Robotic Refueling Mission:

Paving the Way for In-Space Robotic Refueling and Repair

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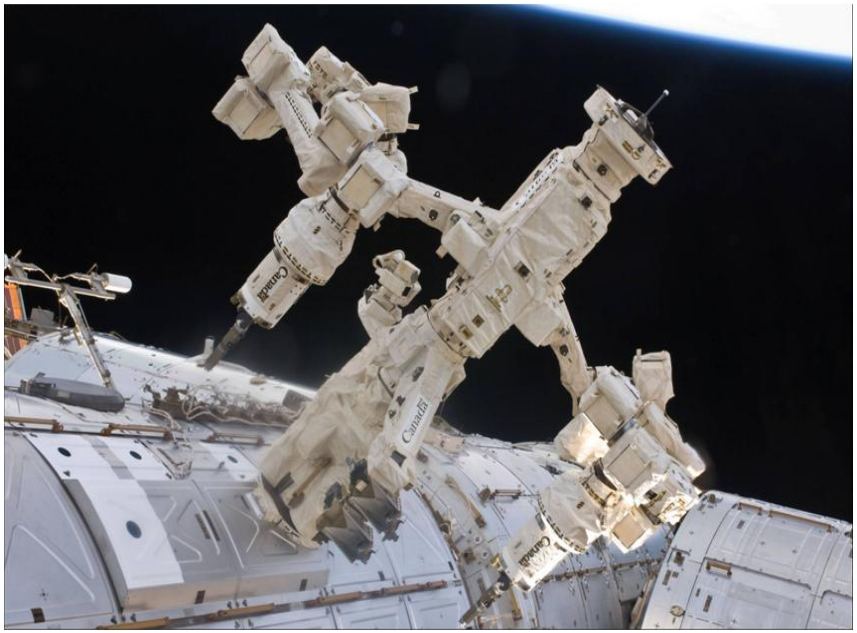
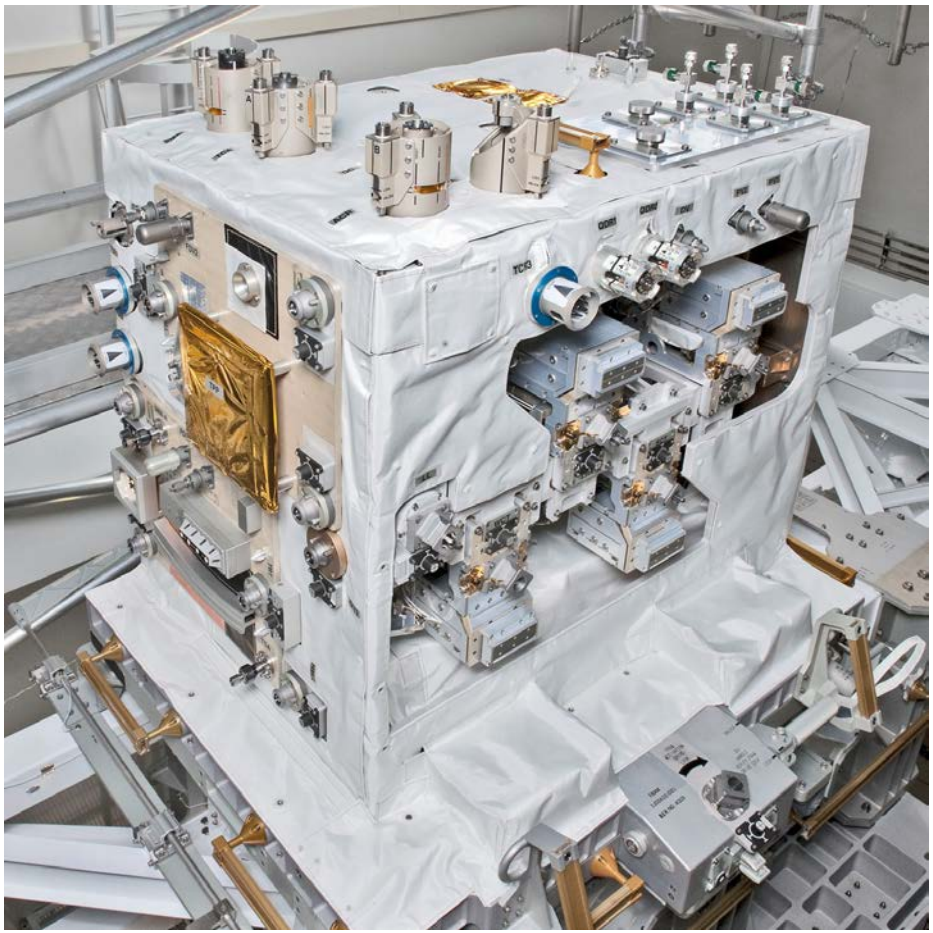
Robotic Refueling Mission (RRM) Overview

Primary Goal: Advance robotic servicing technology by demonstrating the use of innovative robotic tools and techniques to remotely manipulate standard satellite interfaces that were not designed to be manipulated robotically

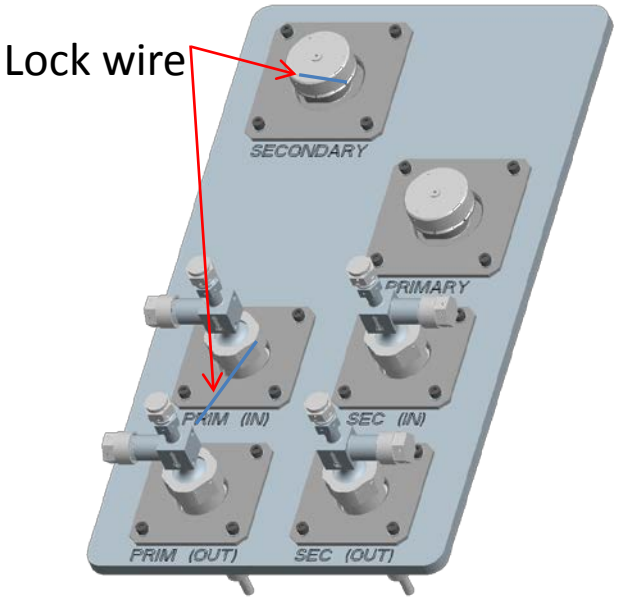
Joint effort between NASA and the Canadian Space Agency (CSA) utilizing: Space Station Remote Manipulator System (SSRMS) or Canadarm2 and Special Purpose Dexterous Manipulator (SPDM) or Dextre





RRM On-Orbit Tasks

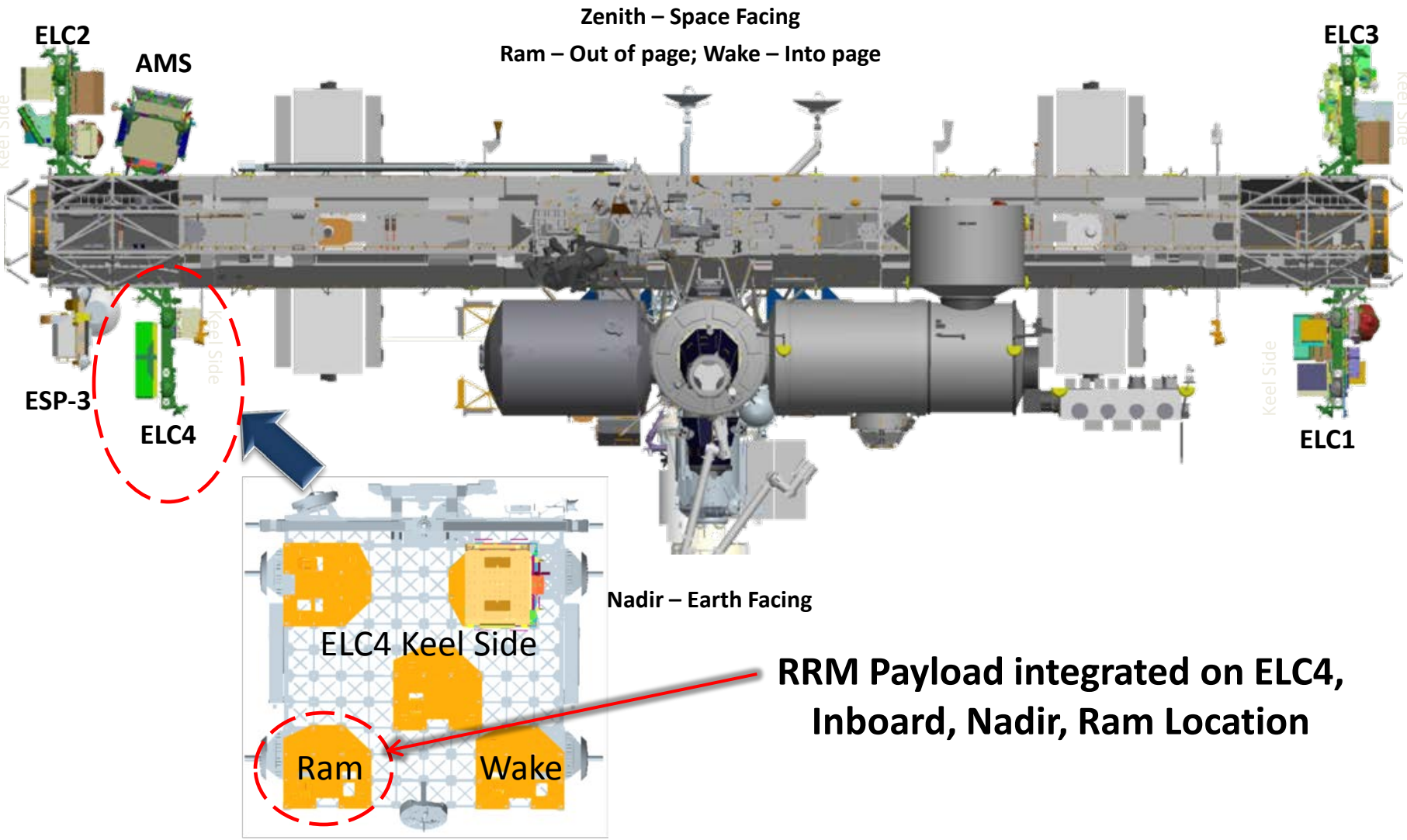
- Six main on-orbit objectives:
  - Vision Task to gather images of satellite interfaces under different orbit day and orbit night conditions
  - Coolant Valve Panel Task to demonstrate cutting safety wire and removing gas fittings found on many NASA satellites
  - Refueling Task that will demonstrate cutting multiple configurations of safety wire, removing tertiary and safety caps, threading on to propellant fill/drain valves and transferring a referee fluid across the interface
  - MLI Manipulation Task to demonstrate peeling back multi-layered insulation
  - Torque Set Task to demonstrate removal of small #10 fasteners
  - RF Connector Task to demonstrate removal of Sub-Miniature A (SMA) termination caps



Coolant Valve Panel

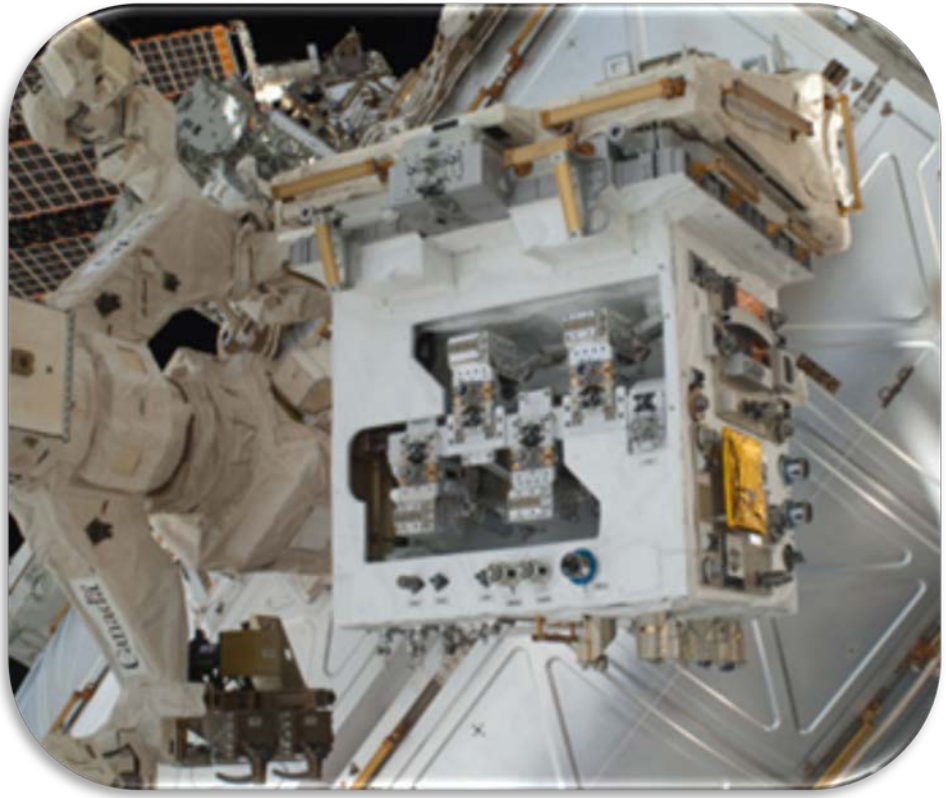

Typical Spacecraft fill/drain valve

RRM On-Orbit Location



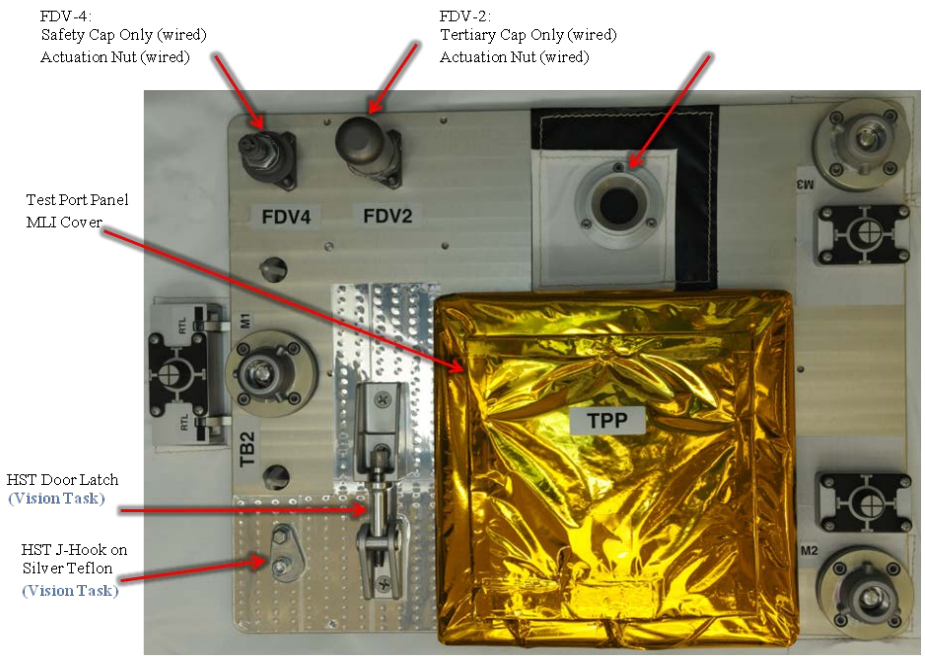
RRM Payload - Overall Description

- Payload Structure
  - Provides mounting support structure for all payload elements including: tool stowage system, flexible hose management system, multiple fill/drain valves and stowage receptacles and task board mounting locations
  - MLI blanketing area to demonstrate manipulation of various fastened blankets…simulating fill/drain valve and closeout panel access
- Fluid Transfer System
  - Provides the plumbing to demonstrate a propellant transfer
  - Contains monitoring devices (pressure transducers and thermostats) and controllable valves
  - Provides 2 fully functioning Fill/Drain Valves for robotic tool task demonstrations
- Electronics
  - Provides the ELC/ExPA power and data interfaces to the payload
  - Provides the control and monitoring services of the Fluid Transfer System
  - Provides the control and temperature services of the entire payload

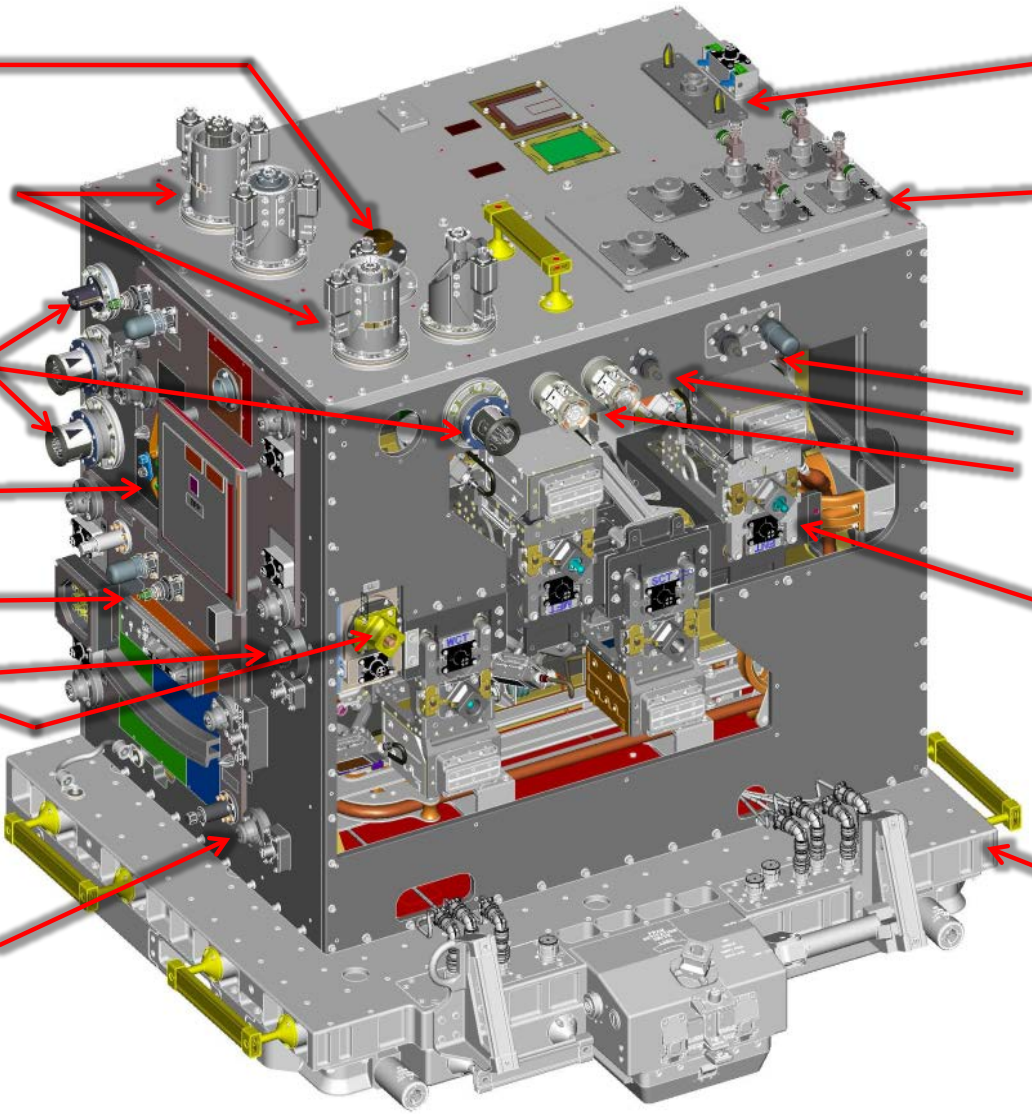


RRM Payload - Overall Description (Cont)

- Interactive & Vision Processing Task Boards
  - Provide various configurations of a Spacecraft propulsion fill/drain valves and fluid and gaseous service valves for robotic tools, cameras and lighting task demonstrations
  - Host an array of 9 recessed Sub-Miniature A (SMA) coaxial receptacles w/terminator caps for robotic tool release, removal and stowage
  - House a fastener block of #10 Torque Set fasteners
  - MLI blanketing area to demonstrate tape shearing and manipulation of panel closeout blanketing
  - Various spacecraft interfaces with an assortment of MLI backgrounds



RRM - Payload Overview



Circular Demo Electrical Connector

Multi-Function Tool (MFT) Tool Adapter Receptacles (4x)

Cap Receptacles (Tertiary [x3] & Safety)

Task Board 2

Task Board 1

Tool Stowage System Launch Lock & Override

Flexible Hose Management System Launch Lock

Spare Task Board Stowage Location

Coolant Valve Panel (CVP)

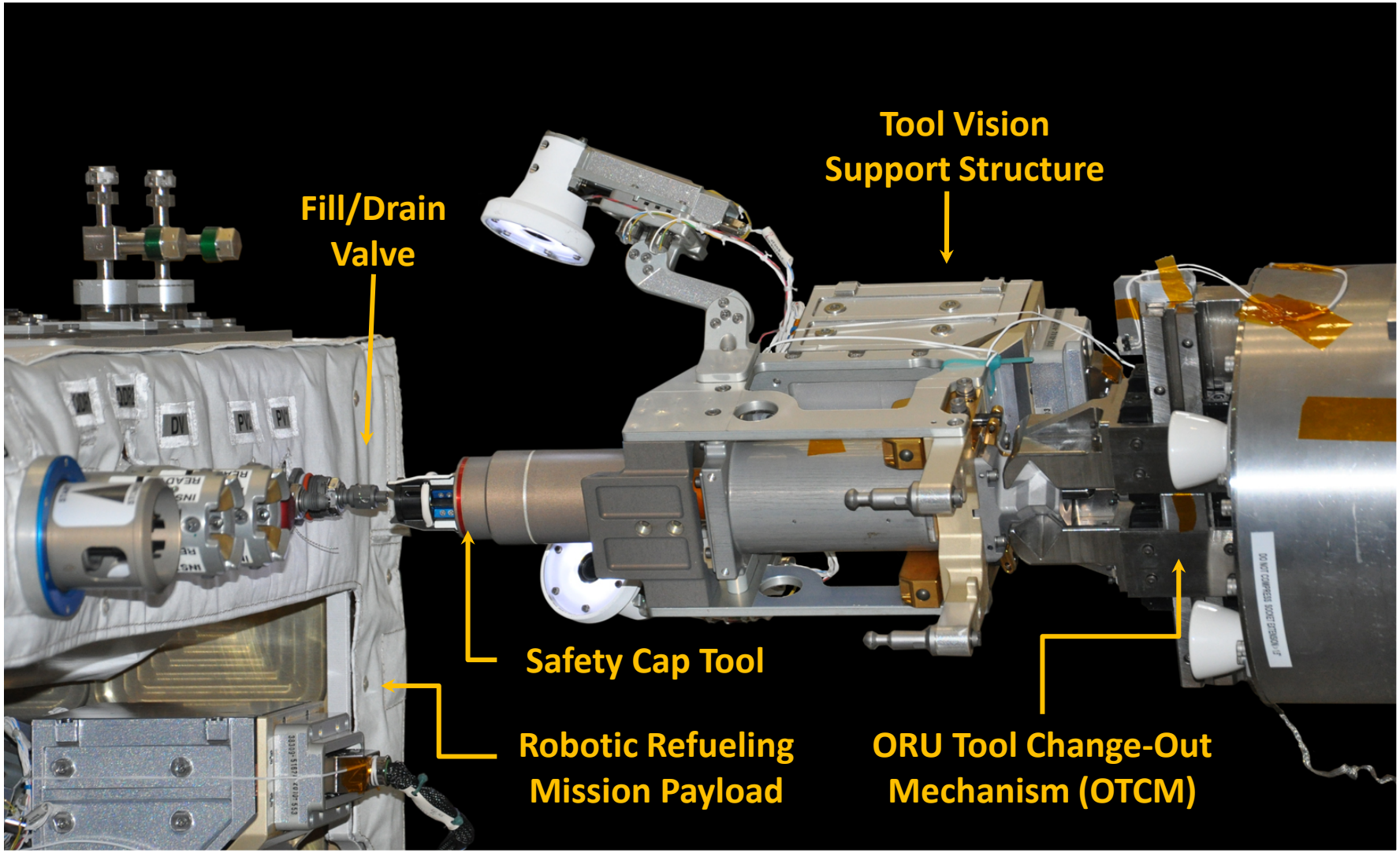
EVR Nozzle Tool (ENT) Interfaces:

- FTS Plumbed Valves (2x)
- "Dummy" Valve
- ENT Quick Disconnect Tips (2x)

Tool Stowage Bench: Supports the four tool complement

ExPA

RRM Hardware



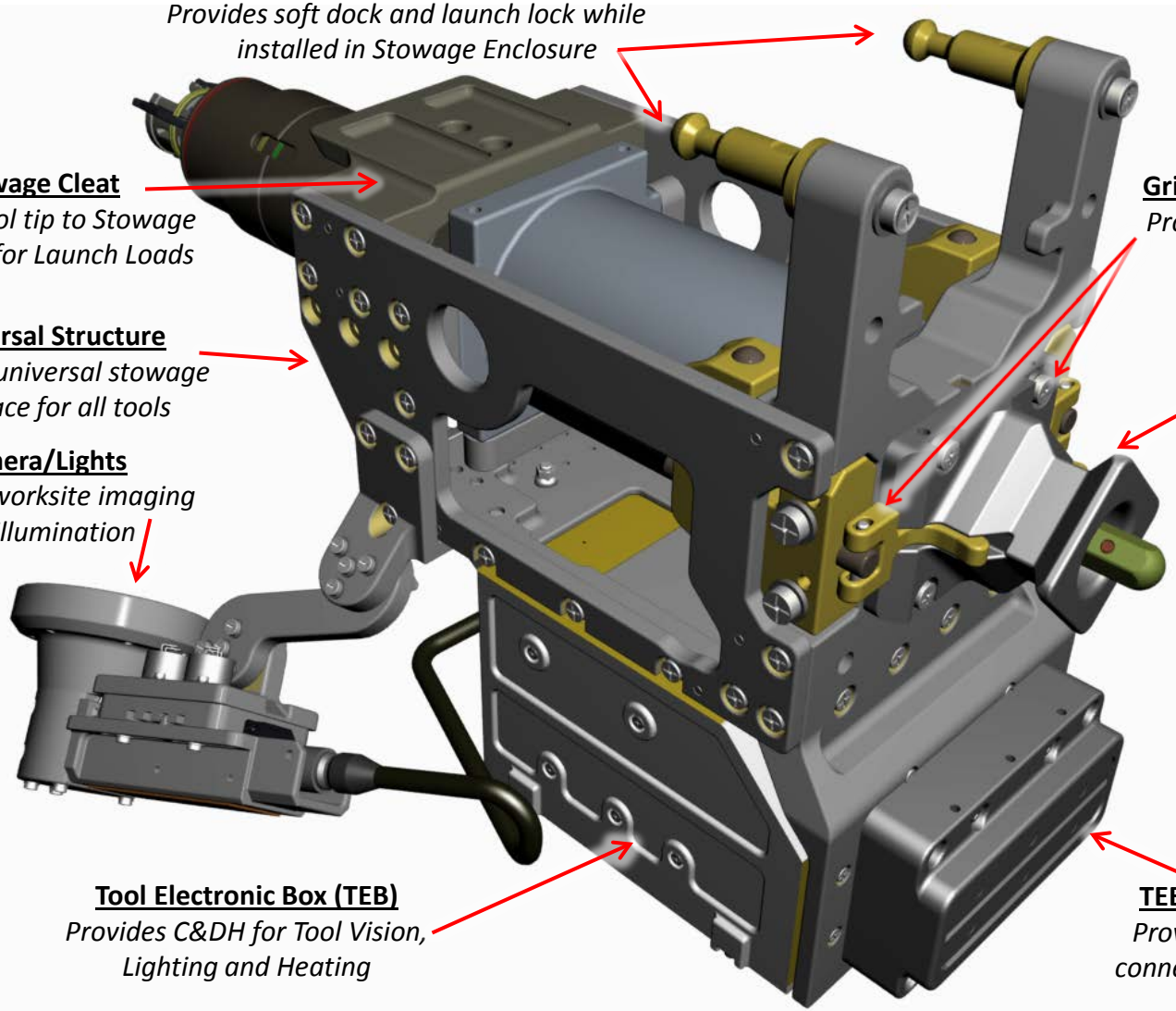
Tool & Vision Support Structure (TVSS)

Bayonet Probe (2x)
Provides soft dock and launch lock while installed in Stowage Enclosure

Stowage Cleat
Couples tool tip to Stowage Enclosure for Launch Loads

Universal Structure
Provides universal stowage interface for all tools

Camera/Lights
Provides worksite imaging and illumination



Gripper Actuated Latch (GAL) (2x)
Provides hard dock while installed in Stowage Enclosure

MicroFixture
Standard OTCM Jaw Interface (Modified to accept GAL)

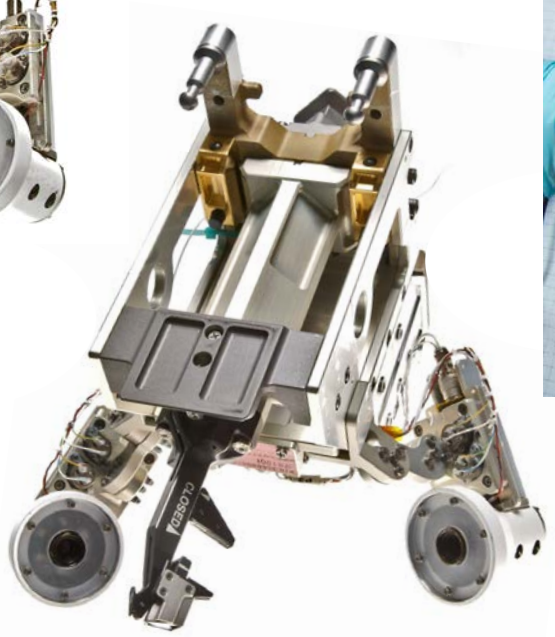
Tool Electronic Box (TEB)
Provides C&DH for Tool Vision, Lighting and Heating

TEB Umbilical Connection
Provides electrical and data connection from OTCM to TEB

RRM Tools

Safety Cap Tool (SCT)

The key to RRM is innovative or "Smart Tools"

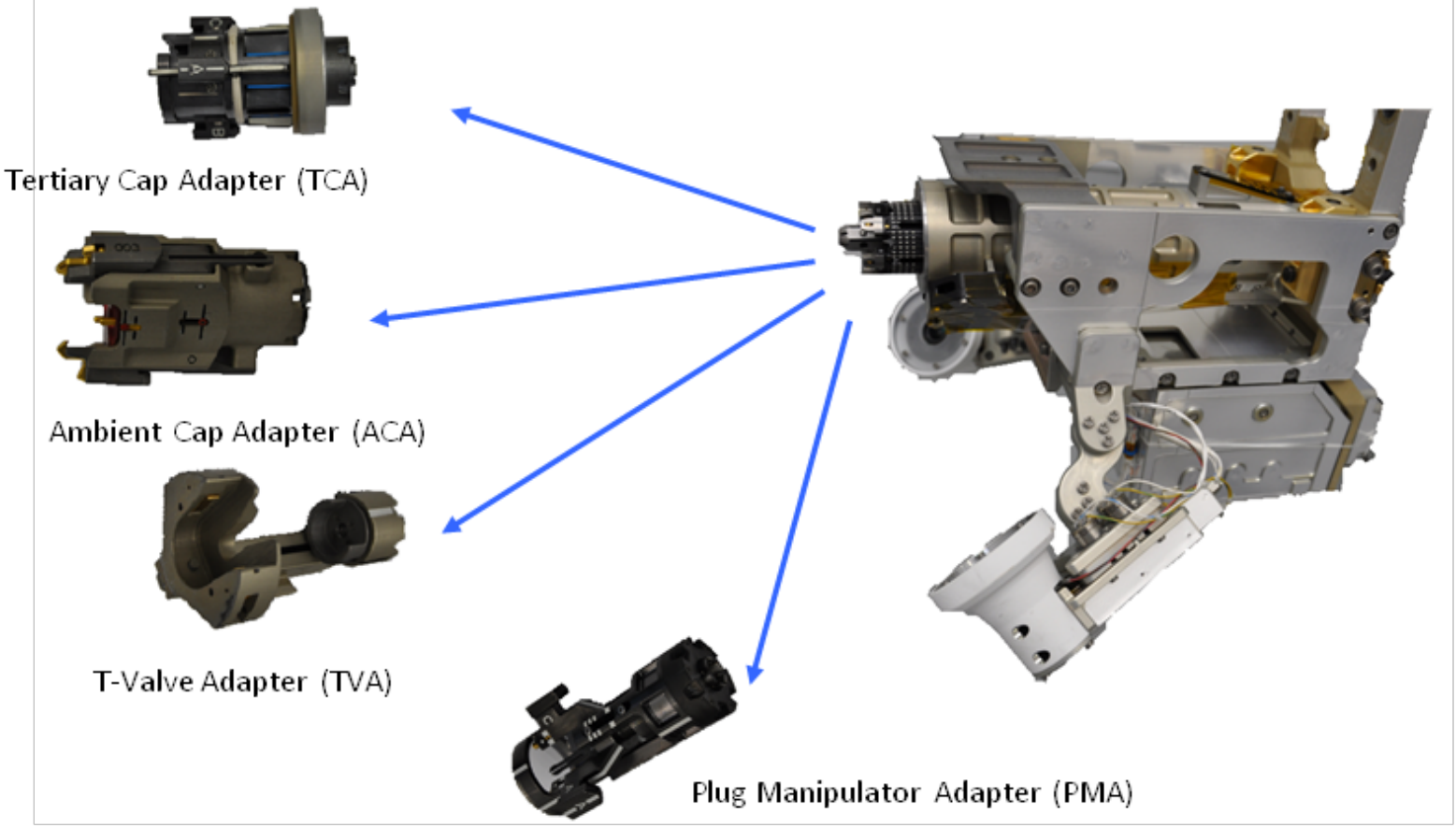


MLI/Wire Cutter Tool (WCT)

EVR Nozzle Tool (ENT)

RRM Tools – Multi-Function Tool (MFT)

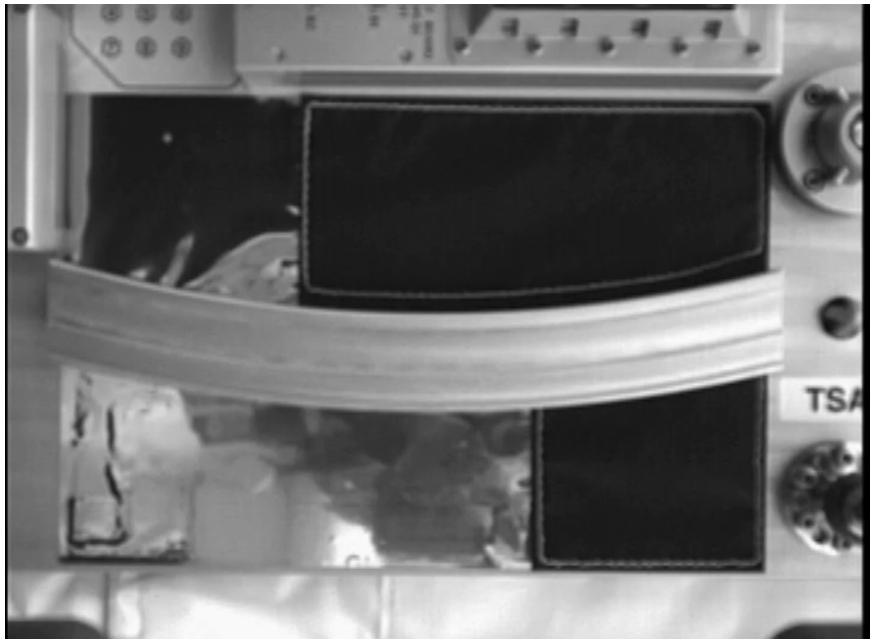
The MFT provides an interface with several adapters. The MFT and Tertiary Cap Adapter accommodate the Tertiary cap removal for the Refueling Task. The MFT then interfaces with the T-Valve Adapter, Ambient Cap Adapter and Plug Manipulator Adapter to address the Coolant Valve Tasks.



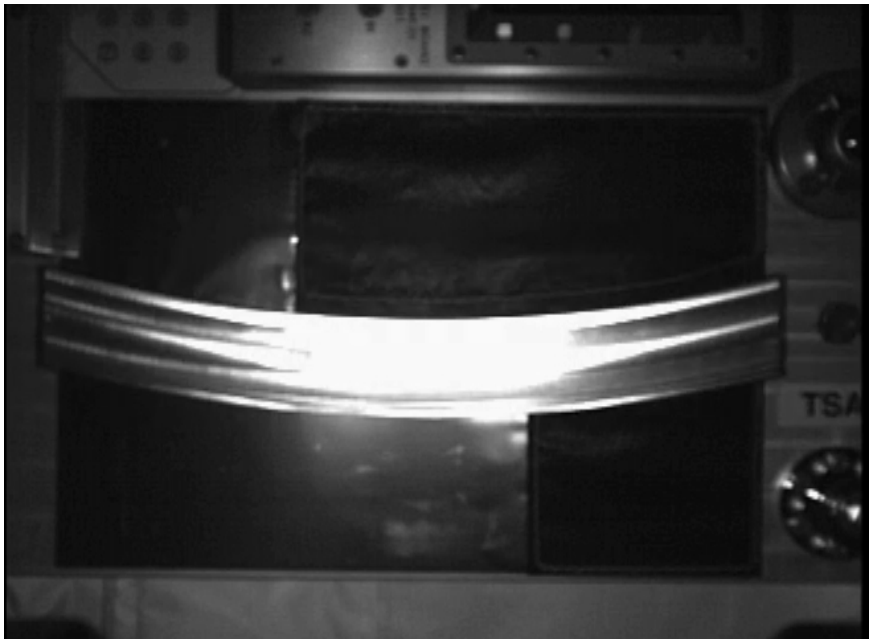
Vision Task On-orbit Summary

Completed September 7, 2011

Purpose: Gather data for mission operators and designers to support development of adequate machine vision algorithms for use on future autonomous robotic operations and potential servicing missions



On-orbit image of marman ring on Task Board 1 taken during "orbit day"

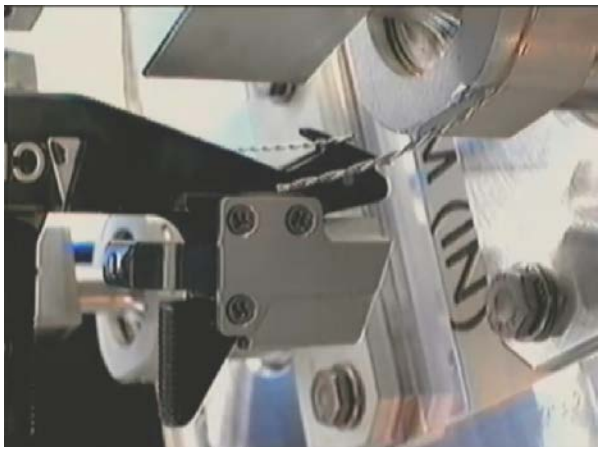


On-orbit image of marman ring on Task Board 1 taken during “orbit night"

On-orbit Operations Summary

GSFC, JSC, MSFC and CSA Teams, March 7th - 9th, 2012

- Successfully unstowed three tools: Safety Cap Tool (SCT), MLI/Wire Cutter Tool (WCT), Multi-Function Tool (MFT) from RRM tool stowage bays
- Completed functional check-outs of mechanisms and cameras of all three tools
  - Actuated each of the tool functions several times to verify post launch operations and ensure optimal lubricant distribution
  - Power cycled the tool cameras to verify operational functionality with the SPDM/ISS Video Systems
- Multi-Function Tool (on OTCM-1) successfully released seven (7) MFT Adapter Launch Locks
- Wire Cutter Tool (on OTCM-2) successfully completed 2 lock wire cutting operations on the RRM Coolant Valve Panel
- MFT and SCT successfully restowed in RRM Stowage Bays



WCT in position to cut T-Valve wire

OTCM/MFT Approaches RRM Adapter Receptacles

MFT Approaches RRM T-Valve Adapter Receptacle - Launch Lock

Video of T-Valve Wire Cutting (8x speed)

Video of Ambient Wire Cutting (Real Time)

Future of In Space Servicing

Robotic satellite servicing in the future could take five different forms:

- Remote survey
  - Provide the ability to fly around a satellite to survey, visually inspect and evaluate a damaged satellite.
- Refueling
  - Offers the capability to extend the life of space assets.
- Relocation
  - Provides the ability to move space assets to new locations including boosting satellites to the correct orbit after an initial failure or serving as a space tug to maneuver a satellite to another location
- Repair
  - Includes fixing or restoring failed spacecraft components as well as deploying stuck appendages
- Replacement
  - Includes changing or supplementing of malfunctioning satellite components

Conclusion

- Primary goal of the Robotic Refueling Mission is to advance robotic servicing technology by demonstrating the use of innovative robotic tools and techniques to remotely manipulate standard satellite interfaces that were not designed to be manipulated robotically.
- RRM operations have been extremely successful to date.
- The Satellite Servicing Capabilities Office (SSCO) at NASA/GSFC is confident that the robotic technologies that exist today are mature enough to effectively service spacecraft robotically in Low Earth Orbit and beyond.
- The time is NOW to start taking action instead of just talking about all the great things that can be done in the future.