Advances in Robotic Servicing Technology Development

Gardell G. Gefke
Vehicle Systems Integration, LLC, College Park, MD, 20740
Alex Janas
Stinger Ghaffarian Technologies, Inc., Greenbelt, MD 20770
Joseph Pellegrino and Matthew Sammons[4]
Orbital ATK, Beltsville, MD 20705
and
Benjamin Reed
NASA/Goddard Space Flight Center, Greenbelt, MD 20771

NASA's Satellite Servicing Capabilities Office (SSCO) has matured robotic and automation technologies applicable to in-space robotic servicing and robotic exploration over the last six years. This paper presents the progress of technology development activities at the Goddard Space Flight Center Servicing Technology Center and on the ISS, with an emphasis on those occurring in the past year. Highlighted advancements are design reference mission analysis for servicing in low Earth orbit (LEO) and near Earth asteroid boulder retrieval; delivery of the engineering development unit of the NASA Servicing Arm; an update on International Space Station Robotic Refueling Mission; and status of a comprehensive ground-based space robot technology demonstration expanding in-space robotic servicing capabilities beginning fall 2015.

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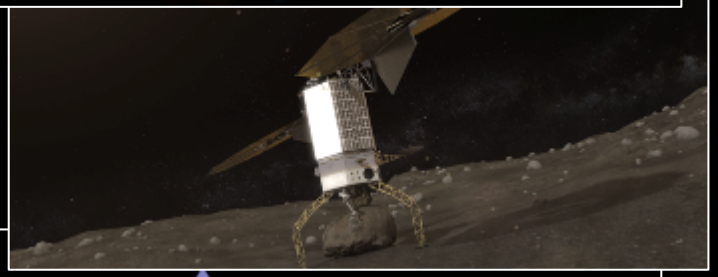

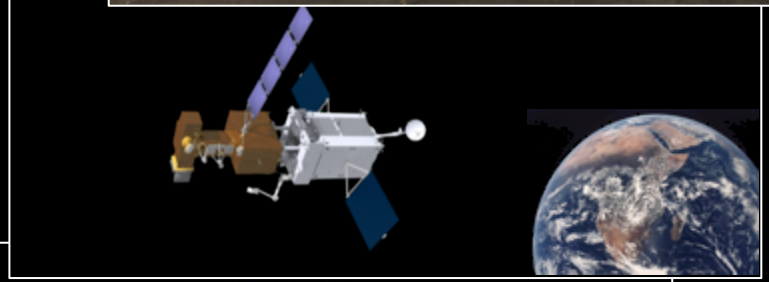

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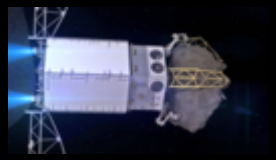
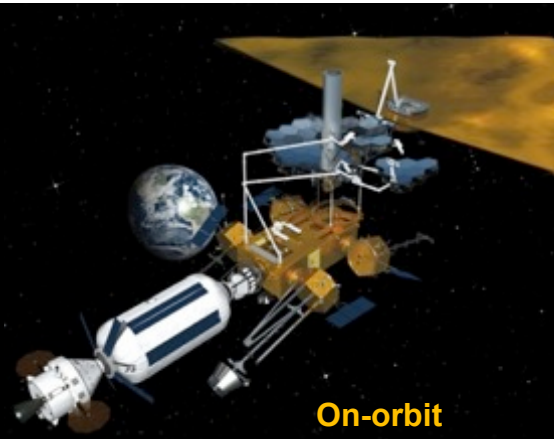
Presented by
Gardell Gefke
Chief Robotic Systems Engineer
Satellite Servicing Capabilities Office
http://ssco.gsfc.nasa.gov
Alex Janas, Benjamin Reed

Servicing Supports Multiple Objectives





On-orbit Assembly

Fleet Management Government and Commercial

Asteroid Redirection

Infrastructure Inspection and Maintenance

Human Exploration

Observatory Servicing

Planetary Defense

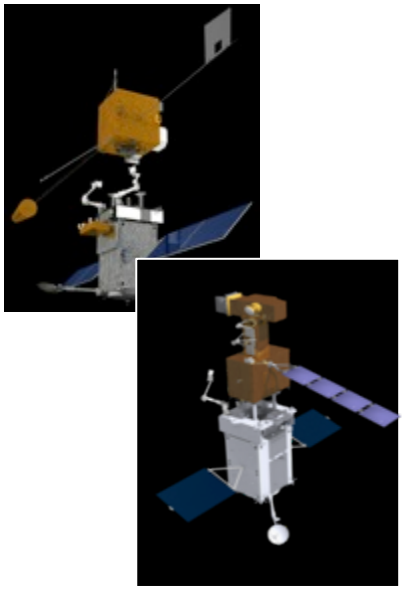
Servicing Capabilities

Propellant Depot

Servicing Servicing Capabilities Office (SSCO)

NASA's Satellite Servicing Capabilities Office is rapidly maturing the robotic servicing technologies that would jumpstart new capabilities for the nation.

Study



Study point design notional missions with guidance from RFI responses

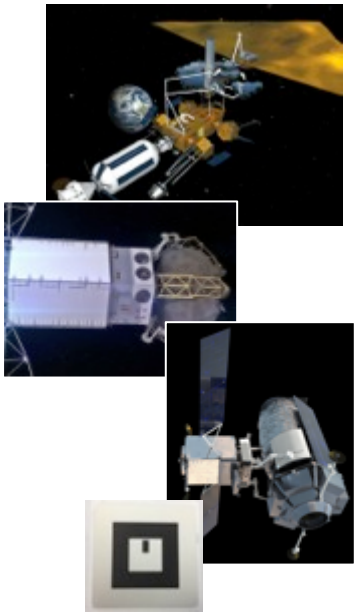
Build

Build hardware & software for experiments in orbit and on the ground

Test

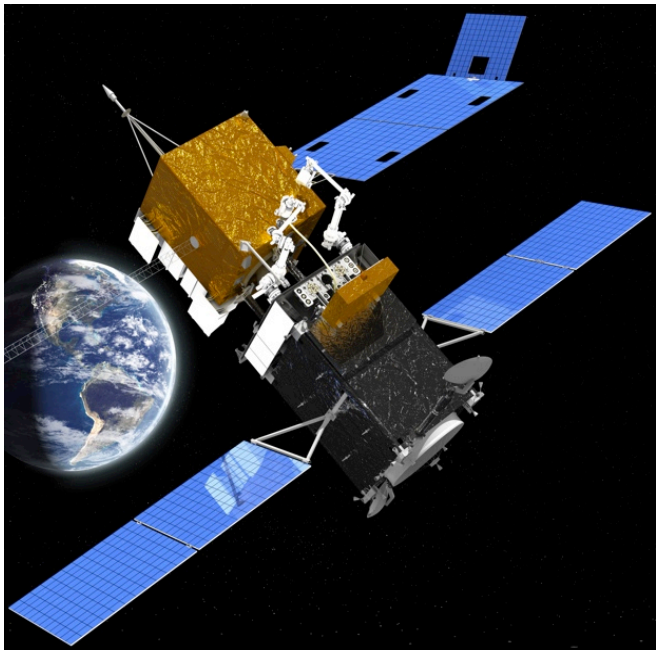
Manage technology development campaign and servicing missions

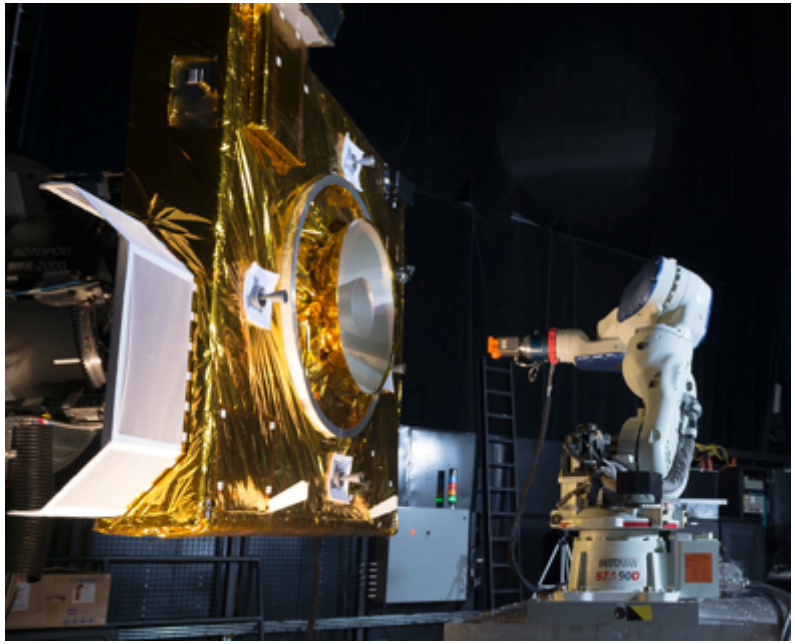
Advise



Design and advise clients on cooperative servicing elements

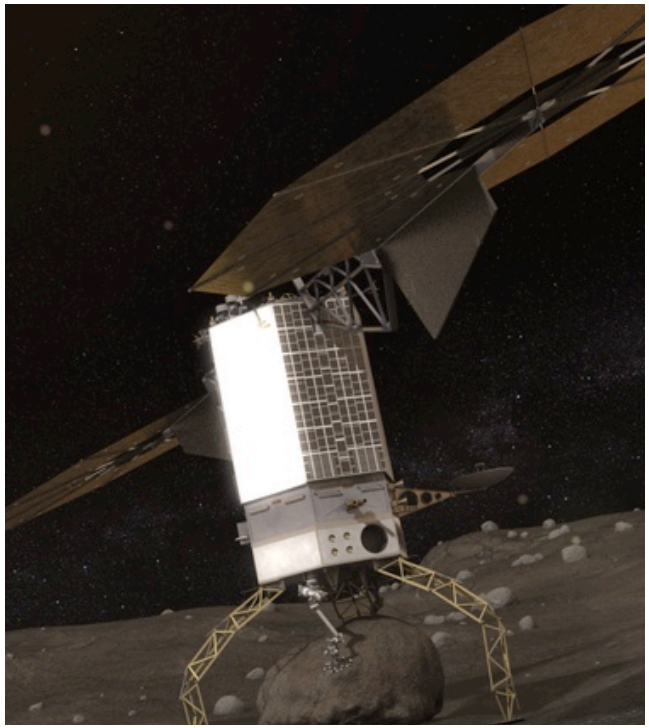
Design Reference Missions

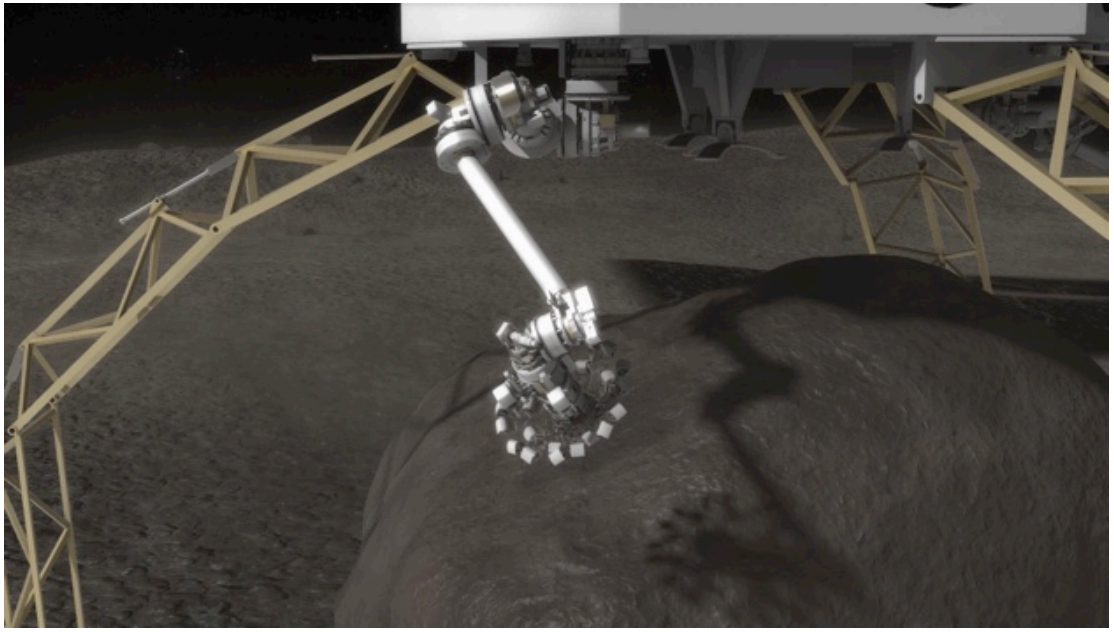




- Design reference missions (Restore-GEO and –LEO):
  - Help identify and drive the development of technologies needed for various servicing missions
  - Establish requirements baselines for a host of servicing scenarios

Asteroid Redirect Robotic Mission
Asteroid Capture and Extraction





Artist's concept of NASA Servicing Arm with Microspine Gripper/Drill

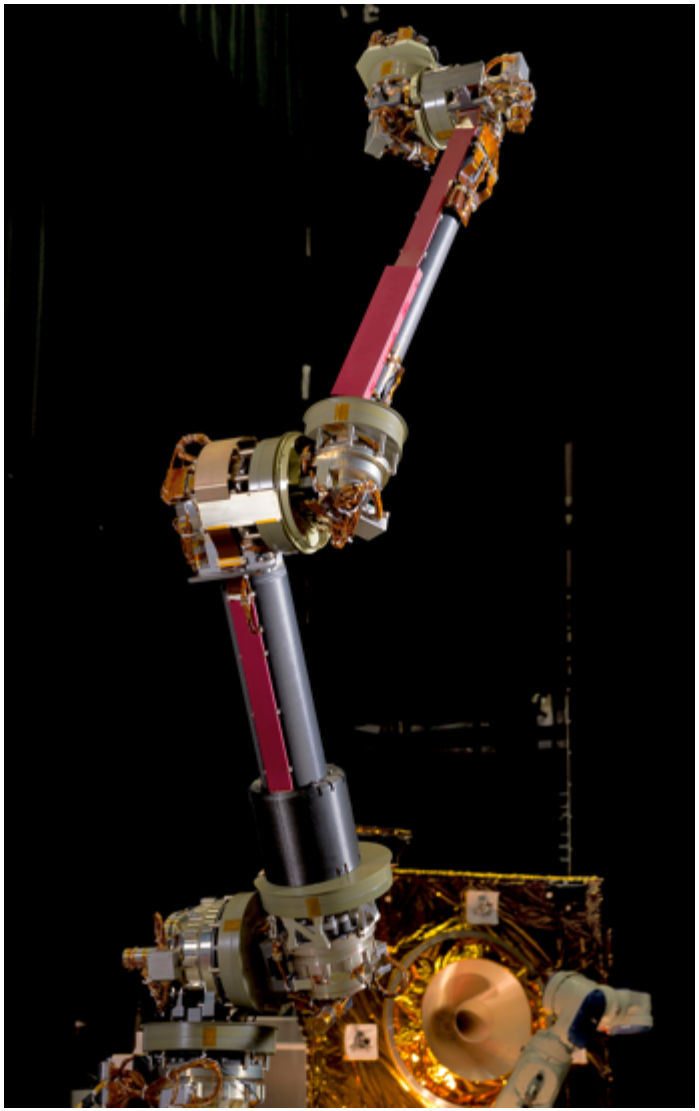
- SSCO robotic technologies as part of ARRM
  - Common control electronics for servicing arms and restraint legs
  - Rendezvous and prox ops sensors and control
  - Payload Module's high-speed computing platform
  - Vision system

NASA Servicing Arm

- Engineering Development Unit of NASA Servicing Arm delivered to NASA GSFC in June 2015
  - Culmination of five-year development and procurement cycle
- 2-meter class, 7 degree-of-freedom arm
  - Mars Rover Arms and DARPA SUMO/FREND heritage
  - Modified slightly to increase mass handling and range of motion
- Dynamic and large range of requirements
  - Autonomous grasp and stiff enough to allow client-service attitude control through a single arm
  - Compliance control for force/torque hazard containment
  - Fine manipulation
  - Applicable to both servicing tasks and asteroid boulder manipulation

EDU Servicing Arm Development Challenges

- Arm stiff enough for Servicer-Client Stack attitude control
  - Side effect: full 1-g capability for all grasp and task operations
    - Reduces reliance on simulation-only validation techniques
    - Eases client acceptance by allowing observation of the end-to-end tasks
- Multi-vendor procurement management
- Use of EDU HW for driving and data gathering



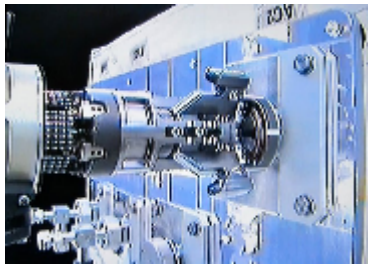
Robot Arm Control

- Autograsp – autonomous mode with tightly controlled touch
- Teleoperations – adapts to a wide range of potential client worksites and types
- Sub-millimeter precision for fine tasks like wire cutting
- Stiffness and strength for multi-ton client/asteroid maneuvering
- Gravity compensation loop to allow the same zero and 1-g PID control loop tuning
- Human-in-the-loop – advanced visual overlays and imposed camera image fusion

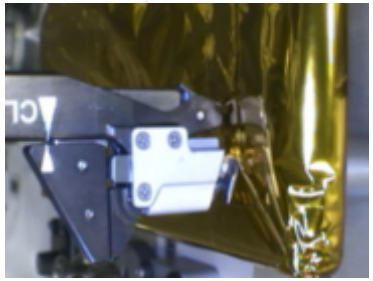
Robotic Refueling Mission: The Challenge

- Develop tools and techniques to refuel and service legacy systems not designed for servicing (and demonstrate capability on ISS using existing robot systems)

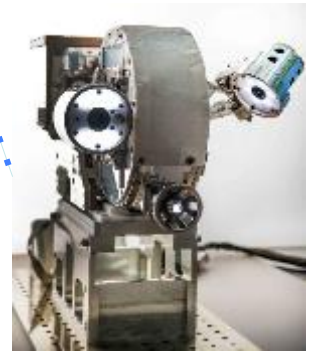
2011 ***2012*** ***2013*** ***2014*** ***2015*** ***2016*** ***2017/2018***



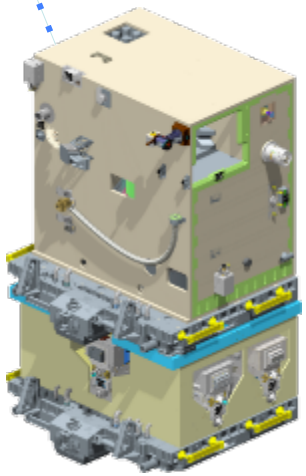
Gas Fittings Removal Task – Completed



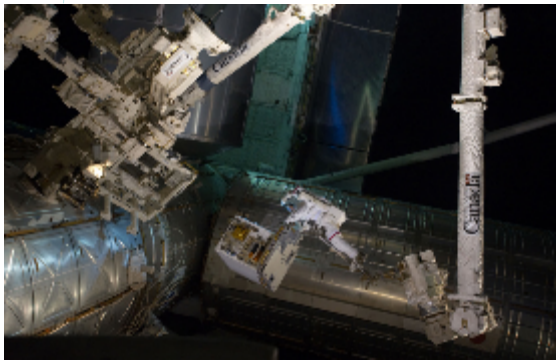
Tertiary Tasks – Completed



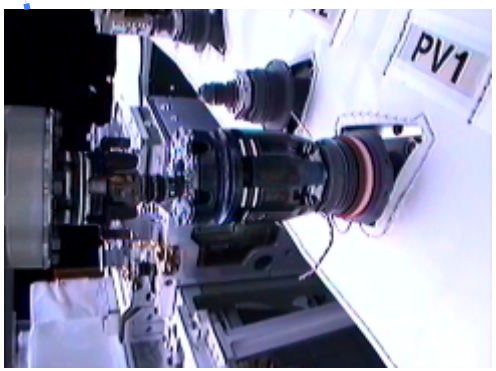
RRM Phase 2 Operations



RRM3 Launch and Operations

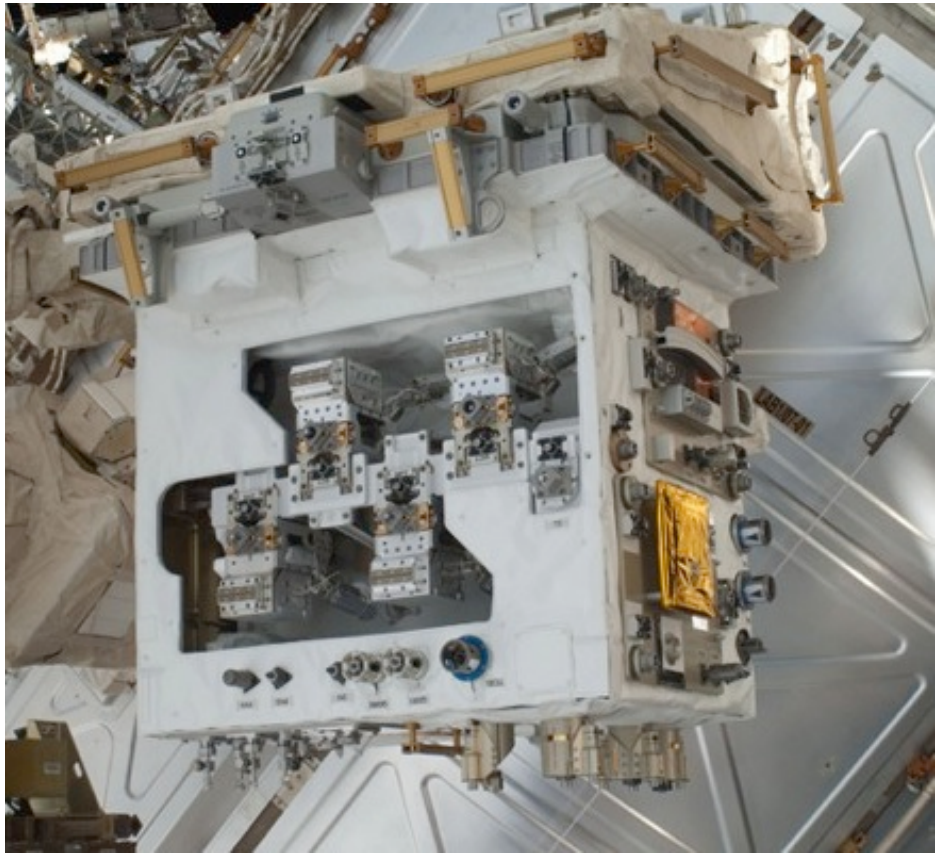


RRM delivered to ISS on STS-135



Refueling Task - Completed

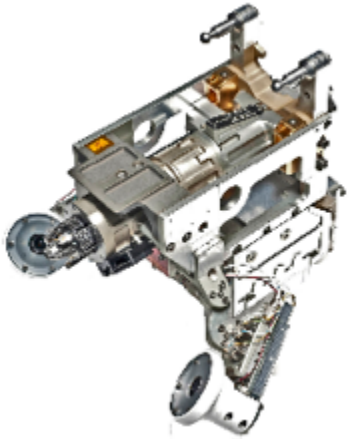
Refueling Technologies Used for On-orbit Testing



Robotic Refueling Mission module

MLI/Wire Cutter Tool

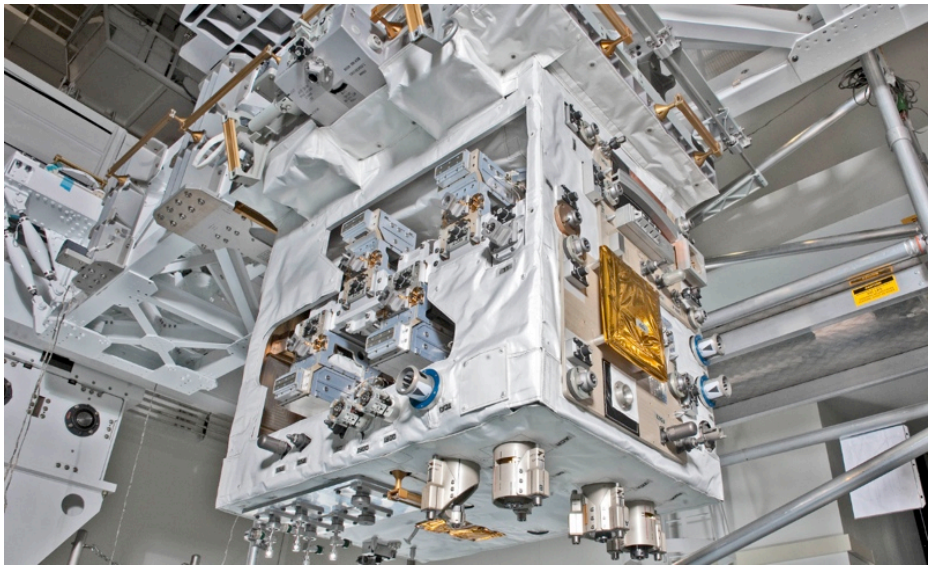
Safety Cap Tool

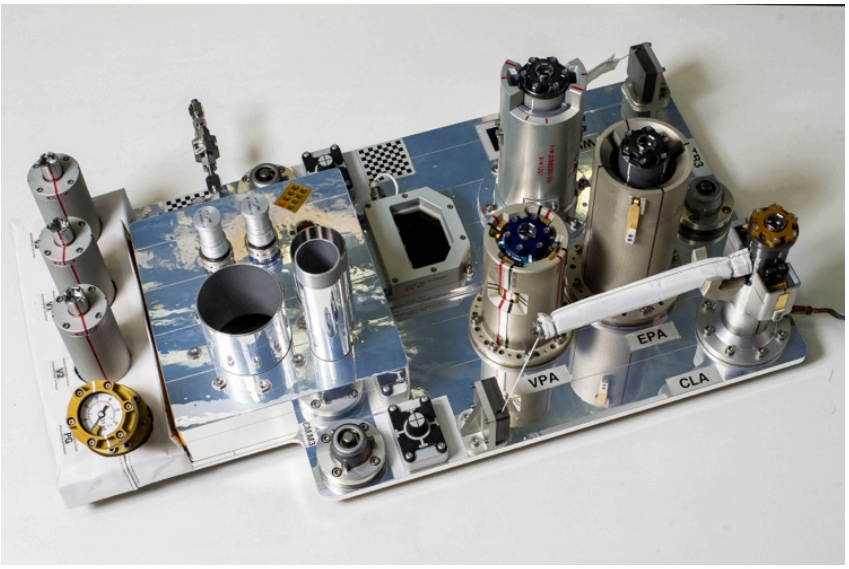


Multifunction Tool

EVR Nozzle Tool

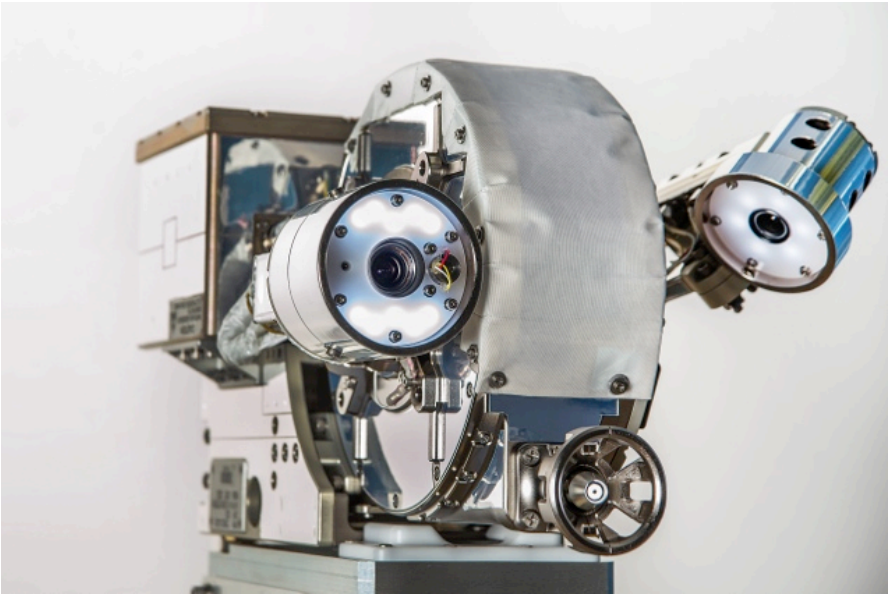
Robotic Refueling Mission 2





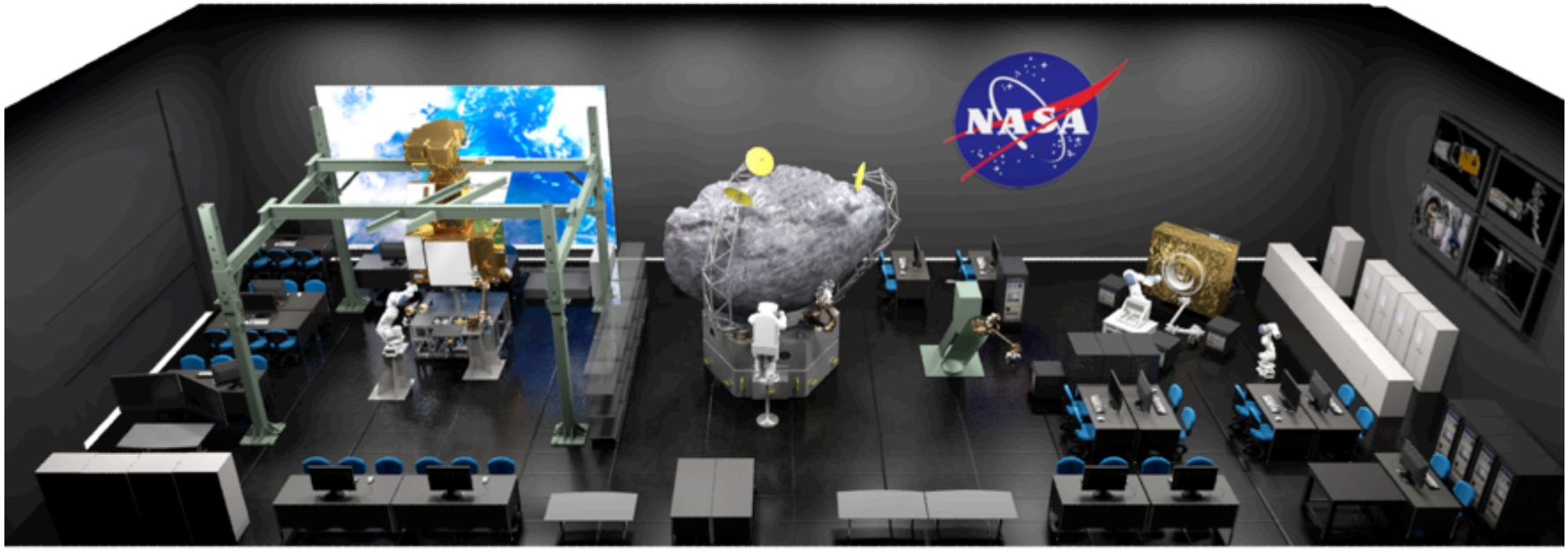
- Two new tasks boards, five new tool adapters
- Activities include:
  - Procedures to prepare a worksite for cryogen transfer
  - Electrical connectors
  - Material sample evaluation
  - Close and mid-range visual inspection
  - Fiducial pose estimation

VIPIR: Visual Inspection Poseable Invertebrate Robot
Demonstrated during RRM operations



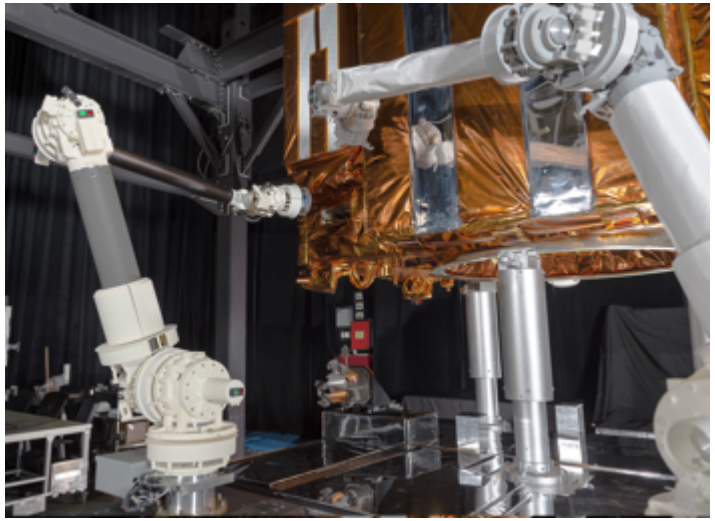
- An 8-24mm optical motorized zoom lens
- A 1.2mm camera mounted on an extendable articulating hose
  - Extended into an obstacle course, pictured above right, during on-orbit operations in May 2015

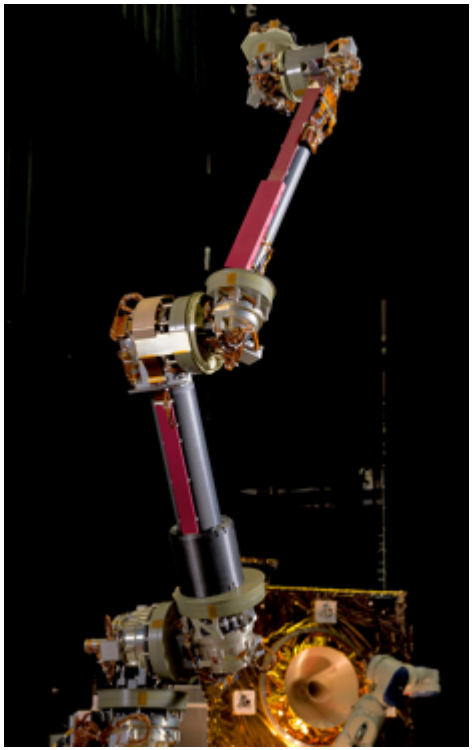
The Cauldron



- Four test cells advancing servicing technologies
- Robots
  - Reach and access, control algorithms, tool evaluations, teleoperations
  - Servicer systems: visual, high-speed computing, on-board video distribution, client berthing system, situational awareness systems
- Autonomous Grasp: rendezvous and prox ops sensors, autograsp testing
- Client spacecraft servicing and refueling: on-orbit operations simulation, propellant transfer, end-to-end operations testing

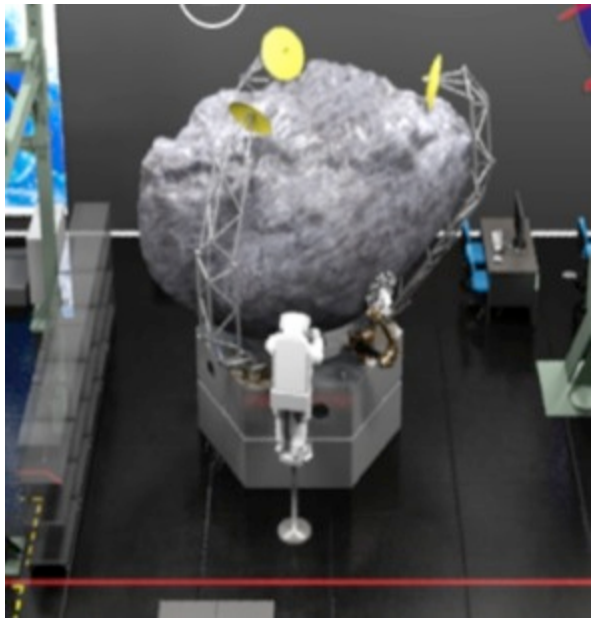
Servicing Technology Advancement





- Full-scale Client Servicing
  - Industrial and EDU arm operations
  - Expands to full hardware-in-loop systems test platform
- EDU Servicing Arm Integration and Test
  - Integrating EDU robot arm with control and ancillary services
  - Pathfinder for flight arm

Servicing Technology Advancement



- ARRM robotic systems test bed
  - Demonstration of Servicing Arm asteroid grasp
  - Full-scale restraint legs mockup
  - Potential use as an EVA planning tool
- Autonomous autograsp of client satellites
  - Full-scale client grasp interfaces
  - Servicer and Client spacecraft relative motion simulation
  - Transition from industrial arm to EDU Servicing Arm in FY16
  - Full hardware-in-loop test bed

Summary

- Servicing technology maturation campaign is yielding results
  - On-orbit: Robotic Refueling Mission 1, 2, and 3; VIPIR inspection tool
  - On the ground: Cauldron robotic servicing test facility with autonomous grasp, ARRM, and full-scale servicing simulator
  - Path to flight hardware: EDU Servicing Arm and control electronics under test at Goddard
  - Verified results are allowing mission planners to design more ambitious and capable missions

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SSCO Coauthors

- Alex Janas, *Stinger Ghaffarian Technologies, Inc.*
- Joseph Pellegrino, *Orbital ATK*
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- Benjamin Reed, *NASA/Goddard Space Flight Center*