The United States Naval Academy
Space Systems Engineering Laboratory

and

Midshipmen Satellite Operation Team
proudly presents...

United States Naval Academy Robotic Repair Satellite (RSat)

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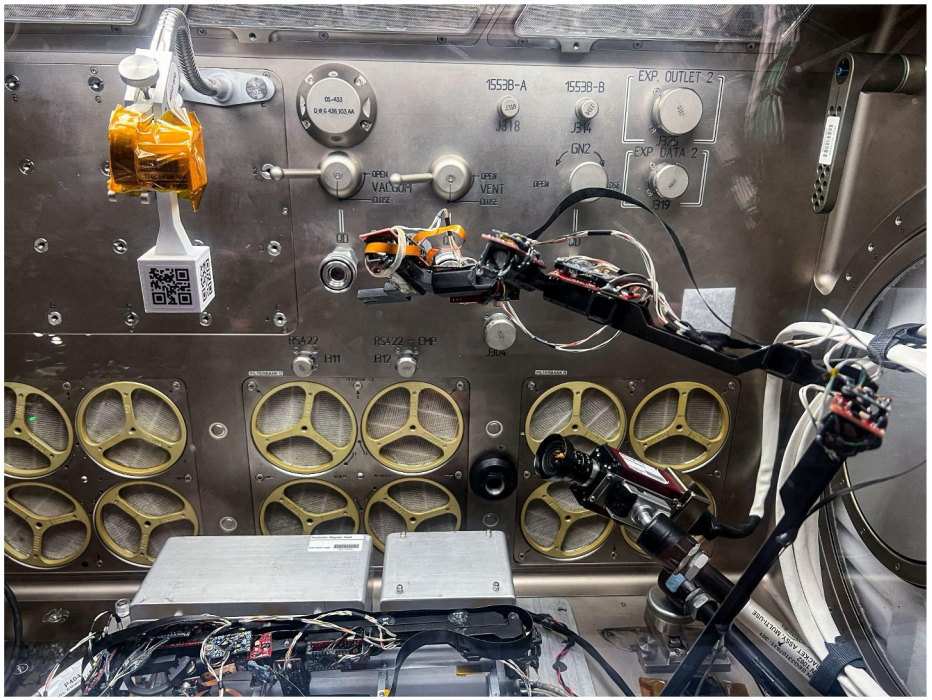


Mission Objective

Goal of RSat

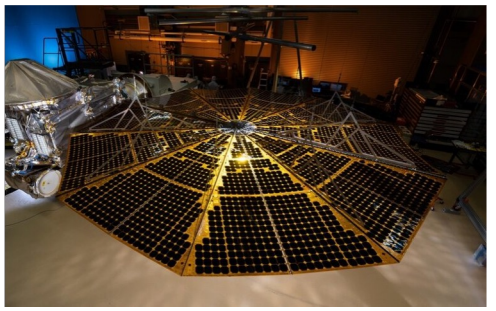
"To demonstrate robotic arm functionality on-orbit, in order to advance **on-orbit servicing**, **assembly**, and **manufacturing capabilities**"

On-Orbit Servicing Challenges

1. Sustainment of increasingly complex operations in space will soon require on-orbit assembly and repair capabilities

2. Current solutions are either too large or too limited in operational scope to be used more broadly

[NASA - Lunar Gateway]



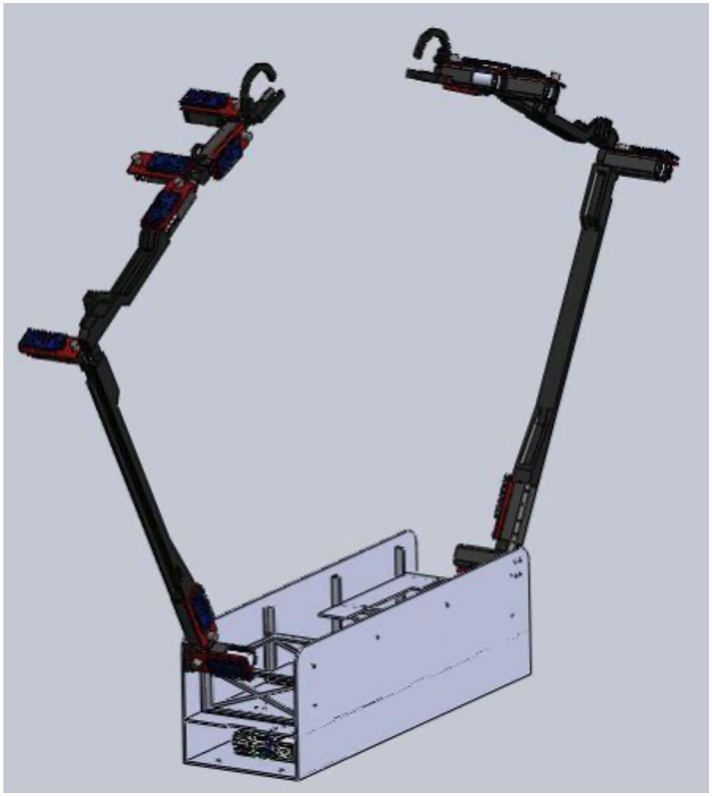
[Lockheed Martin - Lucy Spacecraft]

[NASA - James Webb]

[Boeing - Orbital Express]

The RSat Solution

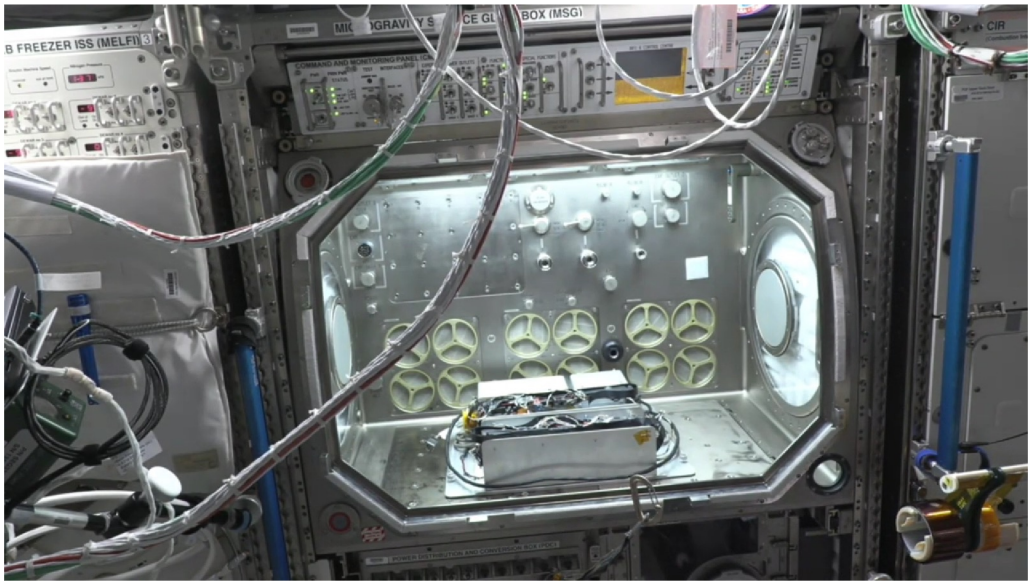
- Our solution to this problem is to develop an **inexpensive**, **reliable**, and **versatile** system capable of on-orbit assembly and repair for a wide variety of missions
- Streamlined and replicable production of robotic arms through utilization of COTS components in CubeSat structure



Current Mission on ISS

Mission Objective: Proof of Concept

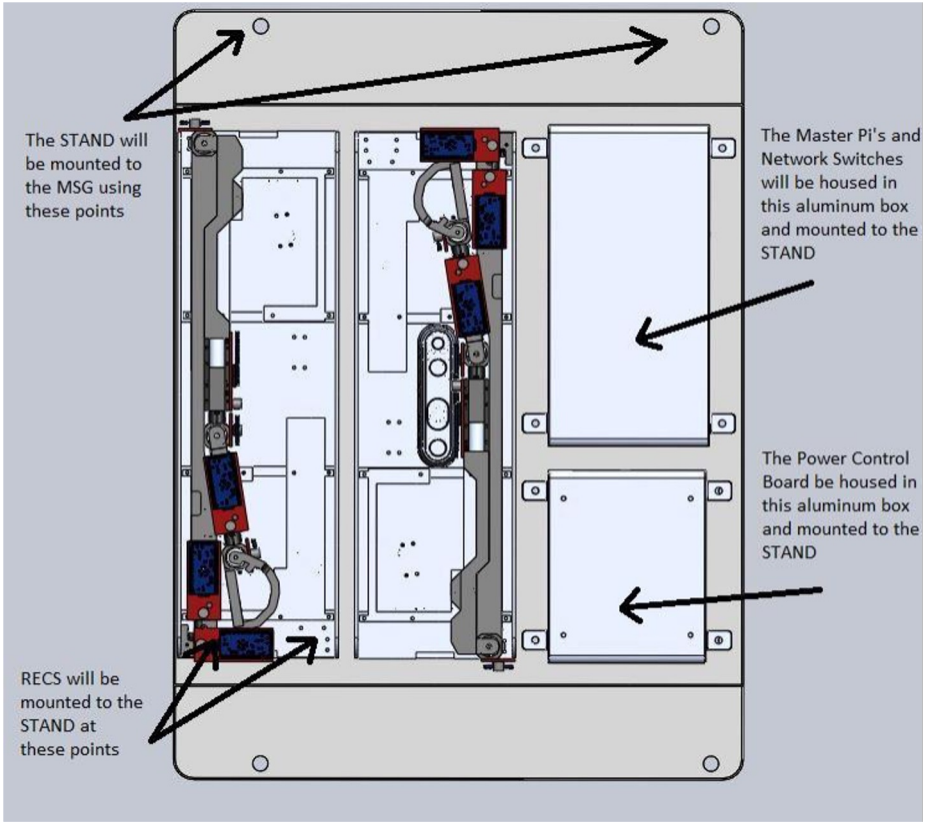
Utilize the ISS Microgravity Service Glovebox (MSG) as a testbed to validate the 6-DOF control, arm coordination, and end imaging and identification capabilities needed to further the development of accessible on-orbit assembly



Design

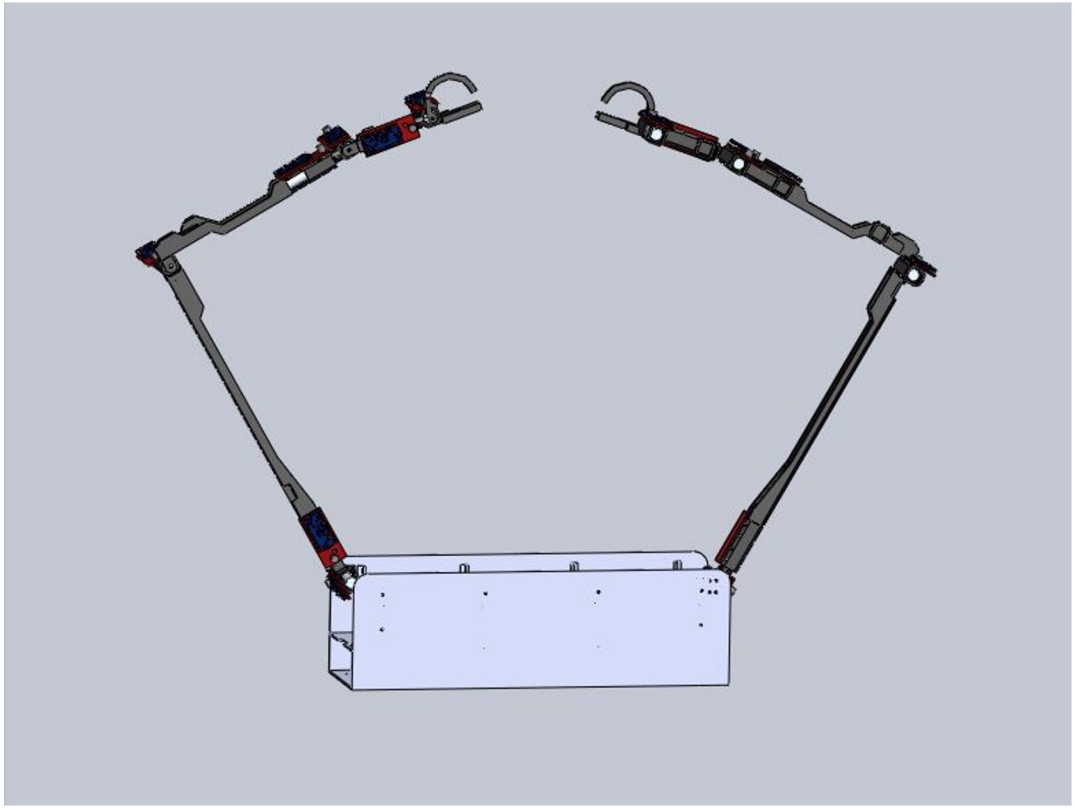
System Design

- Two 3U CubeSats are placed side by side
- Mounted in the MSG
- Each 3U CubeSat houses one robotic arm
  - Design chosen to prevent wire tangling
- Only one 3D camera mounted to only one of the 3U CubeSats



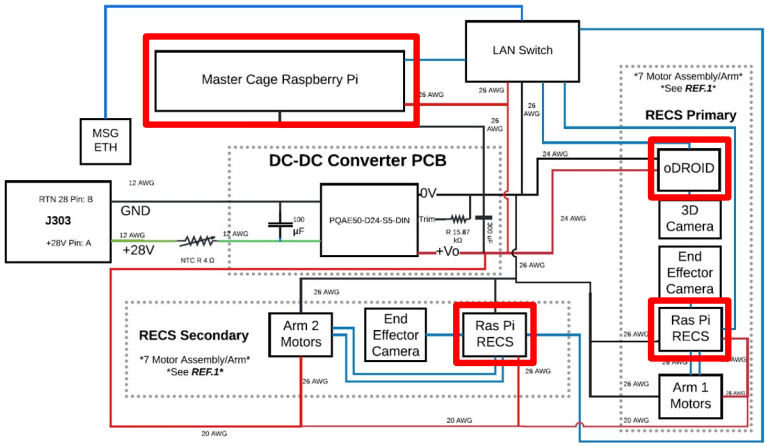
Arm Design

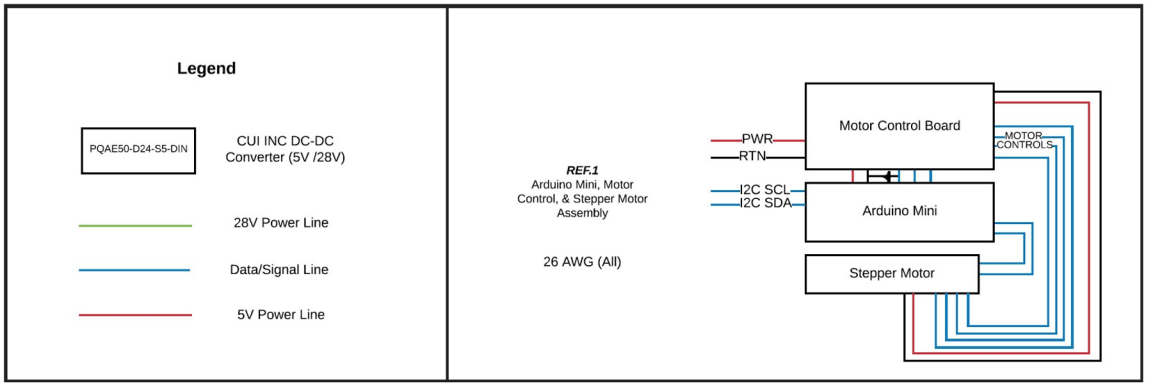
- Each arm has 7 motors
  - 6 motors for each degree of freedom
  - 1 motor for the claw end-effector
- There is a camera placed at each of the end-effector
- Each motor can be commanded individually to move each degree of freedom



Electrical Design

RECS Electrical Diagram rev009 29MAR22





Operations

Roles and Responsibilities While Operating

1. **Voice Loop Operator**
   - Responsible for keeping constant contact with the NASA ground operators via Voice Loop. Also responsible for constantly monitoring the information traffic and managing the team's communication with NASA.
2. **Main Operation Console Operator**
   - Controls the main connection to RSat. The operator is responsible for managing network connection with the payload, and performing command and control functions.
3. **Operation Logger**
   - Keeps track of all the commands that have been executed and most important history of arm movement.
4. **Arm Motion Planner(s)**
   - Runs MATLAB script for each arm to generate the motor solutions

Operations Part 1: 10JAN-02FEB

RSat Installed in MSG and Tested

Day 1: Hardware Install

Goal of the Day: Hardware Install

Results:
Arm 1: 5 of 7 motors functioned as expected.

Arm 2: All motors responsive.

3D camera test was successful.

Challenge 1: Arm 1: Motors 1 and 3 were non-responsive

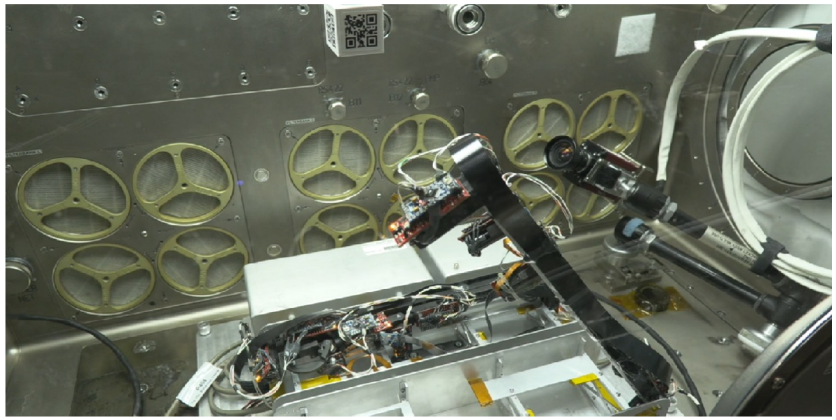
Day 2: Arm Deployment Test

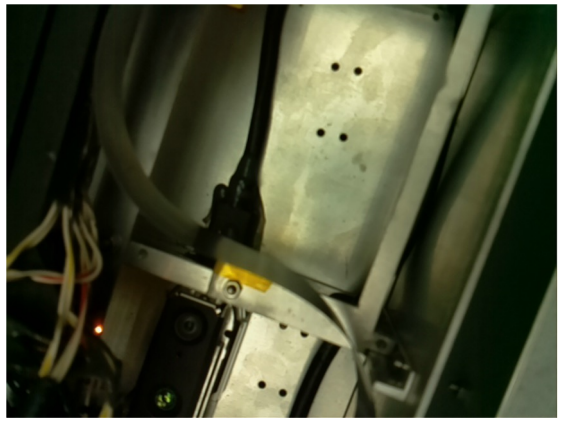
Goal of the Day: Arm Deployment Test

Results: Selfie taken of its metal base. Sent to USNA via WinSCP.

Arm 2: successfully carried out ssh to each microcontroller.

3D camera test was successful.



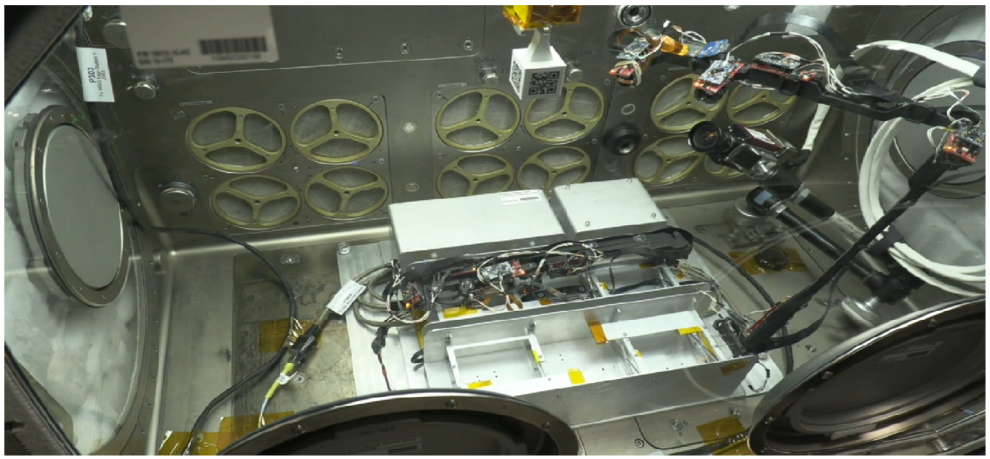


Day 3: Arm Maneuvering Tests

Goal of the Day: Arm Maneuvering Tests

Results:
Arm 2:

- Took multiple photos of the 3D camera and Arm 1.
- Positioned to take a picture of a QR code on the Cube.
- Sent pictures of Arm 1 motors/joints and the 3D camera to USNA



Challenge 1: MasterPi and ArmPi 1 could not be pinged from USNA

Solution: USNA requested a power cycle from MSG and successfully pinged MasterPi and ArmPi 1

Day 4: Arm Maneuvering Tests

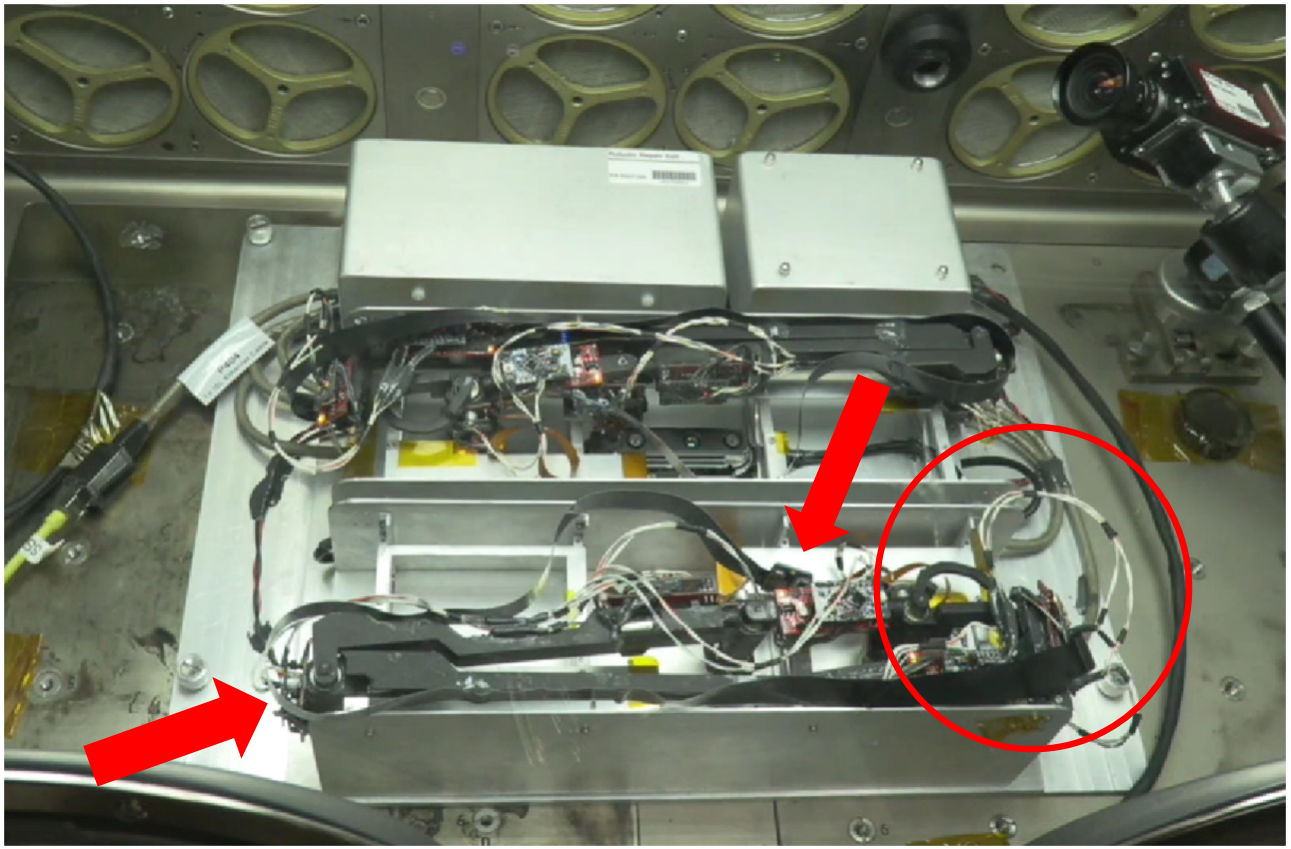
Goal of the Day: Arm Maneuvering Tests

Results: Arm 2 was maneuvered into stow position to prepare for removal from MSG.

Challenge 1: QR Cube was installed too close to the front glass panel of MSG for Arm 2 to approach.

Challenge 2: Arm 2 wire harness and structure had issues clearing the body of Rsat.

Day 4: Move-to-Point Maneuver Test



Operations Part 2: 19MAR-15APR

Target Acquisition

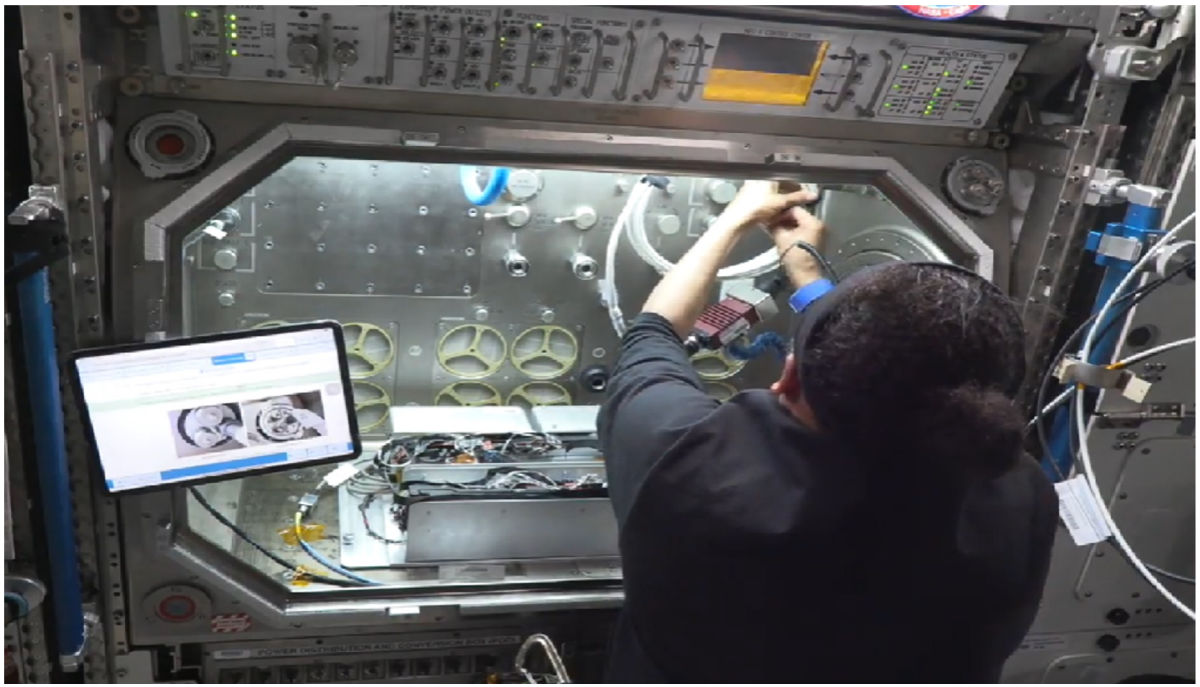
Day 5: Hardware Install

Goal of the Day: Hardware Install

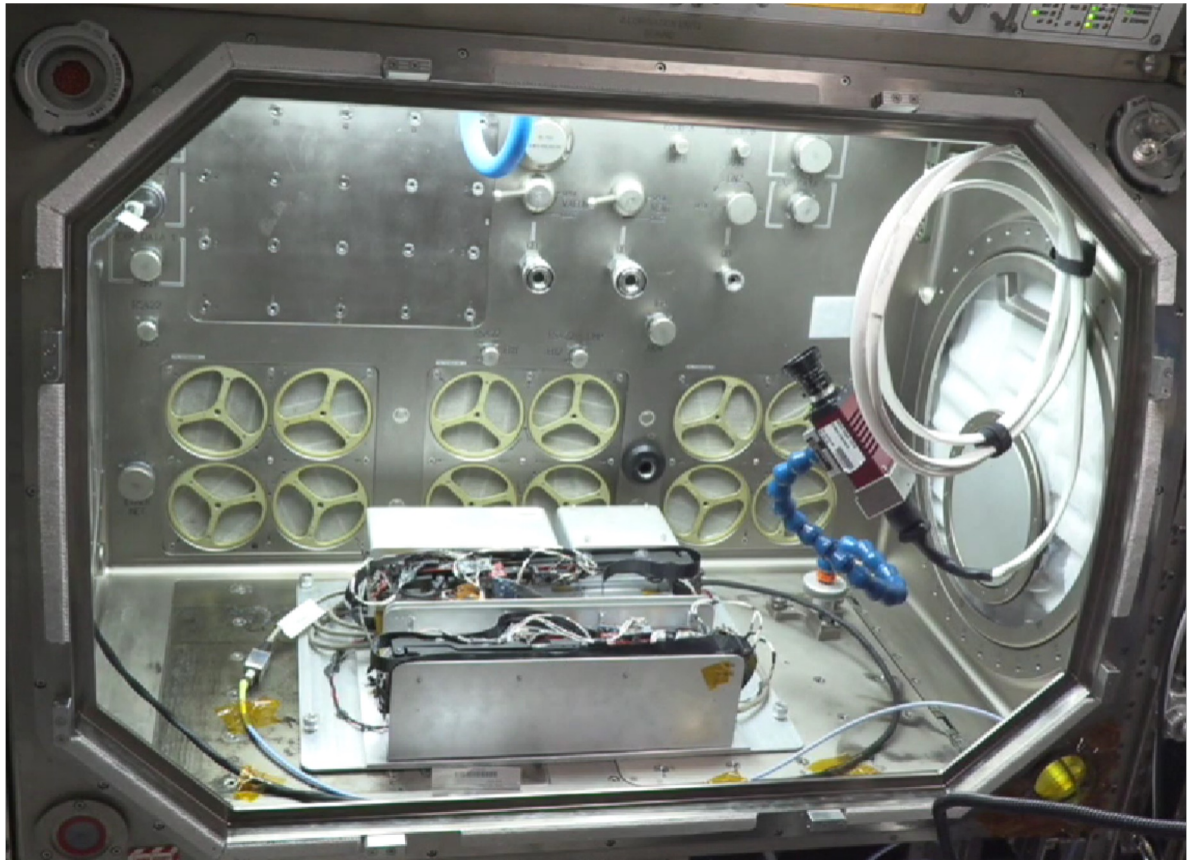
Results: RSat hardware installed and camera set up in MSG.

Challenge 1: Arm 1 Motor 1 and Arm 2 Motor 3 did not reach max angles.

Challenge 2: Arm 2: Motor 3 had limited mobility.



Day 5: Hardware Install



Day 6: Inspect and Grab Ring

Goal of the Day: Inspect Target and Grab Ring

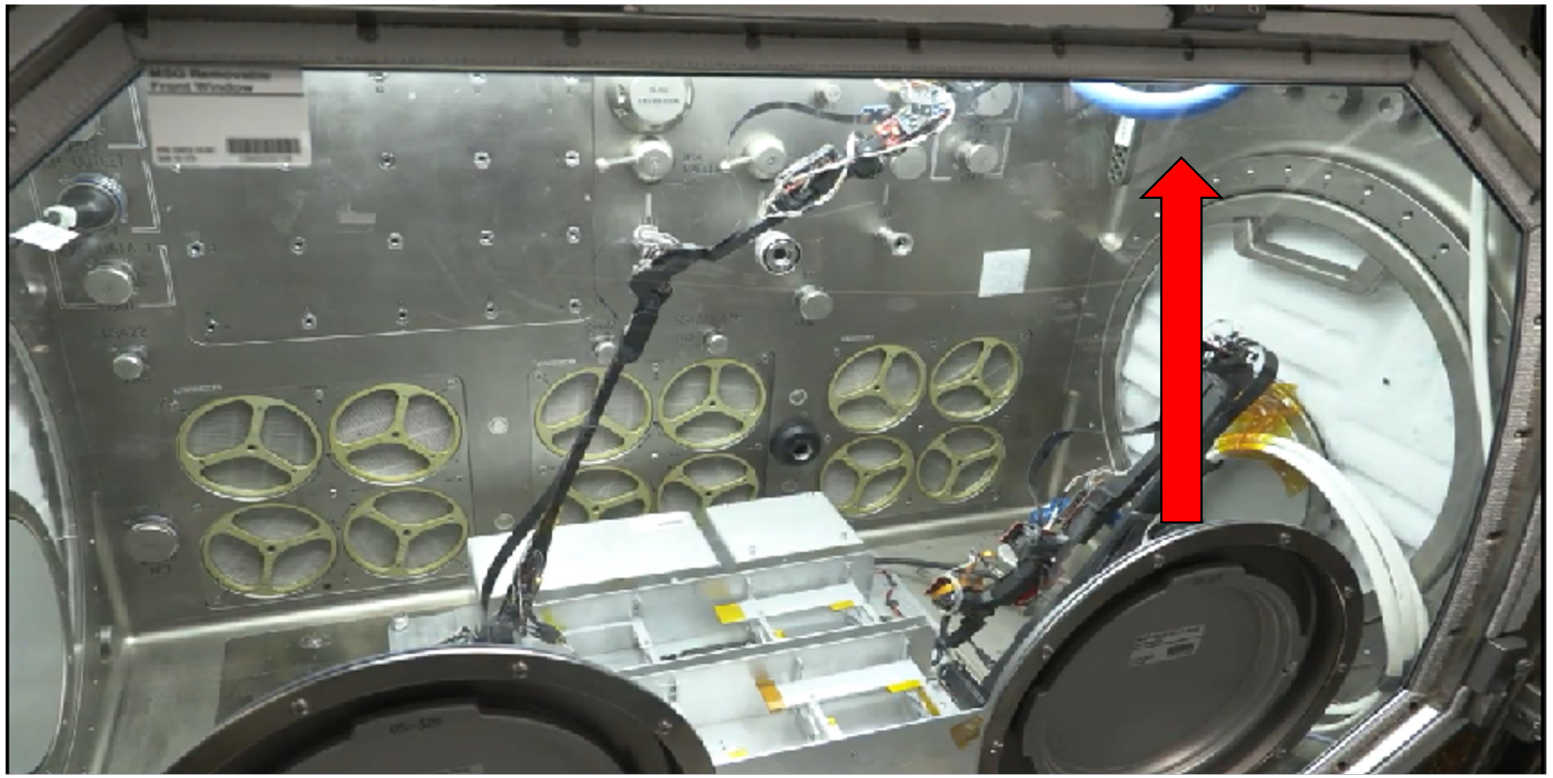
Results: Arm 1 “caught” the target by resting on it.

Challenge 1: Did not have full control of ring.

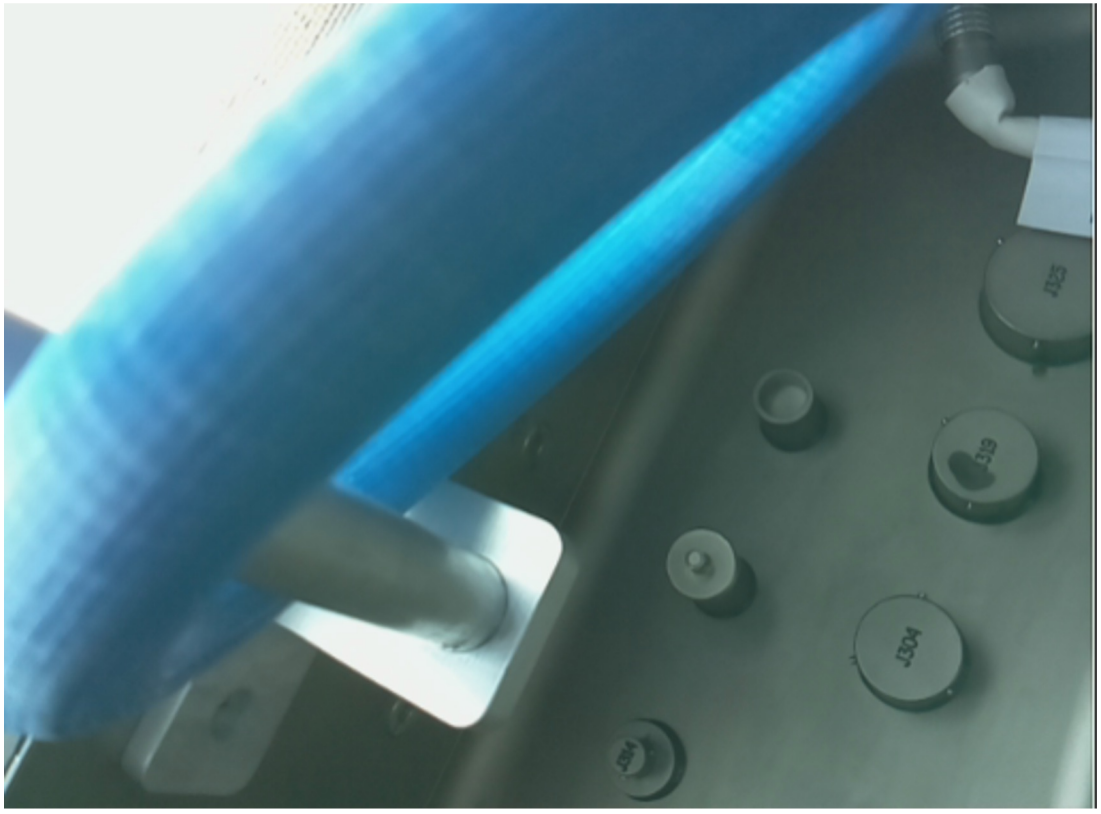
Challenge 2: Network issues caused video interruptions.

Challenge 3: Ring was bumped into the upper corner of the MSG making it much more difficult to grab.

Day 6: Ring Position



Day 6: Ring Position



Day 7: Handshake and Target Inspection

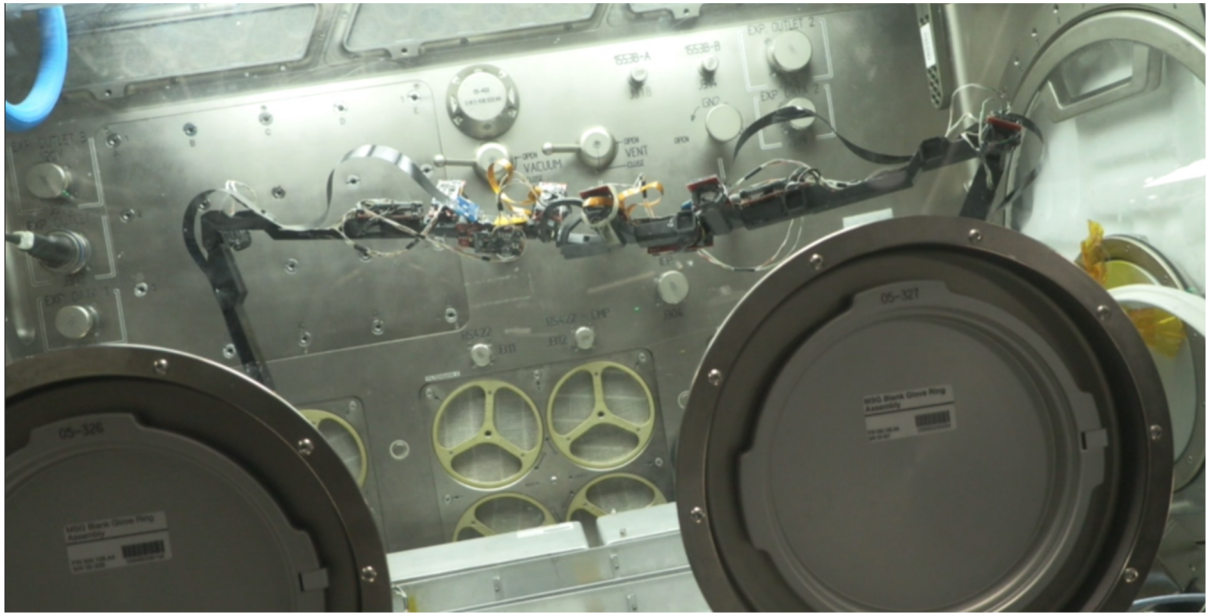
Goal of the Day: Target Inspection/Handoff Maneuvers

Results: Arm 1 and Arm 2 successfully shook hands! This “advanced” procedure was accomplished in 20 minutes.

Challenge 1: Lengthy camera install.

Challenge 2: Camera was bumped during operations; obstructed view partially.

Challenge 3: Reduced ROM of motors due to cabling.



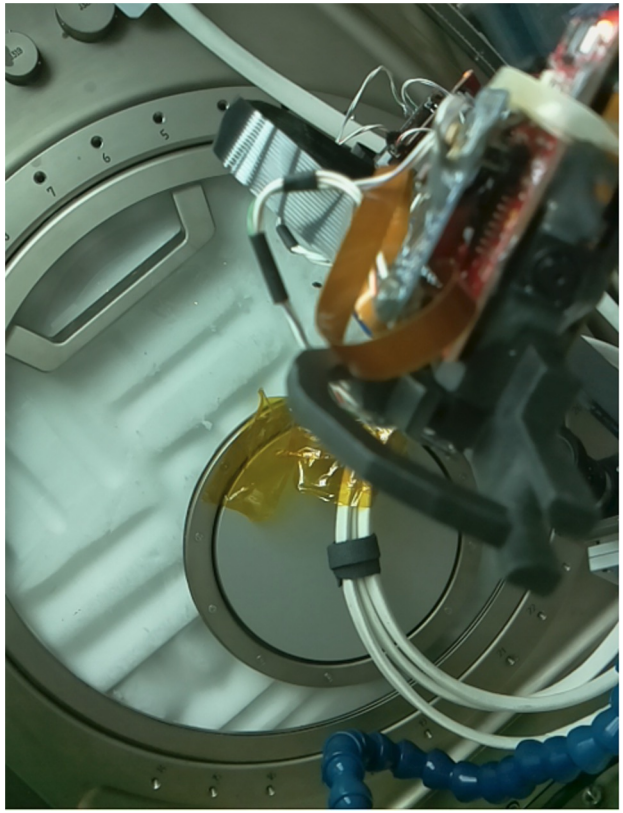
Day 8: Target Inspection

Goal of the Day: Grab ring

Results: Failed to grab ring.

Challenge 1: Camera bumped during operations, readjusted by crew.

Challenge 2: Contact with ring caused it to float too far away.



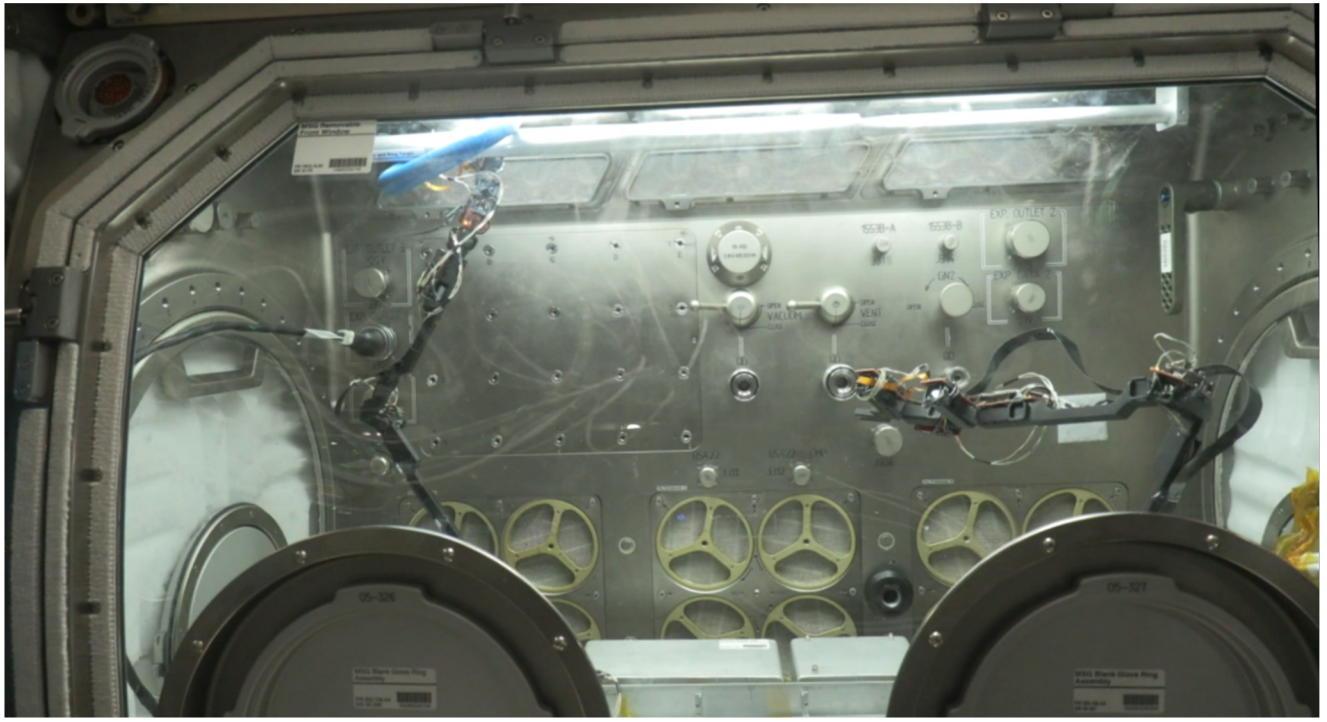
Day 9: Ring Acquisition

Goal of the Day: Grab ring

Results: Ring captured!

Challenge 1: View was obstructed by sticker on MSG window.

Challenge 2: External wiring got caught on the ring.

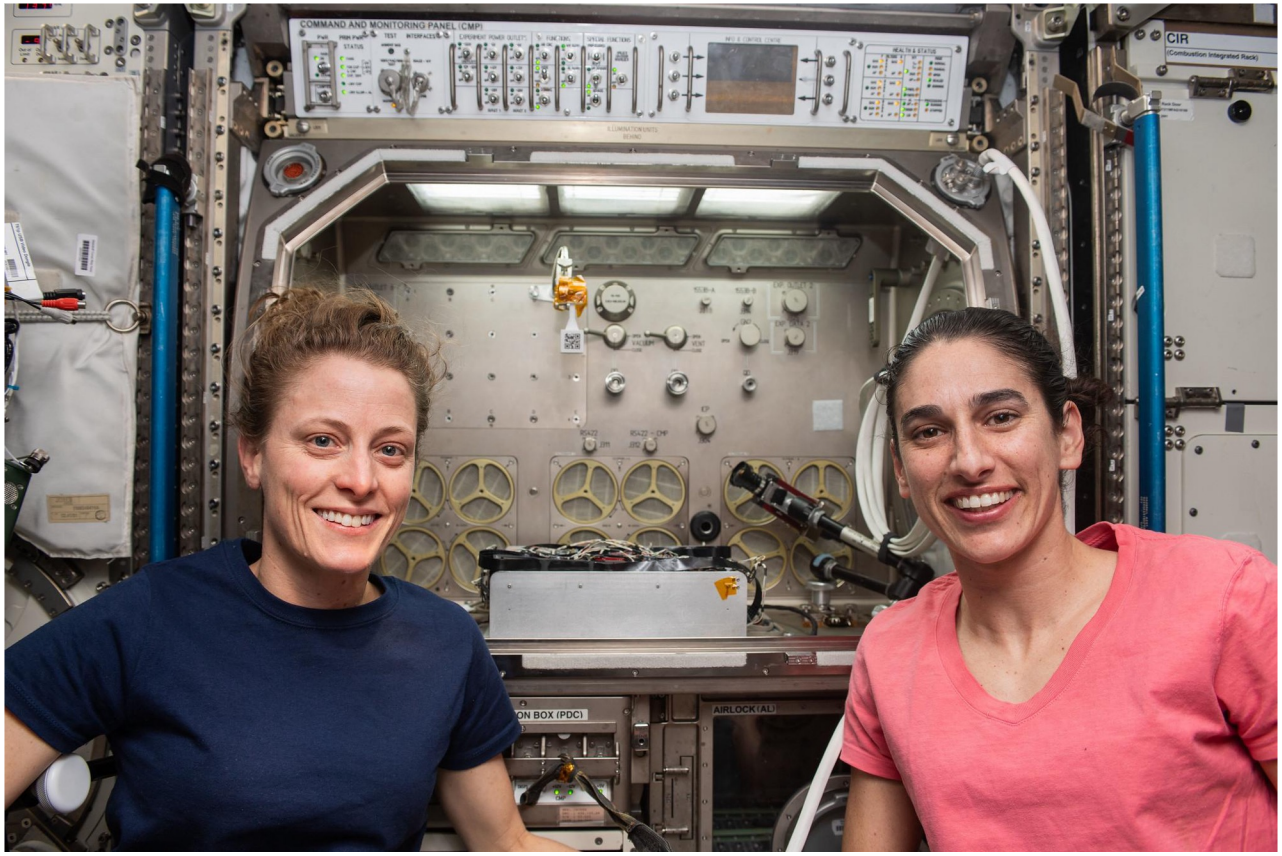


Operations Summary

Over the 9 operating sessions on the ISS, the team achieved:

- Target maneuvers
- A two-arm handshake
- Taking multiple photos of target cube and ring using 3D camera
- Successful acquisition of the ring

Go RSat!



* NASA Flight Engineers Loral O'Hara and Jasmin Moghbeli with RSat

Thank you.
Questions?