

NASA Satellite Servicing Evolution

Future In-Space Operations (FISO) Teleconference
01-11-17

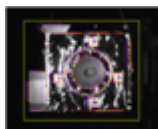
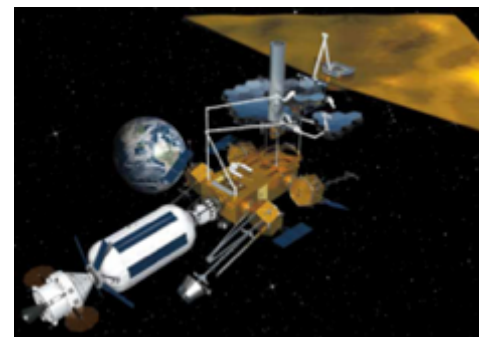
Benjamin B. Reed

Deputy Program Manager

Satellite Servicing Projects Division

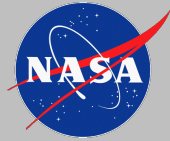
NASA's Goddard Space Flight Center

benjamin.b.reed@nasa.gov





40+ Years of On-Orbit Servicing



1973

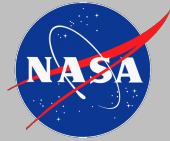


2016





Satellite Servicing Capabilities



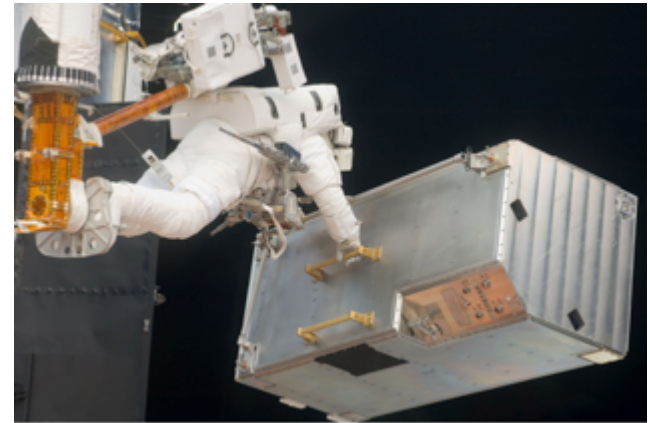
Servicing provides capabilities for resilient architectures.

Remote Inspection

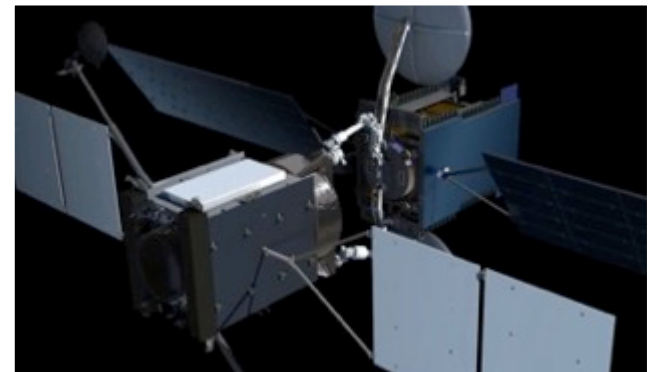
Relocate

Replace

Repair

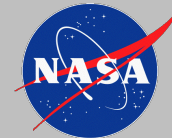


Refuel
Replenish
Assemble





Servicing Supports National Goals



National Space Policy 2010:

Energize **competitive domestic industries** to participate in global markets and advance the development of satellite manufacturing and satellite based services



Increase assurance and resilience of mission-essential functions enabled by commercial, civil, scientific, and national security spacecraft and supporting infrastructure



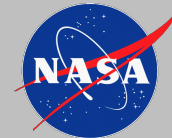
Pursue human and robotic initiatives to develop innovative technologies and **foster new industries**



Servicing is aligned with America's space objectives.



How we do business



Stakeholders

*Continuous
Needs
Assessment*

*Technology &
Capability
Infusion*

Commercial
Owners, Operators, Insurers

Nascent
Servicing
Industry

Spacecraft Manufacturing
Industry

Department of
Interior
USGS

NASA
Science

NASA
Exploration

Other Government
Agencies

Department of
Commerce
NOAA

Satellite Servicing
Capabilities Office

Projects

Raven
Project

Technologies

Relative
Navigation System

Servicing
Avionics



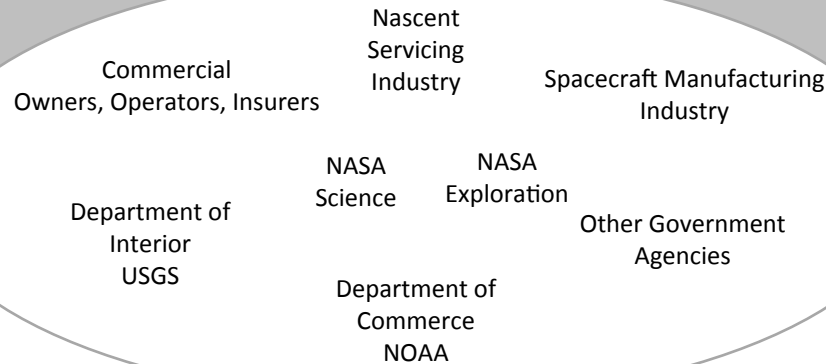
How we do business



Stakeholders

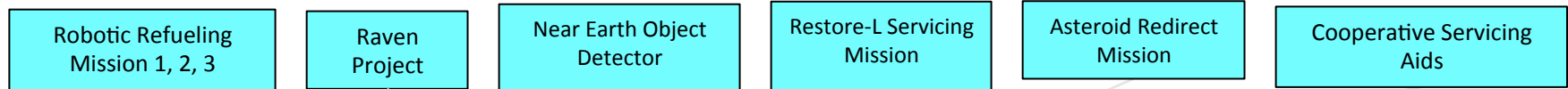
Continuous
Needs
Assessment

Technology &
Capability
Infusion

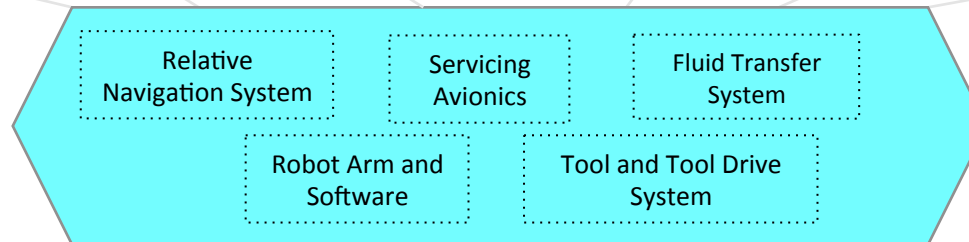


Satellite Servicing
Capabilities Office

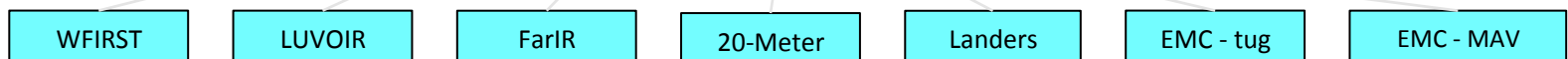
Projects



Technologies

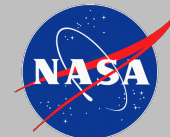


Studies





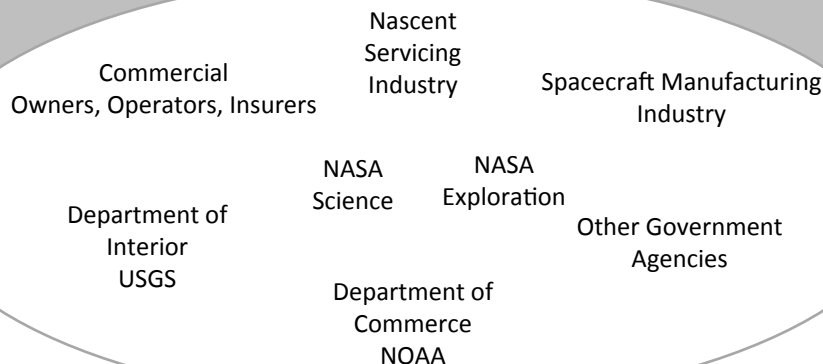
How we do business



Stakeholders

Continuous
Needs
Assessment

Technology &
Capability
Infusion

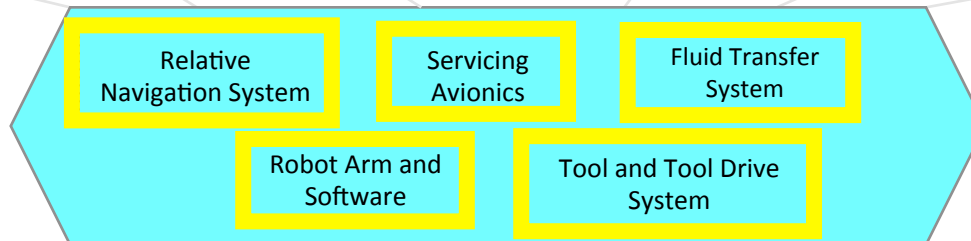


Satellite Servicing
Capabilities Office

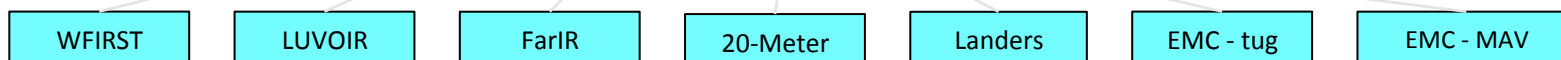
Projects



Technologies

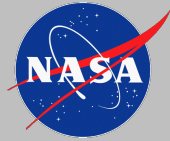


Studies



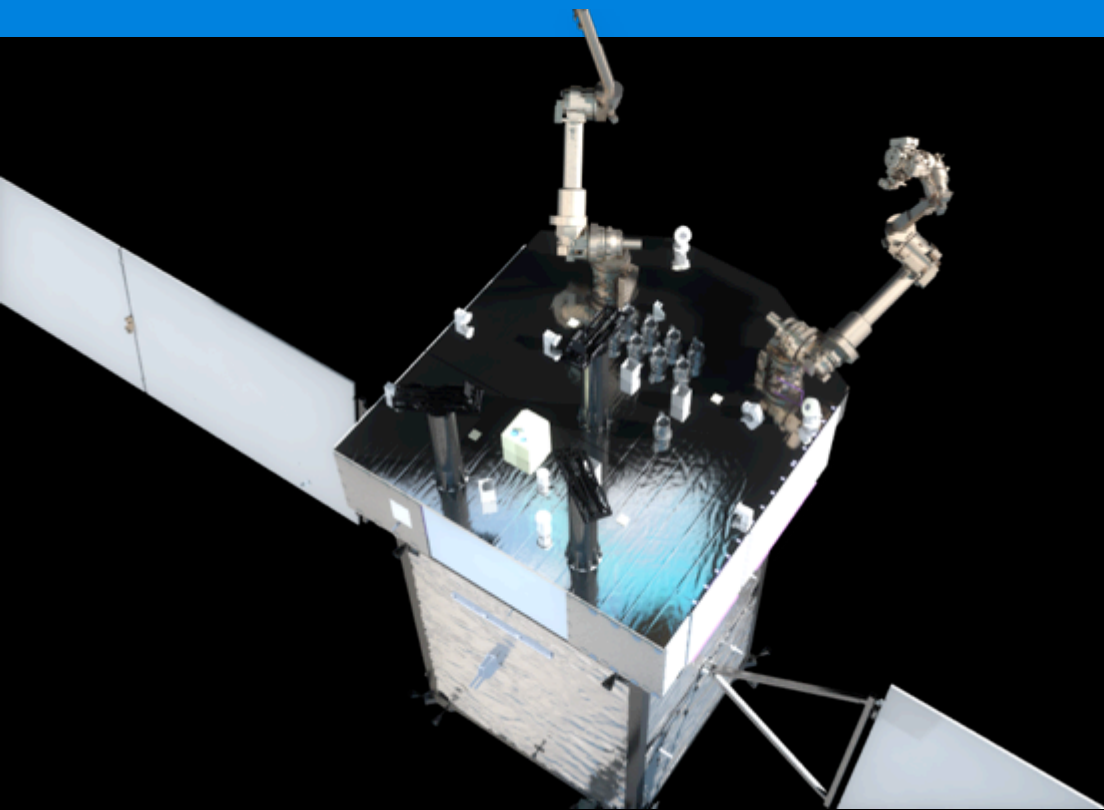


Technology Demonstration Mission



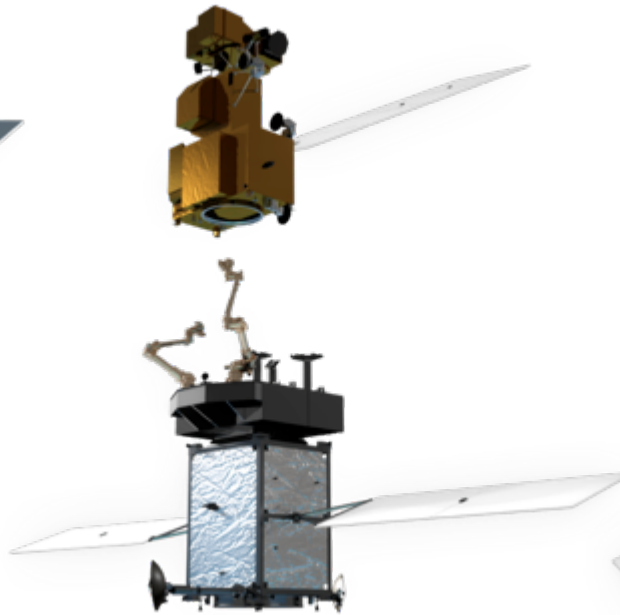
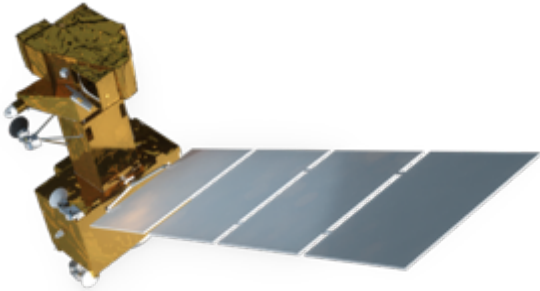
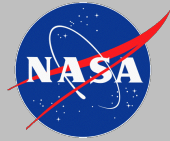
The Restore-L Mission will:

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

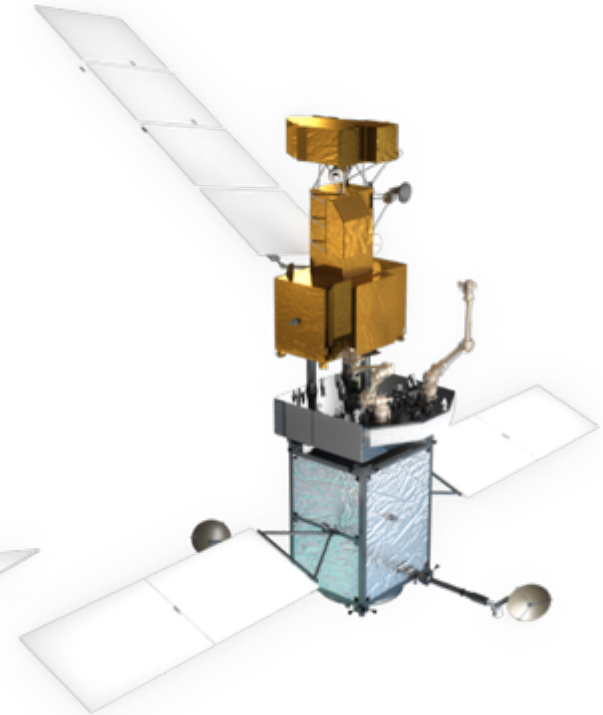




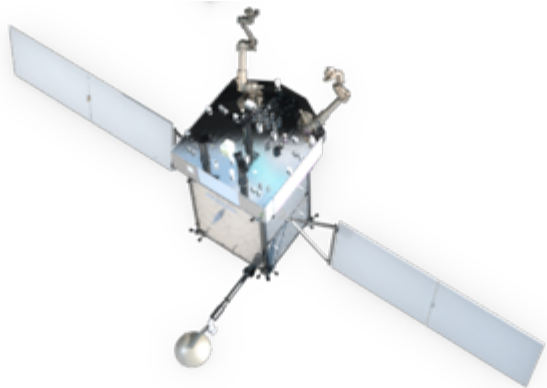
Mission Objectives



Autonomous Grasp



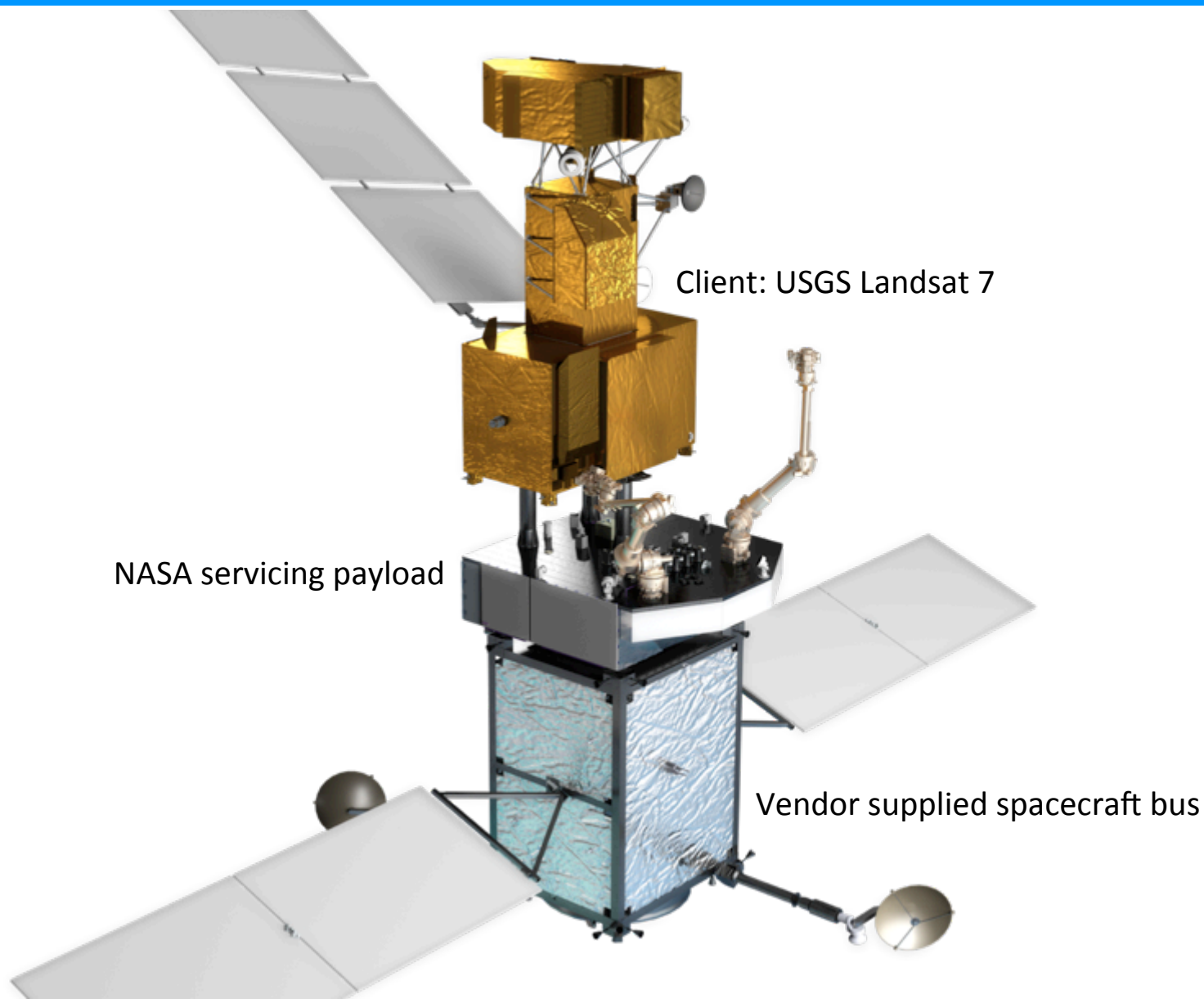
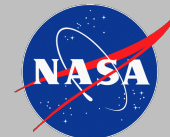
Telerobotic Refuel
& Relocate



Autonomous
Rendezvous

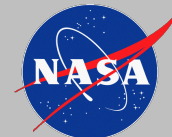


Mated Operations: Refueling & Relocation





Restore-L Technology Portfolio



relative navigation system

Sensor suite (visible, infrared, lidar)
Algorithms (range, bearing, pose)
SpaceCube processor



robot arm & software

NASA Servicing Arm – 7 DoF
Robot Electronics Unit
Robot Flight Software



servicing avionics & software

SpaceCube processor
Video Distribution & Storage Unit



tool drive system & tools

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



propellant transfer system

Propellant Transfer Assembly
Zero-g fluid flow meter
Hose management system

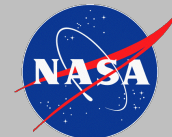
cooperative servicing aids

Rendezvous decals
Cooperative Servicing Valve





Technology Development Timeline



2005-09 2010 2011 2012 2013 2014 2015 2016 2017 2018



Rendezvous & Prox Ops System

Real-time 6-DOF pose of HST



Proximity Sensors & Algorithms

Closed Loop Testing

Closed Loop Testing 2

Autonomous tracking of spacecraft (Raven)



Dexterous Robotics

HST SM4 testing

3-DOF Capture

Zero-G 6-DOF auto tracking

Contact Dynamics Validation

Refueling Procedure Validation

Remote control w/ oxidizer

Receipt of 7-DoF Eng Arm

Engineering arm w/ flight-like algorithms

Receipt of 7-DoF-space qualified Arm



High-speed, Fault-tolerant Computing

Real-time 6-DOF pose of HST



SpaceCube 1.0 (MISSE-7)



SpaceCube 2.0 STP-H4

RRM refueling demo

RROxITT

Flight processor executing robot control algorithms

Comprehensive Refueling Tasks

SpaceCube driving Eng. Arm

Real-time processing of natural feature vision algorithms on a SpaceCube 2.0 (Raven)



Robotic Tools and Tool Drive

Gripper Tool

Four RRM tool on-orbit validation

Oxidizer Tool validation

Inspection tool on orbit

Next-gen refueling tools



Fluid Transfer

Oxidizer seal-less pump evaluation

Ethanol refueling on orbit

Hose tests in zero-g, NBL

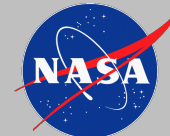
Oxidizer Transfer

Propellant Transfer system

Cryo & Xenon transfer (RRM-3)



Restore-L Mission Context



Technologies

- Relative Navigation Sensors and Algorithms
- Advanced Avionics
- Servicing Robotics
- Servicing Tools
- Propellant Transfer
- Mission Autonomy Manager
- Berthing System
- Vision System

RESTORE-L Advancement

Other SSPD Projects

- Cryogen Transfer
- Cooperative Servicing Aids
- Xenon Transfer
- Modular Components

Capabilities

Remote Inspection

Legacy Rendezvous

Legacy Capture

Legacy Refueling

Client Relocation

Repair

Replenish

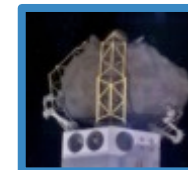
Replace

Assemble

Enabled Missions



Commercial Servicing



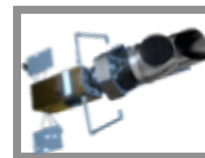
ARRM Capture Module



US Fleet Servicing



Journey to Mars



Cooperative Servicing



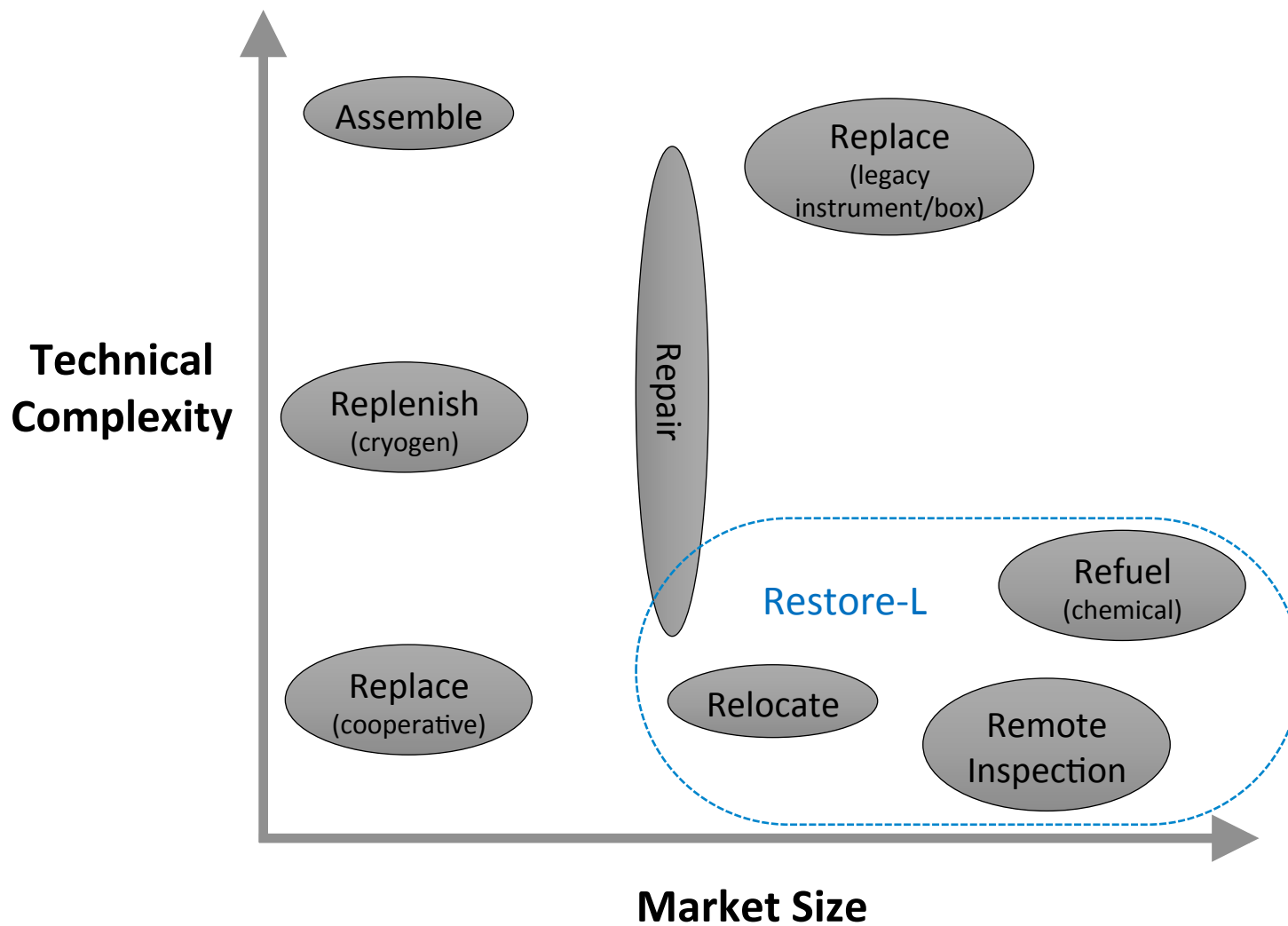
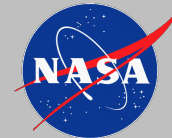
On-Orbit Assembly



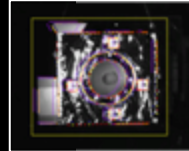
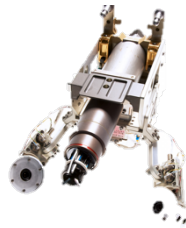
Orbit Debris Mitigation



Capabilities Map

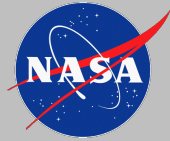


Technology Development





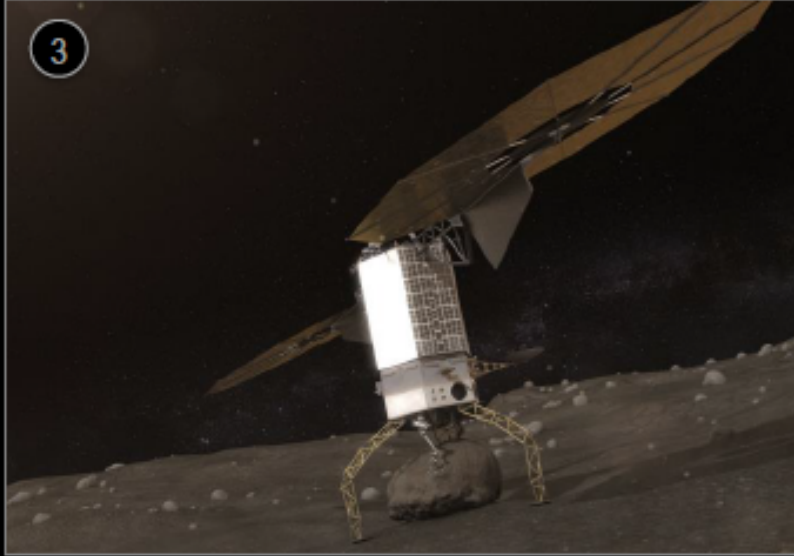
ARM Mission Highlights



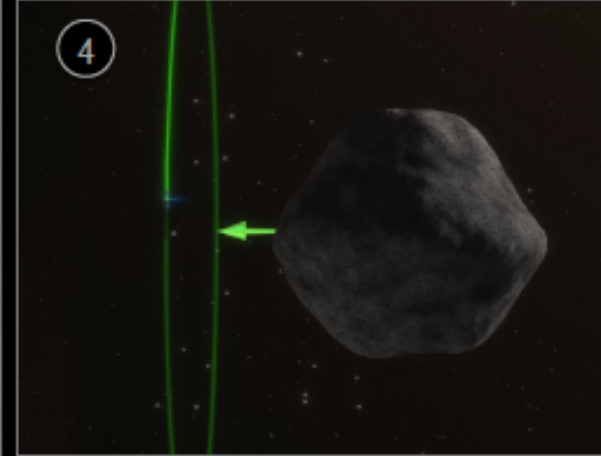
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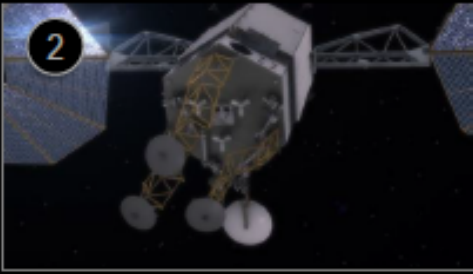
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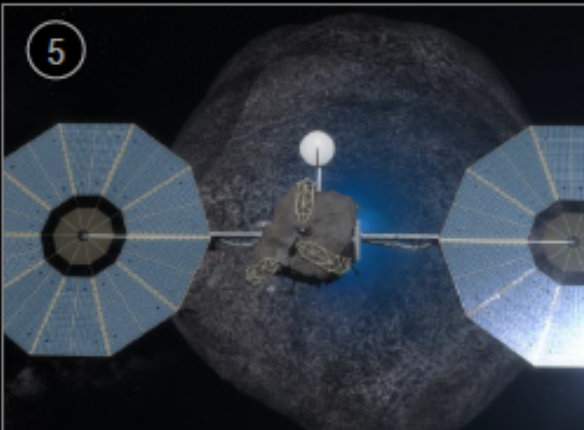
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2



5



6



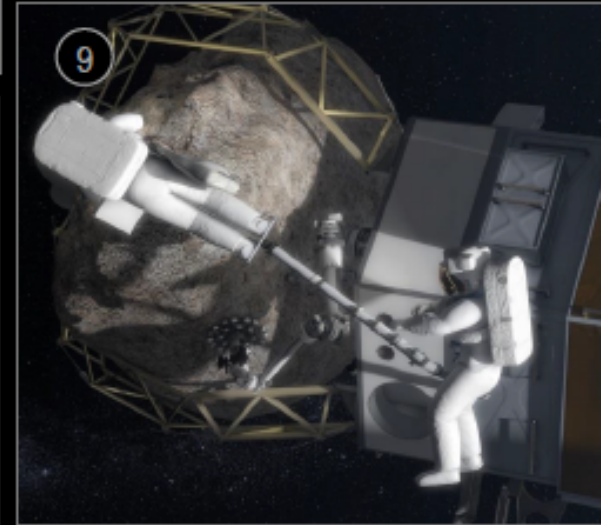
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7



9



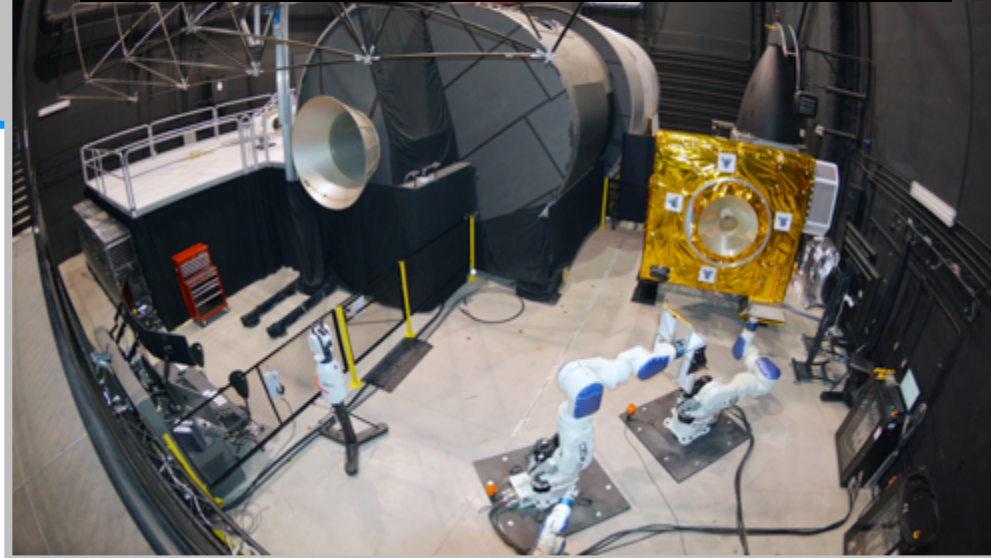


Robotics Facilities

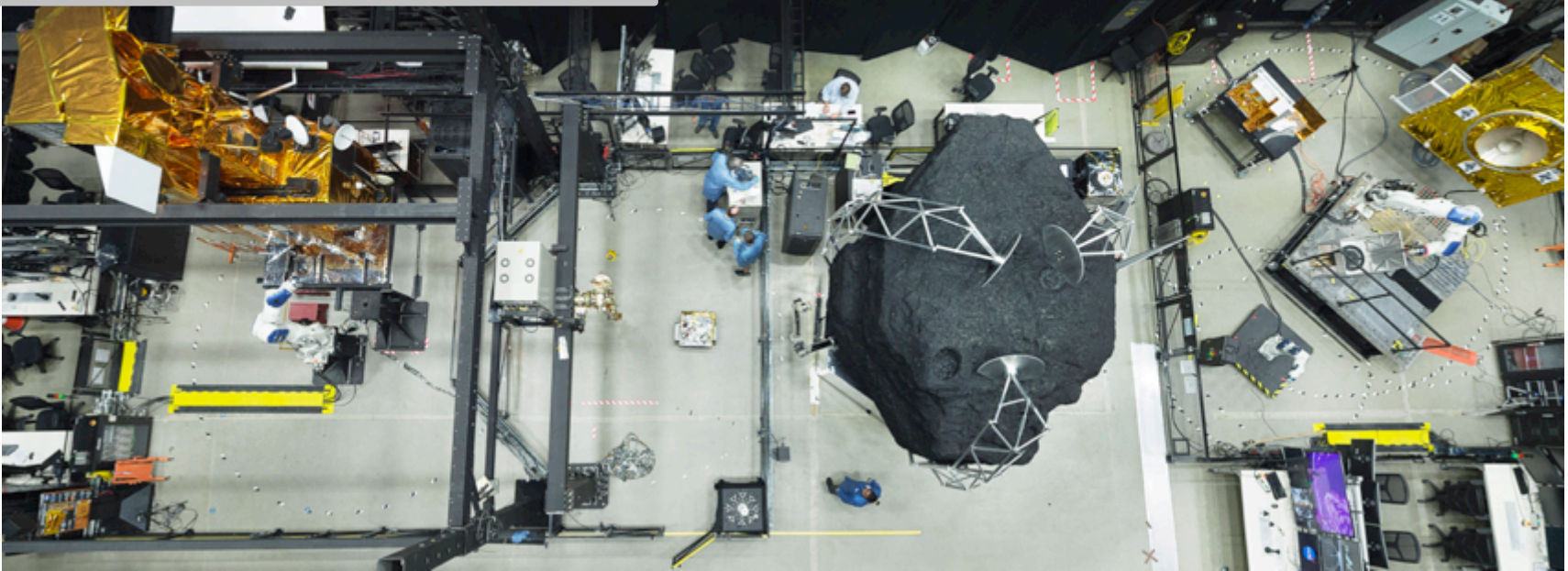
Servicing Technology Center



West Virginia Robotic Technology Center

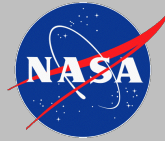


Robotics Operations Center



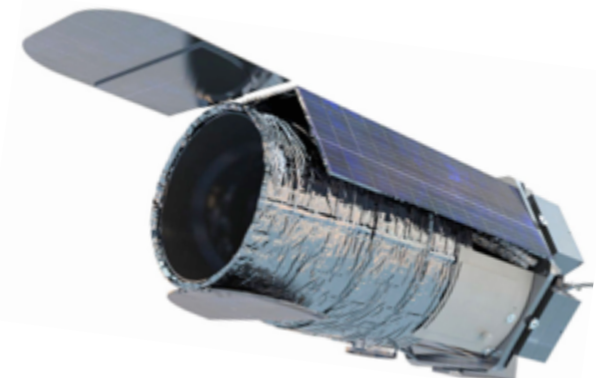
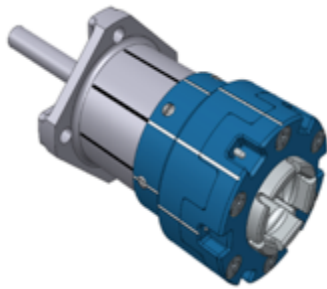
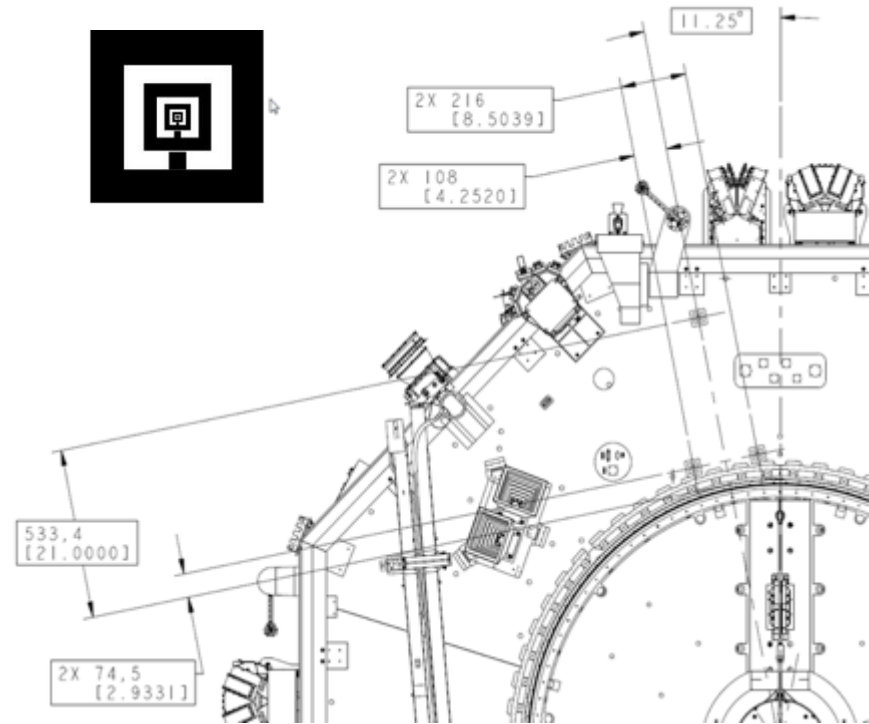


Cooperative Servicing Activities



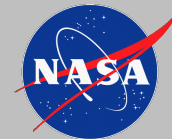
Cooperative Servicing technologies reduce risk, cost, and complexity of servicing missions

- NASA is developing Cooperative Servicing Aids to further enable satellite servicing on future missions
- ~ 6 satellites in orbit now have rendezvous decals
- The Cooperative Servicing Valve (CSV) will be the first product of this effort. The design will be at TRL 6 in 2017 and will fly on ISS in 2018
 - The CSV requires no caps or wires, greatly reducing operations time
- Multiple missions currently in development are analyzing how to incorporate these technologies





What Will The Next 40 Years Hold?



2013



2053





20 Meter?

