# The Restore-L Servicing Mission

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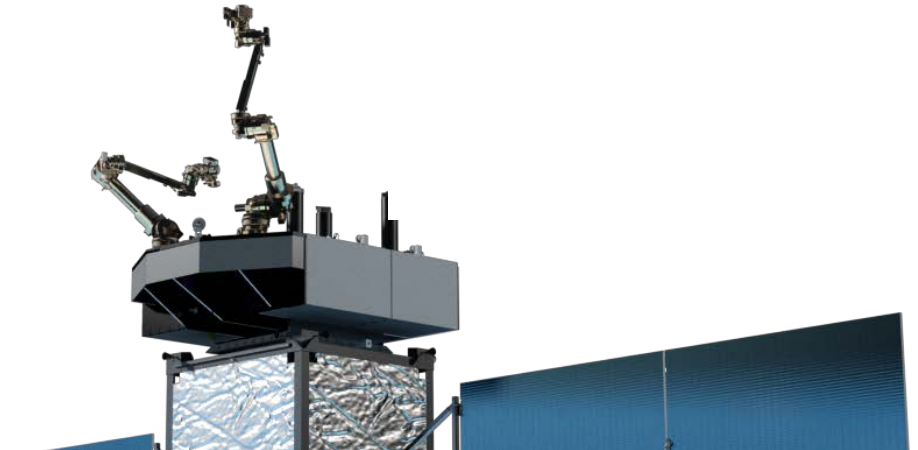
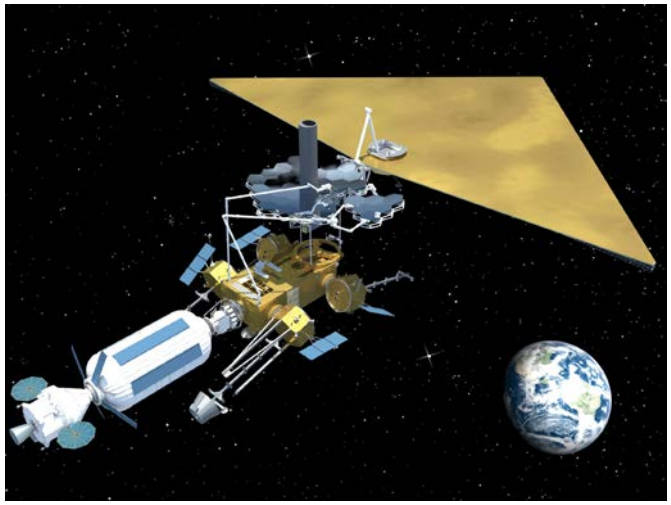



# Science and Exploration



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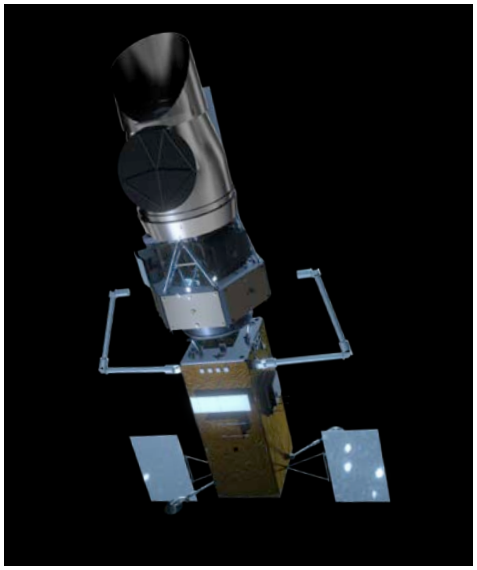

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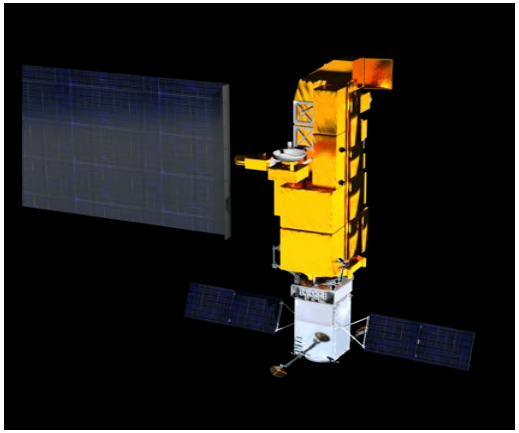
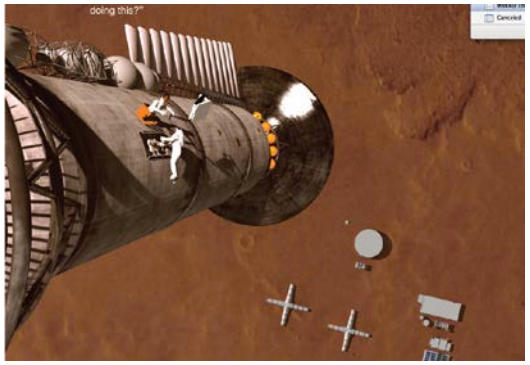


Extend Life

# Science

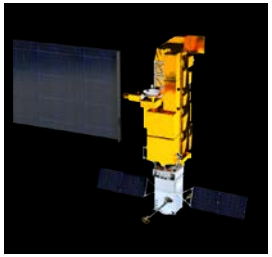
Build



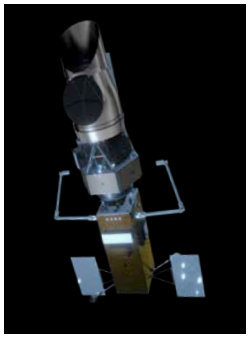
Replace and Repair

Replenish Consumables

# Exploration



Extend Life



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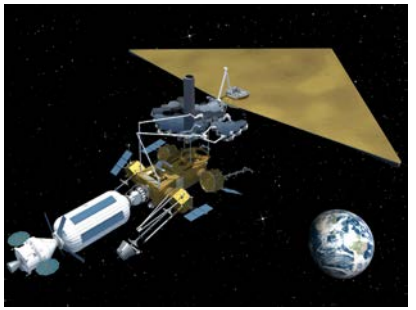
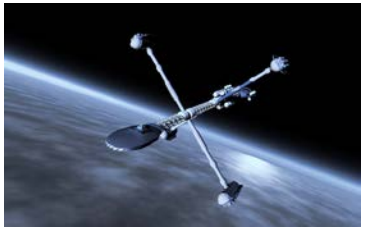


Assemble

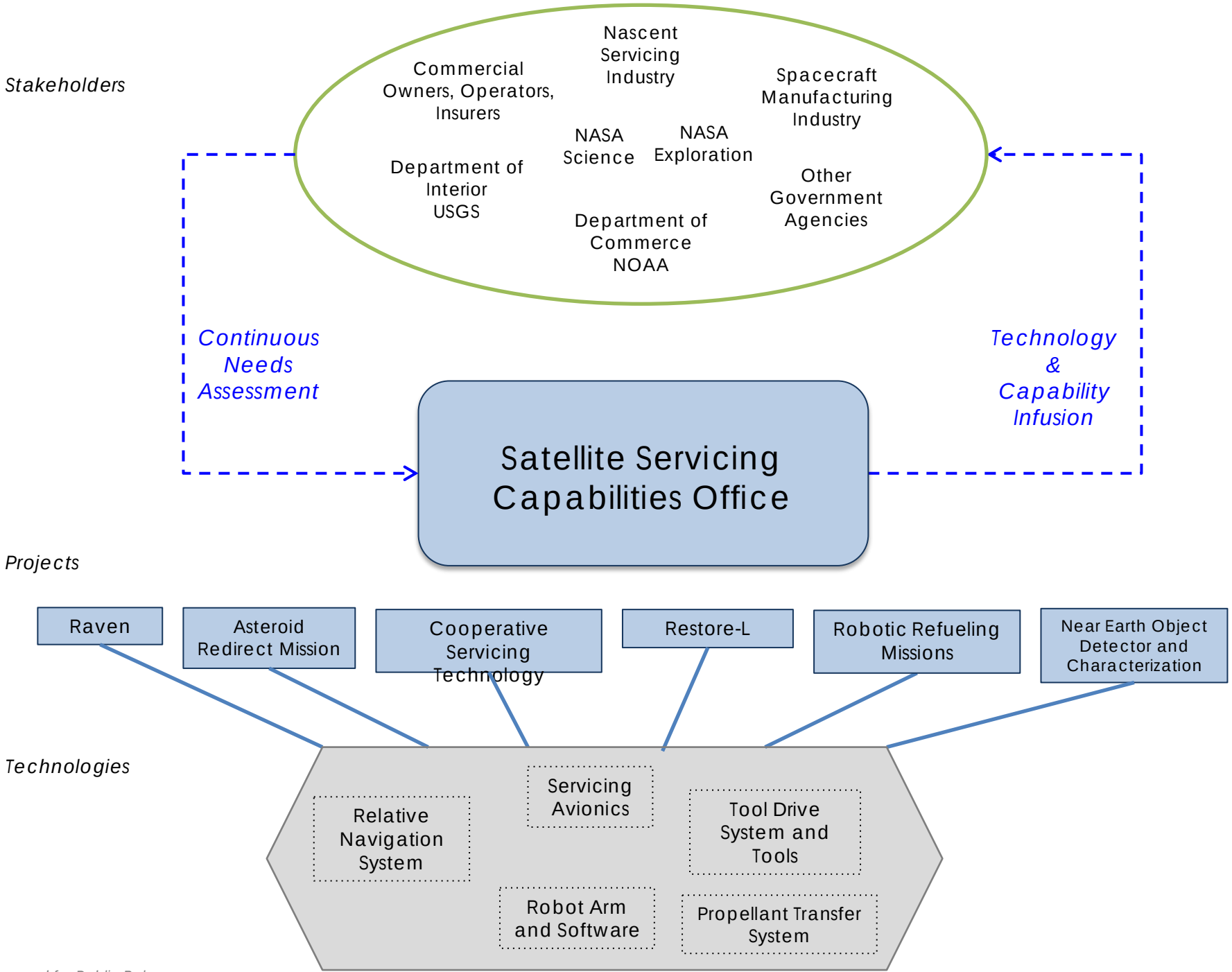
Replenish Consumables

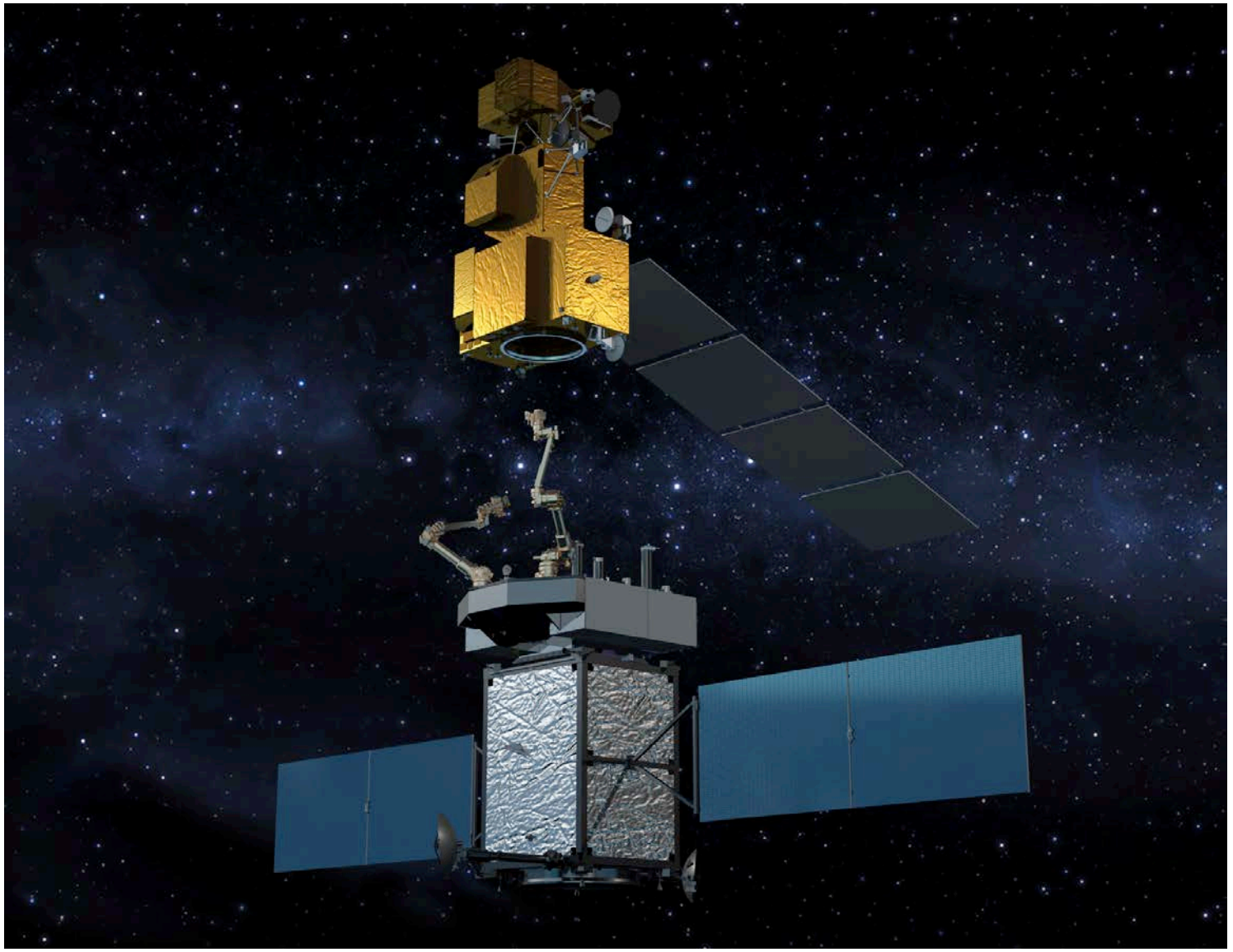
Replace and Repair

Build



# Servicing Capabilities

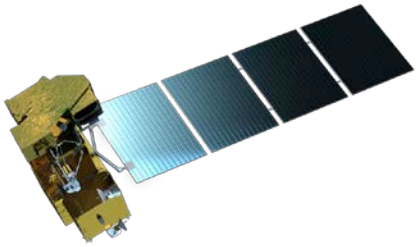


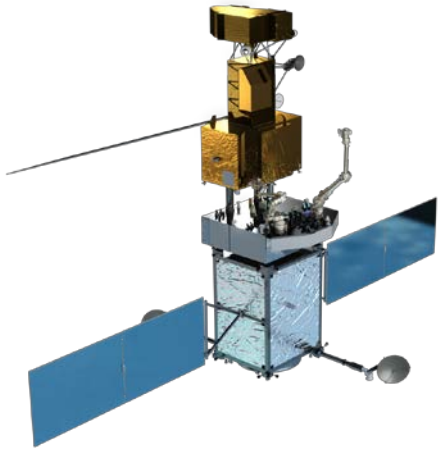


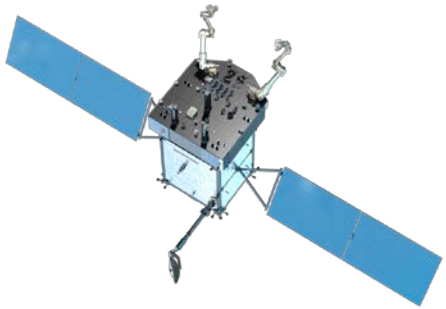
# Restore-L

Technology Demonstration Mission

Pre-formulation Phase: now







Rendezvous

Grasp

Refuel
& Relocate

# Objectives

**HQ** Space Technology Mission Directorate

**Center** NASA's Goddard Space Flight Center

**Project** Satellite Servicing Capabilities Office

**Associated Centers**

Kennedy Space Center

Marshall Space Flight Center

Johnson Space Center

# Management and Team

relative navigation system

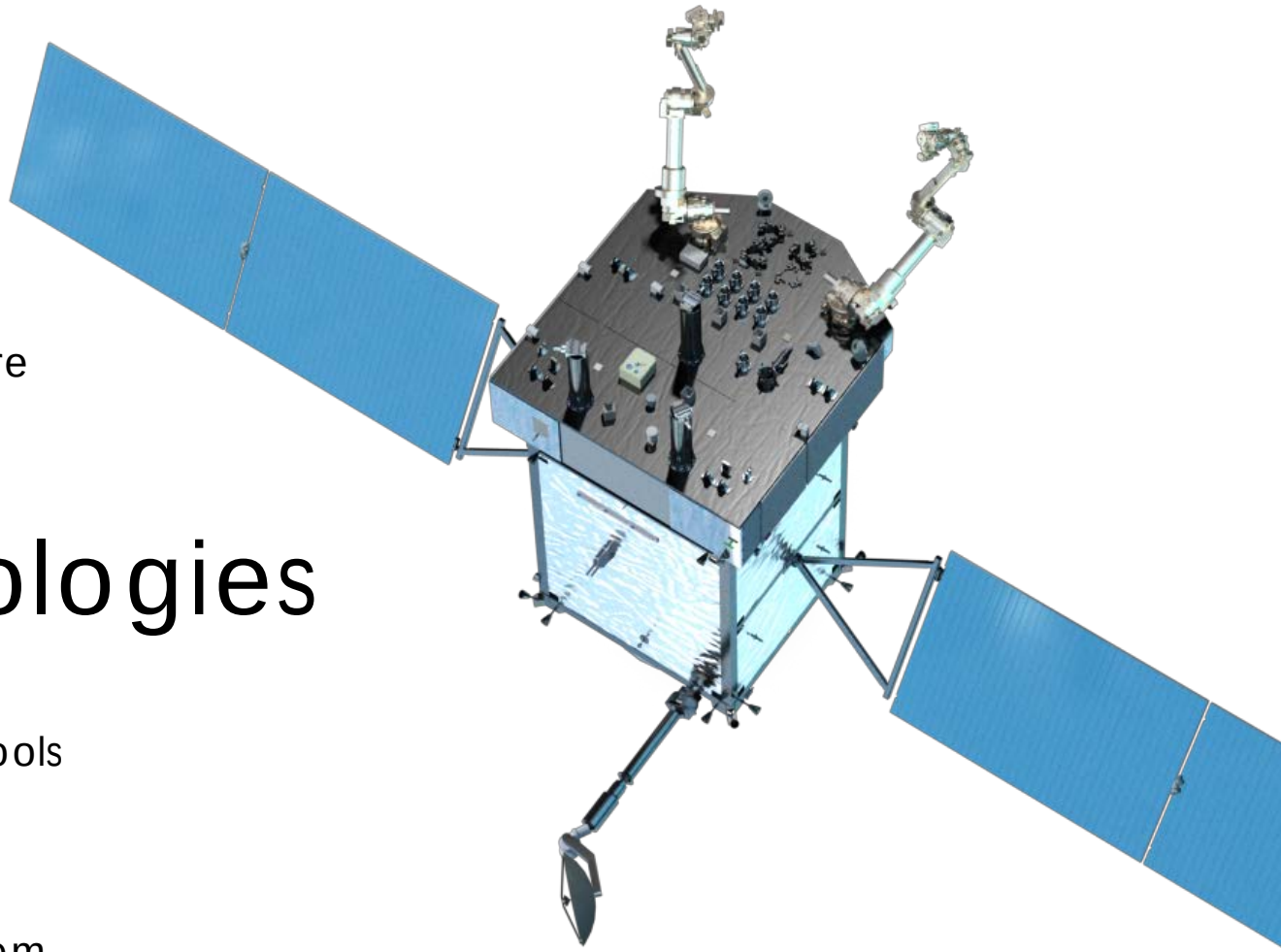
servicing avionics

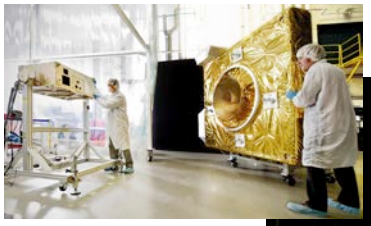
robot arm and software

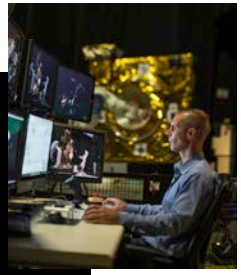
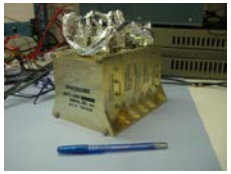
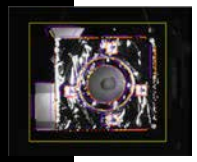
# Technologies

tool drive system and tools

propellant transfer system

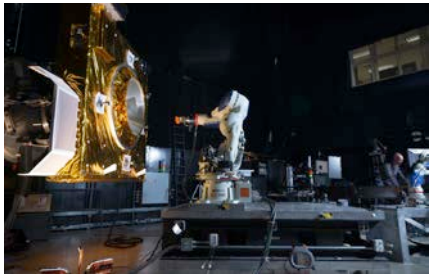
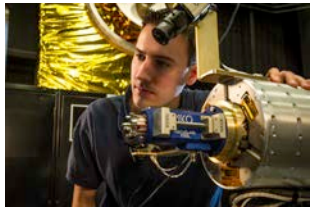







# Technologies

# Relative Navigation

## Objective

- Autonomous, robotic rendezvous with a non-cooperative satellite

## The Challenge

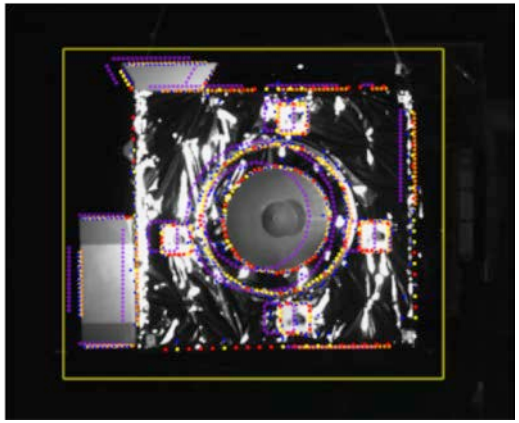
- Autonomous, real-time relative navigation with both non-cooperative and cooperative objects
  - Non-cooperative methods allow rendezvous to legacy space objects
  - Autonomous system allows robust operation across many operational regimes
- Creating a near-turnkey system for multiple future missions

## Technologies that make it possible

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

## Impact

- Results in an off-the-shelf, integrated Government technology set and capabilities



# Servicing Avionics

## Objective

- Avionics to enable autonomous rendezvous and capture of non-cooperative satellites, also teleoperated servicing tasks

## The Challenge

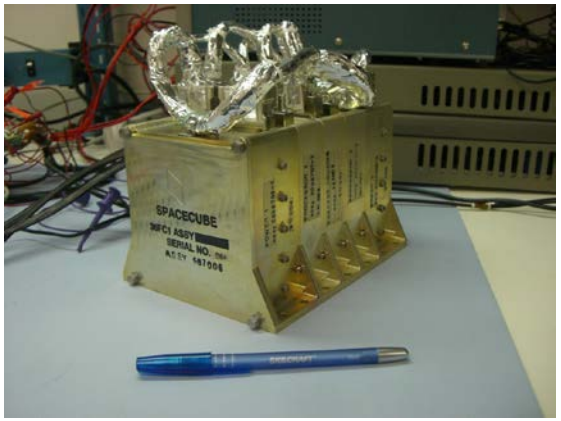
- Running complex vision processing algorithms and robot motion control algorithms in real time on flight-qualified hardware
- Developing methods to parallel process algorithms to accelerate hardware
- Developing a mission-critical system that is flight-qualified and robust to launch and space environment
- High volume video data storage and commandable distribution

## Technologies that make it possible

- SpaceCube processor
- Video Data Storage Unit

## Impact: how America benefits

- Provides enhanced data processing capability to support complex on-orbit servicing tasks
- Remote locations with communication limitations can benefit from increased processing prior to transmitting
- Applicable to missions that need many video sources with limited bandwidth



# Robot Arm and Software

## Objective

- Autonomous grasping of non-cooperative on-orbit satellite
- Teleoperated robotic servicing of legacy interfaces

## The Challenge

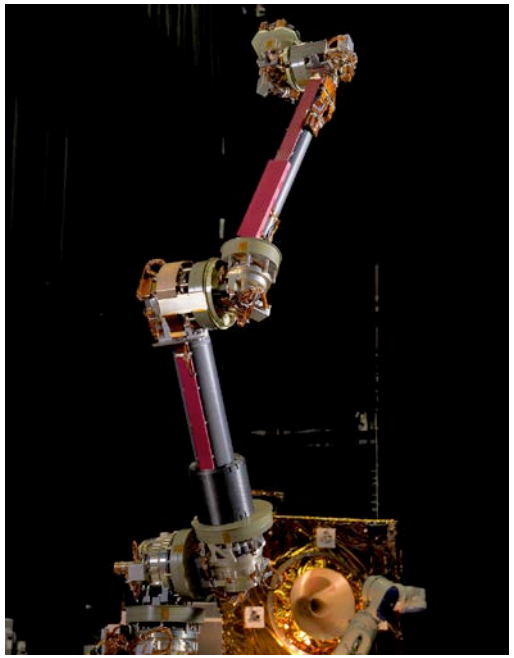
- Autonomous capture of non-cooperative clients
- Teleoperated servicing of non-prepared worksites at LEO, GEO or interplanetary

## Technologies that make it possible

- NASA Servicing Arm – 7 degrees of freedom
- Robot Electronics Unit
- Robot Flight Software

## Impact: how America benefits

- Support of current (SPDM) and future (LEO/GEO servicing, asteroid, etc.) robotic missions
- Accurate local simulation of remote delay – can help with investigating mitigation of cis-lunar and beyond time delay
- Robot and Electronics Unit design is GEO-qualifiable and can be used on future robotic missions



# Tool Drive System and Tools

## Objective

- Multipurpose tools and adapters to service a non-cooperative client

## The Challenge

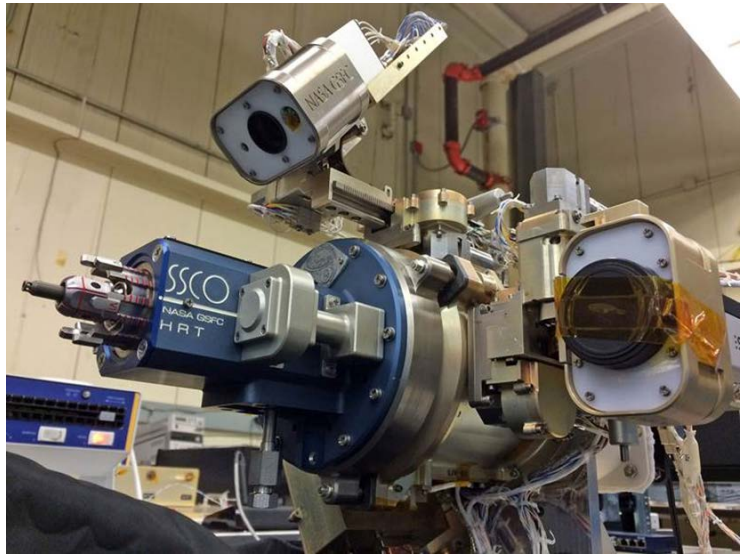
- Create compact, multi-drive tool drive system that enables low-mass, no-motor tools
- Produce suite of robotic tools capable of fault-tolerant operations on unprepared worksites – grasp, inspection, refueling (repair)

## Technologies that make it possible

- Advanced Tool Drive System
- Sophisticated servicing tools and adapters

## Impact: how America benefits

- Otherwise daunting missions become achievable
- American industry gets a jumpstart on on-orbit servicing



# Propellant Transfer System

## Objective

- System capable of transferring propellant to a non-cooperative satellite in orbit

## The Challenge

- Provide propellant on orbit to spacecraft not designed for servicing

## Technologies that make it possible

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

## Impact: how America benefits

- Enables safe and reliable refueling of spacecraft for life extension
- Flexible fleet architecture
- Ability to launch satellites with less initial fuel, allowing for more instruments
- Knowledge learned extensible to other fluid systems: xenon, helium, cryogens
- American industry gets a jumpstart on on-orbit refueling

# Near-Term Milestones

- Mission Concept Review (MCR) - April 7, 2016
- Key Decision Point (KDP) A - May 2016
- System Requirements Review (SRR) – July 2016
- KDP-B - Aug 2016
- Raven launches to ISS – no earlier than August 2016

# Near-term Restore-L Subsystem Milestones (1 of 2)

- Relative Navigation
  - Procurement of sensors
  - Medium-range closed loop testing
  - Relative Navigation Hardware Preliminary Design Review (PDR) – summer 2016
- Vision Subsystem
  - Situational and tele-op camera procurements
  - Vision Subsystem PDR – summer 2016
- Servicing Avionics
  - Development/fabrication of engineering design units (EDUs) boards for SpaceCube, Payload Services Unit (PSU), and Video Data Storage Unit (VDSU)
  - Procurement of EEE long-lead parts

# Near-term Restore-L Subsystem Milestones (2 of 2)

- Robot Arm and Software
  - Testing of EDU robotic arm with first-generation EDU Robotic Electronics Unit
  - Procurement of the first actuator joint
  - Development of second generation EDU Robotic Electronics Unit
  - Robotic Subsystem PDR summer 2016

- Tool Drive System and Tools
  - Testing of the next generation Tool Drive (ATDS)
  - Design and manufacturing of prototype/EDU robotic servicing tools, including a cooperative fueling interface
  - ATDS PDR – summer 2016

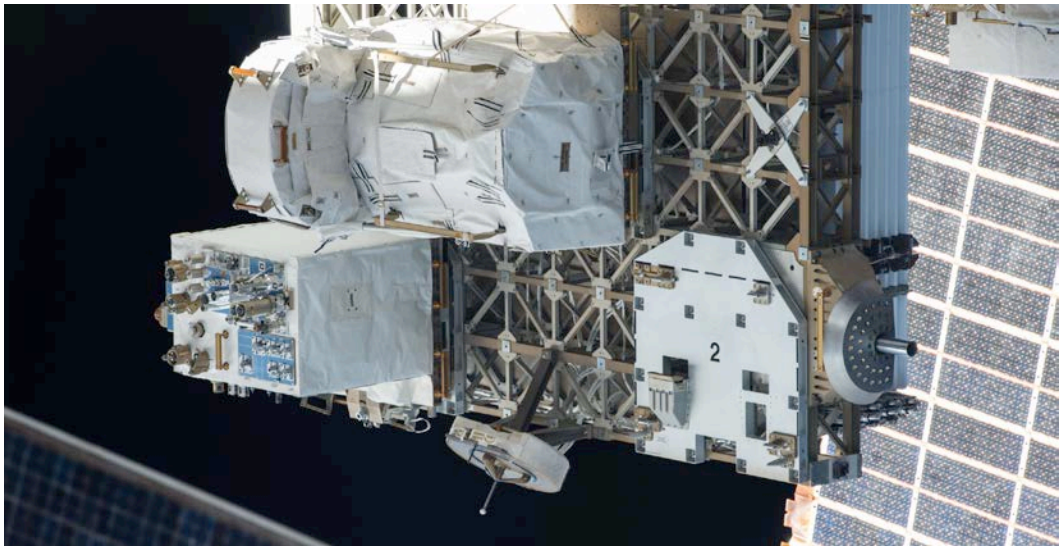
- Propellant Transfer System
  - Integrated end-to-end refueling test with simulated fuel
  - Procurement of long-lead components

# Technology Advancement on Orbit and on the Ground

# Robotic Refueling Mission

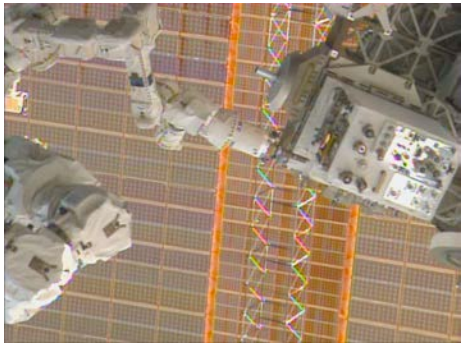
Technology Demonstration on the International Space Station

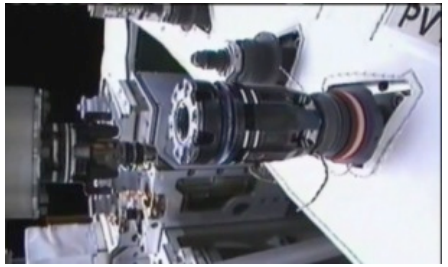
Blanket Manipulation



Wire Cutting

Cap removal

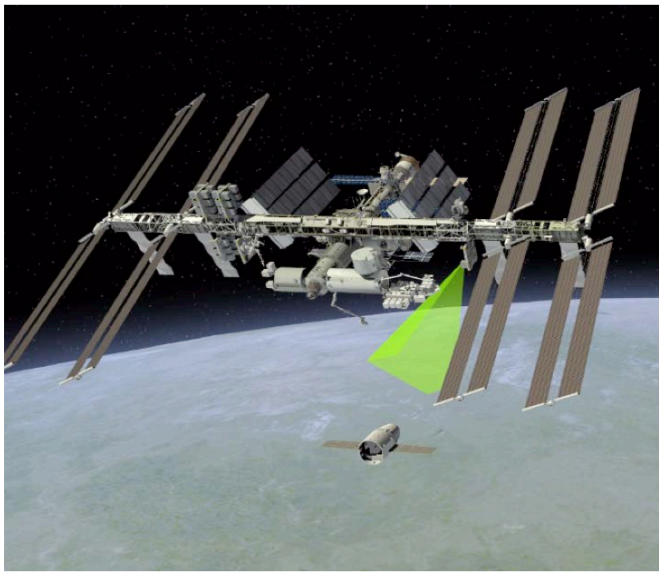




Transferring Mock Propellant

# Raven

Technology Demonstration on the International Space Station



Artist's Concept

Raven payload (pre-launch)

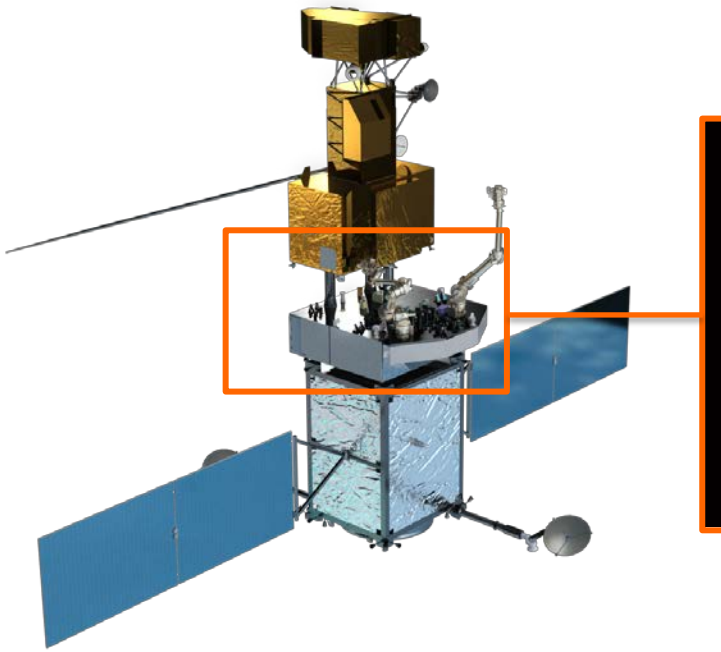
Results in an off-the-shelf, integrated Government technology set/capability applicable to executing future NASA missions

Reduces risk for Orion

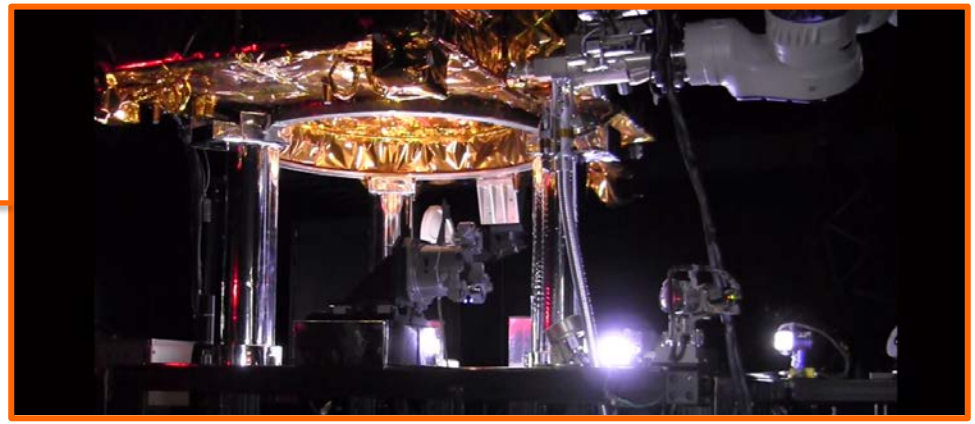
# Robotic Operations Center

# Evaluation of refueling in ‘orbit night’

Robotic Operations Center

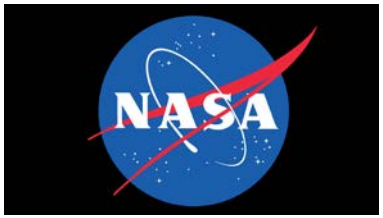


Artist’s Concept



Development in Robotic Operations Center,
Goddard Space Flight Center

Disruptive technologies open fresh possibilities for the future




NASA

Nation

Industry

Servicing Capabilities

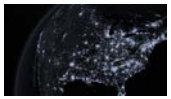
Technologies

# NASA

1. Expanded options for extending the lives of satellites, observatories and spaceships

2. Flight-proven technologies that facilitate upgrade and (self)maintenance of robotic and crewed vehicles

3. Capabilities that support ambitious Science and Exploration architectures: assembly of assets larger than single payload fairings

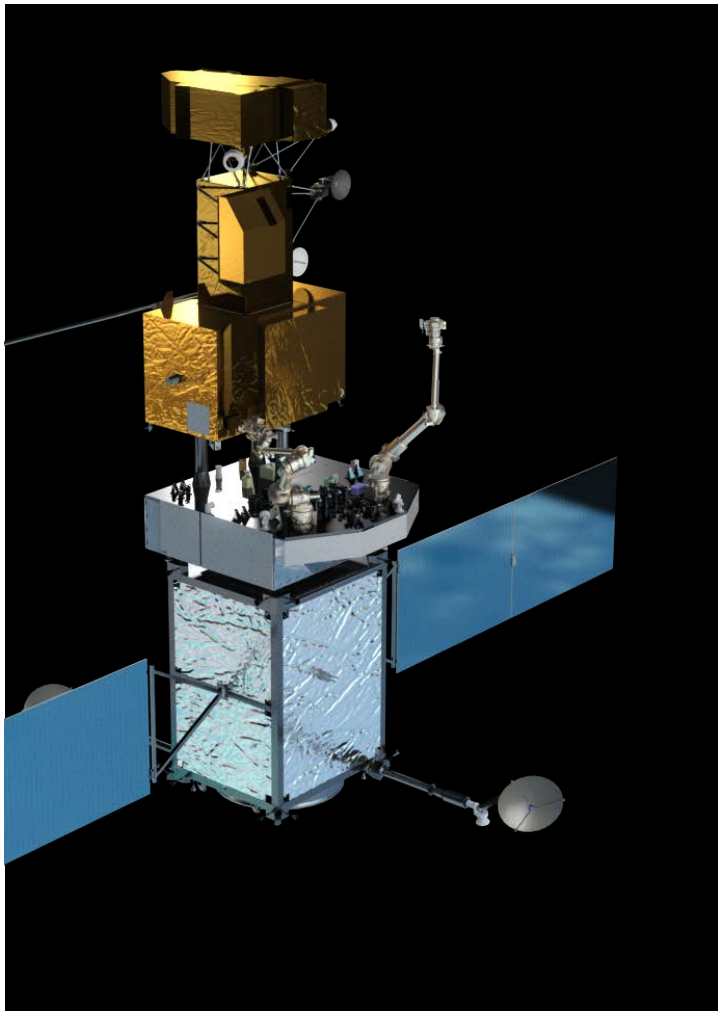
# Nation

1. Global precedence in robotic satellite servicing
2. U.S. fleet management possibilities
3. New commercial industry boosting U.S. economy

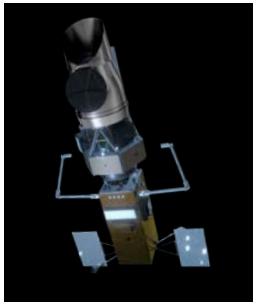

# Nascent Commercial Servicing Industry

Receives flight-proven technologies to jumpstart a commercial industry.

# Restore-L and Asteroid Redirect Mission Synergy



Prolong Life



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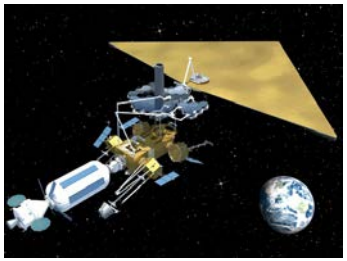


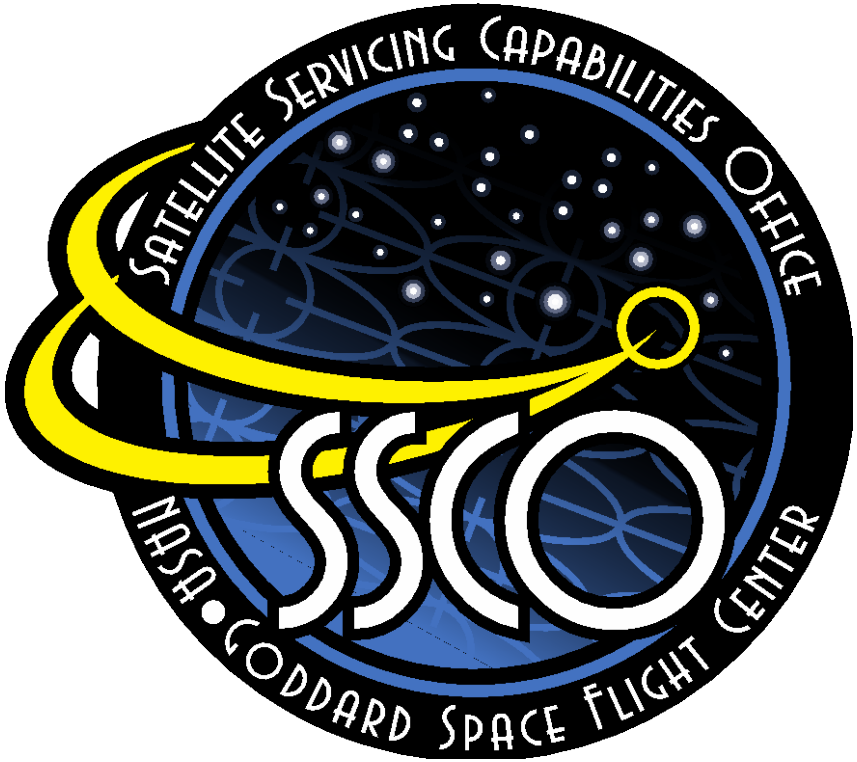
Assemble

# Servicing Capabilities

Replenish Consumables

Replace and Repair

Build




http://ssco.gsfc.nasa.gov