Satellite Servicing, Assembly and Manufacturing Update: Restore-L and IRMA

NAC Technology, Innovation and Engineering Committee Meeting

April 30, 2019

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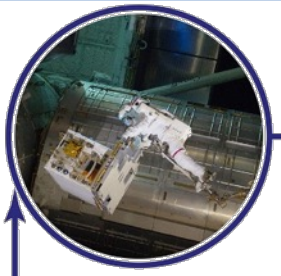
NASA's Rich Heritage of In-Orbit Satellite Servicing



Robotic Refueling Mission
2011 - 2017

Remote Robotic Oxidizer Transfer Test
2014

Robotic External Leak Locator
2015

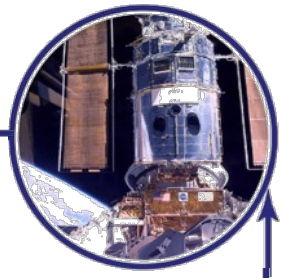
Raven
2017 - 2019

Restore-L
2022 (planned)

Hubble Servicing Mission 4
2009

Hubble Robotic Servicing and Deorbit Mission (HRSDM)
2005

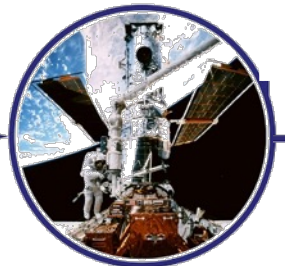
Hubble Servicing Missio 3B
2002



Hubble Servicing Mission 3A
1999

Solar Max
1984

Hubble Servicing Mission 1
1993

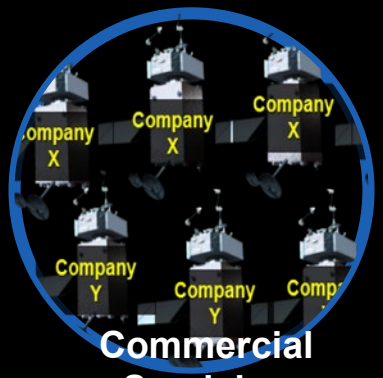


Hubble Servicing Mission 2
1997

HST Orbiting Systems Test (HOST)
1998

Future Objectives

Legacy Fleet Maintenance

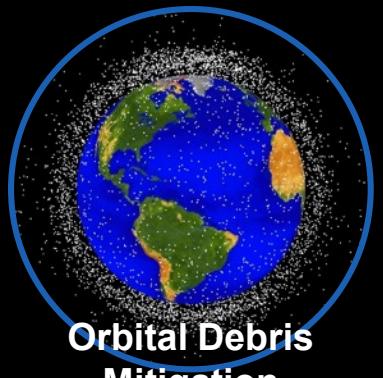


Commercial Servicing

Cooperative Fleet Maintenance and Upgrade

Cooperative Observatory Servicing

Satellite Servicing Technologies



Orbital Debris Mitigation

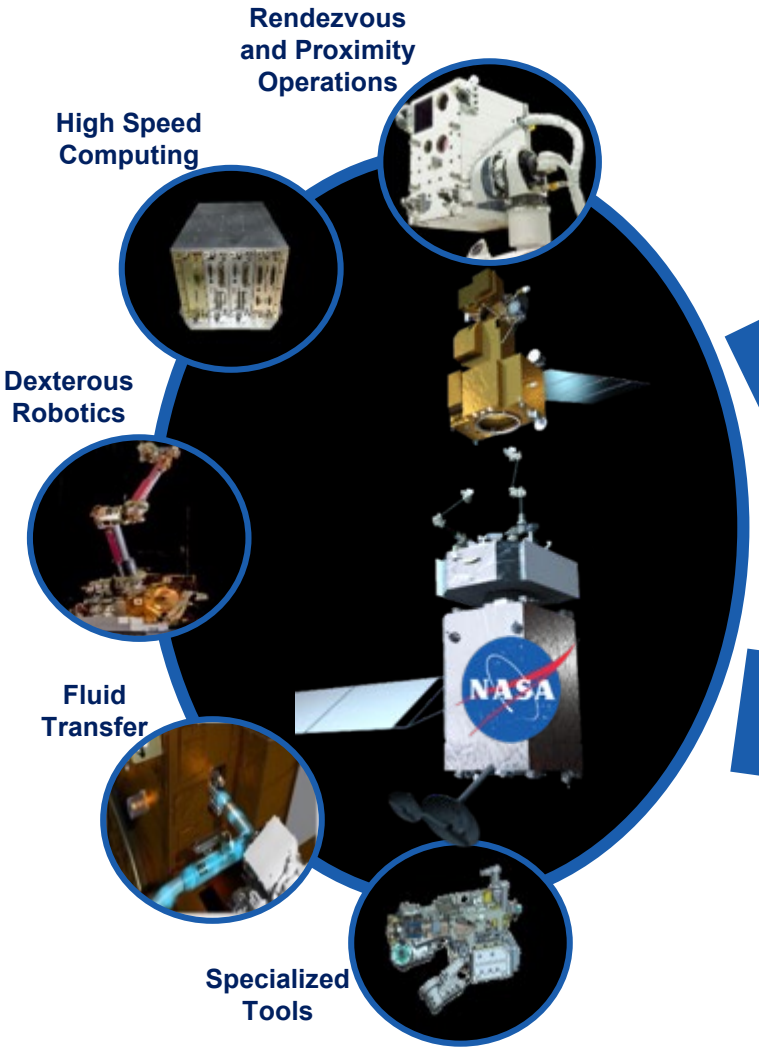
Planetary Defense

In-orbit Assembly

Human Exploration

Technology Transfer Enables Robust Servicing Market

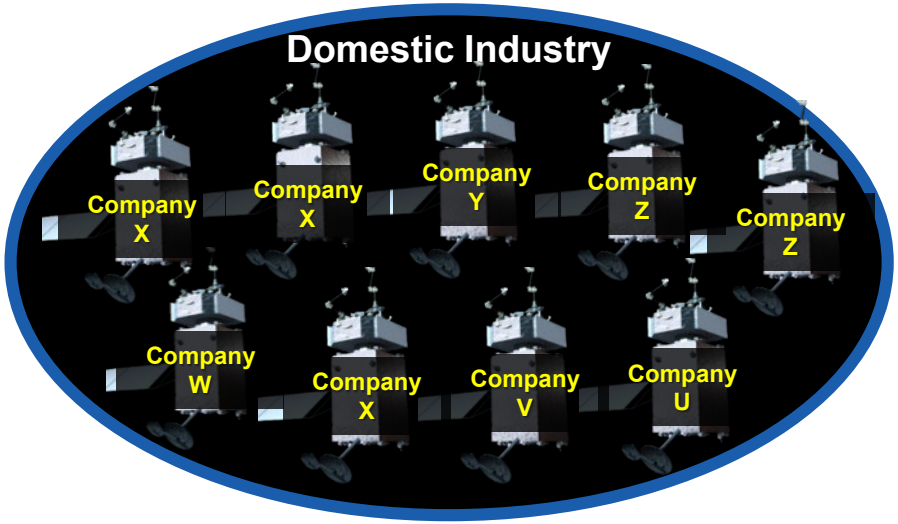
FIRST GENERATION (~2018)



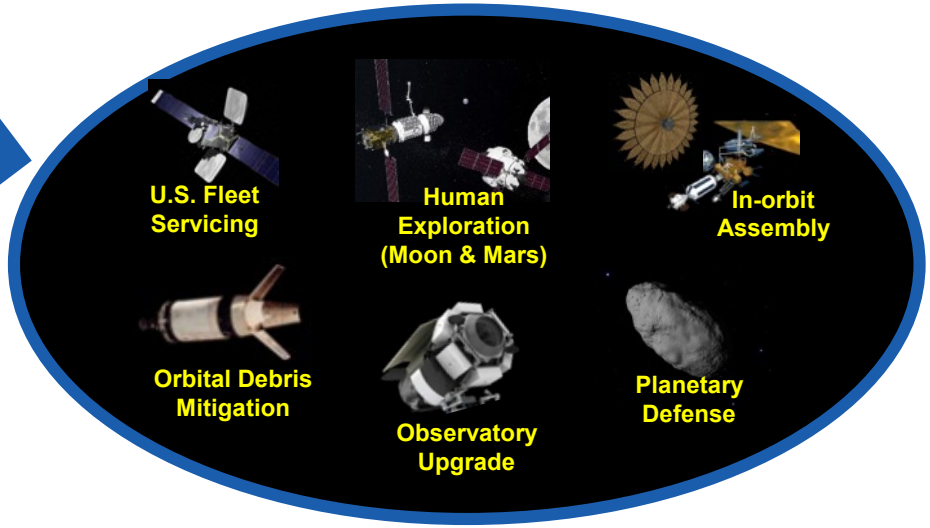
Technology Transfer

Technology Infusion

SECOND GENERATION (~2020)



Competitive Market



Non-recurring Engineering Standards Development

Application of Developed Technology

Satellite Servicing Technology Portfolio

relative navigation system
Sensor suite (visible, infrared, lidar)
Algorithms (range, bearing, pose)
Rendezvous & proximity operations

servicing avionics & software
SpaceCube processor
Video Distribution & Storage Unit

tool drive system & tools
NASA Servicing Arm – 7 DoF
Robot Electronics Unit
Robot Flight Software

robot system
Advanced Tool Drive System
Sophisticated servicing tools (gripper, blanket cutter, wire cutter, cap removal, & nozzle tool) and adapters

fluid transfer system
Propellant Transfer Assembly
Zero-g fluid flow meter
Hose management system
Cryogen and xenon transfer systems

cooperative servicing aids
Rendezvous decals
Cooperative Servicing Valve

Desired Applications

Inspection
- Space Situational Awareness
- Proximate / exquisite

Relocation
- Debris removal
- Derelict satellite
- Functional satellite
  - Orbit insertion / correction
  - Station keeping
  - Decommissioning
- Mega constellation maintenance

Refueling
- Rapid Reconstitution of Capability
- Chemical (Hypergolic), EP (Xenon), Cryo, Pressurant
- ECLSS commodity

Repair
- Simple nudge/poke/pull/snip
- External
- Internal

Replacement
- S/C component
- Instrument / payload

Augmentation
- Leave behind package

Assembly
- Persistent platform
  - Remote Sensing
  - Robotic facility
- Outpost / Gateway
  - Construction
  - Maintenance
- Observatory / Telescope
- Solar Power Facility

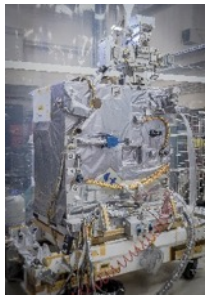
Manufacturing
- Structural members / struts / truss
- Robotic tools
- Simple components
- Thin film deposition
- Contamination removal

Mining
- Sample collection / manipulation
- Prospecting
- ISRU infrastructure

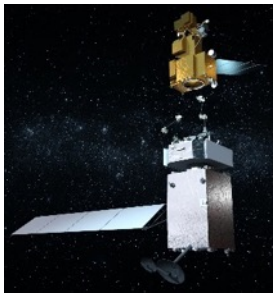
Sample Acquisition/ Return
- Lunar
- Mars
- Comet
- Asteroid

NASA Activities

Technology



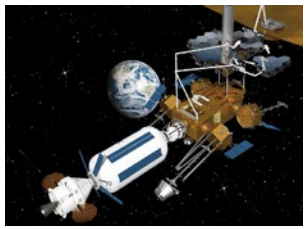
Robotic Refueling Mission 3



Restore-L

In-Space Manufacturing and Assembly Tipping Point

Science

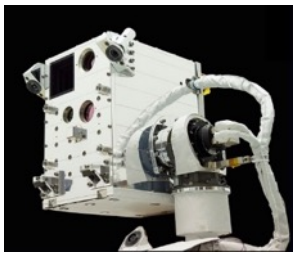


Large Telescope Assembly (iSAT, FASST)

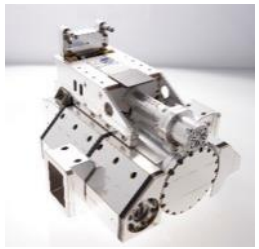
Astrophysics Decadal Studies

Planetary/NEO/Lunar

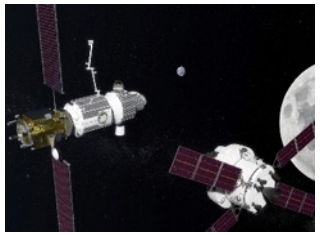
Human Exploration



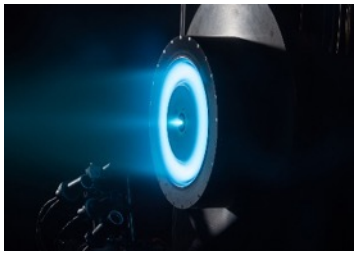
ISS - Raven



ISS - Robotic External Leak Locator / Robotic Stowage



Lunar Gateway



Power Propulsion Element

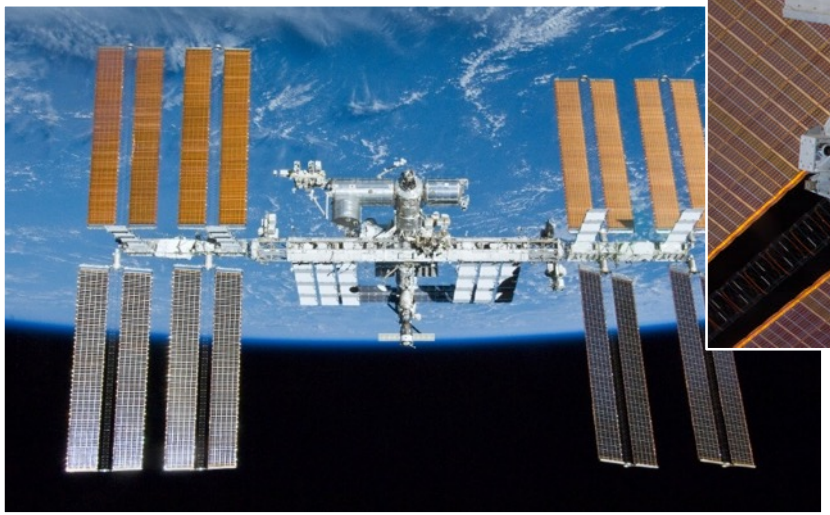
Reusable Lunar Lander

Journey to Mars

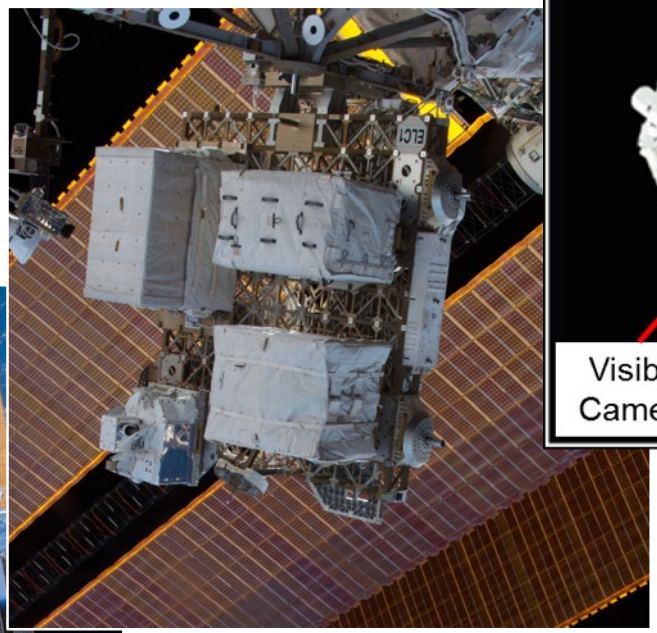
Raven

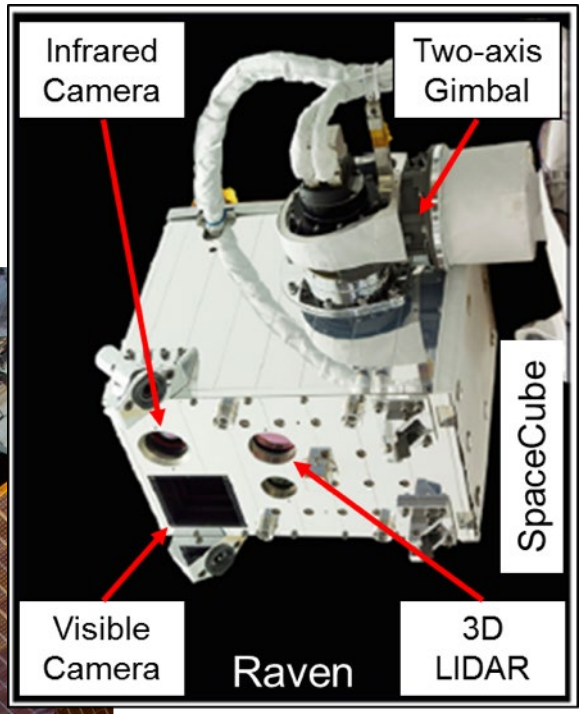
Raven is an on-orbit testbed designed to mature relative navigation sensors & algorithm technologies

- Raven tracks incoming visiting vehicles to the International Space Station (ISS)
- Launched on a Space-X Dragon (CRS-10) in February, 2017



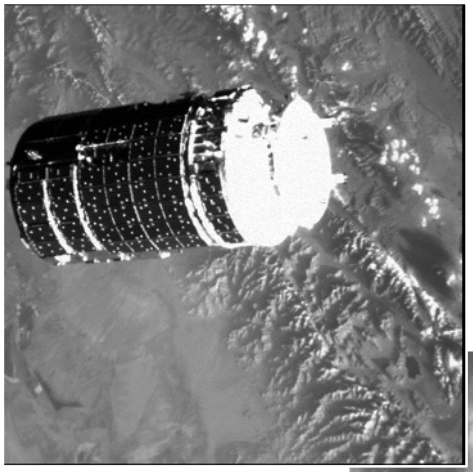
ELC-1/STP-H5



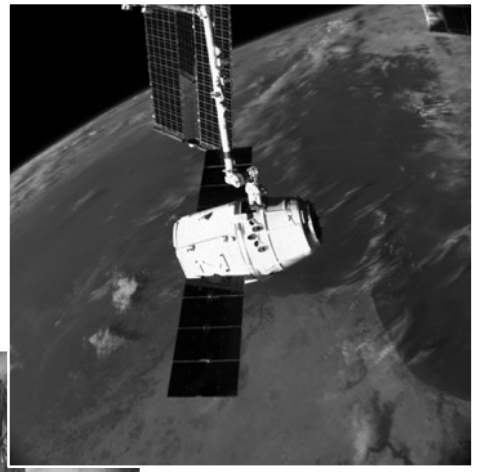


Raven On-Orbit Operations To Date

- SpaceX Dragon (CRS-10) (depart): 3/19/17
- Orbital/ATK Cygnus (OA-7): 4/22/17
- SpaceX Dragon (CRS-11): 6/5/17
- Russian Progress (MS-06): 6/16/17
- Russian Soyuz (MS-05): 7/28/17
- SpaceX Dragon (CRS-12): 8/16/17
- Orbital/ATK Cygnus (OA-8): 11/14/17
- SpaceX Dragon (CRS-13): 12/16/17
- Russian Soyuz (MS-07): 12/19/17
- Russian Soyuz (MS-08): 03/23/18
- SpaceX Dragon (CRS-14): 04/04/18
- Orbital/ATK Cygnus (OA-9): 05/24/2018
- Russian Soyuz (MS-09): 06/08/2018
- SpaceX Dragon (CRS-15): 07/02/2018
- Russian Progress (MS-06): 07/10/2018
- JAXA H-II Transfer Vehicle (HTV7): 09/27/18
- NG Cygnus (NG-10): 11/19/2018



Cygnus

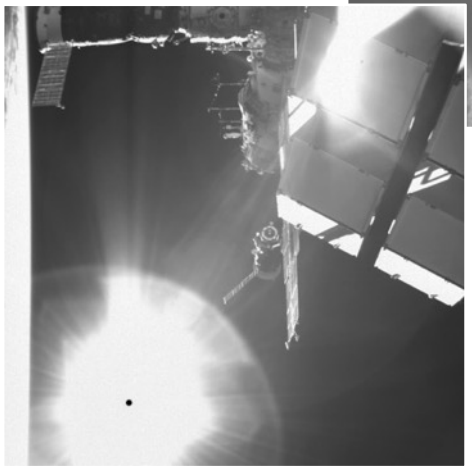


HTV

Dragon

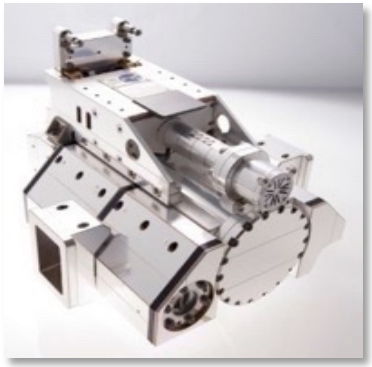
Progress

Soyuz



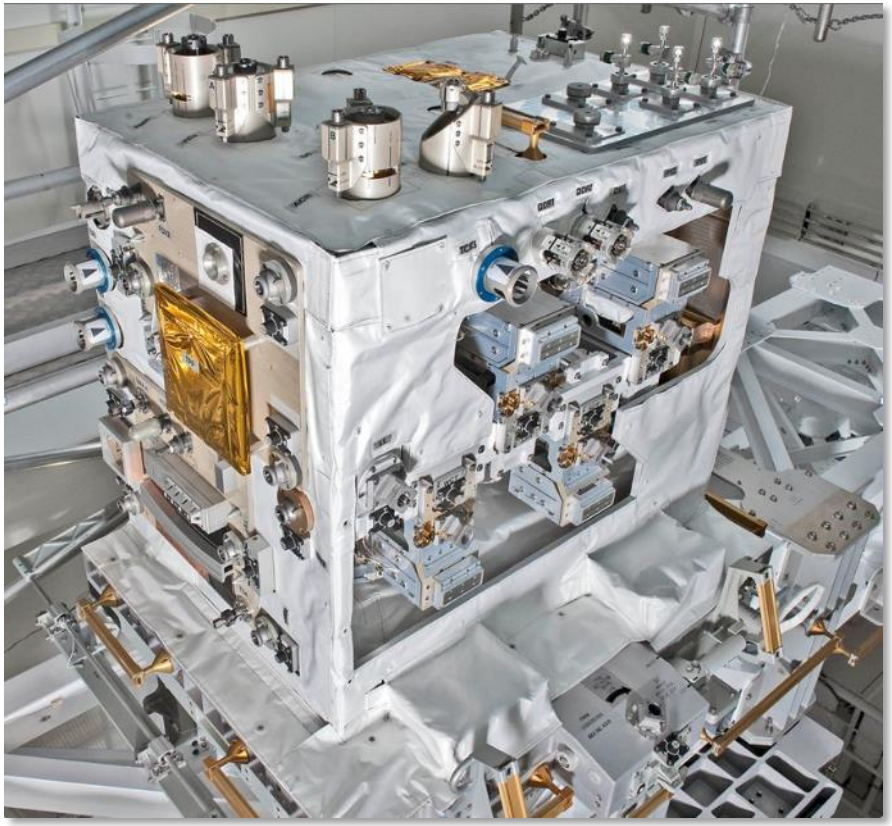
Robotic External Leak Locator

RELL helps the Space Station locate and precisely characterize leaks, eliminating the need for risky spacewalks to identify the source. RELL can also be used in other contexts in-orbit to identify leaks.

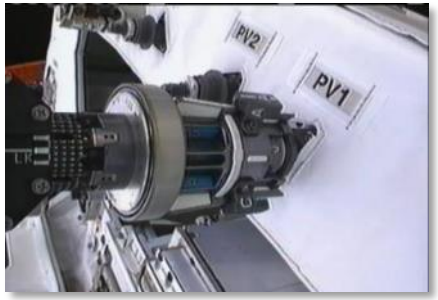


Robotic Refueling Mission: Phase 1 & 2 Overview

RRM launched 2011 and 2013, and tested tools, technologies and techniques to refuel and repair satellites in orbit – especially satellites not designed to be serviced



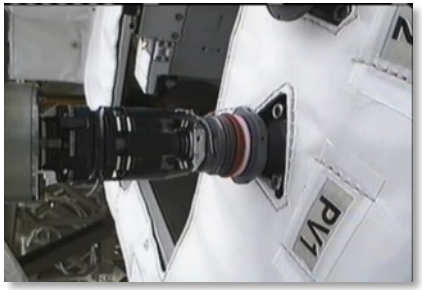
Tertiary Cap Wire Cutting



Tertiary Cap Removal

Actuation Nut Wire Cutting

Safety Cap Removal

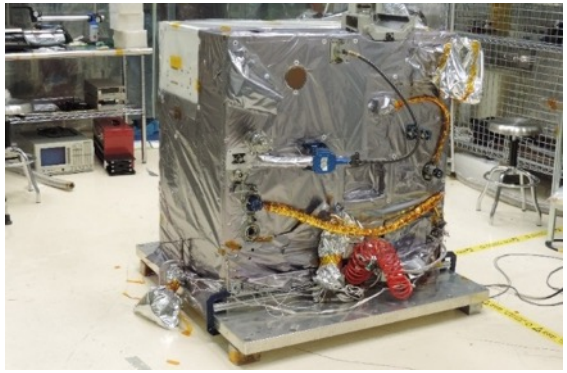


Nozzle Tool Connection

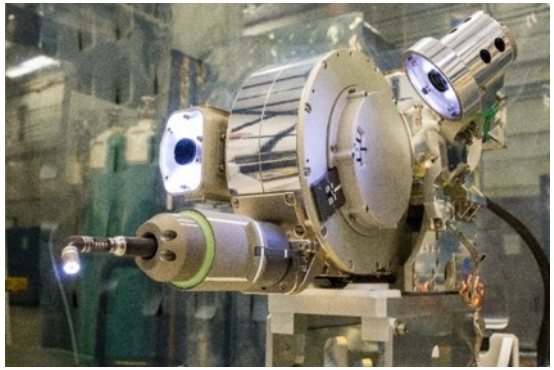
Nozzle Tool Release from Quick Disconnect

Robotic Refueling Mission 3 (RRM3)

RRM3 objective: mature the tools and techniques for the transfer of cryogenic fluid in orbit. The ability to replenish this critical consumable is important for maintaining spacecraft and for enabling long duration space travel to destinations like the Moon and Mars.

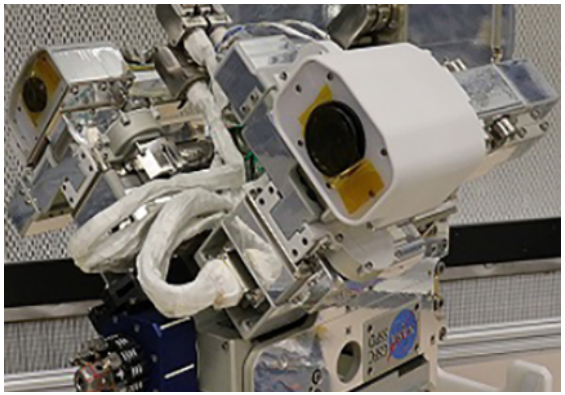


Fluid Transfer Module (FTM)

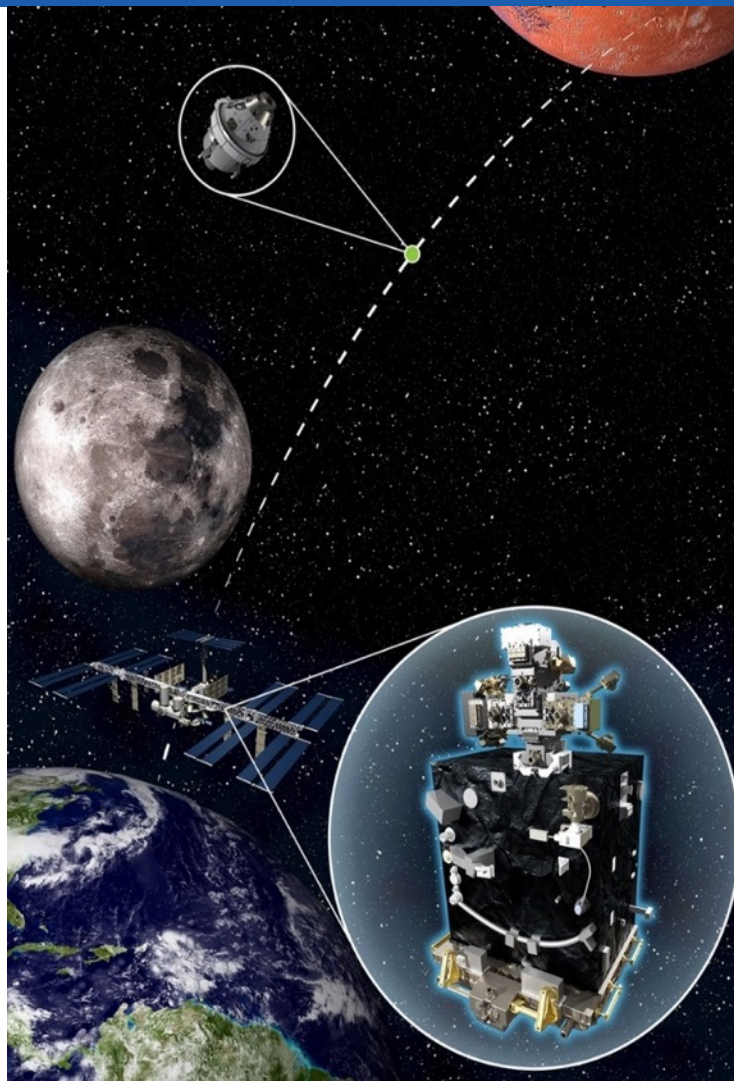


Visual Inspection Poseable Invertebrate Robot 2 (VIPIR2)

Cryogen Servicing Tool CST)



Multi-Function Tool 2 (MFT2)

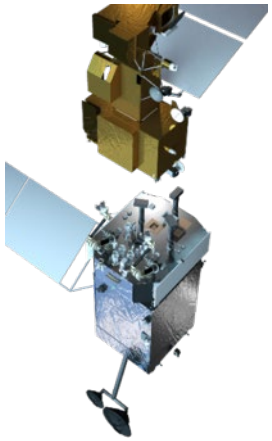


RRM3 Status

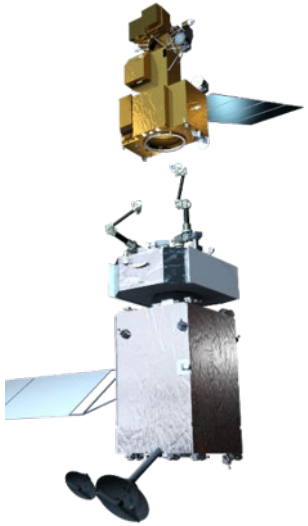
- Launched Dec 5, 2018 and installed on ELC 1
- Nominal operations
  - Cryocooler ops for 4 months – zero boil off
  - RF mass gauge (new technology)
  - Pan/Tilt unit nominal operation
  - Motorized zoom lens nominal operation
- Anomaly occurred on April 8, lost ability to power the liquid methane cryocooler
- Temperature of the liquid methane began to rise as expected
- Anomaly team quickly convened and several attempts were made to restore power to cryocooler
- ISS notified the adjacent experiments of the situation
- On April 11 the pressure of the liquid/gaseous methane exceed the safety burst disk pressure and the methane vented to space, as designed. Root cause is under investigation.
- At no point were the ISS crew members at risk
- The tool pedestal with three tools was successfully installed on April 12
  - Cryogen Servicing Tool
  - Visual Invertebrate Poseable Inspection Robot 2 (VIPIR2)
  - Multi-Function Tool 2
- Operations of the three tools are planned for summer 2019
- https://www.nasa.gov/feature/goddard/2019/robotic-refueling-mission-3-update-april-12-2019

Restore-L

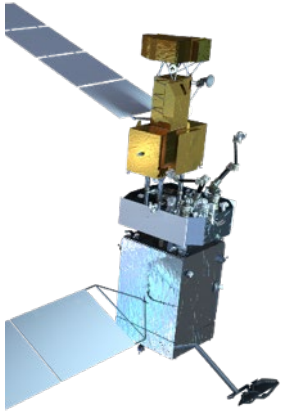
1. Demonstrate national satellite servicing capabilities
2. Advance essential technologies for NASA and national goals
3. Kick-start a new U.S. commercial servicing industry, establishing best practices



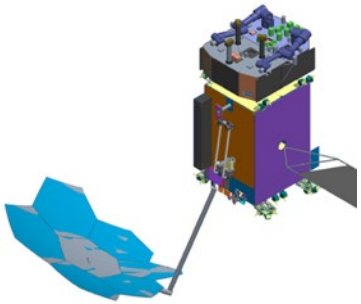
Autonomous Rendezvous, Inspection



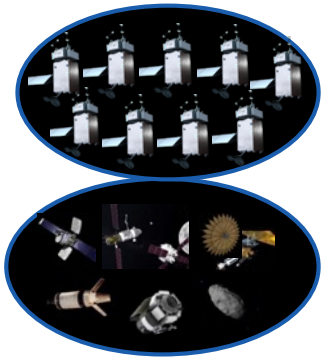
Autonomous Capture



Telerobotic Refuel & Relocate



Telerobotic Assembly & Manufacture



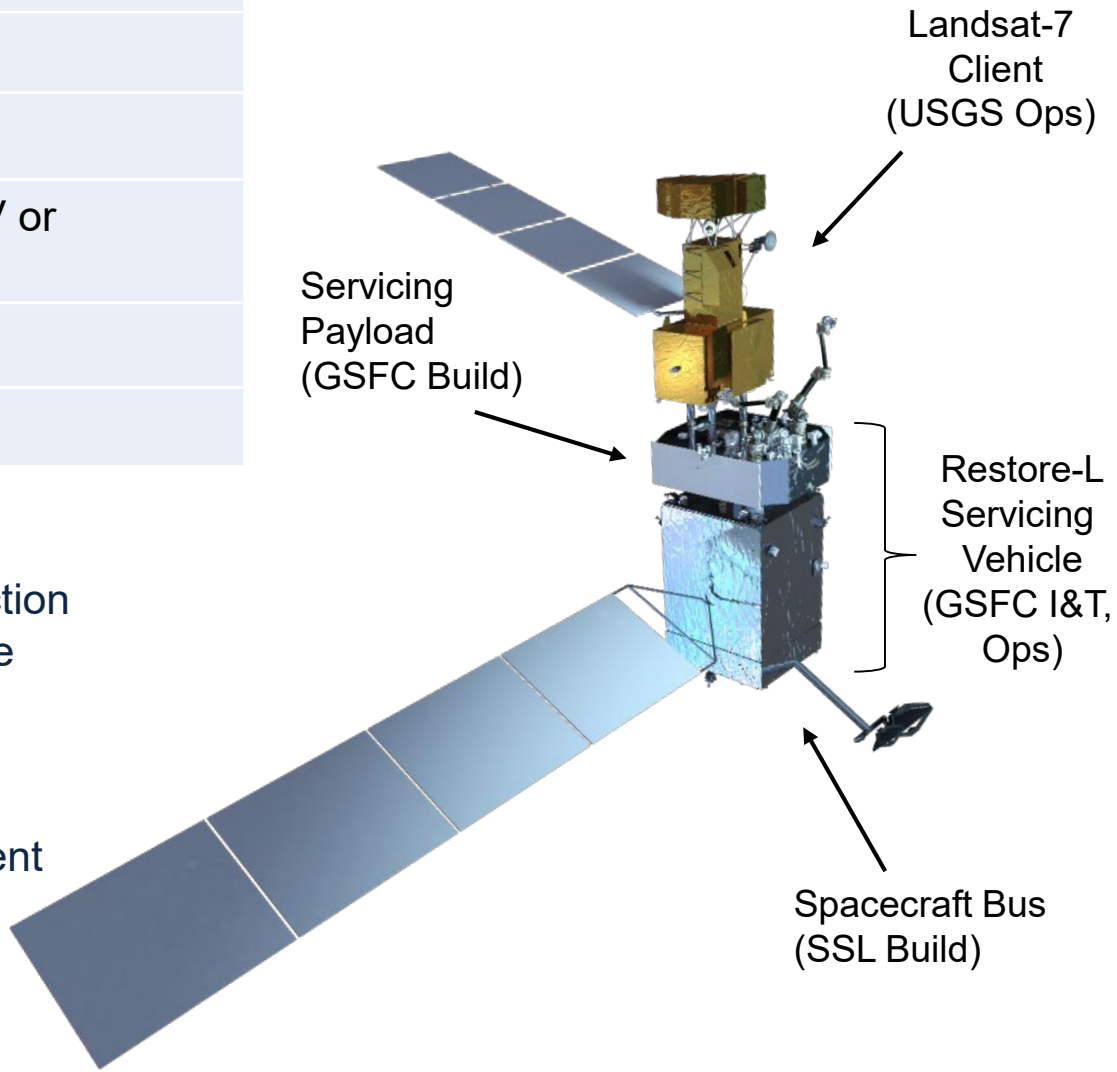
Tech Transfer Industry & U.S. Gov

Mission Overview

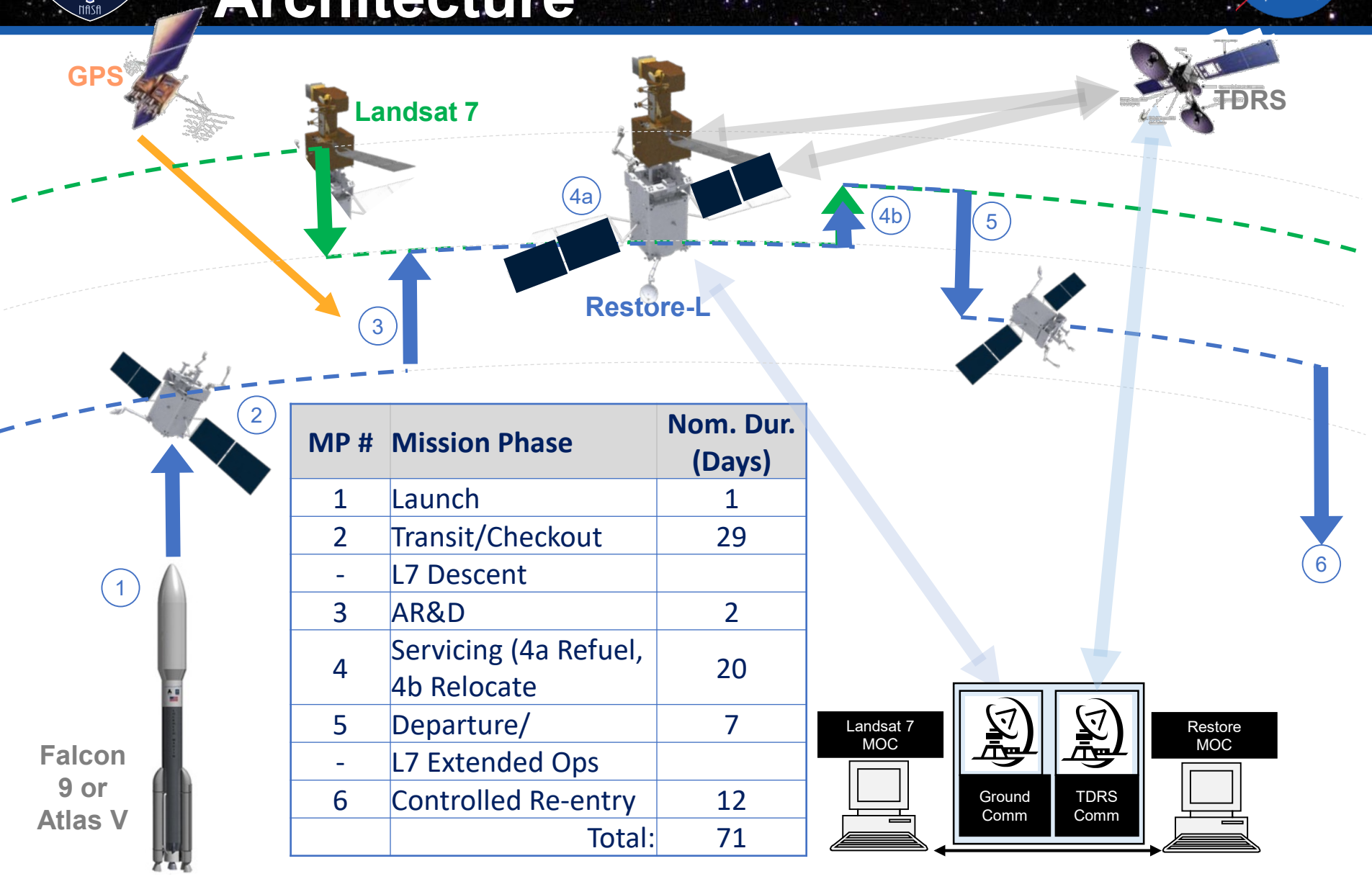
Category/Class	Category 2 / Class C
Mission Life	1 year
Launch	December 2022
Launch Vehicle	Domestic: Atlas V or Falcon-9
Launch Site	VAFB
Client	Landsat-7

Restore-L will demonstrate

- Autonomous rendezvous and inspection
- Autonomous capture of client satellite
- Tele-operated robotic servicing
- Refueling of client satellite
- Relocation of client satellite
- Release and safe departure from client
- 'Best Practices' for safe servicing operations
- Assembly of an RF reflector

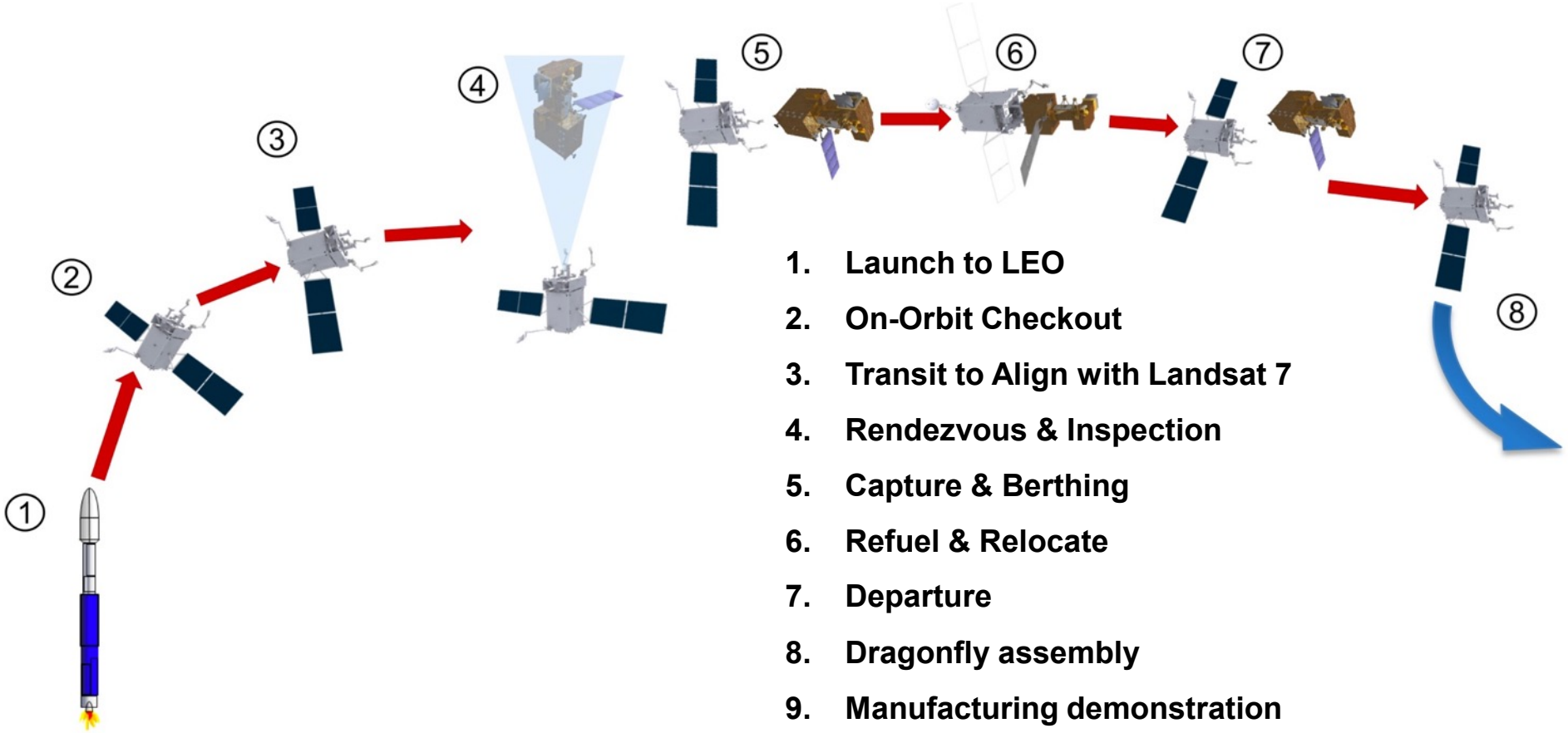


Mission Phases and Architecture



MP #	Mission Phase	Nom. Dur. (Days)
1	Launch	1
2	Transit/Checkout	29
-	L7 Descent	
3	AR&D	2
4	Servicing (4a Refuel, 4b Relocate	20
5	Departure/	7
-	L7 Extended Ops	
6	Controlled Re-entry	12
	Total:	71

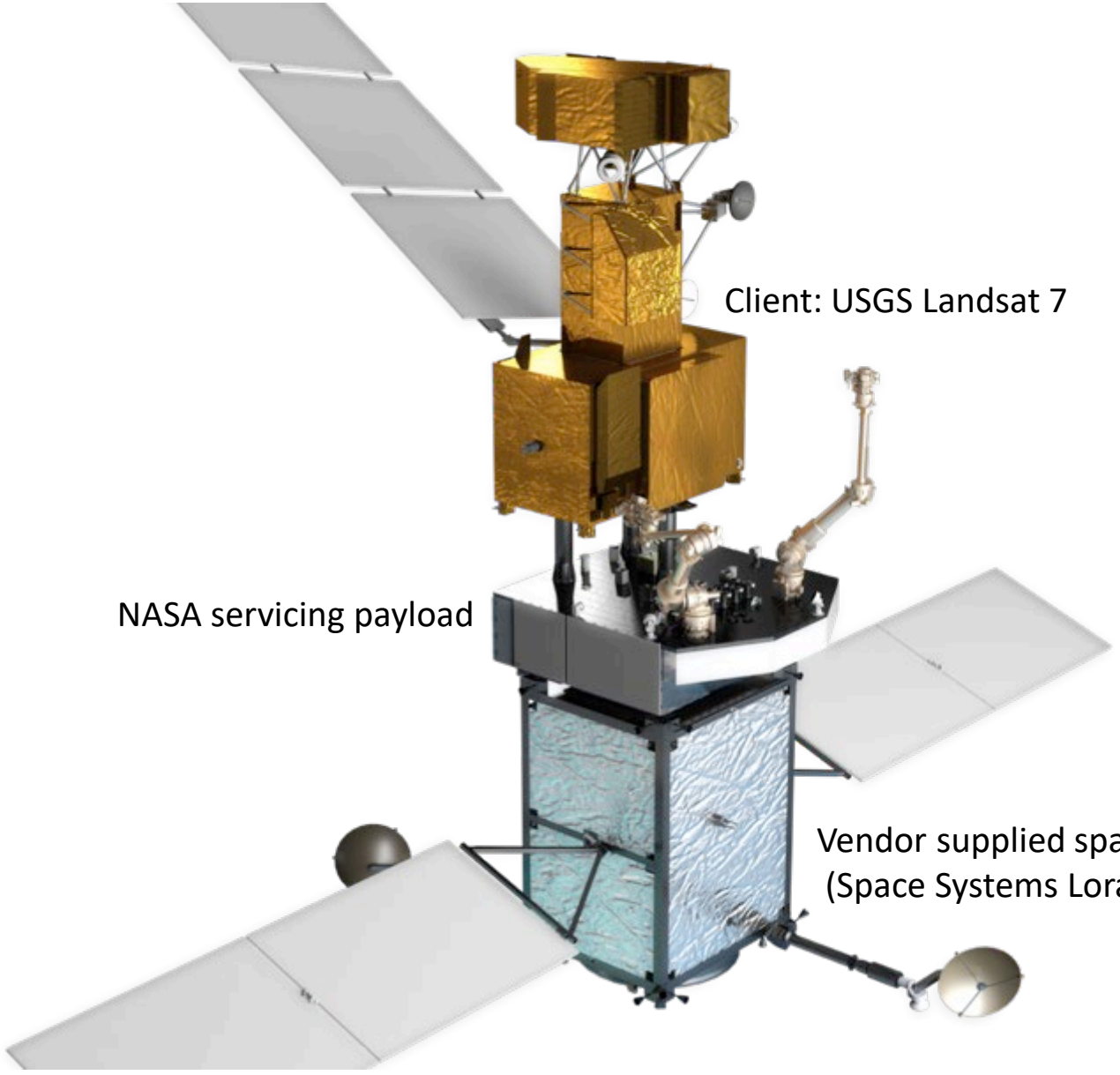
Restore-L Mission Overview



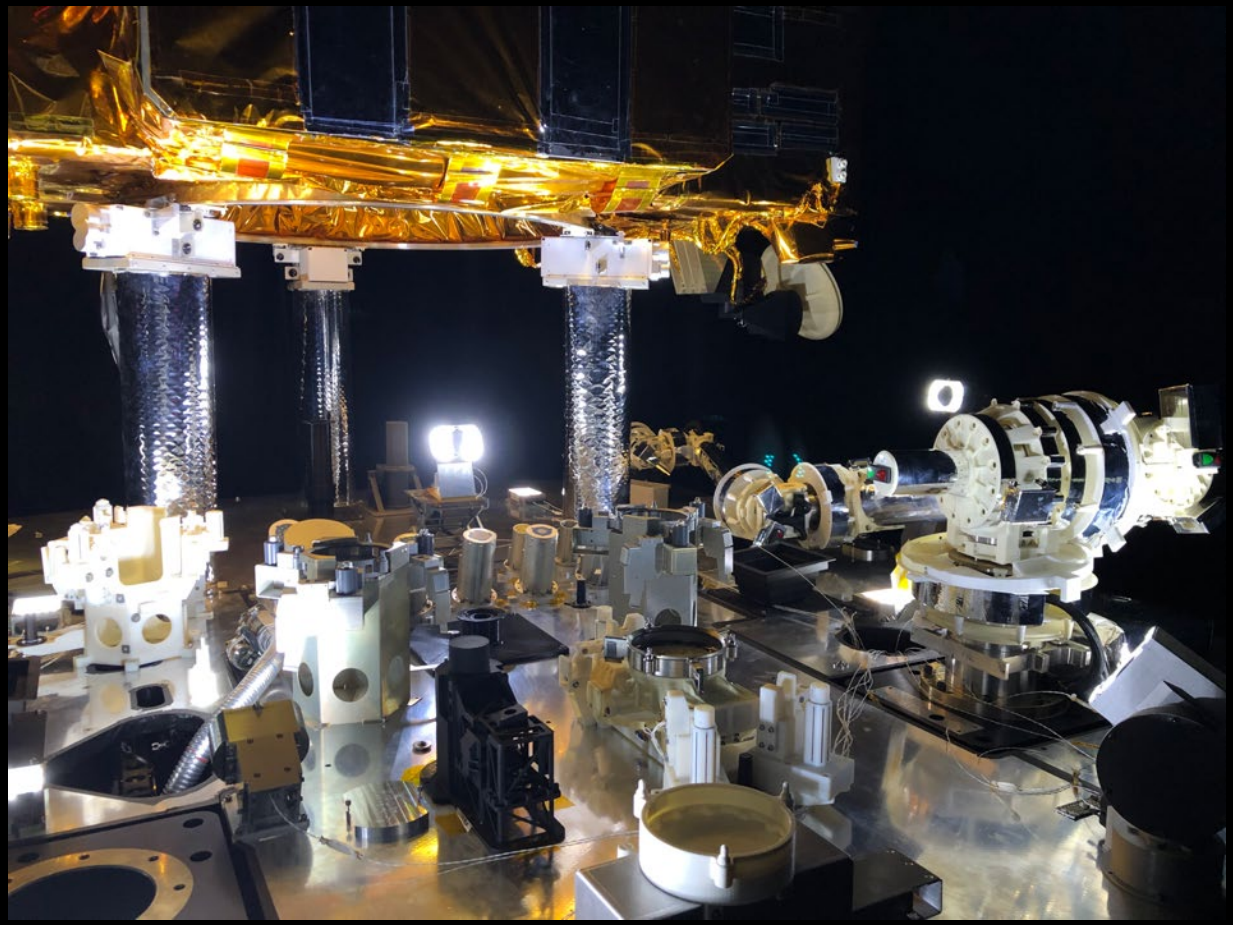
1. Launch to LEO
2. On-Orbit Checkout
3. Transit to Align with Landsat 7
4. Rendezvous & Inspection
5. Capture & Berthing
6. Refuel & Relocate
7. Departure
8. Dragonfly assembly
9. Manufacturing demonstration
10. Available for Extended Mission payloads

14. Disposal

Mated Operations: Refueling & Relocation



Restore-L Mated Configuration



Payload Overview

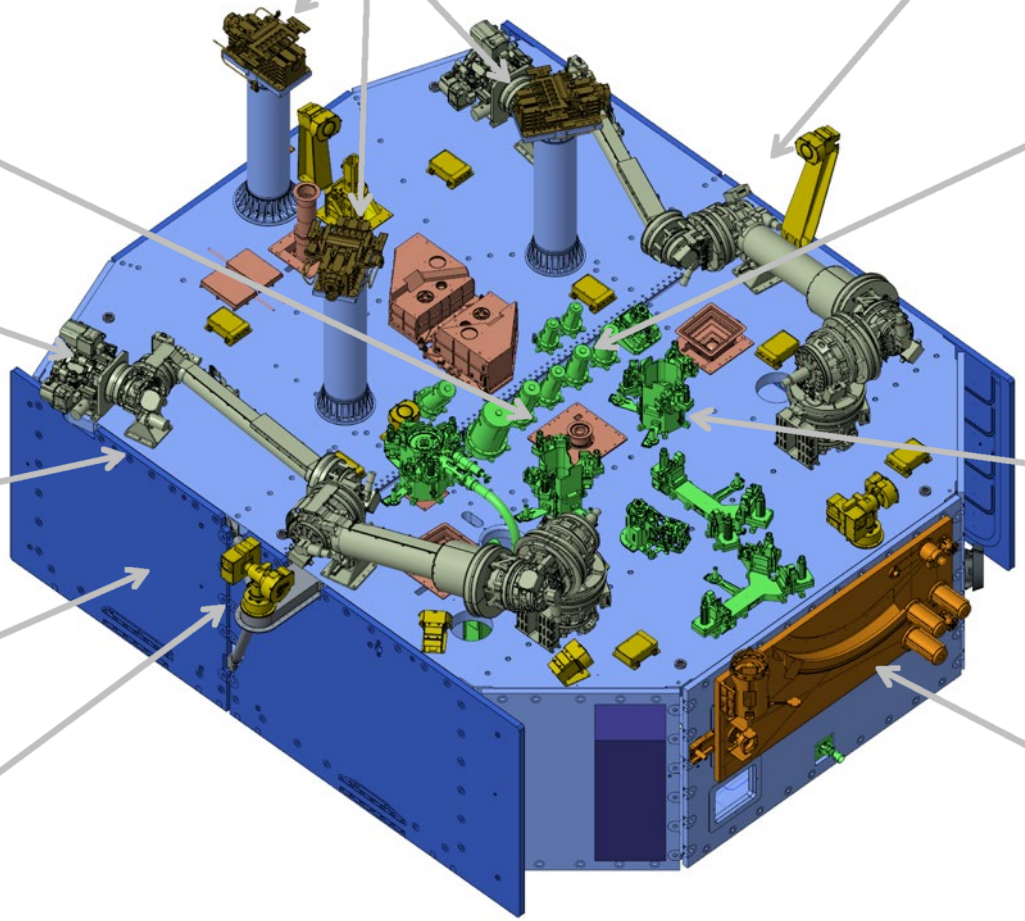
Mechanical Subsystem
Client Berthing System

Robotic Subsystem
7 DOF Arms

RPO Subsystem
LIDAR
Visible Camera
Infrared Camera

Tools\Tool Drive Subsystem
Adapters and Receptacles
Gripper Tool
RATCHiT

Tools\Tool Drive Subsystem
Advanced Tool Drive System (ATDS)



Robot Subsystem
Robot Arm
Launch Locks

Mechanical Subsystem
Tool Stowage Bays
Gripper Stowage Bays

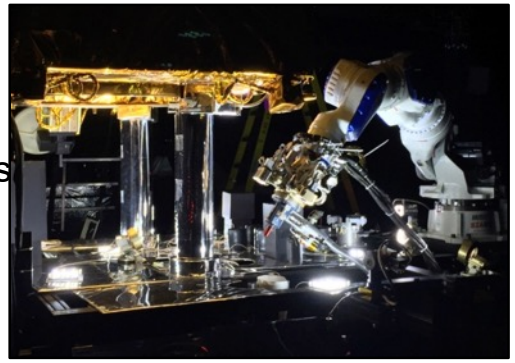
Mechanical Subsystem
Thermal Radiators

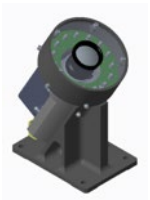
Vision Sensor Subsystem
Pan Tilt Units (2x)

Mechanical Subsystem
Calibration Suite

Restore L Subsystems

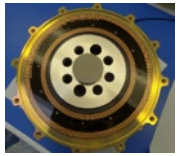
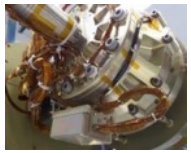
Vision
- ATDS cameras
- Floodlights
- Fixed Situational Awareness cameras
- Long Range Inspection Camera
- PTU Situational Awareness cameras



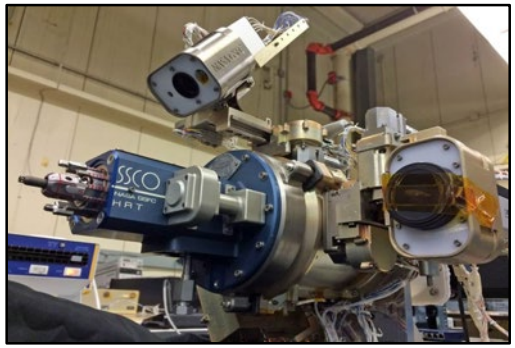
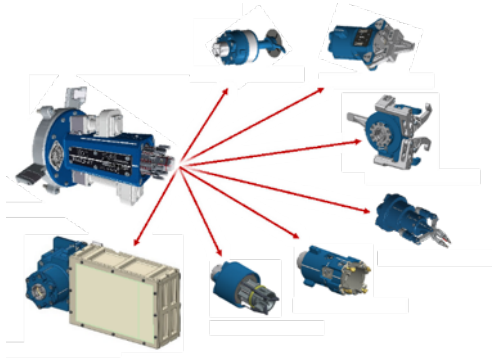




Robot
- 7 degree of freedom, dexterous robotic arm with force torque sensor
- Robot Electronics Unit (REU) and Advanced Tool Drive System
- Robot Software



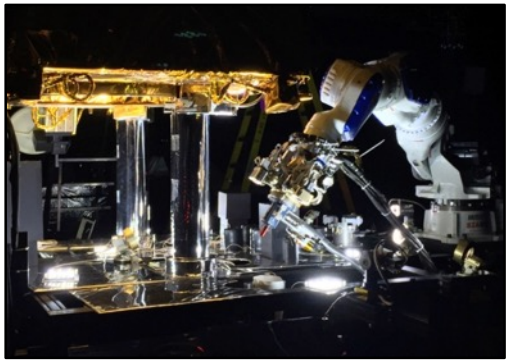



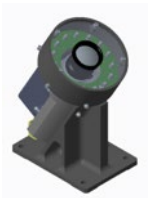
Tools / Advanced Tool Drive System
- Gripper, Refueing and RaChit tools
- Blanket manipulation, wire cutting cap removal and thermal closeout adapters
- Advanced Tool Drive System

Restore L Subsystems

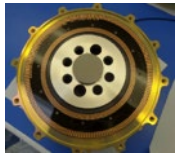
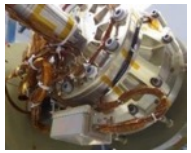
Avionics
- ATDS cameras
- Floodlights
- Fixed Situational Awareness cameras
- Long Range Inspection Camera
- PTU Situational Awareness cameras




Mechanical
- 7 degree of freedom, dexterous robotic arm with force torque sensor
- Robot Electronics Unit (REU) and Advanced Tool Drive System
- Robot Software

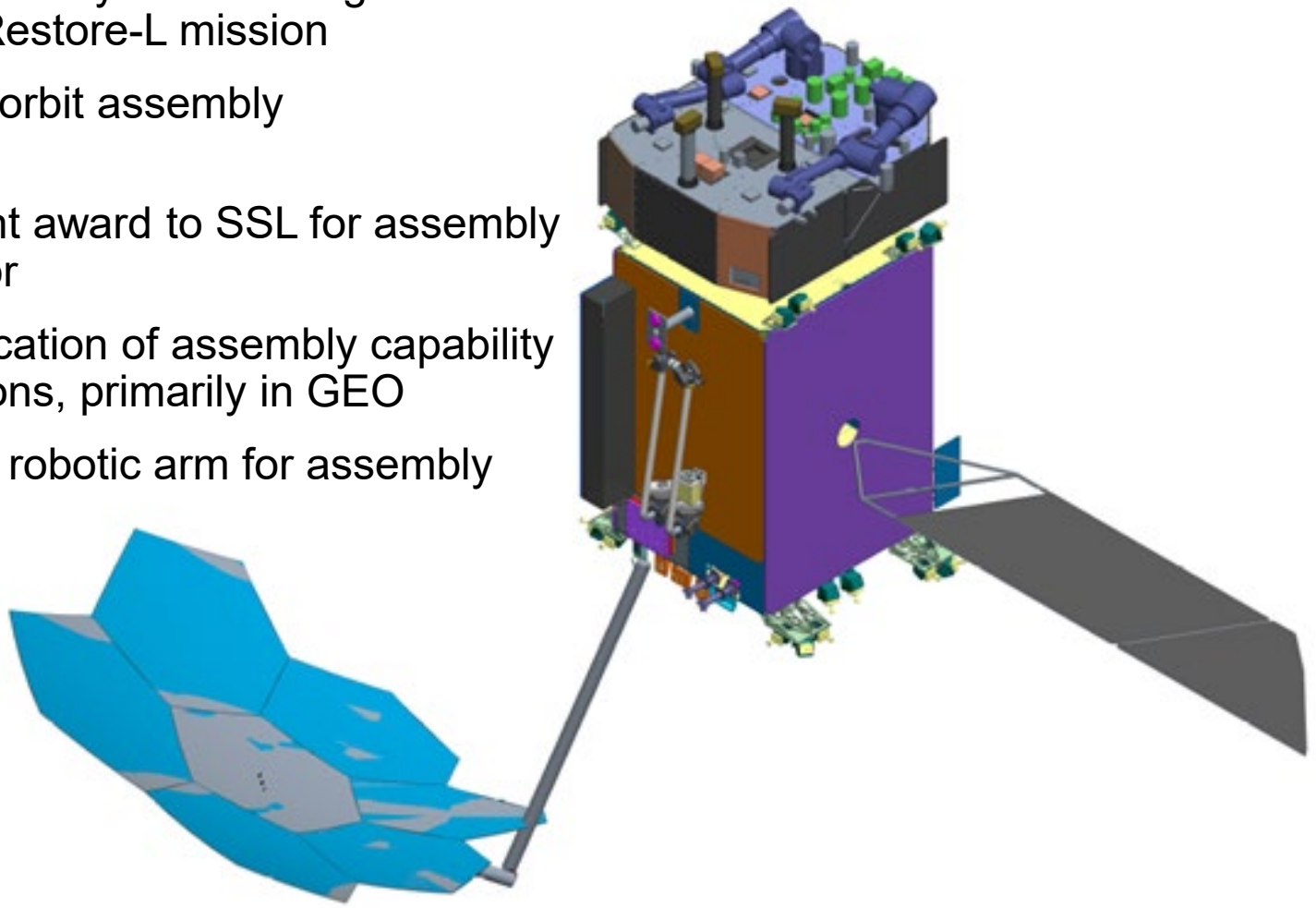


Propellant Transfer System
- Cooperative Servicing Valve
- Guidance and navigation aides
- Cooperative thermal protection systems

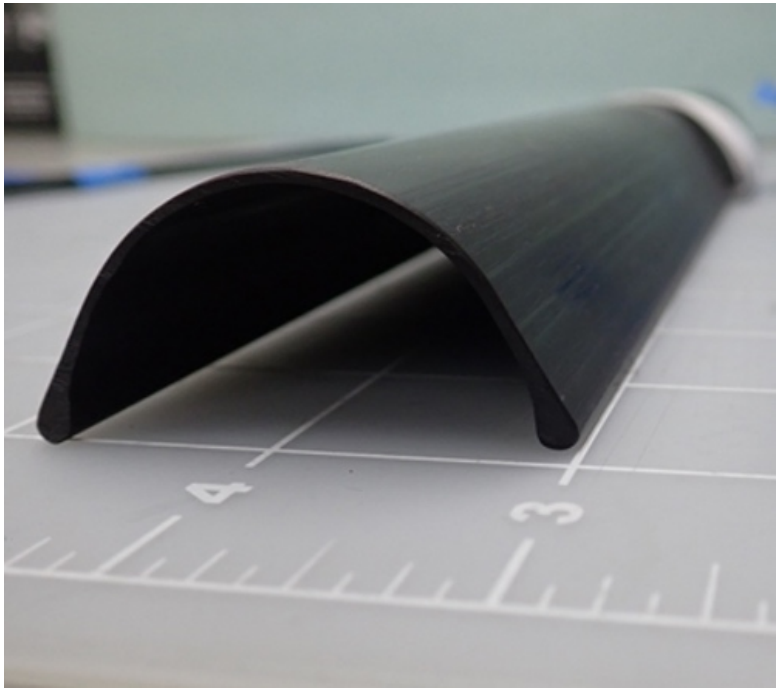
Potential for Dragonfly on Restore-L

- Restore Project is presently establishing a cost and schedule baseline for accommodating Dragonfly – 30 day study concluded good compatibility with Restore-L mission
- Dragonfly is an on-orbit assembly demonstration
- STMD Tipping Point award to SSL for assembly of large RF reflector
- The intended application of assembly capability is for communications, primarily in GEO
- Includes dedicated robotic arm for assembly



Potential for MakerSat on Restore-L

- Restore Project is presently establishing a cost and schedule baseline for accommodating MakerSat – 30 day study concluded good compatibility with Restore-L mission
- MakerSat is an on-orbit manufacturing demonstration complementary with in space assembly
- MakerSat will manufacture and characterize a meters-long Carbon-Fiber/PEEK beam
- Validates pultrusion process for forming longerons and cross-members in Trusselator
- CF/PEEK feedstock tuned to produce desired CTE behavior
- Simple interface to Host S/C:
  - One power line, one data line, separable mechanical interface
  - Deploys a harness/optical fiber along beam



Cooperative Servicing Aids

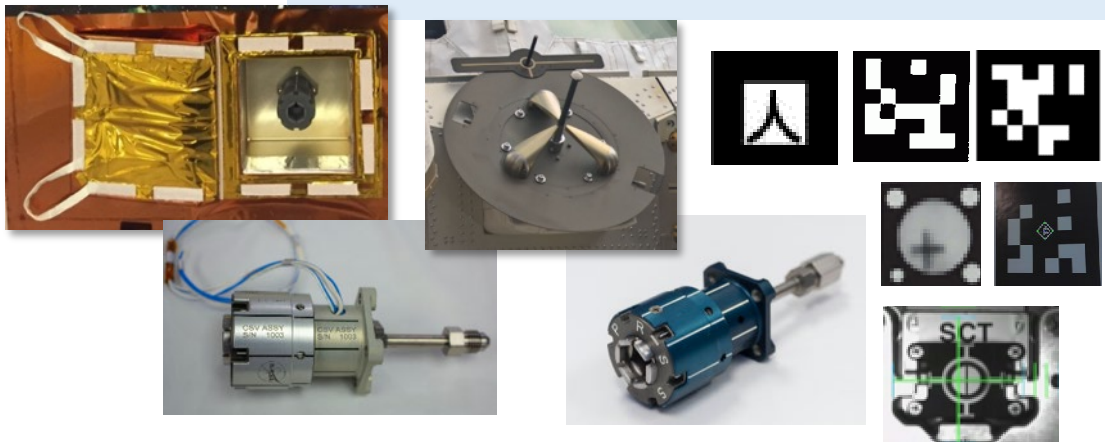
Cooperative servicing aids are elements to new architectures, programs and projects which can help make satellites more easily serviceable.

Why You Should Make Your Satellite Serviceable

- It enhances resilience
- It allows for continued innovation and improvements (e.g. Hubble)
- It's easy
- It's cost-effective
- The technology is ready
- Your competition won't wait

Products that make it possible

- Photos
- Decals
- Robotic Interfaces (valves, fixtures, connectors)
- ORUs designed for replacement
- Sub-assemblies and components built for in-space assembly



Serviceability Is a Spectrum

Level of Effort: High → Low

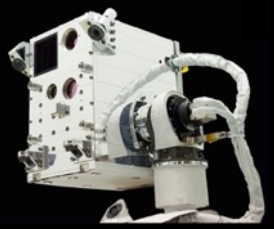
Remote Survey & Rendezvous	Capture & Relocate	Refuel & Replenish	Replace (Bus Module)	Replace (Instrument Module)	Repair & Augment
RF Crosslink	Docking features	Redesigned Fluid System	Servicing Power Mode	High Pin Count/ Data Rate Blind Mate connectors	EVA Aids
Onboard Navigation	Berthing features	Cooperative Fluid Port	Coolant Interface	Coolant Interface	EVR Aids
Laser Reflectors	Appendages accommodate servicing loads	Extra Pressurant	Heat Exchange Interface	Heat exchange Interface	Grapple Fixtures
Rendezvous ACS Mode (Inertial hold)	Berthing Fiducials	Fill Drain Valve Assy Thermal Design	Electrical Blind Mate Connector	Mechanical Latch	Electrical Expansion Ports (Test ports and spare services routed here)
IR Fiducials	Grapple Features	Robot-Friendly FDV Closeout	Mechanical Latch	Precision Alignment Guide	Mechanical Fittings
Visual Fiducials	Grapple Fiducials		Alignment Guide	Grasp Feature and Fiducial	
Reflective Tape	Capture ACS Mode (Free Drift)		Grasp Feature and Fiducial	Captive Fasteners	
Documentation, Photos, CAD	Marman Ring		Captive Fasteners	Design to accommodate Ground Accessibility	
	Documentation, Photos, CAD	Documentation, Photos, CAD	Design to accommodate Ground Accessibility		

SSPD Mission Technologies Applicable to In-Space Assembly

RRM 1 & 2

Mechanical, Electrical, Blind Mate, Robotic Tools, Robotic Operations, Refueling

Raven

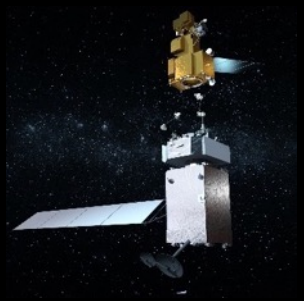


Rendezvous Proximity Operations (RPO)

RRM3

Cryogenic Transfer (life support), Xenon Transfer (SEP), Cooperative Service Valve

Restore-L

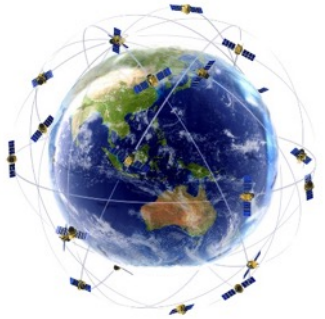


RPO, Avionics, Robot System, Tool Drive System & Tools, Fluid Transfer System, Cooperative Servicing Aids

Establishing Standards – Paving the Way to the Future

- By executing the first-of-its-kind satellite servicing mission thoughtfully and responsibly, NASA aims to establish standards and a global precedent for future servicing activities in space.
- NASA provides subject matter expertise to Consortium for Execution of Rendezvous and Servicing Operations (CONFERS) which brings together government and industry to research and develop consensus-derived technical and operations standards for servicing and rendezvous and proximity operations.
- These standards would provide the foundation for a new commercial repertoire of robust space-based capabilities and a future in-space economy.

CONFERS



Credit: CONFERS

Tech Transfer

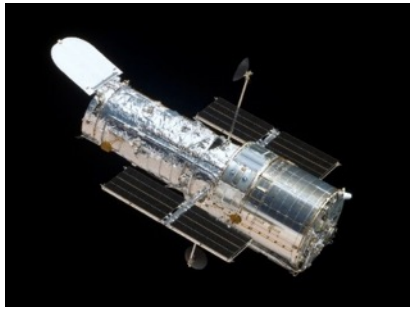
- Industry Day-NASA transfers commercial rights via non-exclusive licenses to domestic entities
  - Three Industry Days: 4/2017, Jan 2018, Dec 2018)
  - Next Industry Day on 9/18/19
  - ~40 companies attended past Industry Day
  - 42 formal requests for information for SSPD tech
- Technology catalog with over 200 items
- Licenses
  - Altius
  - Weintraus
  - SSL (pending)
- Space Act Agreement
  - NGIS

Enabling a New Era

1970s

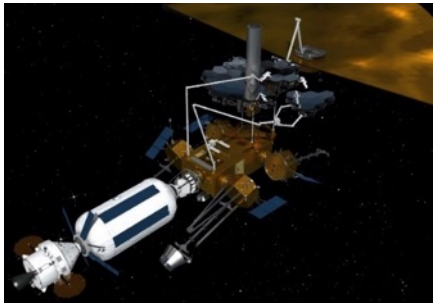
Active Satellites: < 140

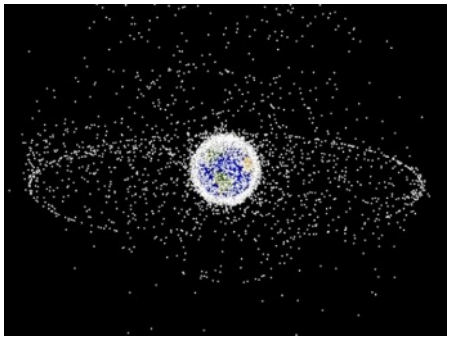
2018



Active Satellites:~1,400

2058





Active Satellites: ~14,000 ?

https://sspd.gsfc.nasa.gov/

@NASA.Satellite.Servicing

@NASA_SatServ