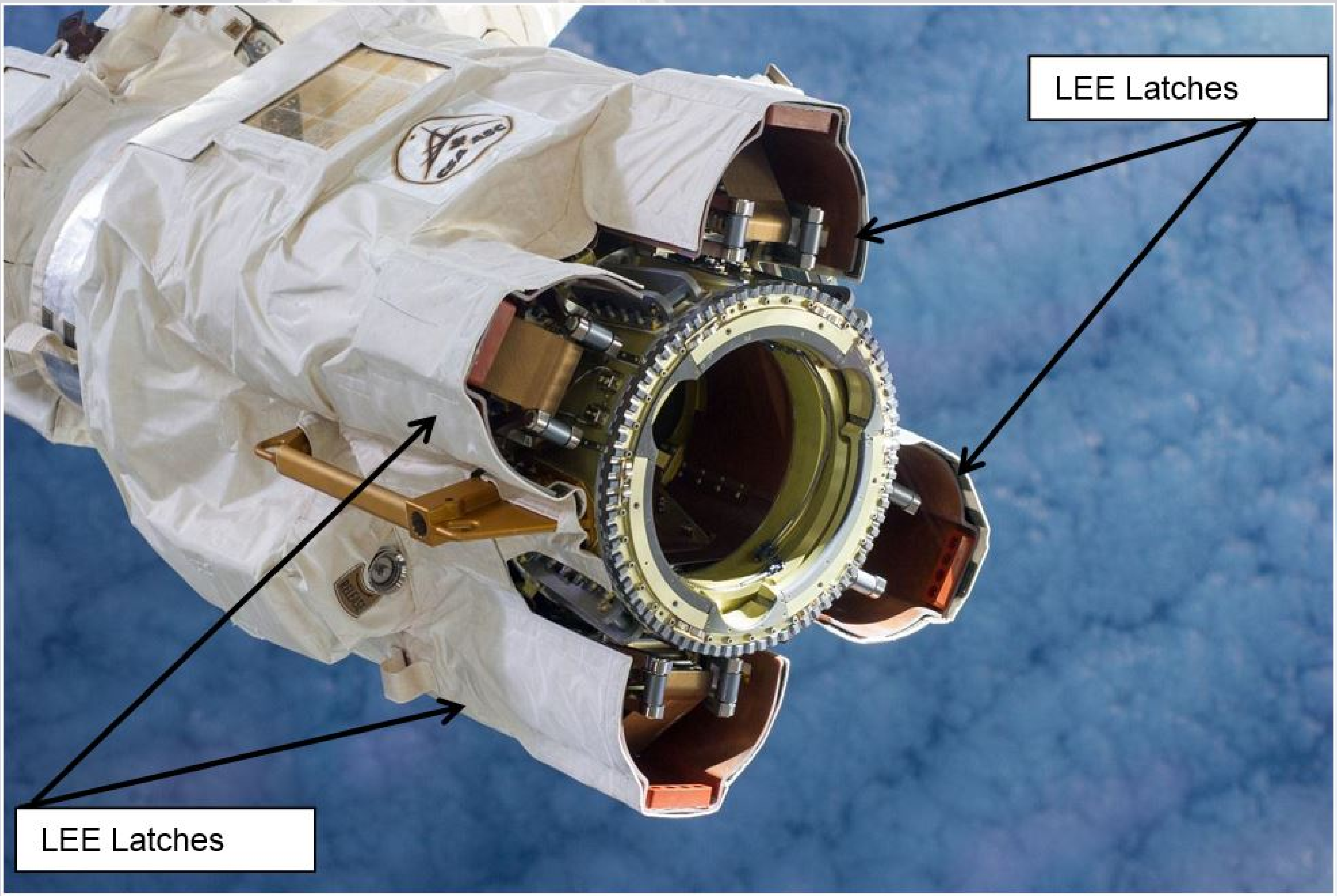
The SSRMS & LEE

- The ISS has a Space Station Remote Manipulator System (SSRMS) (i.e., robotic arm).
  – The SSRMS consists of two booms, joint clusters, and a Latching End Effector (LEE) on each end, referred to as LEE A and LEE B.
  – The LEE grapples, latches, and electrically mates to the ISS to provide a base for the arm. It also is used to grapple, latch, and electrically mate to hardware and resupply vehicles for capturing or moving them.
  – The LEE has four latches that provide some rigidization, electrical power and data to the hardware.

The Space Station Remote Manipulator (SSRMS)



The Latching End Effector (LEE)



The Problem

- Starting in April 2014, data was showing increased current when latching using LEE A.
  - This resulted in motor stall events during latching and latch motor runaways if motion suddenly resumed.
  - A motor stall during a rigidizing operation was also on LEE A. The rigidizing operation is the process by which the LEE creates a rigid interface with a grapple fixture to pull itself onto the structure.
- Concern grew that if the trend continued, LEE A may be unable to latch. This would have significant impacts to SSRMS operations. LEE B was also starting to show degraded performance, but it was not as bad as LEE A.
- FOD was brought in at the first sign of the problem.

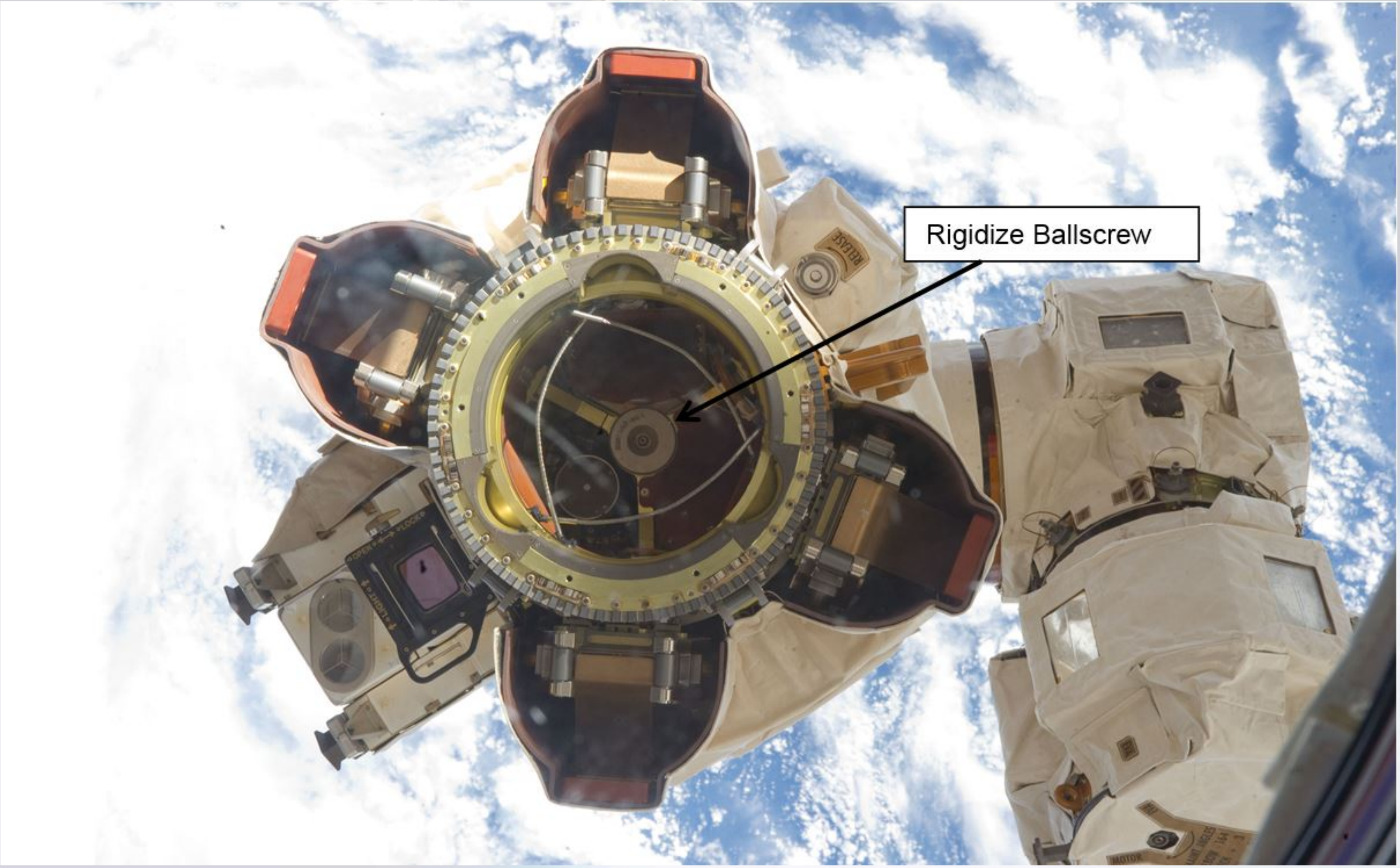
Questions on how to Fix the Problem

- The ISS Program asked several questions that needed to be answered. These questions included:
  - How long can LEE A continue to be used before it is deemed unusable for latching?
  - Would this require a complete remove and replace (R&R) of the LEE?
  - Could the LEE be lubricated on orbit?
  - Could the LEE be lubricated on orbit during an EVA?
  - Could the LEE be lubricated on orbit during an EVA using existing on orbit hardware or would a tool need to be developed on the ground and then launched?

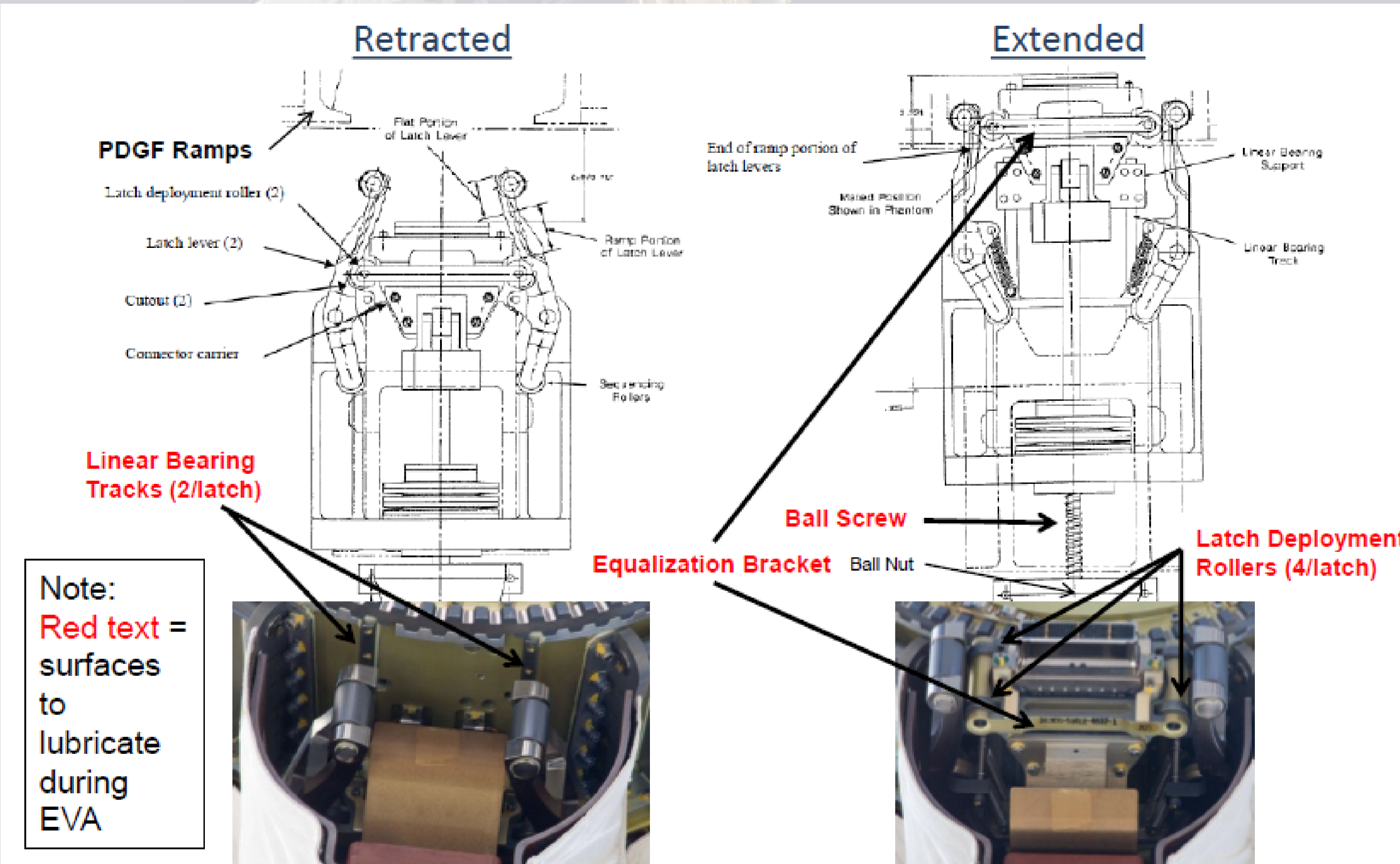
Plan: Potential Route Cause

- It was determined that the most likely culprit of the rising currents was dry-lube degradation.
- There were mechanisms that could potentially be accessed while on orbit. These mechanisms, in priority order, were:
  - Latch Ballscrews
  - Linear Track Bearings
  - Rigidize Ballscrew
  - Latch Equalization Brackets
  - Latch Deployment Rollers
- The Latch Ballscrews were the highest priority mechanism and were the most difficult to access.

Face of the LEE



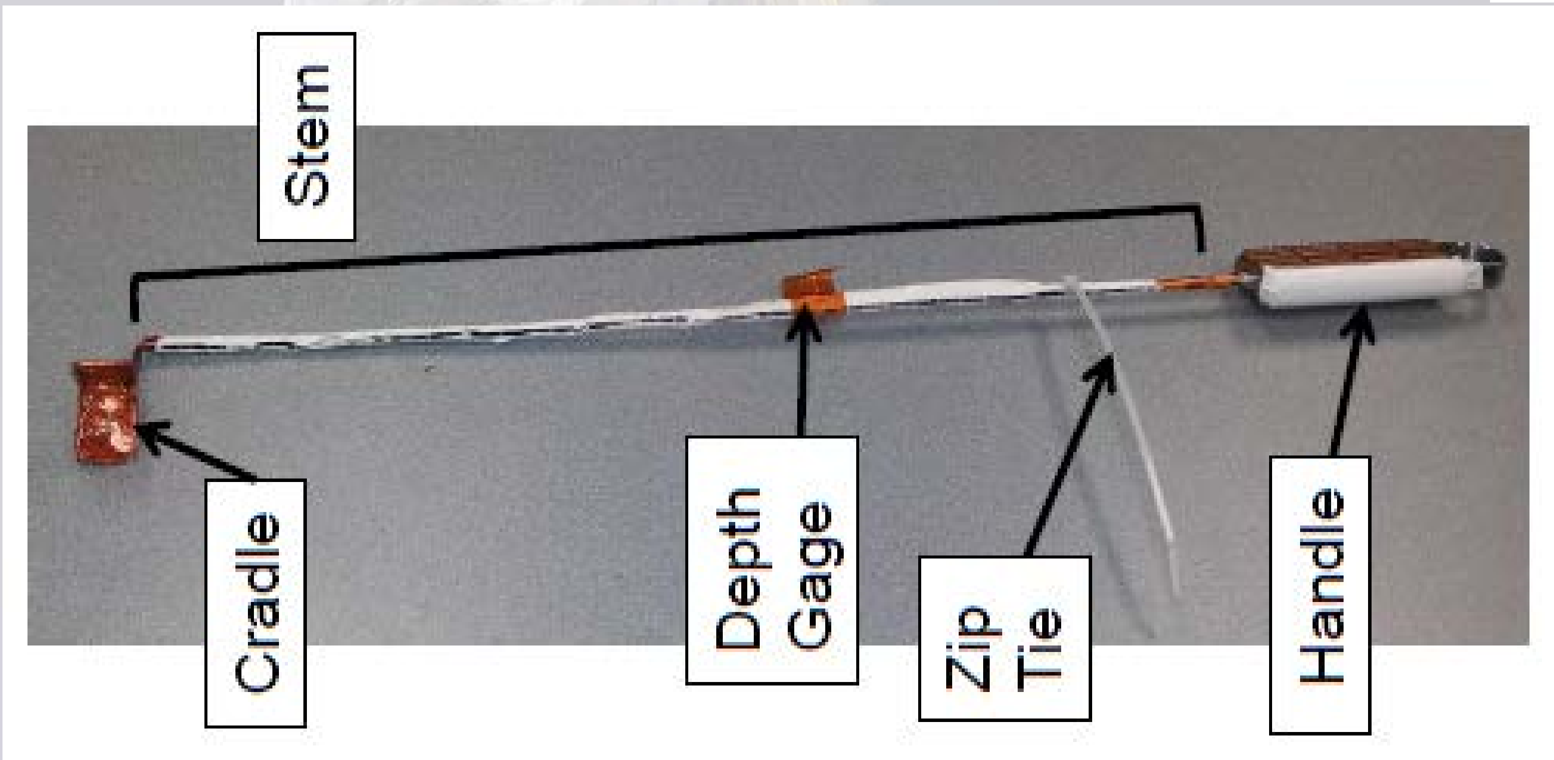
LEE Latch Mechanism Overview



Options to Access the Latch Ballscrews to Fix the Problem

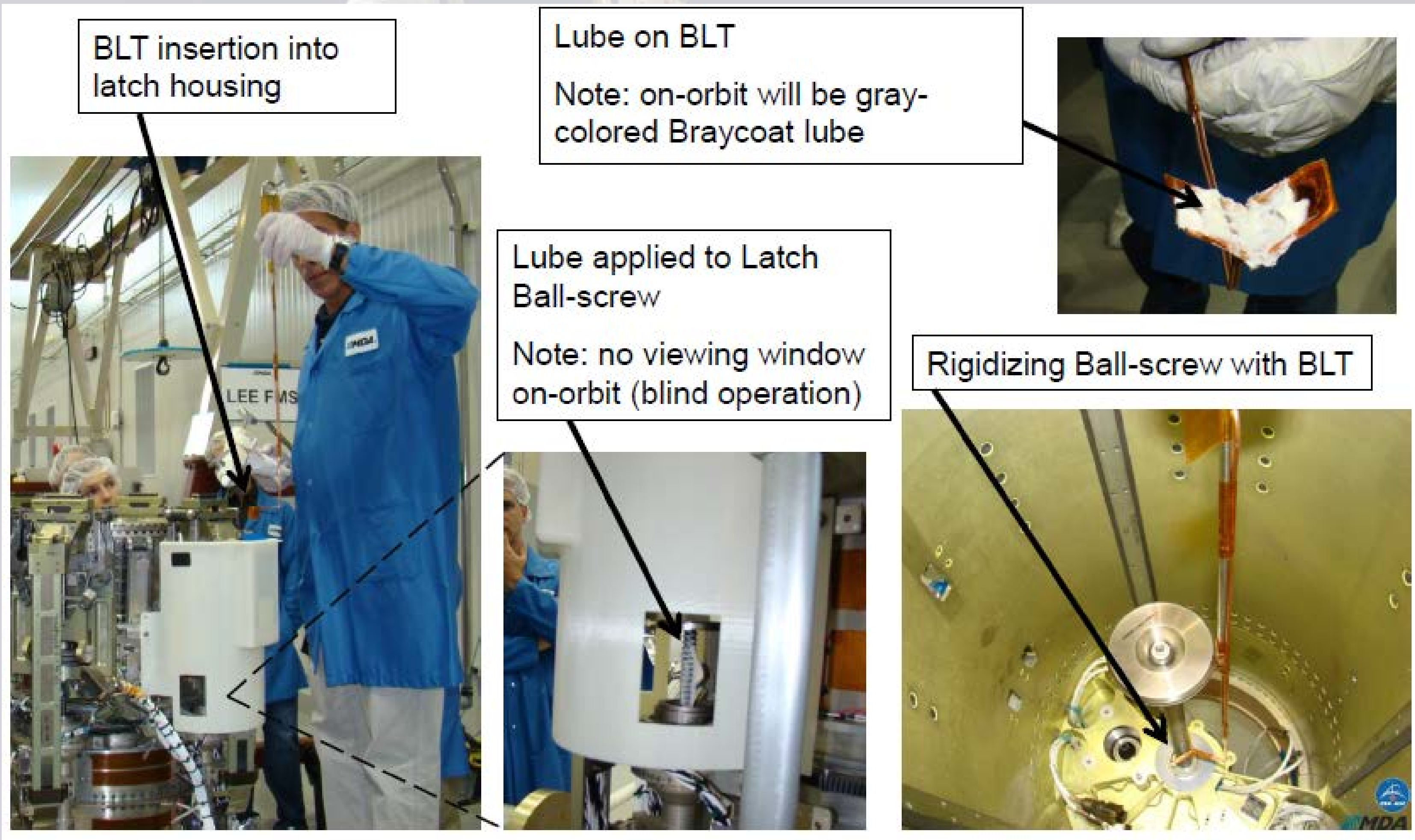
- Option 1: Disassemble the shrouds of the LEE during an EVA to lubricate the latch ballscrews.
- Option 2: Remove the LEE during and EVA, bring it inside to disassemble and lubricate, then reinstall on another EVA.
- Option 3: Create a tool using existing on-board hardware to access and lubricate the latch ballscrews during an EVA.
- Option 4: Develop a tool designed to access the latch ballscrews and launch it to lubricate the latch ballscrews during an EVA.

The Ballscrew Lubrication Tool (BLT) [Option 3 was chosen]



The EVA Grease Gun

Lubrication of Ballscrew with BLT



Video of LEE Lubrication

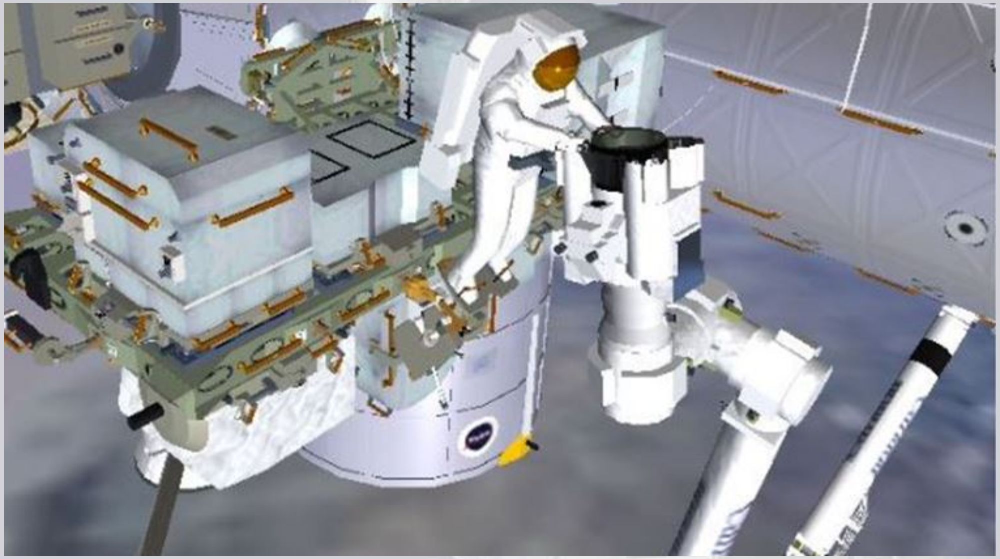
TRAIN

- Create flight-like hardware to train with
  - In the Neutral Buoyancy Lab (NBL)
  - In the Space Station Vehicle Mockup Facility (SVMF)
- Train the ground team
  - Develop and Write the EVA procedures
  - Flight controllers for Mission Control during EVA
- Train Crew members to execute EVA
  - Astronauts were already on orbit when EVA procedures were finalized.

Train Like You Fly

- Proved to be essential to use flight-like hardware for EVA procedure development.
  - Discovered the BLT was too flimsy and could bend too easily, resulting in the latch ballscrew being missed completely. Repeatability was also a concern.
    - The tool was modified. It was stiffened up and more alignment markers were added.
    - Detailed step-by-step procedures were written on how to insert the BLT into the latch, rotate it, and place it on the ballscrew.
  - Discovered the body position and orientation on how the LEE was presented to the EVA crew member needed improvement.
  - All of these steps helped the team gain confidence that the ballscrew would get lubricated every time.
- These changes were major enough that if they were discovered during the EVA, the task would have been unsuccessful or it would have taken so long that it would not have been completed in the available EVA time.
- Training with detailed, flight-like hardware on the ground is critical to success on orbit.

LEE Positions



First Assumed Position

Executed Position

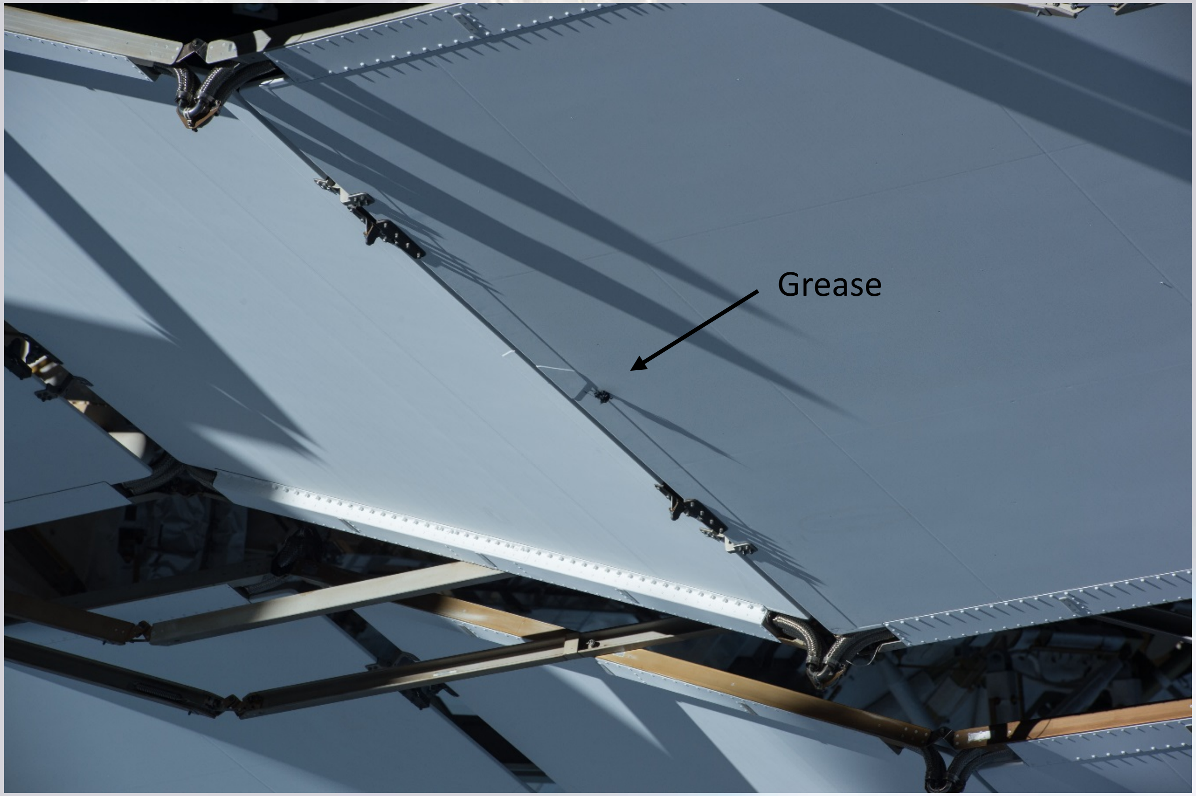
EVA Simulations

- Another aspect of training is to test the ground team in a simulation of the EVA. All parties who would be in the Mission Control Center (MCC) in Houston or tied into the MCC remotely on the actual day of the EVA would participate.
  - The EVA procedures are executed; some aspects nominally, some off-nominally.
  - This tests the coordination, roles, and responsibilities of each party, as well as the procedures from a flight controlling aspect.
  - It also verifies that the team can handle issues and has a good plan for any off-nominal situations that could arise.
- Many months go into training both the crew and the flight control team. The common goal throughout the entire team was to execute an EVA as flawlessly and successfully as possible.

Fly (Execution)

- US EVA 30 took place on February 25, 2015.
- Some glitches occurred during the EVA, but they were overcome.
  - Grease can be difficult to manage and can get messy in a microgravity, vacuum environment.
  - In the planning process, the ground team ensured that if grease did get on unintended areas on the LEE or surrounding hardware, no damage would occur.
  - Coincidentally, months after the EVA, a glob of grease was found on an ISS radiator, presumably after being flung from the BLT.
- The results of the lubrication of LEE A have been very promising. The health of the latches has improved and are presently operating at currents similar to their performance 4 to 5 years prior to this lubrication.

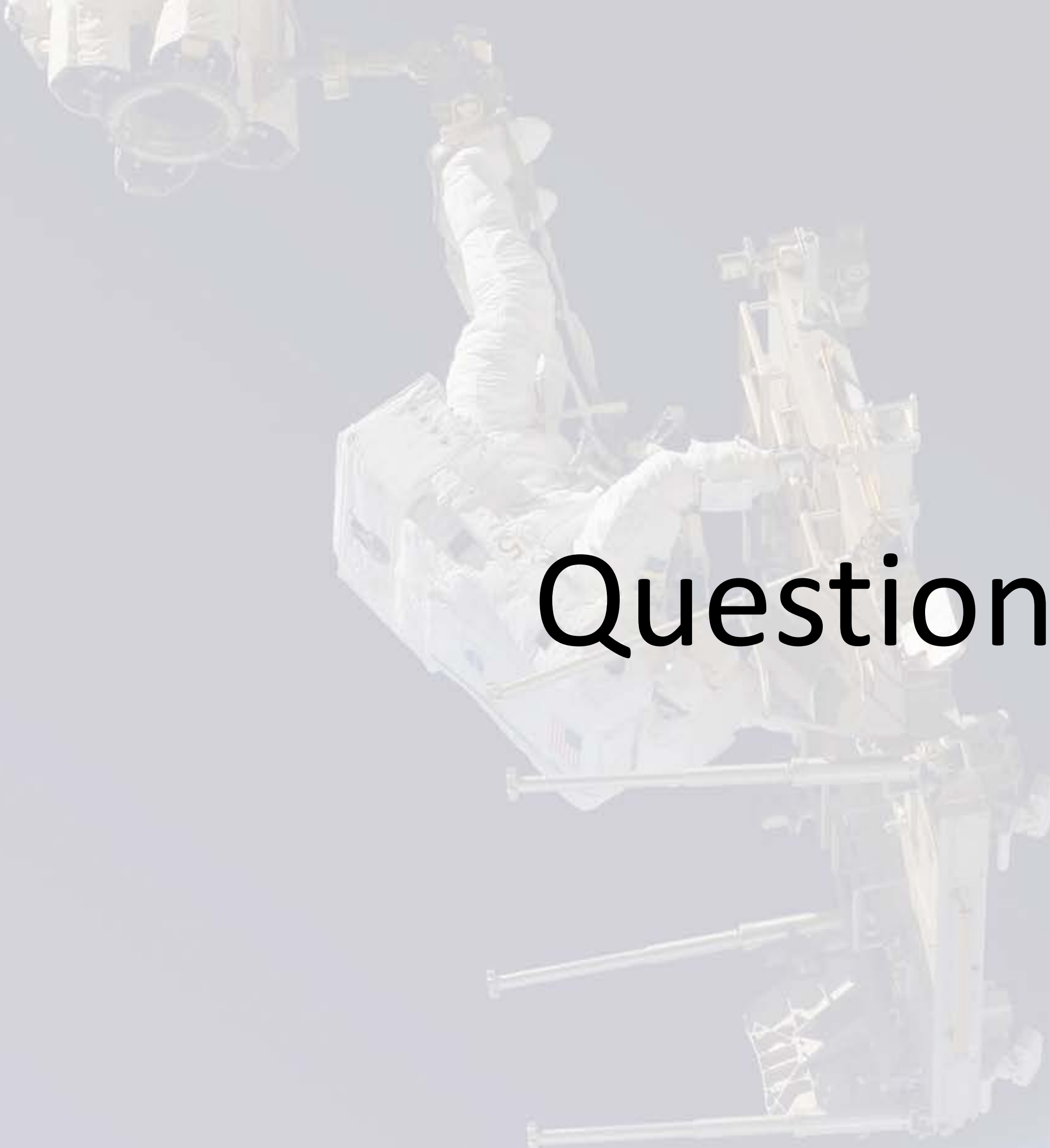
Grease on an ISS Radiator



Conclusion

- Unforeseen maintenance on hardware can occur. Space hardware may not be intended to be repaired via an EVA, but it may be the best option.
- US EVA 30 highlights the importance of creativity and a solid foundation to solve problems with limited resources.
- Taking risks with non-conventional solutions can save EVA time and money.
- For future missions, keeping designs simple and EVA compatible could be beneficial.
  - Resourcefulness of using hardware already on board may be the only option.
  - Using an on-board 3D printer to create a new piece of hardware or a replica of the details of an external piece of hardware that needs to be repaired could be the key to mission success.

- **Future missions need to have a good plan, extensively train every detail, and test the responsible ground personnel to assure they can handle any situation that arises—all of which lead to successful on orbit execution.**



Questions?