

Satellite Servicing Capabilities Office

**Presented at the Second International Workshop on On-Orbit
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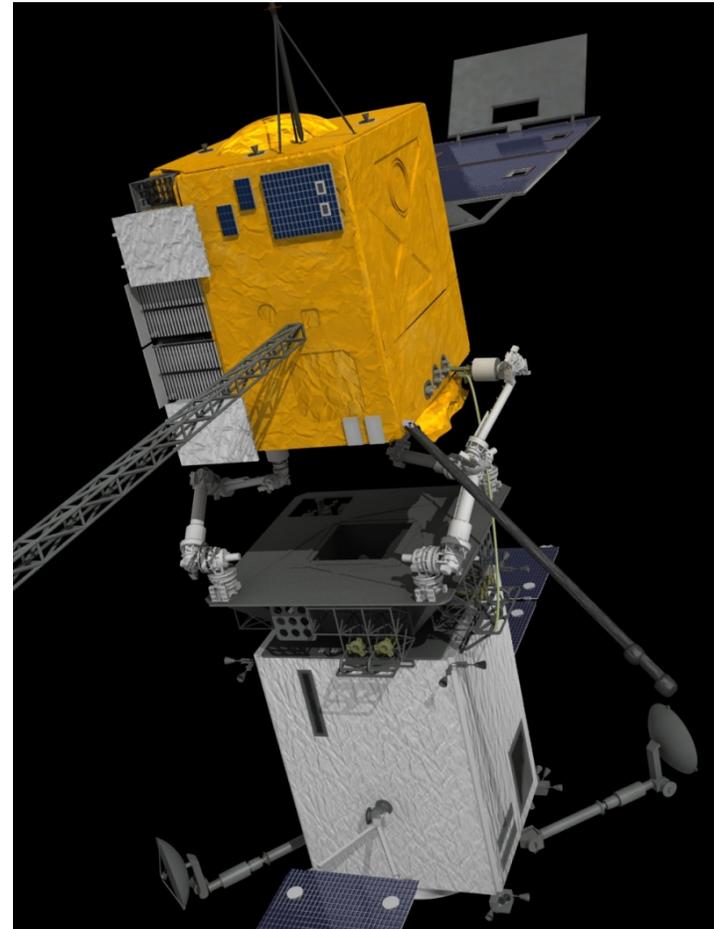
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<http://ssco.gsfc.nasa.gov>

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Satellite Servicing Capabilities Office (SSCO)



- SSCO at NASA's Goddard Space Flight Center exists to:
 - Advance the state of robotic servicing technology to enable the routine servicing of satellites
 - Position the U.S. to be the global leader in in-space repair, maintenance and satellite disposal
 - Help to enable a future U.S. industry for the servicing of satellites
- SSCO has conducted numerous mission studies on manned and robotic servicing concepts (study report at ssco.gsfc.nasa.gov)
- Currently concentrating on a GEO Servicing concept
 - RFI [Development of an On-Orbit Robotic Servicing Capability for Spacecraft](#)
 - Technology development efforts in full swing
 - Notional mission requirements and concept of operations nearly complete
 - Assumes initial servicing of a US Gov't vehicle
 - Expendables allow for servicing of several more vehicles
 - Using a straw-man (custom) bus design to mature system requirements and evaluate feasibility

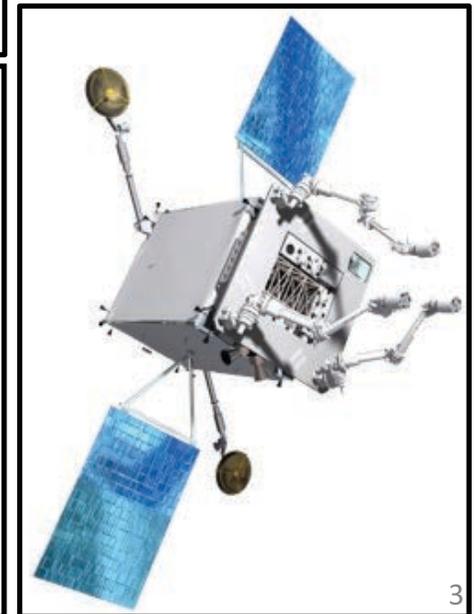
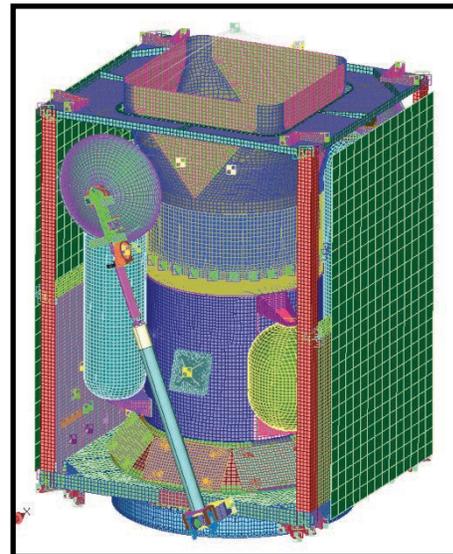
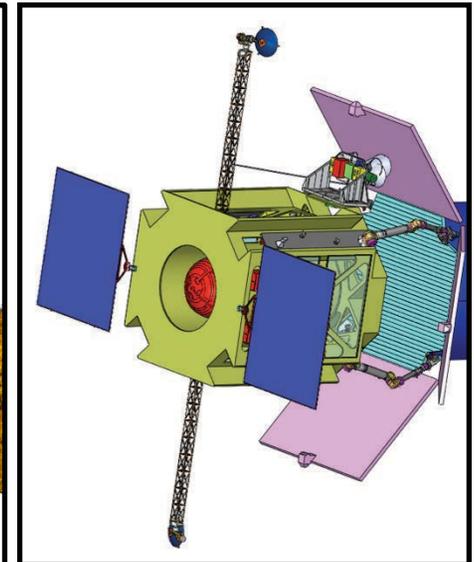
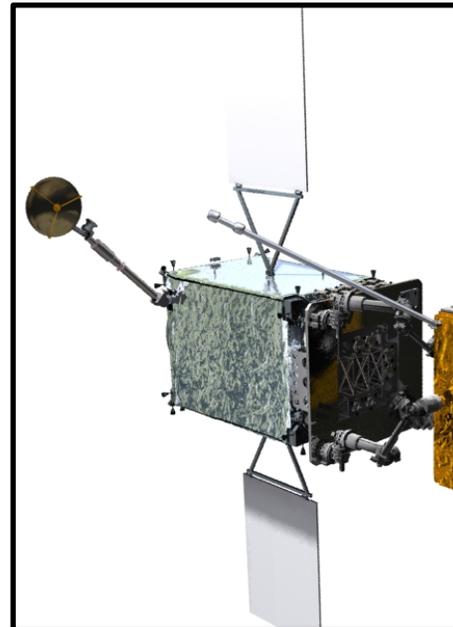


SSCO Servicing Tasks: “The 5 Rs”



Servicing Vehicle Conceptual Layouts

- Remote Survey
 - Diagnose problems
 - Visual inspection of client vehicle
 - Visual close range inspection while mated, or from a corridor approach
- Relocation
 - Maneuver client vehicle for relocation, disposal, station-keeping, etc
- Refueling
 - Hydrazene, MMH, NTO
 - Re-pressurization (He) of client prop system
- Repair
 - Fix stuck or malfunctioning deployable
 - Clear sunshade/blanket obstruction of instrument or communications paths
- Replace ORU
 - Isogrid and available power on Servicer to receive future ORUs
 - ORUs delivered by a re-supply vehicle

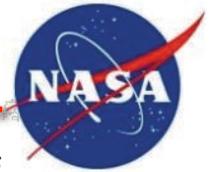


Comparison with Previous Efforts



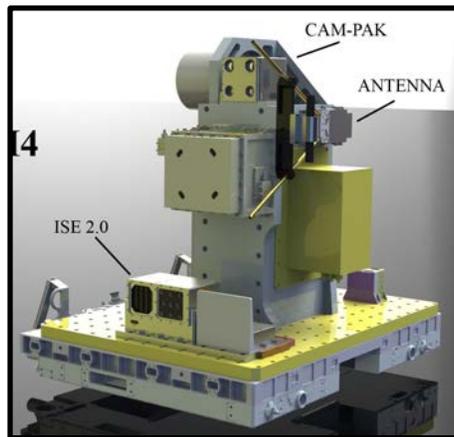
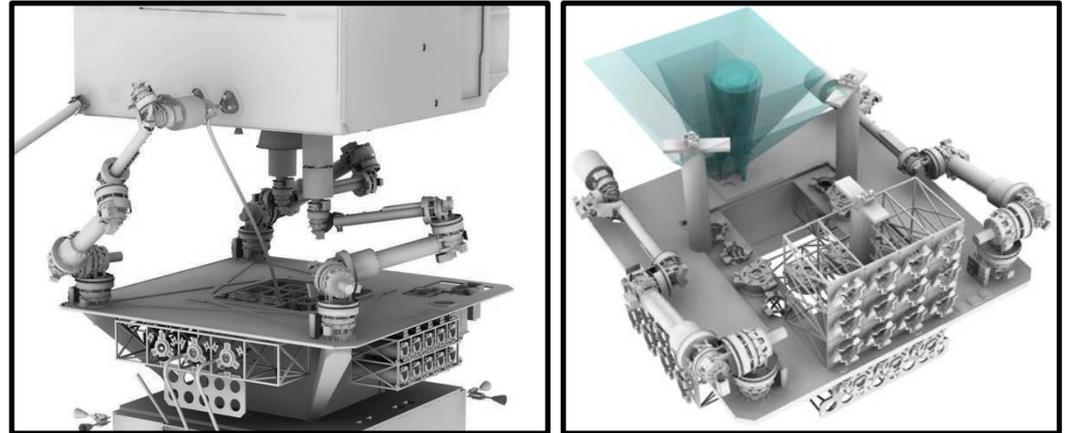
Robotic Servicing Capabilities	XSS-11	ISS	OE	FREND	SSCO
Cut/Manipulate Blanket					X
Prop Transfer via ground F/D valve					X
Deploy/retract propellant hose					X
Complex robotic repairs					X
Simple robotic repairs					X
Non-cooperative client vehicle capture				X	X
Advanced flight processor					X
Transfer ORU		X	X		X
Transfer Oxidizer		X			X
Transfer Fuel		X	X		X
Meter Propellant Flow			X		X
Autonomous capture			X	X	X
Ground contact dynamics test bed			X	X	X
Lidar-based 6DOF pose				X	X
Visible/IR Cam 6DOF pose			X		X
Tool Capture and Stowage		X			X
Robot Tool Drive		X	X	X	X
Inspection proximity operations	X	X	X	X	X
Relative Navigation Filter	X	X	X	X	X
Mission Autonomy Software	X	X	X	X	X

Servicing Payload



- Payload Deck
 - Robot arms, RPO sensors, tools, sit. awareness and remote survey cameras
 - Client berthing mechanism
- Tool Stowage
 - Includes tool launch locks
 - Prototype built and tested
- Payload Avionics
 - SpaceCube 2.0
 - Video storage and comp. unit

Servicing Payload Notional Layouts

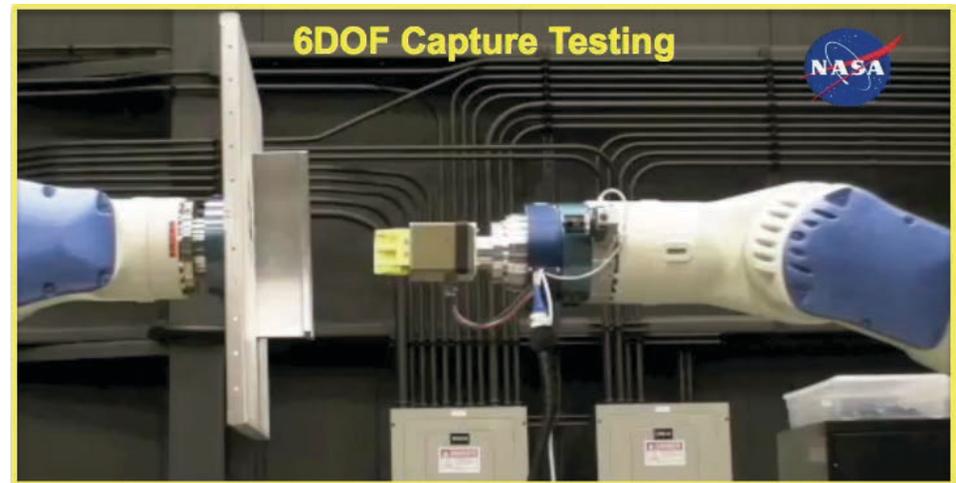


SpaceCube 2.0 ETU (ISE-2.0) on STP-H4 (launch to ISS 2013)

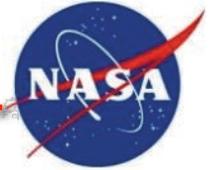


Robot Subsystem

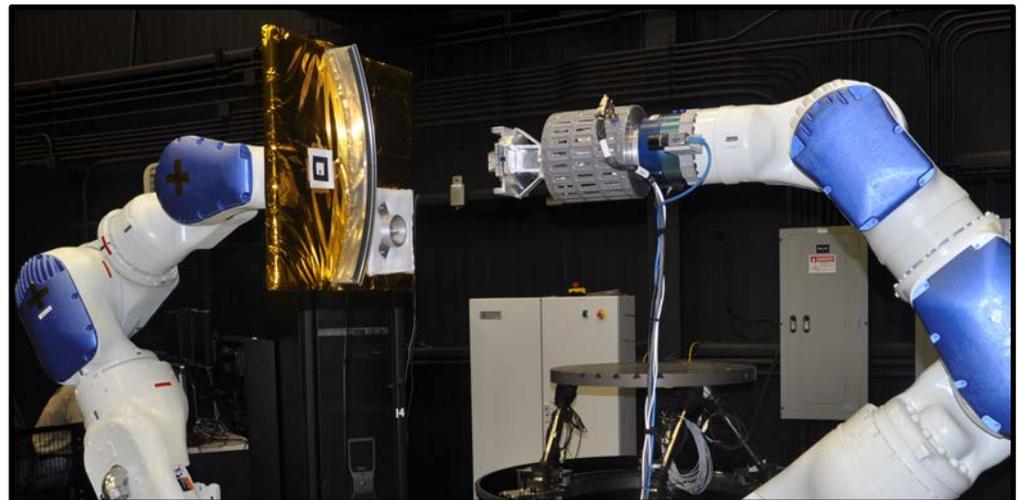
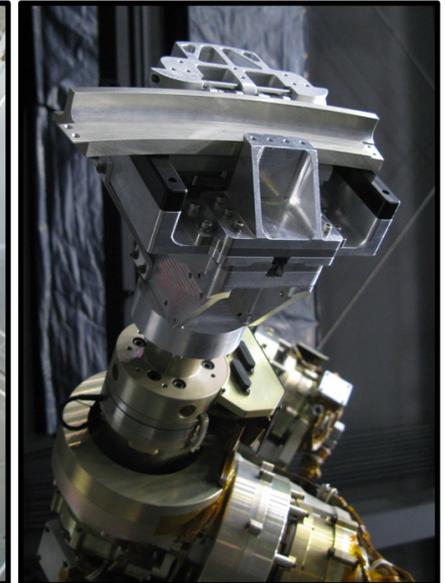
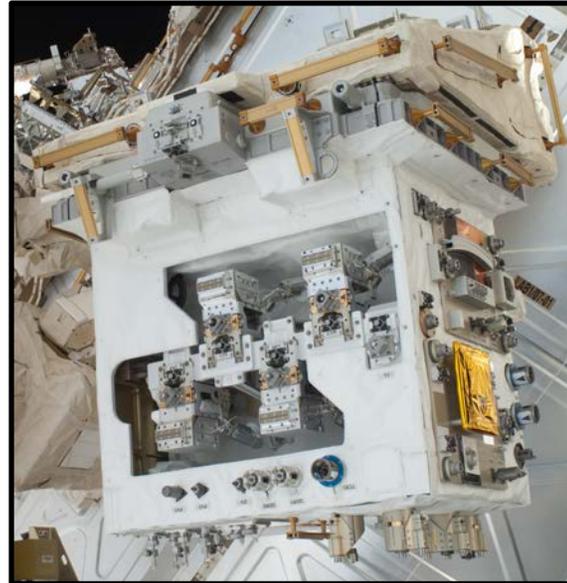
- Servicing payload has options for 2 or 3 7DOF robotic arms
- SSCO Robotics Testbeds
 - Full 6-DOF contact dynamics
 - Motion platforms for tool and sensor test
 - Robot FSW Development
 - Migration of robot software to SpaceCube 2.0 emulator underway
 - Key autonomous non-coop capture tests in 3DOF (complete) and 6DOF (underway)
- Capture tests w/ Marman Ring Gripper Tool
 - 400+ capture tests on FRENEDU w/ 3-DOF air table at NRL



Advanced Tool Drive and Tools



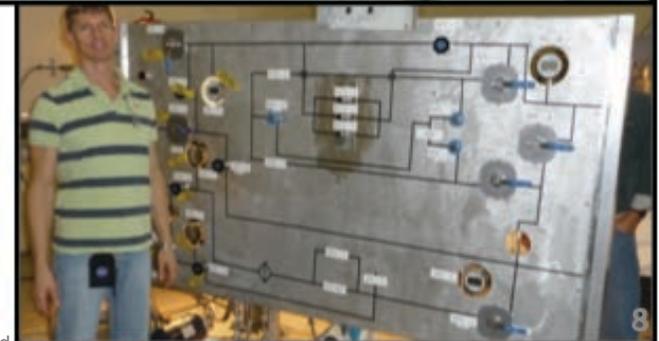
- Robotic Refueling Mission (RRM)
 - Ops underway on ISS (ELC-4)
 - Refueling tools including blanket manipulation, wire cutter, cap removal, nozzle tool with quick disconnect, etc
- Advanced Tool Drive System
 - 3 prototypes built/tested
 - Includes linear drive, 2x rotary drives, tool coupler, camera pointing system
- Marman Band Gripper
 - Prototype built and tested with FRENDA arm
 - Currently testing at GSFC w/ ATDS, 6DOF contact dynamics, multiple Marman rings, lab robot



Propellant Transfer System



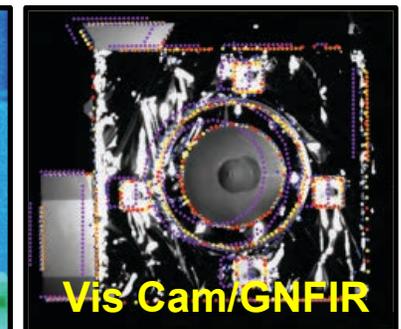
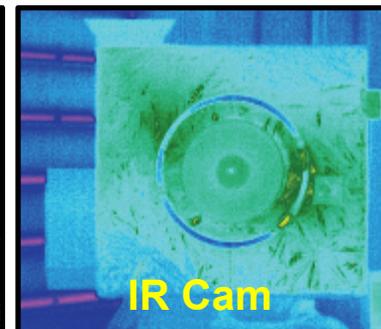
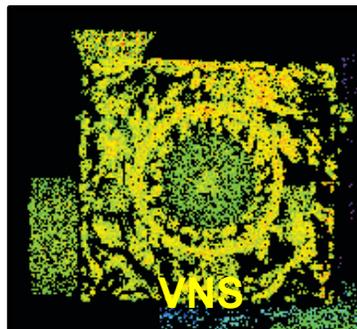
- Hose Management
 - Reel/Box Prototypes built (KSC)
 - Testing underway with prototype Nozzle Tool configurations
- Component Testing
 - WSTF Materials compatibility tests
 - PTS Testbed at KSC
 - Testing pumps, flow meters, bellows accumulator, etc
 - Testing with NTO ref. fluid complete
- Oxidizer is a key challenge... design philosophy is to avoid dynamic seals



AR&D Ground Testbed (Argon)



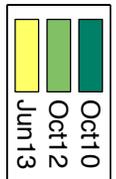
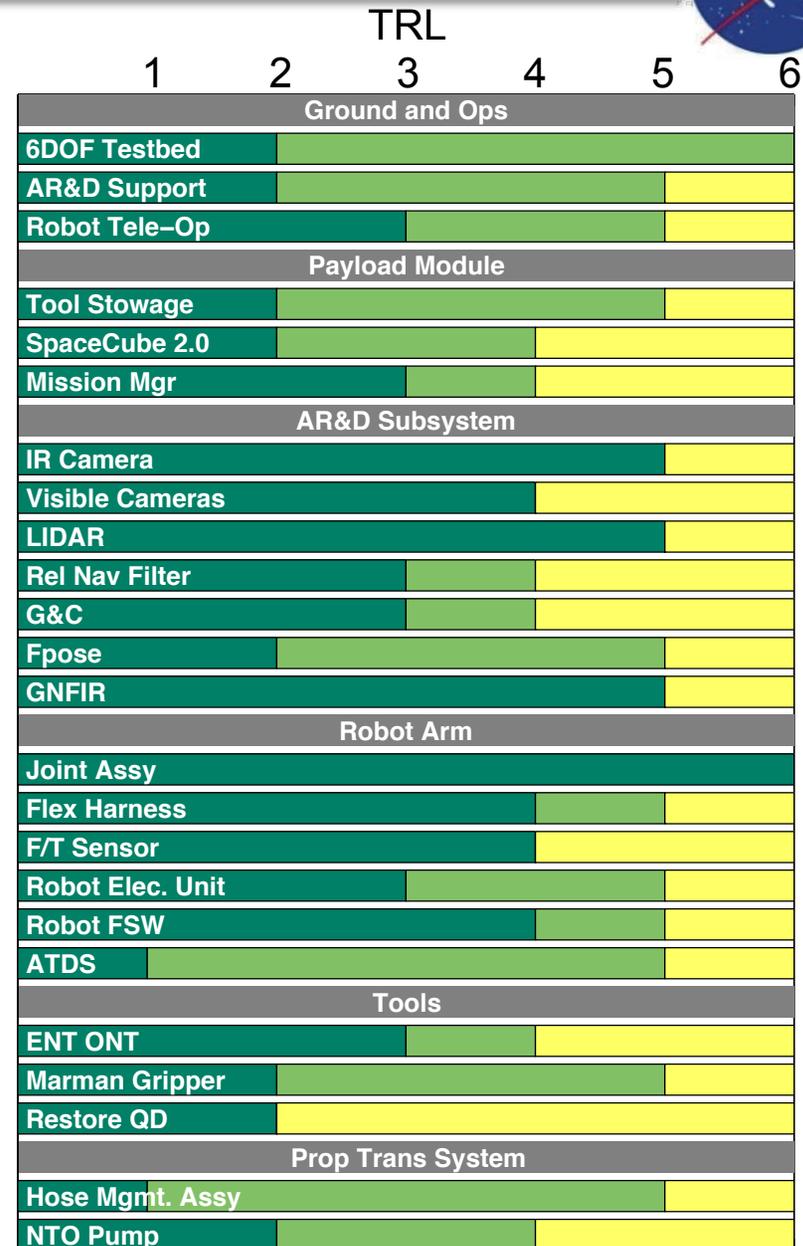
- Visible (2) and IR cams, flash LIDAR
- Non-coop. pose – GNFR and Flashpose
- Relnav filter, G&C in SpaceCube 1.0 EDU
- Tested at GSFC, NRL Prox Ops Testbed



New Servicing Technologies Status



- Significant progress in FY11-12, most critical technologies to at least TRL 5
- FY12-13 funding brings critical technologies to TRL 6



SSCO Linkage to NASA's Technology Areas



TA01 • LAUNCH SYSTEMS

SOLID ROCKET PROPULSION SYSTEMS

- Propellants
- Case Materials
- Nozzle Systems
- Hybrid Rocket Propulsion Systems
- Fundamental Solid Propulsion Technologies

LIQUID ROCKET PROPULSION SYSTEMS

- LH₂/LOX Based
- RP/LOX Based
- CH₄/LOX Based
- Detonation Wave Engines (Closed Cycle)
- Propellants
- Fundamental Liquid Propulsion Technologies

AIR BREATHING PROPULSION SYSTEMS

- TBCC
- RBCC
- Detonation Wave Engines (Open Cycle)
- Turbine Based Jet Engines (Flyback Boosters)
- Ramjet/Scramjet Engines (Accelerators)
- Deeply-cooled Air Cycles
- Air Collection & Enrichment System
- Fundamental Air Breathing Propulsion Technologies

ANCILLARY PROPULSION SYSTEMS

- Auxiliary Control Systems
- Main Propulsion Systems (Excluding Engines)
- Launch Abort Systems
- Thrust Vector Control Systems
- Health Management & Sensors
- Pyro & Separation Systems
- Fundamental Ancillary Propulsion Technologies

UNCONVENTIONAL / OTHER PROPULSION SYSTEMS

- Ground Launch Assist
- Air Launch / Drop Systems
- Space Tether Assist
- Beamed Energy / Energy Addition
- Nuclear
- High Energy Density Materials/Propellants

TA02 • IN-SPACE PROPULSION TECHNOLOGIES

CHEMICAL PROPULSION

- Liquid Cryogenic
- Gels
- Solid
- Hybrid
- Cold Gas/Warm Gas
- Micro propulsion

NON-CHEMICAL PROPULSION

- Electric Propulsion
- Solar Sail Propulsion
- Thermal Propulsion
- Tether Propulsion

ADVANCED (TRL <3) PROPULSION TECHNOLOGIES

- Beamed Energy Propulsion
- Electric Sail Propulsion
- Fusion Propulsion
- High Energy Density Materials
- Antimatter Propulsion
- Advanced Fission
- Breakthrough Propulsion

SUPPORTING TECHNOLOGIES

- Engine Health Monitoring & Safety
- Propellant Storage & Transfer
- Materials & Manufacturing Technologies
- Heat Rejection
- Power

TA03 • SPACE POWER & ENERGY STORAGE

POWER GENERATION

- Energy Harvesting
- Chemical (Fuel Cells, Heat Engines)
- Solar (Photo-Voltaic & Thermal)
- Radioisotope
- Fission
- Fusion

ENERGY STORAGE

- Batteries
- Flywheels
- Regenerative Fuel Cells
- Power Management & Distribution
- EDIR
- Management & Control
- Distribution & Transmission
- Wireless Power Transmission
- Conversion & Regulation

CROSS CUTTING TECHNOLOGY

- Analytical Tools
- Green Energy Impact
- Multi-functional Structures
- Alternative Fuels

TA04 • ROBOTICS, TELE-ROBOTICS & AUTONOMOUS SYSTEMS

SENSING & PERCEPTION

- Stereo Vision
- LIDAR
- Proximity Sensing
- Sensing Non-Geometric Terrain Properties
- Estimating Terrain Mechanical Properties
- Tactile Sensing Arrays
- Gravity Sensors & Celestial Nav.
- Terrain Relative Navigation
- Real-time Self-calibrating of Hand-eye Systems

MOBILITY

- Simultaneous Localiz. & Mapping
- Hazard Detection Algorithms
- Active Illumination
- 3-D Path Planning w/ Uncertainty
- Long-life Extr. Enviro. Mechanisms
- Robotic Jet Backpacks
- Smart Joints
- Robot Swarms
- Walking in Micro-g

MANIPULATION

- Motion Planning Alg., High DOF
- Sensing & Control
- Robot Arms (light, high strength)
- Dexterous Manipul., Robot Hands
- Sensor Fusion for Grasping
- Grasp Planning Algorithms
- Robotic Drilling Mechanisms
- Multi-arm / Finger Manipulation
- Planning with Uncertainty

HUMAN-SYSTEMS INTEGRATION

- Crew Decision Support Systems
- Immersive Visualization
- Distributed Collaboration
- Multi Agent Coordination
- Haptic Displays
- Displaying Range Data to Humans

AUTONOMY

- Spacecraft Control Systems
- Vehicle Health, Prog./Diag Systems
- Human Life Support Systems
- Planning/Scheduling Resources
- Operations
- Integrated Systems Health Management
- EDIR & Diagnosis
- System Monitoring & Prognosis
- V&V of Complex Adaptive Syst.
- Automated Software Generation
- Software Reliability
- Semi Automatic Systems

AUTON. RENDEZVOUS & DOCKING

- Rendezvous and Capture
- Low Impact & Androgynous Docking Systems & Interfaces
- Relative Navigation Sensors
- Robust AR&D GNSS-C Algorithms & FSW
- Onboard Mission Manager
- AR&D Integration & Standardizn.

RTA SYSTEMS ENGINEERING

- Human safety
- Refueling Interfaces & Assoc. Tools
- Modular / Serviceable Interfaces
- High Perf., Low Power Onboard Computers
- Environment Tolerance
- Thermal Control
- Robot-to-Suit Interfaces
- Common Human-Robot Interfaces
- Crew Self-Sufficiency

TA05 • COMMUNICATION & NAVIGATION

OPTICAL COMM. & NAVIGATION

- Detector Development
- Large Apertures
- Lasers
- Acquisition & Tracking
- Atmospheric Mitigation

RADIO FREQUENCY COMMUNICATIONS

- Spectrum Efficient Technologies
- Power Efficient Technologies
- Propagation
- High & Ground Systems
- Earth Launch & Reentry Comm.
- Antennas

INTERNETWORKING

- Disruptive Interact. Networking
- Adaptive Network Topology
- Information Assurance
- Integrated Network Management
- Long-life Extr. Enviro. Mechanisms

POSITION, NAVIGATION, AND TIMING

- Timekeeping
- Time Distribution
- Onboard Auto Navigation & Maneuver
- Sensors & Vision Processing Systems
- Relative & Proximity Navigation
- Auto Precision Formation Flying
- Auto Approach & Landing

INTEGRATED TECHNOLOGIES

- Radio Systems
- Ultra Wideband
- Cognitive Networks
- Science from the Comm. System
- Hybrid Optical Comm. & Nav. Sensors
- RF/Optical Hybrid Technology

REVOLUTIONARY CONCEPTS

- X-Ray Navigation
- X-Ray Communications
- Neutrino-Based Navigation & Tracking
- Quantum Key Distribution
- Quantum Communications
- SQUID Microwave Amplifier
- Reconfigurable Large Apertures

TA06 • HUMAN HEALTH, LIFE SUPPORT & HABITATION SYSTEMS

ENVIRONMENTAL CONTROL & LIFE SUPPORT SYSTEMS & HABITATION SYS.

- Air Revitalization
- Water Recovery & Management
- Waste Management
- Habitation
- Extravehicular Activity Systems
- Pressure Garment
- Portable Life Support System
- Power, Avionics and Software

HUMAN HEALTH & PERFORMANCE

- Medical Diagnosis / Prognosis
- Long-Duration Health
- Behavioral Health & Performance
- Human Factors & Performance

ENVIRONMENTAL MONITORING, SAFETY & EMERGENCY RESPONSE

- Sensors: Air, Water, Microbial, etc.
- Fire: Detection, Suppression
- Protective Clothing / Breathing
- Remediation

RADIATION

- Risk Assessment Modeling
- Radiation Mitigation
- Protection Systems
- Space Weather Prediction
- Monitoring Technology

TA07 • HUMAN EXPLORATION DESTINATION SYSTEMS

IN-SITU RESOURCE UTILIZATION

- Destination Reconnaissance, Prospecting, & Mapping
- Resource Acquisition
- Consumables Production
- Manufacturing & Infrastructure Emplacement

SUSTAINABILITY & SUPPORTABILITY

- Logistics Systems
- Maintenance Systems
- Repair Systems
- "ADVANCED" HUMAN MOBILITY SYSTEMS
- EVA Mobility
- Surface Mobility
- Off-Surface Mobility

"ADVANCED" HABITAT SYSTEMS

- Integrated Habitat Systems
- Habitat Evolution
- Mission Operations & Safety
- Crew Training
- Environmental Protection
- Remote Mission Operations
- Planetary Safety

CROSS-CUTTING SYSTEMS

- Modeling, Simulations & Destination Characterization
- Construction & Assembly
- Dust Prevention & Mitigation

TA08 • SCIENCE INSTRUMENTS, OBSERVATORIES & SENSOR SYSTEMS

REMOTE SENSING INSTRUMENTS / SENSORS

- Detectors & Focal Planes
- Electronics
- Optical Components
- Microwave / Radio
- Lasers
- Cryogenic / Thermal

OBSERVATORIES

- Mirror Systems
- Structures & Antennas
- Distributed Aperture
- In-Situ Instruments / SENSOR
- Particles, Charged & Neutral
- Fields & Waves
- In-Situ

TA09 • ENTRY, DESCENT & LANDING SYSTEMS

AEROASSIST & ATMOSPHERIC ENTRY

- Rigid Thermal Protection Systems
- Flexible Thermal Protection Systems
- Rigid Hypersonic Decelerators
- Deployable Hypersonic Decelerators
- Instrumentation & Health Monitoring
- Entry Modeling & Simulation

DESCENT

- Attached Deployable Decelerators
- Trailing Deployable Decelerators
- Supersonic Retropropulsion
- GN&C Sensors
- Descent Modeling & Simulation

LANDING

- Touchdown Systems
- Egress & Deployment Systems
- Propulsion Systems
- Large Body GN&C
- Small Body Systems
- Landing Modeling & Simulation

VEHICLE SYSTEMS TECHNOLOGY

- Architecture Analyses
- Separation Systems
- System Integration & Analyses
- Atmosphere & Surface Characterization

TA09 • ENTRY, DESCENT & LANDING SYSTEMS

ENGINEERED MATERIALS & STRUCTURES

- Lightweight Structures
- Damage Tolerant Systems
- Coatings
- Adhesives
- Thermal Protection & Control

ENERGY GENERATION & STORAGE

- Energy Storage
- Energy Generation

PROPULSION

- Propellants
- Propulsion Components
- In-Space Propulsion

SENSORS, ELECTRONICS & DEVICES

- Sensors & Actuators
- Nanoelectronics
- Miniature Instruments

TA10 • NANOTECHNOLOGY

MATERIALS

- Lightweight Structure
- Computational Design
- Flexible Material Systems
- Environment
- Special Materials

STRUCTURES

- Lightweight Concepts
- Design & Certification Methods
- Reliability & Sustainment
- Test Tools & Methods
- Innovative, Multifunctional Concepts

MECHANICAL SYSTEMS

- Deployables, Docking and Interfaces
- Mechanism Life Extension Systems
- Electro-mechanical, Mechanical & Micromechanisms
- Design & Analysis Tools and Methods
- Reliability / Life Assessment / Health Monitoring
- Certification Methods

MANUFACTURING

- Manufacturing Processes
- Intelligent Integrated Manufacturing and Cyber Physical Systems
- Electronics & Optics Manufacturing Process
- Sustainable Manufacturing

CROSS-CUTTING

- Nondestructive Evaluation & Sensors
- Model Based Certification & Sustainment Methods
- Loads and Environments

TA11 • MODELING, SIMULATION, INFORMATION TECHNOLOGY & PROCESSING

COMPUTING

- Flight Computing
- Ground Computing

MODELING

- Software Modeling & Model Checking
- Integrated Hardware & Software Modeling
- Human-System Performance Modeling
- Science & Engineering Modeling
- Frameworks, Languages, Tools & Standards

SIMULATION

- Distributed Simulation
- Integrated System Lifecycle Simulation
- Simulation-Based Systems Engineering
- Simulation Based Training & Decision Support Systems

INFORMATION PROCESSING

- Science, Engineering & Mission Data Lifecycle
- Intelligent Data Understanding
- Semantic Technologies
- Collaborative Science & Engineering
- Advanced Mission Systems

TA12 • MATERIALS, STRUCTURES, MECHANICAL SYSTEMS & MANUFACTURING

ENVIRONMENTAL AND GREEN TECHNOLOGIES

- Corrosion Prevention, Detection, & Mitigation
- Environmental Remediation & Site Restoration
- Preservation of Natural Ecosystems
- Alternate Energy Prototypes

TECHNOLOGIES TO INCREASE RELIABILITY AND MISSION AVAILABILITY

- Advanced Launch Technologies
- Environment-Hardened Materials and Structures
- Inspection, Anomaly Detection & Identification
- Fault Isolation and Diagnostics
- Prognostics Technologies
- Robotics / Telerobotics
- Communications, Networking, Timing & Telemetry

TECHNOLOGIES TO IMPROVE MISSION SAFETY/MISSION RISK

- Range Tracking, Surveillance & Flight Safety Technologies
- Landing & Recovery Systems & Components
- Weather Prediction and Mitigation
- Robotics / Telerobotics
- Safety Systems

TA13 • GROUND & LAUNCH SYSTEMS PROCESSING

ENVIRONMENTAL AND GREEN TECHNOLOGIES

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TA14 • THERMAL MANAGEMENT SYSTEMS

CRYOGENIC SYSTEMS

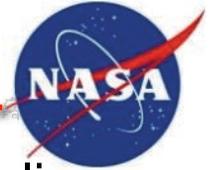
- Passive Thermal Control
- Active Thermal Control
- Integration & Modeling

THERMAL CONTROL SYSTEMS

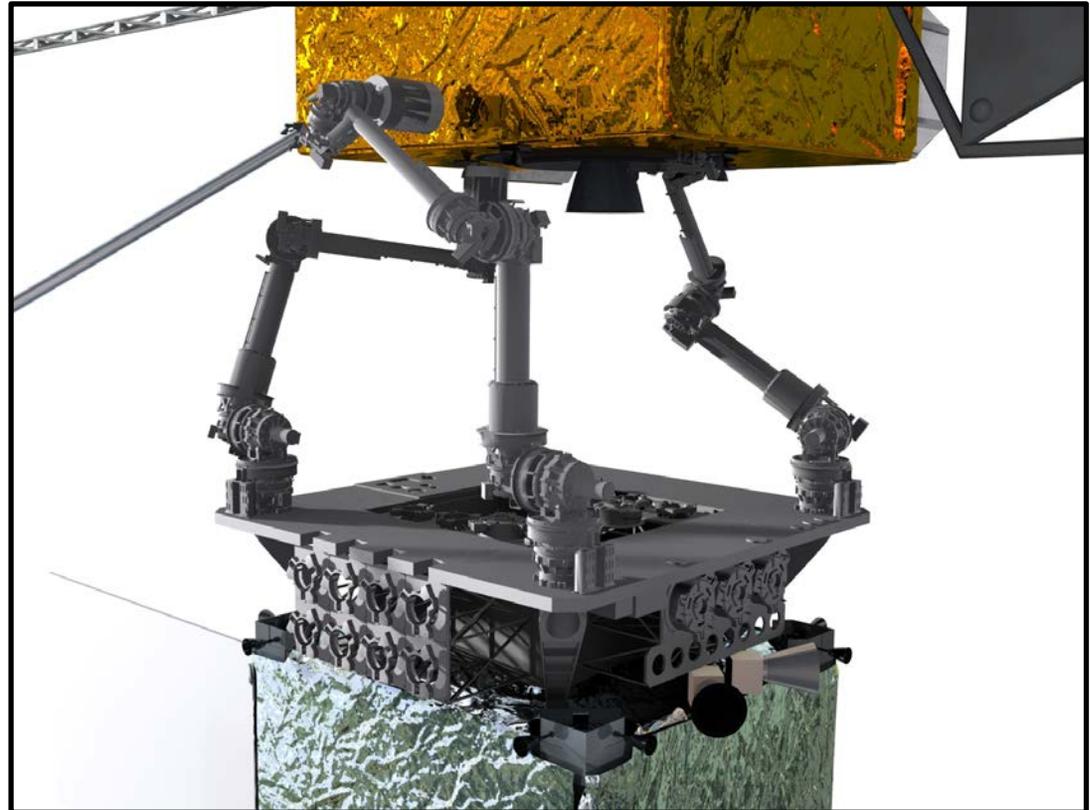
- Heat Acquisition
- Heat Transfer
- Heat Rejection & Energy Storage
- Thermal Protection Systems
- Entry / Ascent TPS
- Plume Shielding (Convective & Radiative)
- Sensor Systems & Measurement Technologies

Space Technology Roadmaps STR • TABS TECHNOLOGY AREA BREAKDOWN STRUCTURE

Some Key Technical Challenges



- Non-cooperative servicing – rendezvous, prox ops, capture, refueling
- Control of mated Servicer-Client stack, and robot tele-operation in presence of flexible modes
- Materials compatibility in pumps, flow meters, hose, and nozzle tool
- High performance computing to host robot and AR&D algorithms
- Mass optimization to maximize fuel available for servicing
- Absence of hi-fidelity ground simulators of potential clients



Conclusions



- SSCO is more than half way through a thorough ground and space technology development and test campaign
- Key requirements and ConOps of a notional GEO servicing mission defined
- Technical challenges are well understood
- The time for robotic servicing has arrived – let's fly a mission!

