
National Aeronautics and Space Administration
Satellite Servicing Technology Development
25 July 2011
GCDPO
Rev. A
NASA
Space Technology Program, Office of Chief Technologist

Satellite Servicing History and Near Future

- **NASA**
  - **1984: Solar Max Capture, Repair and Re Deploy**
  - **1992: Intelsat VI Capture and Re Deploy**
  - **1993: Hubble Repair, Servicing Missions 1-4**
  - **2004: Demo of Autonomous Rend. Tech.**
  - **2010: GSFC Satellite Servicing Study**
  - **2011: DARPA/OCT Manned Geo Servicing Study**
  - **2011+: Robotic Refueling Mission on ISS**
- **Other US Agencies**
  - **2004: Air Force XSS 10 and 11**
  - **2007: DARPA Orbital Express**
- **Other Countries**
  - **1997: NASDA ETS-VI Rendezvous and robotics**

Why Robotic Satellite Servicing at GEO?

- There are a significant number of spacecraft at GEO
  - Over 100 government-owned spacecraft
  - Over 360 commercial communication satellites

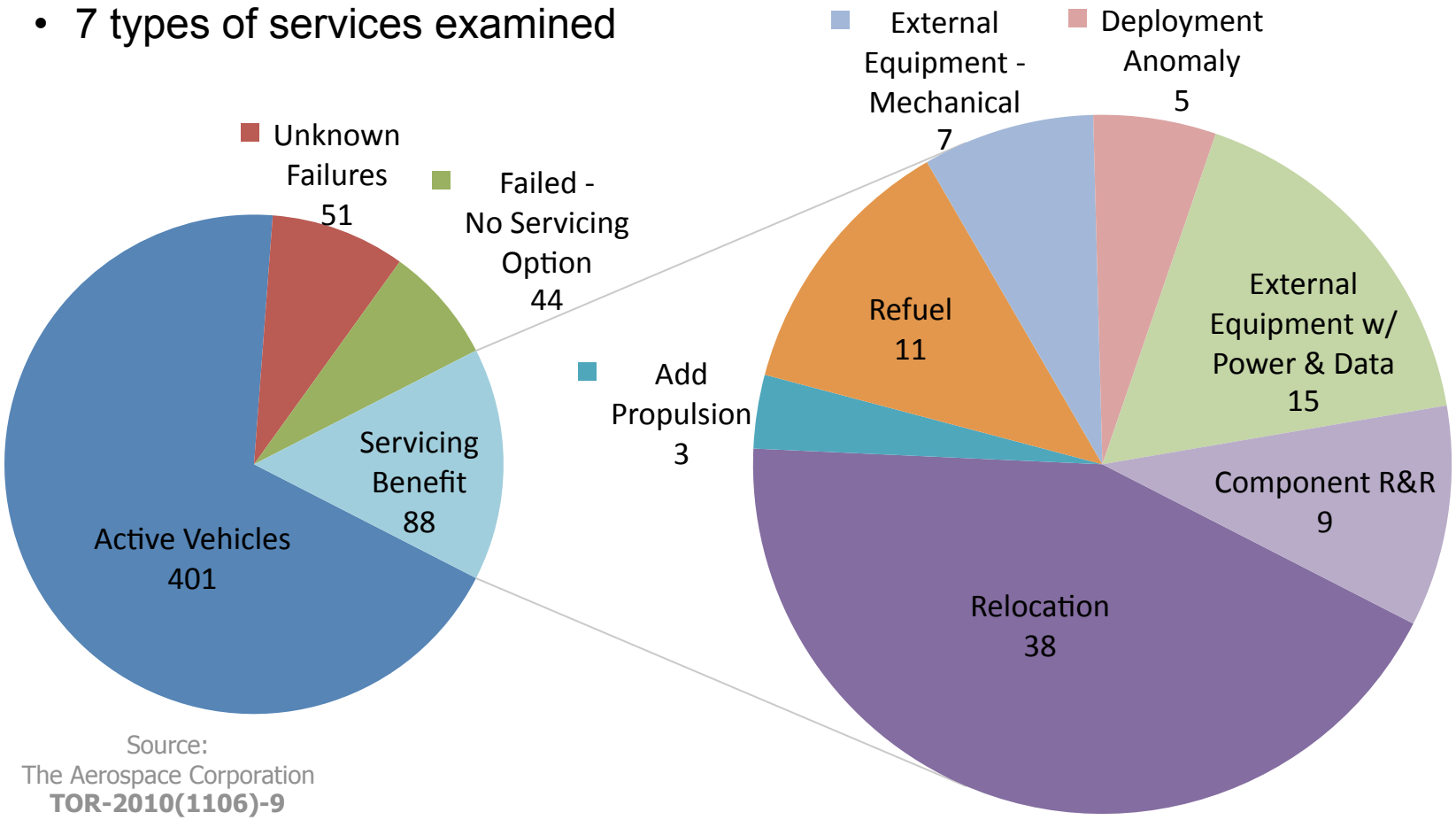
- On average per year:
  - 2 satellites run into technical difficulties and require disposal
  - 4 satellites prematurely exhaust their propellant supply
  - 2 satellites are inadvertently placed in to incorrect orbits
  - 20 satellites are retired at the end of their designed mission life

- In 2008 and 2009 alone, four GEO satellites were left to expire without performing end-of-mission orbit-raising maneuvers

- Significant national security interests could take advantage of servicing

GEO satellite end-of-life statistics

- 584 unclassified GEO missions from all countries, launched 1990-2010
- 88 missions ended which could have benefited from servicing
- 7 types of services examined



Source:
The Aerospace Corporation
TOR-2010(1106)-9

NASA Activity

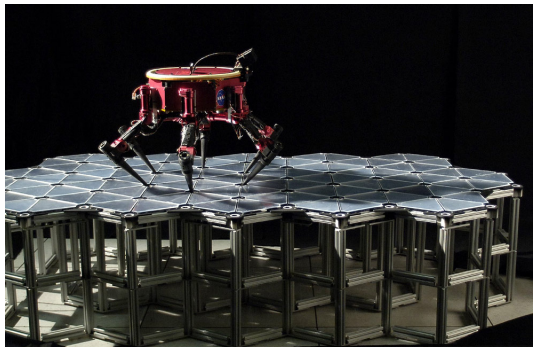
- **RFI, Dec, 2009:** NASA issued an RFI seeking information on the feasibility of using human spaceflight or robotic missions for servicing existing and future spacecraft.

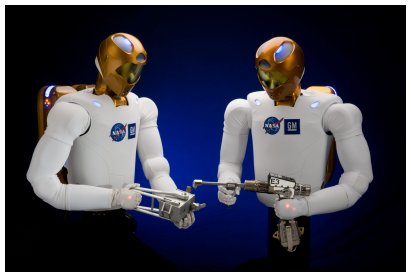
- **Workshop, Mar. 2010**: In conjunction with the 2009 RFI, NASA conducted an open workshop March 24-26, 2010 to bring potential users and providers of on-orbit servicing capabilities together with the NASA study team. http://ssco.gsfc.nasa.gov/servicing_study.html.

- **SOMD, GSFC**
  - Robotic Refueling Mission (RRM)
    - Launched on STS-135
  - Dexterous Pointing Package (DPP)
    - Demonstration with ground facilities
- **SOMD/OCT/DARPA, JSC**
  - Manned Geo Servicing (MGS) joint study with DARPA
- **SOMD/OCT**
  - Exploring Robotic Satellite Servicing Capability
  - Foster development of a commercial capability
  - In support of exploration capability

Robotic Servicing Functions (LEO, GEO and Beyond)

- **Inspection**
  - External, In Structure
- **Relocation**
  - Solve Launch Failure, End of Mission
- **Resolve Deployment Failure**
  - Antennae, Solar Array, Mechanisms
- **Refuel**
  - Handle Connectors and Hoses
- **Add Components**
  - De-Orbit stages, new Elements
- **Swap Robot Compatible Parts**
  - Instruments, Batteries
- **Dexterous Manipulation**
  - Non Robot Compatible Tasks, Contingency





Robotic Satellite Servicing Capability Objectives

- ***Robotic satellite servicing capabilities may include satellite inspection, recovery, repair, relocation and orbital transfer, refueling, subsystem or component replacement, or other services that extend the life or capabilities of on-orbit assets***
  - NASA wishes to foster the creation of a domestic commercial industry capability that may meet both future government and non-government needs
  - NASA wishes to foster the development of robotic capability to augment and support complex manned servicing, assembly, and exploration capability

- NASA is developing strategies for supporting the development of commercially-financed, -developed, -owned and –operated on-orbit robotic servicing capabilities for existing and future spacecraft, particularly strategies involving partnerships and collaboration with private domestic entities that leverage the Government's existing intellectual property, technological resources, and expertise in this area.

- NASA is developing exploration technologies for complex man / robotics servicing, assembly, and missions beyond LEO

Satellite Servicing Vision

Enable the movement of commercial, national security, and exploration assets at GEO to platforms

- De-integration of the satellite
- Adaptable to market needs
- Limitless grown potential
- Economies of scale

- Satellite serving
  - Inspection/assembly
  - Repair/replace
  - Remove/dispose
- Other purposes
  - Depot
  - R&D
  - Science
  - Defendable position

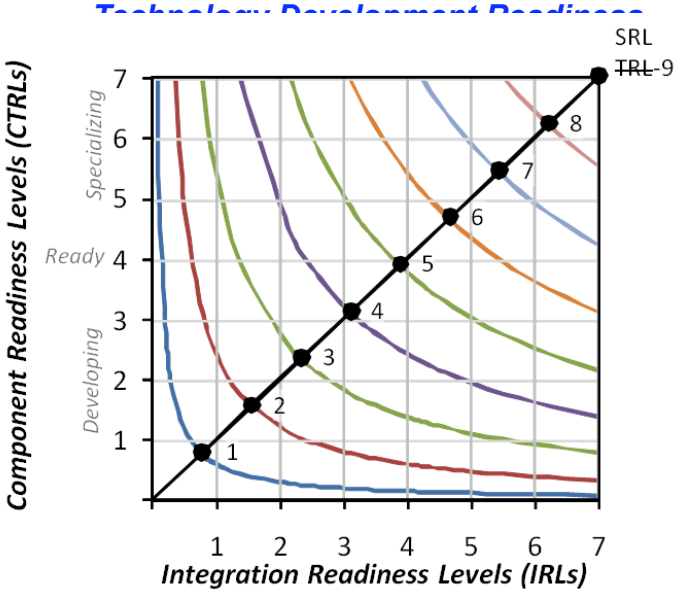
Satellite Servicing Critical Technologies

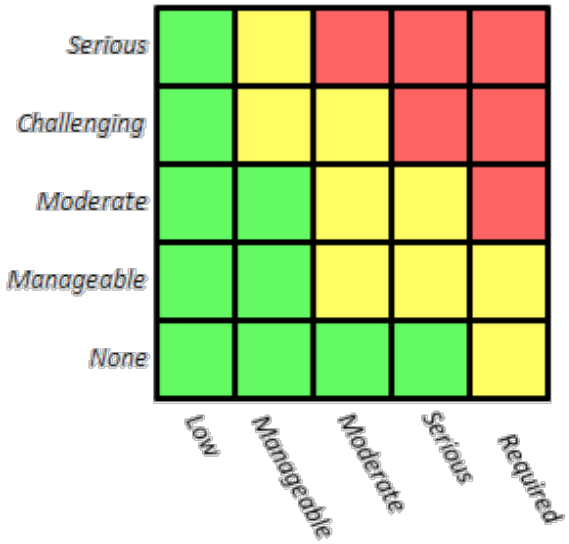
- NASA Technology Roadmaps (Under Review by NRC)
  - Tech Area 2, In-Space Propulsion Technologies
    - Upper Stages, Transfer Missions, Tethers, Beyond Chemical Fuel
  - Tech Area 4, Robotics, Tele-Robotics and Autonomous Systems
    - Autonomous Rendezvous and Docking, Grappling, Berthing, Servicing Manipulation, Sensing and Perception, Inspection, Repair
  - Tech Area 5, Communication and Navigation
    - Position, Navigation and Timing, GPS, Relative Proximity Navigation

- Development Approaches
  - NASA will continue collaboration with industry, and other agencies and organizations
  - Where possible we use lab, facility and analog testing of approaches
  - We utilize the ISS for technology demonstrations

Critical Technology and the Risk

1. In-Space Propulsion
   a. Upper Stages and Transfer
   b. Tethers and Beyond Chemical Propulsion
2. Robotic Manipulation
   a. Grappling and Berthing
   b. Servicing Manipulation
3. Rendezvous and Docking
   a. Multiple Range and Lighting Challenges
   b. Tumbling and Uncooperative Objects
4. Sensing and Perception
   a. Object Identification
   b. 6 Axis Pose Estimation
5. Navigation
   a. Relative Proximity Navigation
   b. Navigation and Timing

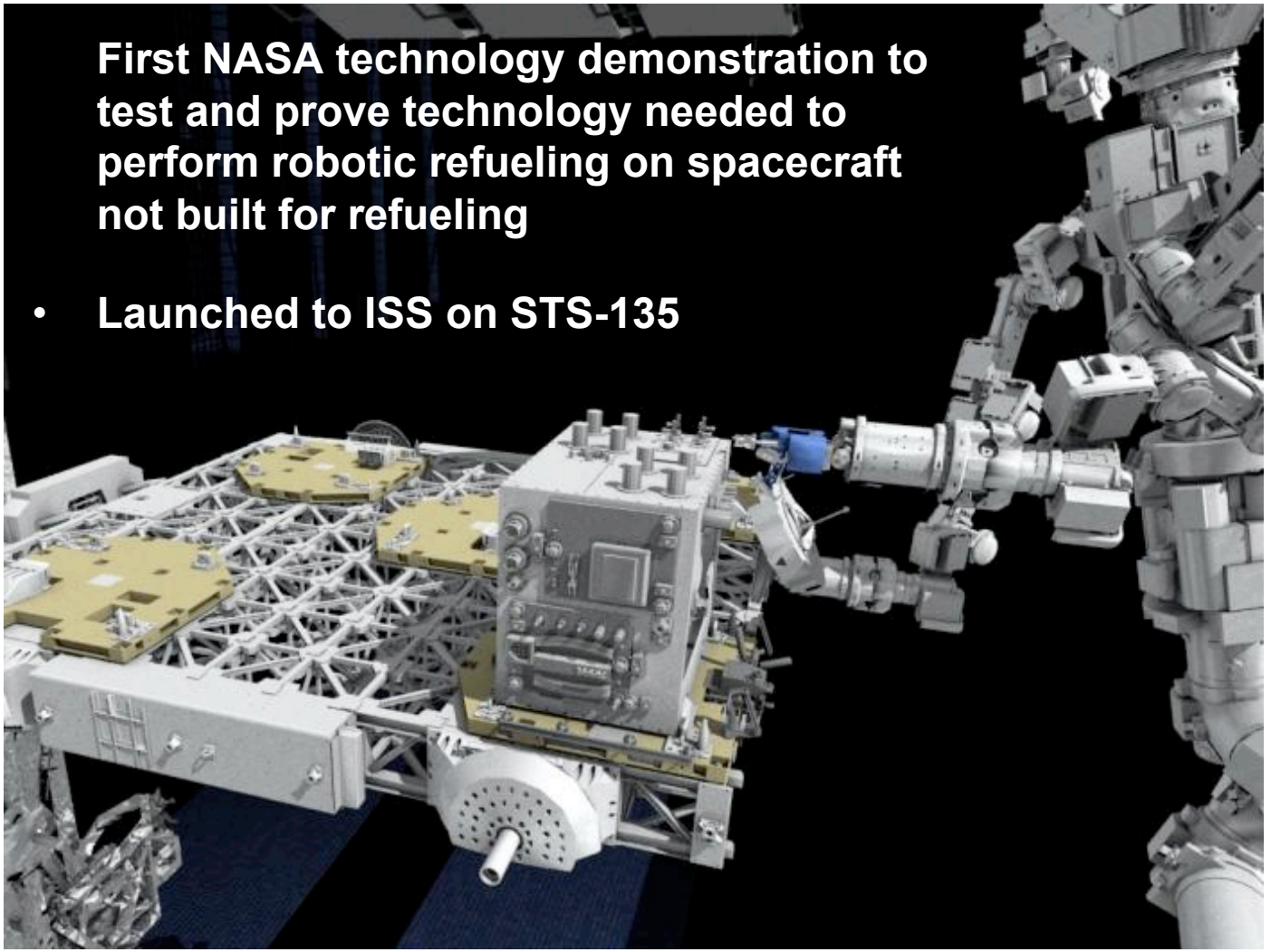




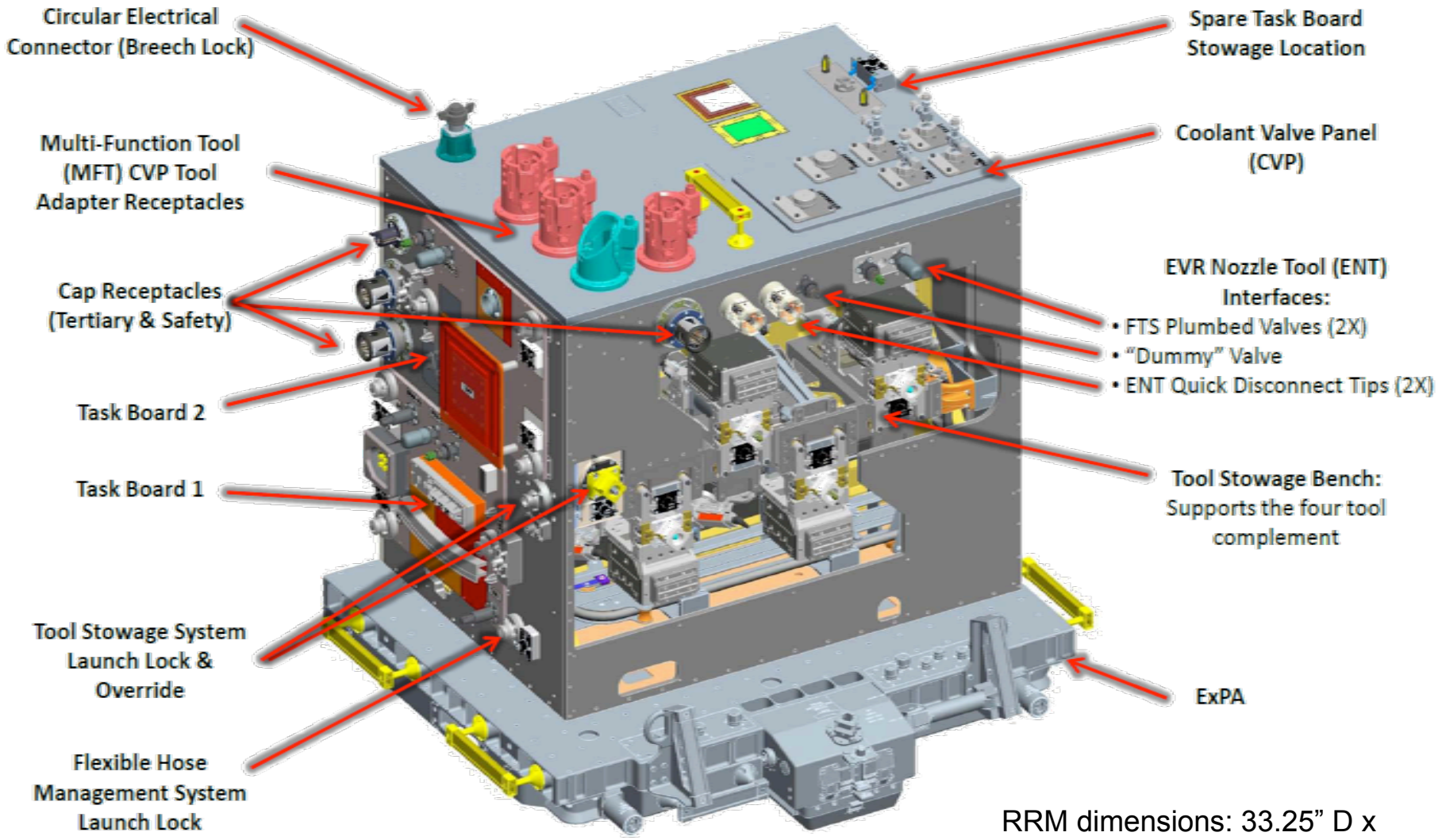
Robotic Refueling Mission (RRM)

First NASA technology demonstration to test and prove technology needed to perform robotic refueling on spacecraft not built for refueling

- Launched to ISS on STS-135



RRM Assembly

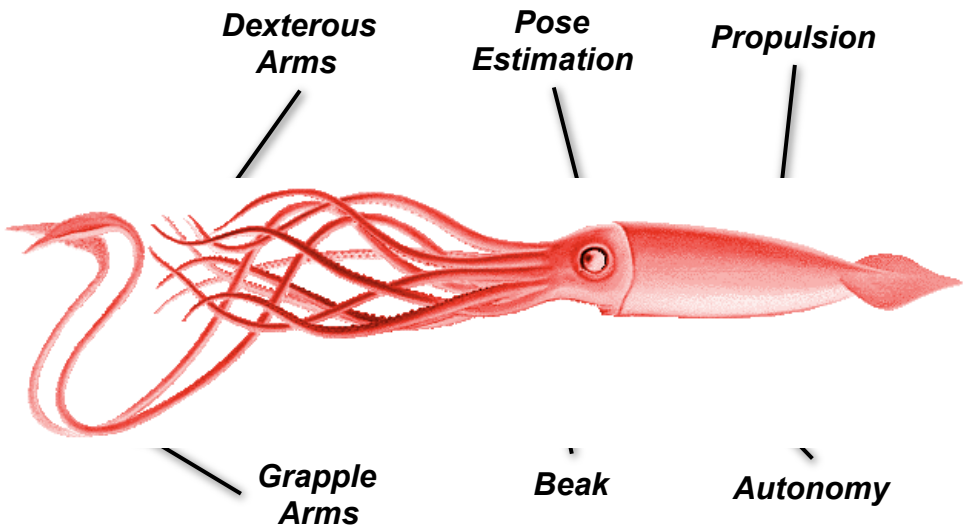


RRM dimensions: 33.25" D x 44.81" W x 43.190" H

Exploration Robotics Servicing

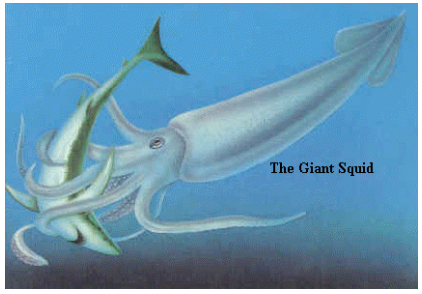
- Squid Design
  - Neutral Buoyancy Specialist
  - 6 Axis Thrust Control
  - Long Reach Grapple Arms
  - Dexterous Work Arms
  - Beak for Final “Docking”
  - Eye for Rendezvous and Prc
  - Fully Autonomous Control

Mother Nature’s Solution: Giant Squid



- Squid Tactics and Prey
  - Neutral Buoyancy Pursuit
  - Non Cooperative Targets
  - Grapple, Manipulate, Bite

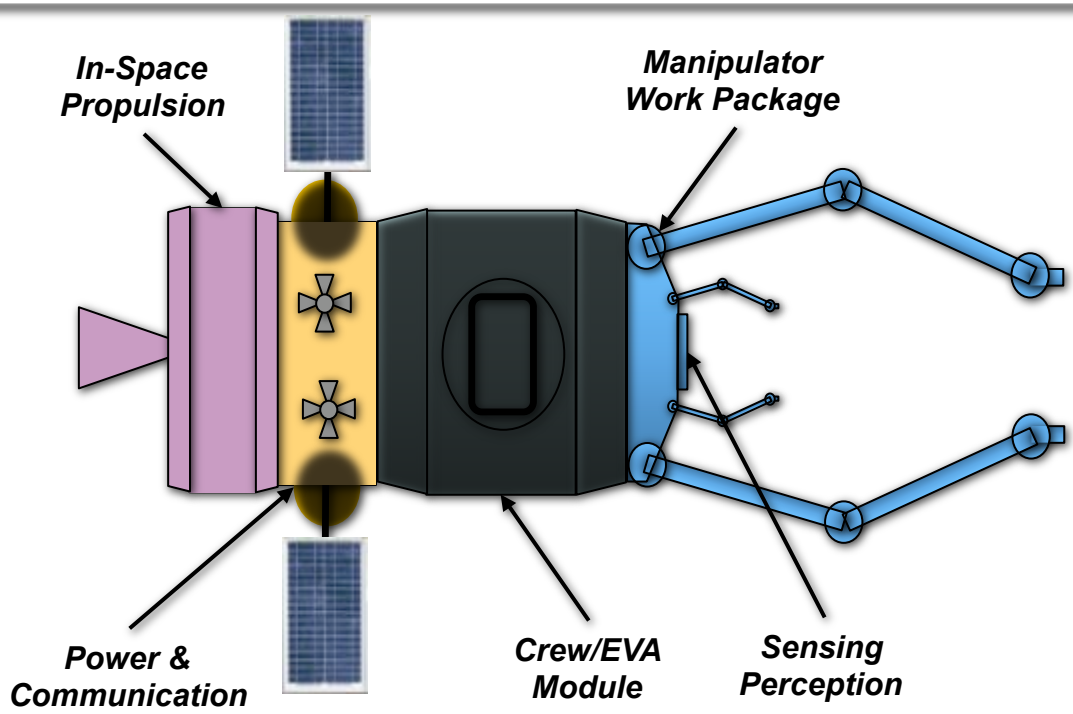
Non cooperative Targets (Fact and Fiction)

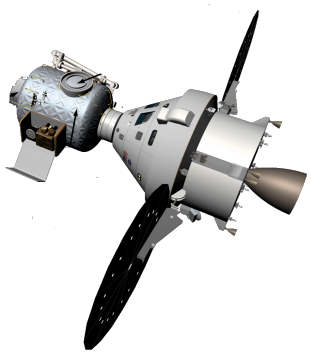


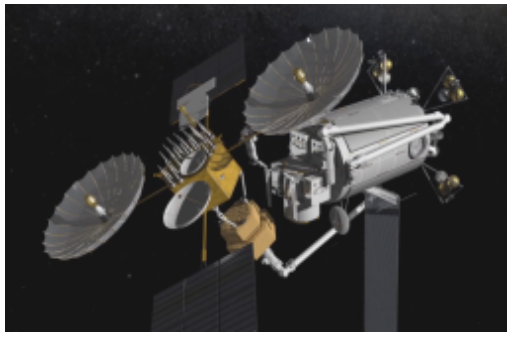
For exploration capability we need the ability to capture, control, and manipulate in space for servicing, assembly, and mobility

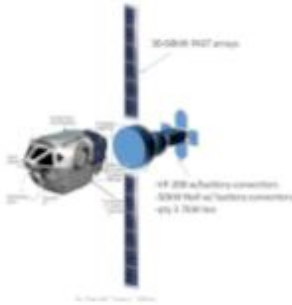
Engineering Solution: Building Block Approach

- Manipulator Work Package
  - Long Reach Grapple Arms
  - Dexterous Work Arms
  - Docking Fixtures/Decks
- Sensing and Perception
  - Long to Short Range
  - 6 Axis Pose Estimation
- Communication
  - In-Space Assets
  - To Earth
- Power
  - Solar Arrays
  - Batteries
- In-Space Propulsion
  - Upper Stage
  - RCS
- Pressurized Human Modules
  - Living Quarters/Protection
  - Command and Control
  - EVA Suit Ports/Locks



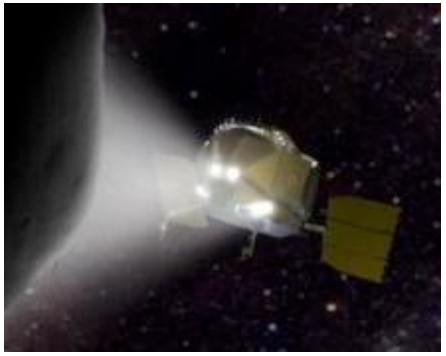




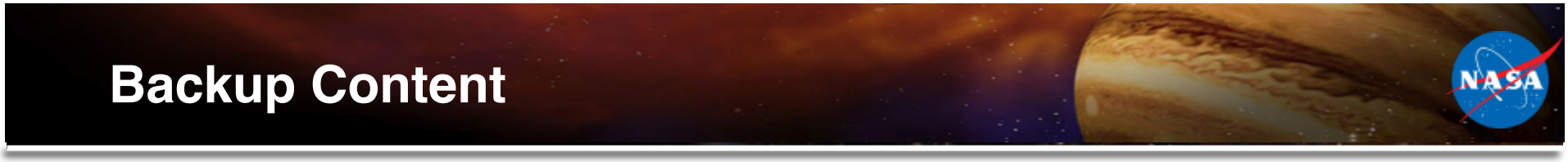


Recommended Path Forward

- Develop Key Space Technologies
  - In-Space Propulsion
  - Robotic Manipulation
  - Rendezvous and Docking
  - Sensing and Perception
  - Navigation
- Technology Push Experiments
  - On NASA's ISS
  - With Collaborators
  - As Secondary Payloads
- Provide Matured Technology
  - For ISS Visiting Spacecraft
  - For Commercial Efforts
  - For National Security
  - For Exploration



Backup Content



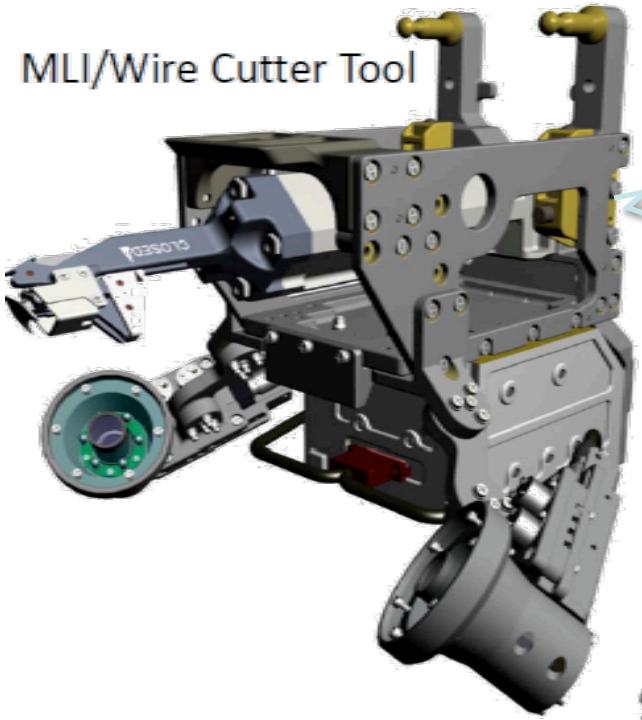
- Government Capability Supporting Commercial RSS Development
- RRM Tools
- Refueling and Coolant Valve Panel Task
- System Readiness Levels

Suggested Government Capability Supporting Commercial RSS Development

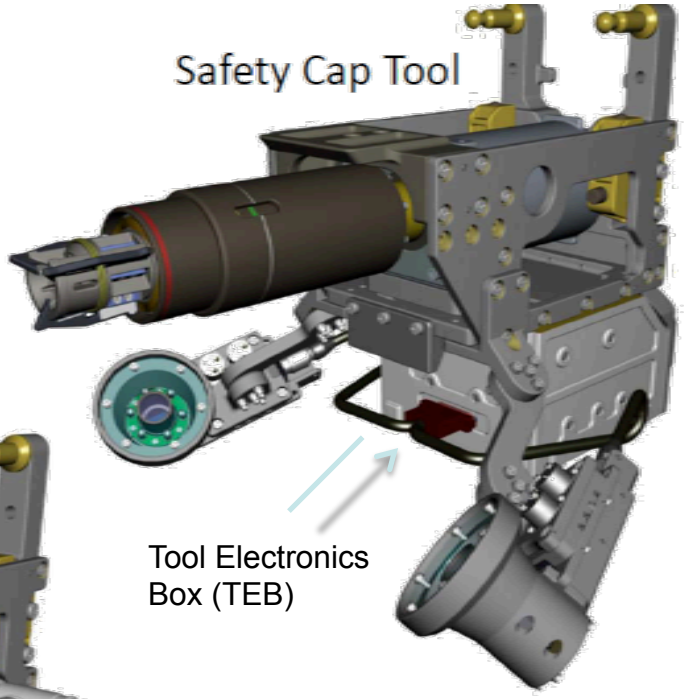
NASA has the capability to offer the following resources and capabilities to a lead commercial partner for satellite servicing:

- Six government patents related to satellite servicing,
- Family of tools to conduct precision repair and replacement activity,
- Family of special robotic tools for refueling,
- Integration and Test Facilities,
- Autonomous Rendezvous and Capture (AR&C) sensor technology,
- Space Cube high speed computer systems,
- A robotic front-end system that includes active arms (each arm having a seven-degree-of-freedom capability),
- An approach and rendezvous system (with a vision capability from 10 km to customer satellite capture),
- A variety of end-effectors and tools to accomplish capture, repair, and replacement tasks,
- Mission integration and testing of the entire system at NASA's Goddard Space Flight Center,

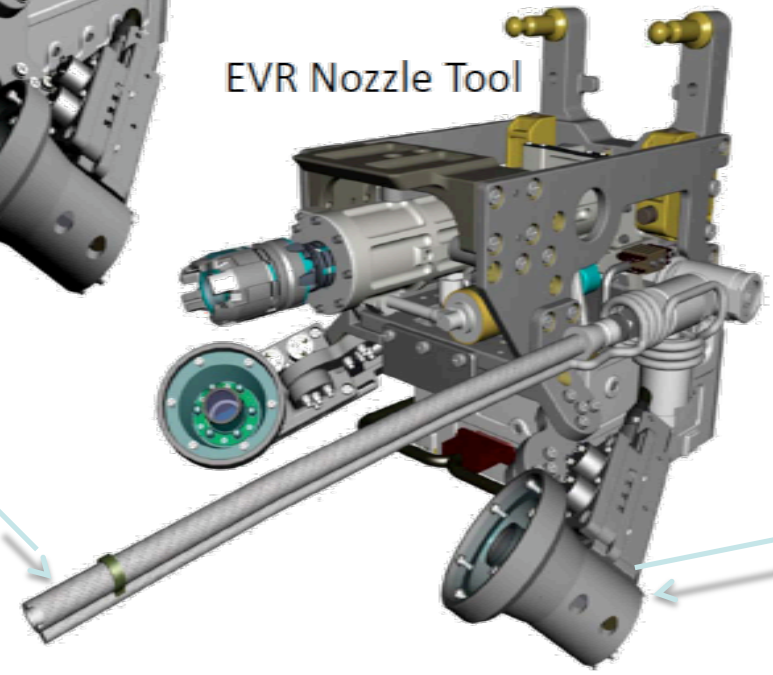
Three of Four RRM Tools



Dextre OTCM mechanical/electrical connection



Tool Electronics Box (TEB)

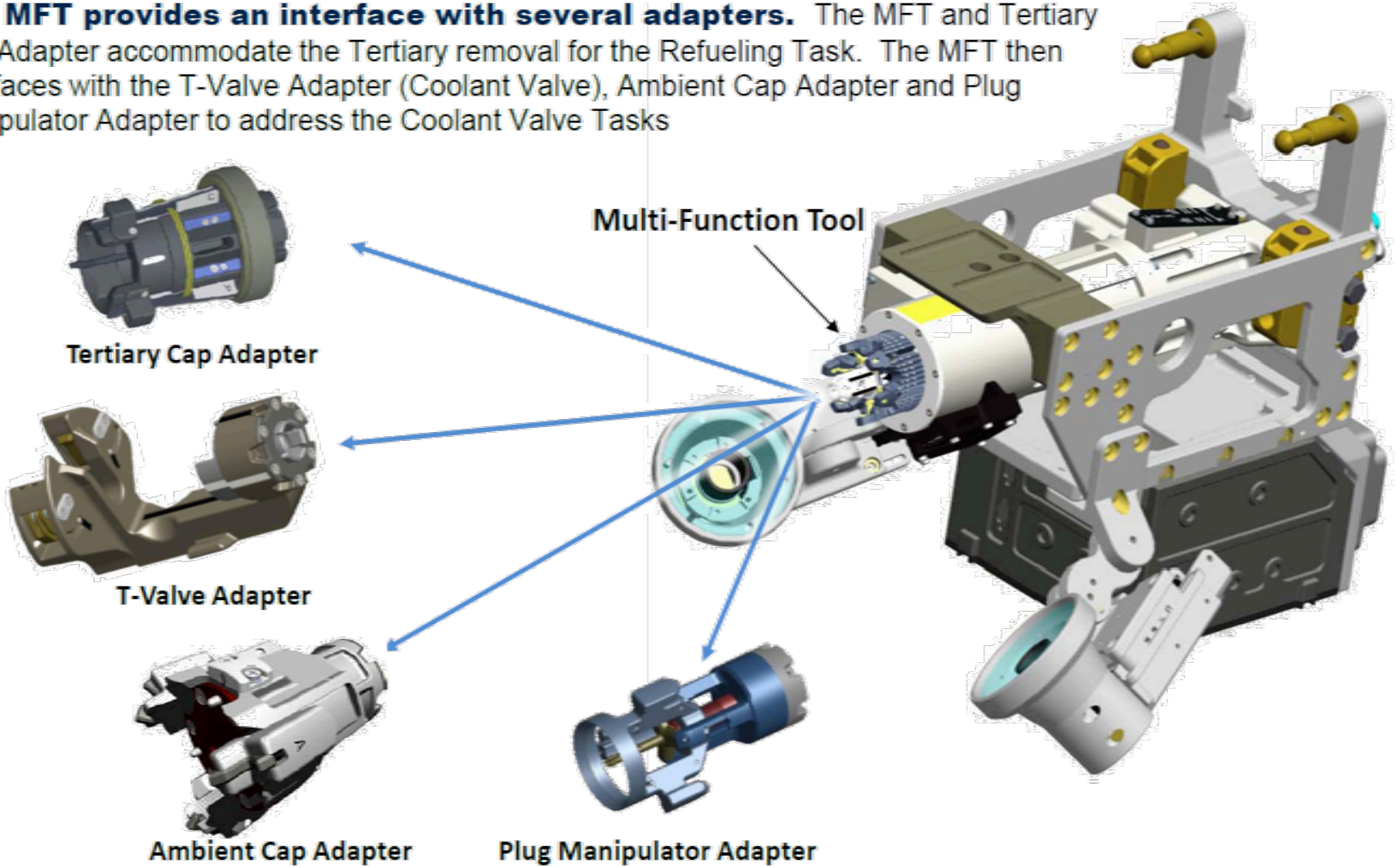


Flex Hose for Nozzle Tool

2 cameras per tool with integral high illumination lighting

Refueling and Coolant Valve Panel Task

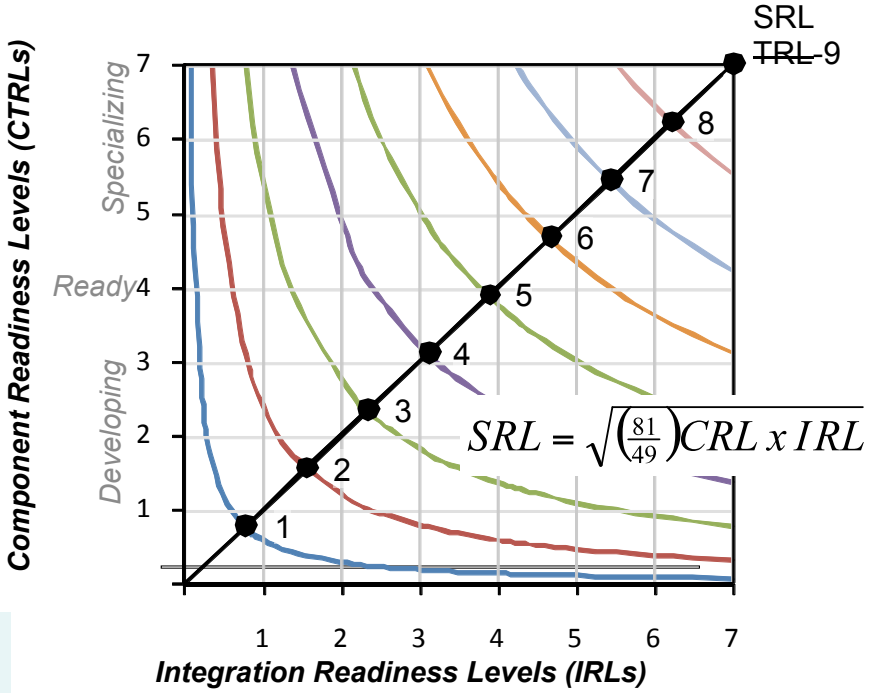
The MFT provides an interface with several adapters. The MFT and Tertiary Cap Adapter accommodate the Tertiary removal for the Refueling Task. The MFT then interfaces with the T-Valve Adapter (Coolant Valve), Ambient Cap Adapter and Plug Manipulator Adapter to address the Coolant Valve Tasks



~~Technology~~ System Readiness Levels

We Need "Mental Models" for Discussion and Analyzing Technology Development

CTRL-7: Finalize Design to an Application
CTRL-6: Mature Design to an Application
CTRL-5: Specialize Design to an Application
CTRL-4: Refine Basic Design
CTRL-3: Prove Basic Design
CTRL-2: Defined in Technology and Design
CTRL-1: Defined in Basic Principles



SRL-9: Proven Characterized Technology
SRL-8: Technology demonstrated in Application
SRL-7: Technology Demonstrated in Application Prototype
SRL-6: Prototype Demonstration
SRL-5: Validation at Environment Conditions
SRL-4: Breadboard Validation in Laboratory
SRL-3: Proof-of-Concept
SRL-2: Concept Defined in Technology
SRL-1: Concept Defined in Basic Principles

IRL-7: Fully Verified and Validated
IRL-6: Application Adaptability of interface
IRL-5: Design Control of Interface
IRL-4: Quality and Assurance at Interface
IRL-3: Compatibility Established
IRL-2: Interaction Characterized
IRL-1: Interface Defined