In-space Servicing, Assembly, and Manufacturing (ISAM) State of Play

2025 Edition

John Mulvaney, Dr. Dale Arney, Christina Williams, Jose Morel
NASA Langley Research Center

Christopher Stockdale
Analytical Mechanics Associates, Inc.

Christopher Whitlock
NASA Intern, University of Kansas

Vishruth Balaji
NASA Intern, Texas A&M University

A document to characterize the current state of ISAM capabilities.

EXECUTIVE SUMMARY

The future of spaceflight will yield increasingly more ambitious missions to support civil, national security, and commercial space sectors. Achieving some of these missions will not be feasible by launching an integrated, fully functioning system on a single launch vehicle. Future science and human exploration missions will require payloads that are larger than any foreseeable launch vehicle fairing, national security missions will require persistent assets that are mobile and resilient, and commercial space missions will require cost-effective ways to update to the latest technology on orbit.

In-space Servicing, Assembly, and Manufacturing (ISAM) can vastly expand the performance, availability, and lifetime of space systems compared to the traditional paradigm of launching an asset with no intent to ever interact with it again. ISAM capabilities foster an ecosystem that changes the space operations paradigm, creating the foundation for sustainable exploration and serving as a multiplier for other capabilities like space logistics, power generation, and reusability.

Previous achievements in ISAM have enabled ambitious human and robotic space missions. The assembly, operation, and maintenance of NASA's International Space Station (ISS); servicing missions to the Hubble Space Telescope (HST); and Northrop Grumman's Mission Extension Vehicle (MEV) demonstrate the dramatic operational missions that can be achieved using ISAM capabilities. Many current and upcoming flight demonstrations are advancing areas that will enable the next generation of civil, national security, and commercial space missions.

This document describes the current state of ISAM missions, activities, and technologies to the best ability of the authors. Compiling and organizing the available ISAM capabilities will help mission designers incorporate ISAM technologies into their concepts, create the starting point for technology development plans and roadmaps, and provide technologists a survey of the field they are developing. This document divides the ISAM capabilities into 11 functional capability areas that describe the functions or activities that can be performed in space using ISAM.

- **Robotic Manipulation**: Robotic manipulators have flown on a variety of missions, from surface robotics on Mars to long reach manipulation on the ISS. New manipulation systems are being developed to increase autonomy, reduce cost, and expand the capability of space robotics.
- **Rendezvous & Proximity Operations (RPO), Capture, Docking, and Mating**: This capability is the first step in an ISAM mission and has been included in space flight since Gemini VIII in 1966. Advancements in autonomy, formation flying, standardization/interoperability, and mating operations will make future ISAM missions more routine.
- **Relocation**: Moving a client space object with a servicing spacecraft or tug presents a large opportunity for sustainable space operations such as mission extension, debris removal, and maneuverability. After the first commercial relocation mission in 2019, many companies are currently developing relocation spacecraft with the intent to offer relocation as a commercial service.

- **Prepared Repair, Maintenance, Upgrade, and Installation**: Prepared servicing is the center of an ISAM ecosystem where the client space object and ISAM servicing spacecraft are co-designed to operate together. Modular interfaces are being developed to support spacecraft in this ecosystem with mechanical, fluid, power, data, and thermal connections.
- **Unprepared Repair, Maintenance, Upgrade, and Installation**: Providing services to a legacy client space object that is not prepared to receive those services ensures currently deployed assets may appreciate future, extended utility. Activities to develop mission-specific functionality are important for tangential missions like debris removal, scavenging, and manipulating non-cooperative spacecraft.
- **Refueling and Fluid Transfer**: Storable fluid transfer has been demonstrated multiple times, including to support operational missions like the ISS. The future is heading toward commercial refueling services (especially for storable fluids), and demonstrations are planned to test large-scale cryogenic fluid transfer in space to support human exploration.
- **Structural Manufacturing and Assembly**: The technologies that enable constructing or assembling structures in space to create spacecraft, components, or subsystems are wide ranging. Historically focused on astronaut assembly, the current advancements in this capability area emphasize autonomous robotic manufacturing and assembly.
- **Recycling, Reuse, & Repurposing**: Recycling, reuse, and repurposing include technologies which transform readily available in-space materials for future use. The eventual future in this capability area is in expanding the materials that can be reused, tailoring the performance of those materials, and understanding the mission implications.
- **Parts and Goods Manufacturing**: The initial capability for parts and goods manufacturing in space is focused on the use of 3D printed plastics. Production techniques currently in development aim to expand the production capabilities to metals, electronics, and in-situ regolith-based materials.
- **Surface Infrastructure**: Excavation, construction, outfitting, and operations on a planetary body will require advancements in surface logistics and horizontal (landing pads, roads, etc.) and vertical (power, habitation, etc.) construction.
- **Inspection and Metrology:** Inspection and metrology are needed to survey and analyze configuration, size, shape, state of repair, or other features of interest in space. The systems to perform these tasks include free-flyer inspection, non-destructive evaluation, close (robotic) inspection, and visual or multispectral inspection.

In addition to the 11 functional capability areas, three cross-cutting capability areas are included for entries which have broad impact on the field of ISAM. Entries included within the cross-cutting capability areas are activities, developments, or documentation that support technologies within the 11 functional capability areas or provide valuable insights for ISAM technology development or mission planning. The cross-cutting capability areas include:

- **Software and Algorithms:** Software and algorithms are used to support a wide range of ISAM activities, particularly those involving rendezvous and proximity operations or robotic manipulation. Current ISAM-specific developments are focused on modeling and simulation, multi-agent frameworks, and autonomy.
- **Management, Logistics, and Operations:** Management, logistics, and operations are the capabilities that allow further exploration into space. Development for this capability area is often prompted by large-scale human endeavors into space, such as the operation of the ISS or the Artemis missions.
- **Laws, Policies, and Standards:** Laws, policies, and standards provide the guiderails for operating in space. Due to the recent emergence of ISAM technologies, ISAM-specific guidance is just recently becoming available through organizations such as the FCC (regulations) or CONFERS (standards).

To provide more context for the recorded ISAM entries, this document also includes an overview of ISAM developers and facilities. ISAM developers are companies, government organizations, or academic institutions which are identified as a developer for one or more of the activities captured in this document. The developers range greatly in areas of expertise, organizational size, and space mission experience, further highlighting the diverse background of those invested in ISAM capabilities. To provide context as to where much of this work occurs, several facilities with ISAM-specific capabilities are described within this document. Location, ownership, and capabilities are highlighted for each of the included facilities, with the hope that shared use of facilities may become normalized within the ISAM community, thereby reducing overall facility cost and unnecessary redundancy in facility capabilities.

The 2025 edition of the *ISAM State of Play* is part of a continuing journey to encourage the use of ISAM capabilities in space. Compiling and organizing the current state of ISAM provides a resource for those working in the ISAM ecosystem to ensure that the advancements being made build upon the investments of the past. The state of play is ever changing as new capabilities are developed, and this document will be periodically updated to ensure that it is relevant to those who need it in the future.

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TABLE OF ACRONYMS

Acronyms and abbreviations used in the document are defined below.

AC-10	Aerocube-10
ACCESS	Assembly Concept for Erectable Space Structures
ACME	Additive Construction with Mobile Emplacement
ADRAS-J	Active Debris Removal by Astroscale Japan
AEON	Autonomous Entity Operational Network
AFRL	Air Force Research Laboratory
AIAA	American Institute for Aeronautics and Astronautics
AM	Additive Manufacturing
AMF	Additive Manufacturing Facility
AMS	Alpha Magnetic Spectrometer
ANGELS	Automated Navigation and Guidance Experiment for Local Space
APAS	Androgynous Peripheral Attachment System
APS-R	Astroscale Prototype Servicer for Refueling
ARMADAS	Automated Reconfigurable Mission Adaptive Digital Assembly Systems
ASPIN	Augmentation System Port Interface
ASTRO	Autonomous Space Transport Robotic Operations
ATDS	Advanced Tool Drive System
ATHLETE	All-Terrain Hex-Limbed Extra-Terrestrial Explorer
ATV	Automated Transfer Vehicle
AXCIS	Advancement of Exploration Components for In-Space Servicing
BEAM	Baseline Environment for Autonomous Modeling
BFF	BioFabfrication Facility
CAESAR	Compliant Assistance and Exploration SpAce Robot
CAS	Common Attachment System
CAT	Capture Bay for Active Debris Removal
CDR	Critical Design Review
CHAPEA	Crew Health and Performance Analog
CNC	Computerized Numerical Control
CONFERS	Consortium for Execution of Rendezvous and Servicing Operations
COSMIC	Cleaning Outer Space Mission through Innovative Capture
CPOD	CubeSat Proximity Operations Demonstration
CRD2	Commercial Removal of Debris Demonstration
CRG	Cornerstone Research Group
CRISSP	Customizable, Recyclable ISS Packaging
CRS	Commercial Resupply Service
CST	Cryogenic Servicing Tool
D4R	Design for Removal
DARPA	Defense Advanced Research Projects Agency
DART	Demonstration for Autonomous Rendezvous Technology
Dextre	Special Purpose Dexterous Manipulator
DIANE	Démonstration d'Inspection et Amarrage Novatrice Embarquée

DISCMAN	DIsk-Shaped Configurable and Modular vAcuum uNit
DIU	Defense Innovation Unit
DOC	Department of Commerce
DOF	Degree of Freedom
EASE	Experimental Assembly of Structures in EVA
EBW	Electron Beam Welding
EC	European Commission
ECLSS	Environmental Control and Life Support System
EELV	Evolved Expendable Launch Vehicle
ELC	Express Logistics Carrier
ELSA-d	End-of-Life Services by Astroscale-demonstration
ELSA-M	End-of-Life Service by Astroscale-Multiple
EMM	Experimental Module Manipulator
ERA	European Robotic Arm
EROSS	European Robotic Orbital Support Services
ESA	European Space Agency
ESAMM	Extended Structure Additive Manufacturing Machine
ESPA	EELV Secondary Payload Adapter
ETS	Engineering Test Satellite
EU	European Union
EVA	Extravehicular Activity
EVR	Extravehicular Robotic
eXCITe	eXperiment for Cellular Integration Technology
EXPRESS	EXpedite the PRocessing of Experiments to Space Station
FAA	Federal Aviation Administration
FabLab	Multimaterial Fabrication Laboratory
FARE	Fluid Acquisition and Resupply Experiment
FCC	Federal Communications Commission
FDM	Fused Deposition Modeling
FFRDC	Federally Funded Research and Development Center
FLEX	Flexible Logistics and EXploration
FRAM	Flight Releasable Attachment Mechanism
FREND	Front-end Robotics Enabling Near-term Demonstration
FSP	Fission Surface Power
GaLORE	Gaseous Lunar Oxygen from Regolith Electrolysis
GEO	Geostationary Earth Orbit
GHOST	GITAI S2's extraveHicular multi-Objective in-Space Servicing Task Demonstration
GOLD	General Purpose Latching Device
GRASP	Guideless Resilient Androgynous Serial Port
GRC	Glenn Research Center
GRIP	Grappling Resupply Interface for Products
GSFC	Goddard Space Flight Center
HMA	Hose Management Assembly
HMFG	Heavy-Metal Fluoride Glasses
HST	Hubble Space Telescope

HTP	High-Test Peroxide
HTV	H-II Transfer Vehicle
IBDM	International Berthing and Docking Mechanism
ICF	Industrial Crystallization Facility
IDA	Instrument Deployment Arm
IDD	Interface Definition Document
IDSS	International Docking System Standard
IEEE	Institute of Electrical and Electronics Engineers
IERIIS	International External Robotic Interface Interoperability Standards
IOD	In-Orbit Demonstration
IPEx	ISRU Pilot Excavator
IRSIS	International Rendezvous System Interoperability Standards
ISA	In-Space Assembly
ISAM	In-space Servicing, Assembly, and Manufacturing
ISFR	In-Situ Fabrication and Repair
ISM	In-Space Manufacturing
ISO	International Organization for Standardization
ISRU	In-situ Resource Utilization
ISS	International Space Station
iSSI	intelligent Space System Interface
ITS	Integrated Truss Structure
ITU	International Telecommunications Union
IVA	Intravehicular Activity
IVR	Intravehicular Robotic
JAXA	Japan Aerospace Exploration Agency
JEM SFA	Japanese Experiment Module Small Fine Arm
JEM	Japanese Experiment Module
JEM-RMS	Japanese Experiment Module Remote Manipulator System
JOINS	JOining Demonstrations IN Space
KDP	Inorganic potassium dihydrogen phosphate
LANCE	Lunar Attachment Node for Construction and Excavation
LaRC	NASA Langley Research Center
LASAR	Lunar Assembly and Servicing by Autonomous Robotics
LASRS++	Langley Standard Real-time Simulation in C++
LCS	Laser Camera System
LDDM	Launch-Hardened Deploy and Docking Mechanism
LEO	Low-Earth Orbit
LEXI	Life Extension In-orbit
LGF	Latchable Grapple Fixture
LH2	Liquid Hydrogen
LINCS	Local Intelligent Networked Collaborative Systems
LOX	Liquid Oxygen
LPGCF	Low Profile Grapple Fixture
LSMS	Lightweight Surface Manipulation System
LTVS	Lunar Terrain Vehicle Services

M3LT	Microwave Melter of Martian and Lunar Terrain
MAMBA	Metal Advanced Manufacturing Bot-Assisted Assembly
MAVERIC	Marshall Aerospace Vehicle Representation in C
MCF	Micro-Conical Fitting
MEP	Mission Extension Pod
MER	Mars Exploration Rover
MEV	Mission Extension Vehicle
MICE	Mechanical Interface for Capture and Extraction
MIT	Massachusetts Institute of Technology
MLV	Medium Launch Vehicle
MMH	Monomethyl hydrazine
MMIC-I	Mobile Metamaterial Internal Co-Integrator
MMPACT	Moon-To-Mars Planetary Autonomous Construction Technology
MODSIM	Modelling and Simulation
MON-3	Mixed Oxides of Nitrogen
MRTAS	Modified Rocketdyne Truss Attachment Mechanism
MRV	Mission Robotic Vehicle
MSF	Modular Space Foundry
MSFC	Marshall Space Flight Center
MSG	Microgravity Science Glovebox
MSL	Mars Science Laboratory
MSTIC	Manufacturing of Semiconductors and Thin-film Integrated Coatings
MuJoCo	Multi-Joint Dynamics with Contact
MVACS	Mars Volatiles and Climate Surveyor Robotic Arm
N2H4	Hydrazine
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NDS	NASA Docking System
NExIS	NASA’s Exploration & In-space Services
NEXTSat	Next Generation Satellite and Commodities Spacecraft
NICER	Neutron star Interior Composition Explorer
NINJAR	NASA Intelligent Jigging and Assembly Robot
NOM4D	Novel Orbital and Moon Manufacturing, Materials, and Mass-efficient Design
NRHO	Near-Rectilinear Halo Orbit
NRL	Naval Research Laboratory
NTIA	National Telecommunications and Information Administration
NTO	Nitrogen Tetroxide
NTS	National Technical Systems
ODME	On-Demand Manufacturing of Electronics
OEDMS	Orbital Express Demonstration Manipulator System
OMD	Outpost Mars Demo
OMV	Orbital Maneuvering Vehicle
ORFOM	Orbital Fiber Optic Production Module
ORS	Orbital Refueling System
ORU	Orbital Replacement Unit

OSAM	On-orbit Servicing, Assembly, and Manufacturing
OTCM	ORU Tool Changeout Mechanism
OTV	Orbital Transfer Vehicle
P3E	Passive Pose and Position Engine
PACT	Planetary Automated Compaction Tool
PAO	Payload ORU Accommodation Unit
PASS	Precision Assembled Space Structures
PAUT	Phased Array Ultrasonic Test
PDGF	Power and Data Grapple Fixture
PIL-BOX	Pharmaceutical In-space Laboratory Bio-crystal Optimization Xperiments
PJVS	Programmable Josephson Voltage Standard
PMA	Pressurized Mating Adapter
PODSAT 1	Payload Orbital Delivery Satellite
PRM	Passive Refueling Module
PROBA-1	PRoject for OnBoard Autonomy
PSI	Plume Surface Interaction
PTS	Propellant Transfer Subsystem
PVGF	Power and Video Grapple Fixture
RAFTI	Rapidly Attachable Fluid Transfer Interface
REACT	Relevant Environment Additive Construction Technology
RegISS	Redwire Regolith Print
RELL	Robotic External Leak Locator
RiTS	Robotic Tool Stowage
RMCT	Robot Micro-Conical Tool
ROS	Robot Operating System
ROSA	Roll out Solar Arrays
RPO	Rendezvous and Proximity Operations
RPOD	Rendezvous, Proximity Operations and Docking
RRM	Robotic Refueling Mission
RROxiTT	Remote Robotic Oxidizer Transfer Test
RRP	Redwire Regolith Print
RSGS	Robotic Servicing of Geosynchronous Satellites
RTAS	Rocketdyne Truss Attachment System
RTAS	Rocketdyne Truss Attachment System
SAGE	Stratospheric Aerosol and Gas Experiment
SAMURAI	Strut Assembly, Manufacturing, Utility, and Robotic Aid
SCOUT	SpaceCraft Observe and Understand Things
SEEKER	Space Environmental Effects
SFA	JAXA Small Fine Arm
SFMD	Storable Fluid Management Demonstration
SHA	Sample Handling Assembly
SHEARLESS	Sheath-based Rollable Lenticular-Shaped and Low-Stiction Composite Booms
SHOOT	Superfluid Helium On-Orbit Transfer
SIMPL	Satlet Initial-Mission Proofs and Lessons
SIMPLE	Sintered Inductive Metal Printer with Laser Exposure

SIROM	Standard Interface for Robotic Manipulation of Payloads
SOLLI-E	Scaling Omnidirectional Lattice Locomoting Explorer
SOUL	Spacecraft on Umbilical Line
SO-WARM	Solar On-Orbit Welder for Assembly, Repair, and Manufacturing
SpaceFORM	Space Facility for Orbital Remote Manufacturing
SPDP	Structural, Power, and Data Port
SPHERES	Synchronized Position Hold Engage and Reorient Experimental Satellite
SPIDER	Space Infrastructure Dexterous Robot
SRMS	Shuttle Remote Manipulator System
SSAS	Segment-to-Segment Attachment System
SSPICY	Small Spacecraft Propulsion and Inspection Capability
SSRMS	Space State Remote Manipulator System
STMD	Space Technology Mission Directorate
STOMP	Site Preparation Tooling for Operations on Mobility Platforms
STP	Space Test Program
STS	Space Transportation System
SunRISE	Sun Radio Interferometer Space Experiment
TALISMAN	Tendon-Actuated Lightweight In-Space MANipulator
TCAM	Twisted and Coiled Artificial Muscles
TCMM	Turbine Ceramic Manufacturing Module
TDM	Technology Demonstration Mission
TLT	Tall Lunar Tower
TSCM	Turbine Superalloy Casting Module
TuFF	Tailored Universal Feedstock for Forming
TVAC	Thermal Vacuum Chamber
UDMH	Unsymmetrical Dimethylhydrazine
UIUC	University of Illinois Urbana-Champaign
ULTOR	Ultra Lethal Targeting by Optical Recognition
UMD SSL	University of Maryland Space Systems Laboratory
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space
UNIGLO	Universal Intelligent Glass Optics Manufacturing Module
Vespa	Vega Secondary Payload Adaptor
VIPIR	Visual Inspection Poseable Invertebrate Robot
VSS	Vision Sensor Subsystem
VTRE	Vented Tank Resupply Experiment
XDA	eXploration Dexterous Arm
xGEO	Cislunar Orbital Regime (beyond GEO)
XLA	eXploration Large Arm
XSS	Experimental Satellite System

1 INTRODUCTION

Historically, spacecraft are constructed on Earth and launched as an integrated, fully functioning system on a single launch vehicle. This approach constrains the size, volume, mass, and mission design of those systems, as they must fit within the given launch vehicle fairing. Additionally, the operational life of the system is indirectly limited due to an inability to perform refueling, maintenance, repairs, or upgrades after deployment.

The future of spaceflight will yield increasingly more ambitious missions to support civil, national security, and commercial space sectors. Realizing these ambitious missions is not feasible using the traditional paradigm. For example, future science and human exploration missions will require payloads that are larger than any foreseeable launch vehicle fairing, national security missions will require persistent assets that are mobile and resilient, and commercial space missions will require cost-effective ways to update to the latest technology on orbit.

ISAM is an emerging set of capabilities that enables inspection, repair, upgrade, assembly, relocation, and construction of space assets. This set of capabilities is also referred to as On-orbit Servicing, Assembly, and Manufacturing, or OSAM.

1. *Servicing* is the alteration of a spacecraft after its initial launch.
2. *Assembly* is the aggregation and connection of components to create a larger asset, such as a spacecraft or structure.
3. *Manufacturing* is the transformation of raw materials into usable spacecraft components or structures.

ISAM can vastly expand the performance, availability, and lifespan of space systems compared to the traditional paradigm. Incorporating these ISAM capabilities may decrease upfront cost, introduce pay-as-you-go options for deploying space assets, and enable spacecraft larger than launch vehicle fairing dimensions. ISAM capabilities will leverage and foster an ecosystem that changes space operations, creating the foundation for sustainable exploration and serving as a multiplier for other capabilities like space logistics, space power, and reusability.

This document compiles and organizes the current state of ISAM missions, activities, and technologies. Understanding where these capabilities currently stand will help mission designers incorporate ISAM technologies into their concepts, create the starting point for technology development plans and roadmaps, and provide technologists a survey of the field they are developing. The authors recognize that ISAM is broad, and they are unlikely to have captured everything that has been or is being done in the area. As a result, new versions of the ISAM *State of Play* will be released periodically, and the community is encouraged to submit suggestions, corrections, and comments to the authors via email at LARC-DL-ISAM-SOP@mail.nasa.gov.

2 History of ISAM

While ISAM is an emerging set of capabilities, previous use of ISAM has enabled ambitious space missions. The assembly and maintenance of the ISS, the servicing operations of the HST, and the operations of Northrop Grumman's MEV demonstrate the dramatic missions that can be achieved using ISAM capabilities. Many current and upcoming flight demonstrations are advancing areas that will enable the next generation of civil, national security, and commercial space missions.

Figure 1 provides an overview of a selection of the major operational missions that use ISAM and the flight demonstrations that have advanced ISAM capabilities. These missions are further detailed and correlated with more specific *State of Play* entries in Section 6.

After Hubble was launched in 1990, five Space Shuttle missions flew to the orbiting observatory for EVA astronaut repair and upgrade of the system in space. Japan launched the ETS-VII to demonstrate robotic servicing, and it was the first uncrewed spacecraft equipped with a robotic arm. Orbital Express was a joint DARPA and NASA mission that demonstrated RPO, refueling, and module replacement. The ISS was assembled and serviced over multiple flights, spanning several decades, using a variety of vehicles from the United States (Shuttle), international partners (e.g., Soyuz, Progress), and industry (e.g., Dragon, Cygnus). The suite of RRM experiments to the ISS have demonstrated the storage and robotic transfer of fluids using specialized tools as well as the robotic manipulation of cooperative and legacy spacecraft interfaces. Aboard the ISS, NASA's ISM project has demonstrated various manufacturing capabilities inside the pressurized volume. MEV-1 and MEV-2 are currently providing life extension capabilities to unprepared clients in GEO. Finally, the MRV, developed through DARPA's RSGS program, plans to launch in 2026 and provide servicing capabilities to assets in GEO.

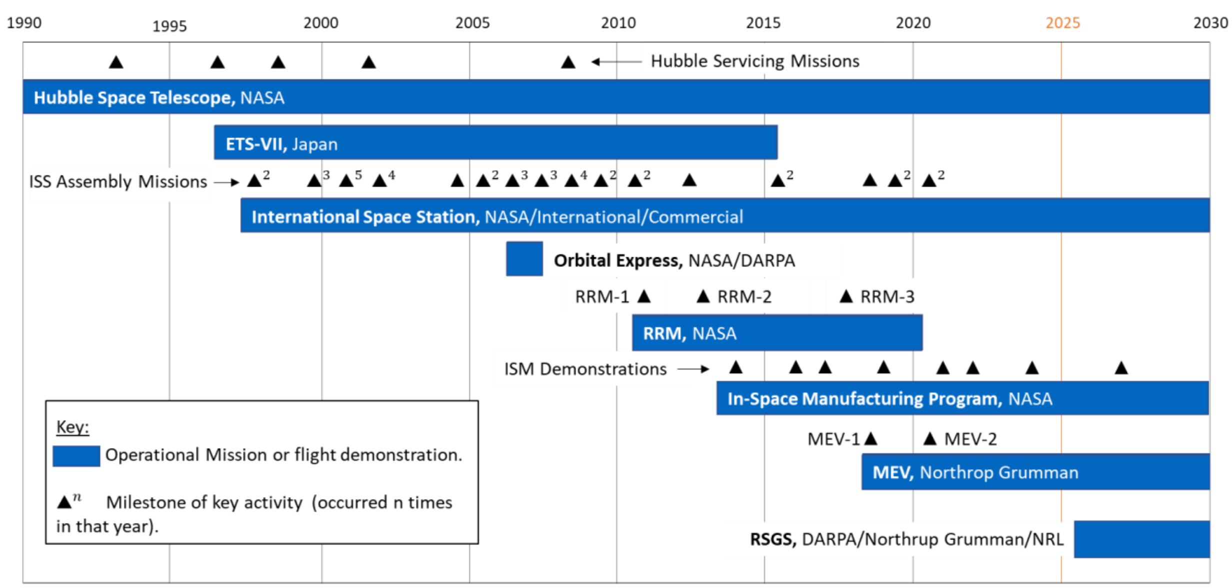

Figure 1: There is a long history of ISAM capabilities being used and advanced in ambitious operational missions (e.g., ISS, Hubble, and MEV) and flight demonstrations (e.g., Orbital Express). These missions and demonstrations have been performed by civil, national security, and commercial space organizations.

3 ISAM Functional Capability Areas

This document organizes the identified ISAM missions, activities, and technologies into 11 capability areas that describe the functions or activities that would be performed in space using ISAM. These capability areas are distinct activities that may be performed during an ISAM-enabled mission, and several activities may combine to achieve a given mission. The 11 functional capability areas are:

- **Robotic Manipulation**: Involves manipulating payloads and spacecraft subsystems with a robotic manipulator. Includes robotic activities such as driving/releasing bolts, cutting, placing modules, and assisted deployment.
- **RPO, Capture, Docking, and Mating**: Involves multiple spacecraft maneuvering in proximity to each other (RPO) and could include connecting participating spacecraft together (Capture, Docking, and Mating). Includes crewed or autonomous docking/berthing, remote inspection, and formation flying.
- **Relocation**: Involves the maneuvering of one spacecraft by another into a new orbit or orientation. Includes boosting, repositioning, deorbit, debris removal, and life extension.
- **Prepared Repair, Upgrade, Maintenance, and Installation**: Involves adding or replacing components on a client space object that is prepared to receive those components. These operations are performed to repair or upgrade that component, perform a maintenance swap-out, or install a new component that expands the capability of the spacecraft. Includes systems with modular interface connections and payload/component swap-out or upgrade.
- **Unprepared Repair, Upgrade, Maintenance, and Installation**: Involves adding or replacing components on a client space object that was not intended to receive those components. Includes more complex operations to access the interfaces and make new connections.
- **Refueling and Fluid Transfer**: Involves transferring fluid from one spacecraft to another. Includes cryogenic and non-cryogenic propellants/fluids and transfer in orbit or on a lunar or planetary surface.
- **Structural Manufacturing and Assembly**: Involves fabricating or assembling structures in space to create spacecraft components or subsystems. Includes manufacturing (e.g., 3-D printing, extruding) and assembly of structures with various interfaces, joining approaches, and precision.
- **Recycling, Reuse, & Repurposing**: Involves the use of material already in space to fabricate new material, components, spacecraft, or structures. Includes recycling the material from old spacecraft parts for new manufacturing feedstock and reusing old spacecraft parts as-is in new spacecraft.
- **Parts and Goods Manufacturing**: Involves producing spare parts, subsystems, and components for use in space. Includes manufacturing inside and outside of pressurized vessels with multiple materials and sizes.

- **Surface Infrastructure**: Involves excavating, constructing, and outfitting infrastructure on a planetary surface and the logistics to support operations. Includes horizontal (e.g., landing pads, roads) and vertical (e.g., power, habitation) construction, using regolith to build structures, assembly of erected structures, and offloading and mobility of material.

- **Inspection and Metrology:** Involves observation of systems in space to understand their configuration, size and shape, or other features of interest. Includes free-flyer inspection, non-destructive evaluation, close (robotic) inspection, and space situational awareness.

Figure 2 presents the capability areas that are used or advanced in the operational missions and flight demonstrations from Figure 1. Table 1 in Section 6 breaks down the specific activities or subsystems from each mission that demonstrated the capability areas identified in Figure 2. The ISS uses the most ISAM capabilities through its assembly and servicing operations that heavily involved astronauts. The ISS has also been a platform that supports other demonstration missions (e.g., RRM demonstrations and the ISM activities) that advance capabilities in ISAM and other areas. Technologies in every capability area have been used or demonstrated on orbit.

Name	Organizations	Robotic Manipulation	RPO, Capture, Docking, and Mating	Relocation	Prepared Repair, Upgrade, Maint., and Installation	Unprepared Repair, Upgrade, Maint., and Installation	Refueling and Fluid Transfer	Structural Manufacturing & Assembly	Recycling, Reuse, and Repurposing	Parts and Goods Manufacturing	Surface Infrastructure	Inspection and Metrology
ETS-VII	NASDA (now JAXA)	DEMO	DEMO									
HST	NASA		OPERATING	OPERATING	OPERATING	OPERATING						
ISM	NASA							DEMO	DEMO	DEMO	DEMO	
ISS	Multiple (NASA, International, Commercial)	OPERATING	OPERATING	OPERATING	OPERATING	OPERATING	OPERATING	OPERATING				OPERATING
MEV	Northrop Grumman		OPERATING	OPERATING								
Orbital Express	DARPA, NASA	DEMO	DEMO		DEMO		DEMO					DEMO
RRM	NASA GSFC					DEMO	DEMO					DEMO
RSGS	DARPA, Northrop Grumman, NRL	PLANNED	PLANNED	PLANNED	PLANNED	PLANNED						

OPERATING Operational Mission Uses Capability; DEMO Flight Demonstration Advances Capability; PLANNED Planned Flight Demonstration Advances Capability

Figure 2: Operational missions and flight demonstrations have used and advanced ISAM capabilities, and planned missions will demonstrate more. Robotic Manipulation; RPO, Capture, Docking, and Mating; and Inspection and Metrology capability areas have been used in most of these missions, and the ISS has used and demonstrated many of these ISAM capability areas.

The purpose of this document is to continuously collect previous and ongoing ISAM development activities, technologies, and facilities to describe the current state of ISAM. Each activity or technology collected is categorized into one or more of the capability areas as entries into a repository. These activities and technologies are referred to collectively as "entries" throughout the rest of this document. Figure 3 presents the total number of entries for each capability area. RPO, Capture, Docking, and Mating is the most prolific, and many of the nascent or forward-looking capability areas, such as Recycling, Reuse, and Repurposing, have fewer activities.

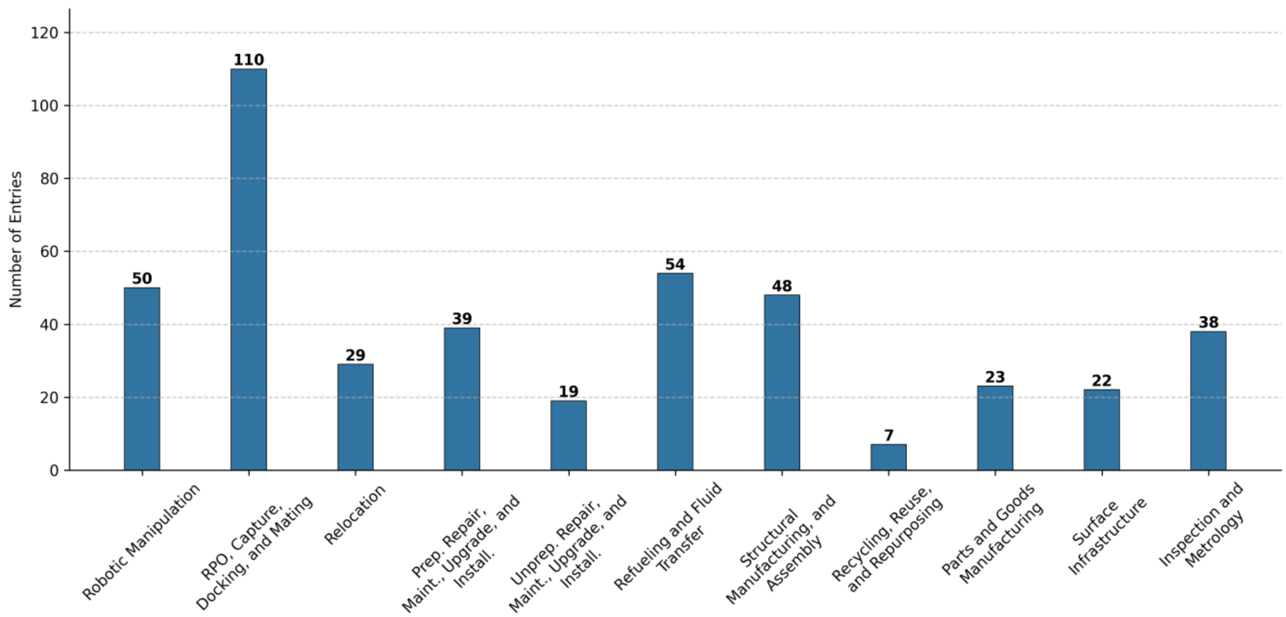

Figure 3: The activities or technologies collected in this document are categorized into the capability areas. This bar chart represents the number of activities in each of the functional capability areas.

Each capability area section contains an overview and the current state of that capability area. The current state includes systems or components that have been flown, have been demonstrated on the ground, or have hardware under development. Together, the information provides insight into the current state and future direction of capability area development. Additional details on the entries for each functional capability area can be found in Section 8, which also contains information about the use/demonstration date, developing organization, country of origin, and select performance parameters.

3.1 Robotic Manipulation

Robotic Manipulation is the capability to manipulate parts, payloads, subsystems, or space objects. A robotic manipulator can grapple a spacecraft during rendezvous, place new modules on an existing spacecraft or platform, perform intricate actions like cutting or welding, move and arrange components for in-space assembly, and assist in the deployment of large structures like solar arrays.

There are different classes within the robotic manipulation capability area based on the scale of the manipulator and its utility. Long reach manipulators have lengths greater than 8 meters and have been used in microgravity to manipulate large space systems. Short reach manipulators with lengths less than 8 meters have been used on spacecraft in microgravity and on surface systems like landers and rovers. It was determined that 8 meters was a suitable discriminator between long and short reach manipulators due to the clustering of manipulators above and below 8 meters, as shown in Figure 4, and the difference in use cases between the two divided groups.

Long reach manipulators such as the SRMS and SSRMS, known as Canadarm and Canadarm2 respectively, have supported NASA's human space exploration missions since 1981 through operation on Shuttle and the ISS. These robotic manipulators are teleoperated and support end effectors that attach to common grapple fixtures. The Chinese Core Module Manipulator, with 7 degrees of freedom and a 10-meter reach, has provided long reach capabilities similar to the SSRMS on board the Tiangong space station since the station's launch in 2021. These long reach manipulators provide capabilities such as hosted payload repositioning, visiting vehicle berthing, and EVA support.

Short reach manipulators, such as Dextre and the JEM SFA, have been used to support servicing activities and experiments aboard the ISS. Both Dextre and the SFA attach to the end of long reach manipulators that place them near their tasks and provide finer articulation capabilities. Short reach manipulators have also been prevalent on the Martian surface on board landers and rovers such as Phoenix, Curiosity, and Perseverance to perform experiments, digging, sample collection and handling, and other complex tasks.

New developments in robotic manipulation are focused on increased capability and reduced cost. Planned long reach manipulators, such as NASA's 20-meter TALISMAN and the GITAI 10-meter S10, can provide future manipulation options for microgravity operations. On the surface, extreme environments (e.g., dust, temperature, lighting conditions) are driving requirements for robotic manipulators which will enable payload offloading and surface operations, such as NASA's LSMS and MDA's Lunar Outpost LTVS SKYMAKER manipulator. Several short reach manipulators currently in development, including the ARMADAS robotic manipulators, Motiv's xLink, and the GITAI's IN2, can autonomously reposition themselves onboard the host spacecraft to expand their working envelope and further support assembly or servicing tasks. A summary of robotic manipulators, their maximum reach, and their development status is found in Figure 4.

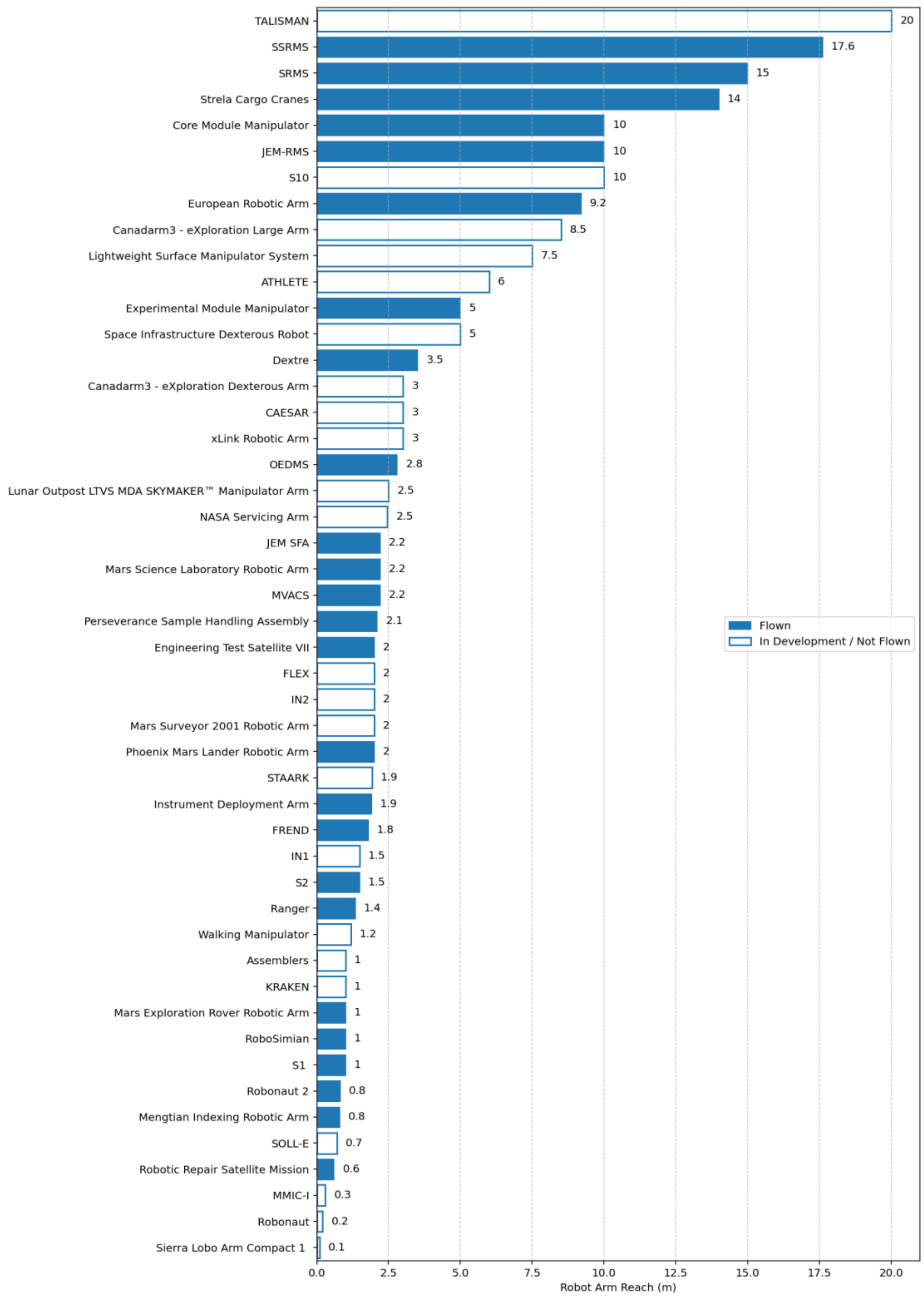

Figure 4: Robotic manipulators have flown for a variety of missions, from surface robotics to long reach manipulation on the ISS. Many are being developed to increase autonomy, reduce cost, and proliferate the use of space robotics. This figure displays the baseline configuration length for variable length arms.

3.2 RPO, Capture, Docking, and Mating

Rendezvous and Proximity Operations (RPO), Capture, Docking, and Mating is the capability area enabling interaction between spacecraft. Rendezvous is the process of reducing the distance between two space objects by orbital maneuvers made by one or both of the space objects. Proximity operations is the maintenance of relative distance and/or relative orientation between two space objects by orbital maneuvers by one or both of the space objects. Capture refers to a physical connection between two space objects, often two free flying spacecraft through the use of a robotic manipulator. Docking refers to the rigid connection between two space objects without the use of a robotic arm. Mating is a general term that refers to two objects or interfaces establishing a physical connection. RPO, capture, docking, and mating is required for any interaction between spacecraft and is therefore a necessary first step for many ISAM operations, such as relocation, prepared and unprepared servicing, refueling and fluid transfer, and structural manufacturing and assembly. For this reason, this capability area has the most entries of any of the functional capability areas, as shown in Figure 3.

The first docking in space occurred during the Gemini VIII mission on March 16, 1966. Shortly after, the first autonomous docking was demonstrated with the mating of the uncrewed Kosmos 186 and the uncrewed Kosmos 188 on October 30, 1967. Since these initial operations, innumerable examples of RPO, capture, docking, and mating have occurred in space. The construction and maintenance of the ISS has contributed to significant advancement in this capability area due to the number of missions which include RPO and autonomous docking by vehicles such as the Space Shuttle, Soyuz, Progress, Cygnus, Cargo Dragon, Crew Dragon, and Starliner.

Major advancement towards fully autonomous mating of uncrewed spacecraft has been in progress since the Japanese ETS-VII mission in 1998, which demonstrated utility for uncrewed rendezvous and docking techniques. Two AFRL micro-satellite missions in 2003 and 2005 demonstrated RPO with an active and inactive client. In 2007, Orbital Express demonstrated automated rendezvous and capture using both robotic grapple and direct docking, transfer of propellant, and transfer of a spacecraft component. Between 1981 and 2011, the Space Shuttle was extensively used to deploy, retrieve, or service spacecraft, including the ISS and HST, all of which involved RPO, capture, docking, and mating capabilities. An inventory of Space Shuttle rendezvous activities may be found in the NASA publication *History of Space Shuttle Rendezvous.*

Servicing spacecraft that provide station keeping to, relocate, transfer fuel to, or complete repairs on incapacitated satellites have recently advanced the state-of-the-art for this capability area due to the need to first perform RPO, capture, docking, and mating operations. Northrop Grumman's MEV-1 and MEV-2, which provide life extension services to satellites within GEO, capture spacecraft using a retractable probe inserted into the client spacecraft's liquid apogee engine. Astroscale's LEXI servicing spacecraft plans to capture spacecraft within GEO using four robotic arms which grasp the client spacecraft's launch adapter ring. Starfish Space's Otter, which plans to offer relocation services in GEO beginning in 2026, is a space tug equipped with the Nautilus capture mechanism, capable of attaching to a broad array of space objects without the need of a prebuilt docking interface. Future missions, such as Northrop Grumman's MRV, Astroscale's APS-R, Katalyst's SHIELD, and the United States Space Force's Tetra-5, Tetra-6, and Victus

Nox, also expect to advance the state-of-the-art of RPO, capture, docking, and mating for use during in-space servicing missions

A critical technology in the field of docking and mating operations is the grapple fixture. A mechanical connection between the two spacecraft is required in order to facilitate any other activities on orbit, such as refueling, life extension, or servicing. Some examples of grapple fixtures include the Docking Plate (Astroscale), DogTag (Altius Space Machines), and Mechanical Interface for Capture and Extraction (GMV, AVS, and ESA). These interfaces are often simplistic mechanical structures designed for multiple types of grappling. Servicer spacecraft can grapple these types of interfaces using robot arms and grippers, magnets, smooth surface adhesion, and even harpoon capture. Fiducial markers integrated with the mechanical interface can be targeted by a servicer spacecraft and used to support RPO maneuvers. These types of passive interfaces are lightweight, easy to attach to a client satellite, and ensure spacecraft are prepared for future in-space servicing.

More advanced mechanical interfaces, often integrated into prepared interfaces, require more intricate integration into spacecraft and offer expanded utility, such as transferring power, data, or fluids through the interface. Prepared interfaces currently in development include the ASPIN (Lockheed Martin), iSSI (iBOSS), PRM (Northrop Grumman), RAFTI (Orbit Fab), and many others detailed in Section 8. Through launching prepared interfaces, the complexity of docking with spacecraft and subsequent servicing operations is reduced, thereby reducing the necessary complexity of a servicing vehicle. An overview of mechanical interfaces captured in this capability area is found in Figure 5. The interfaces are categorized based on intended use and development status.

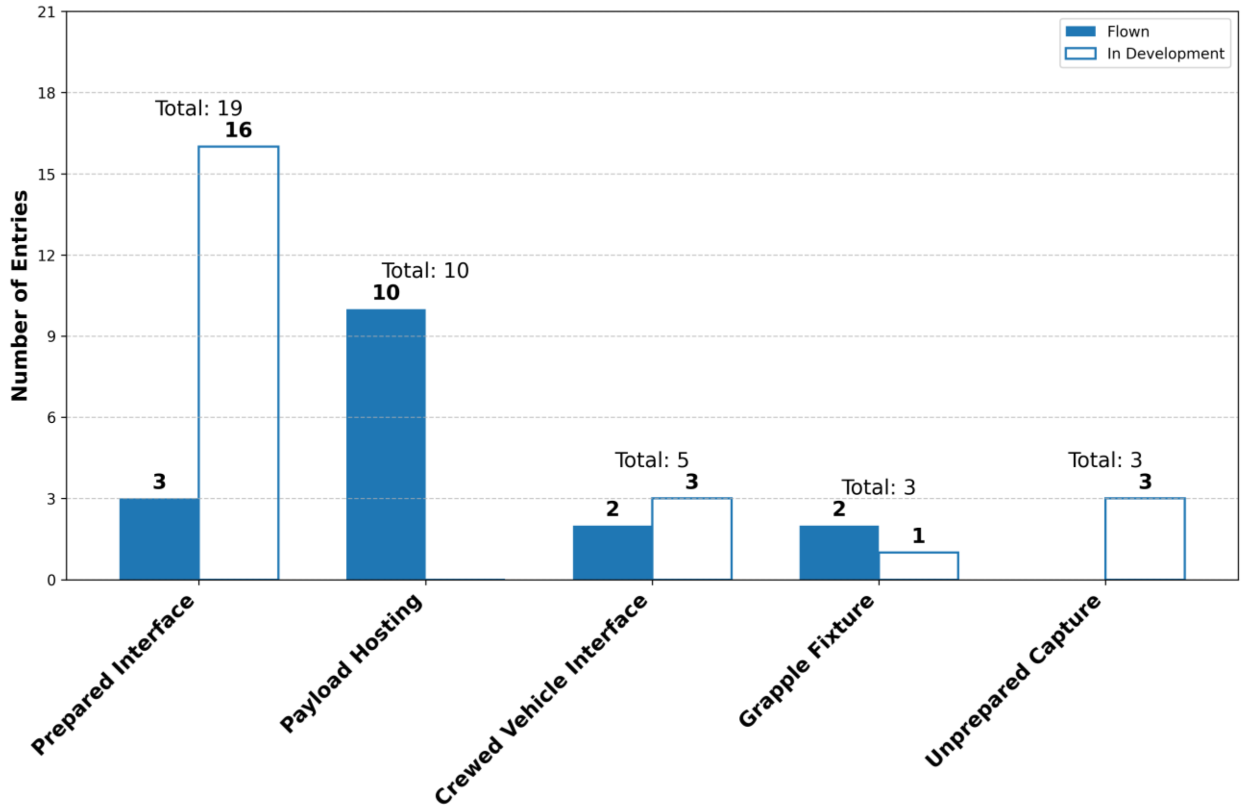

Figure 5: Mechanical interfaces between spacecraft are critical to capture, docking, and mating and serve to reduce complexity for future servicing missions. Interface technologies from this capability area are categorized according to use case and development status. Prepared interfaces are interfaces incorporated into a spacecraft to provide means for future servicing. Payload hosting refers to interfaces used to mount payloads to a host vehicle, such as the ISS. Crewed vehicle interfaces include mechanical interfaces used on crewed spacecraft. Grapple fixtures are simple mechanical features installed onto client spacecraft to simplify mechanical capture in space. Finally, unprepared capture refers to mechanisms which would be integrated into a servicing spacecraft and are designed to captures unprepared clients.

3.3 Relocation

Relocation refers to the capability of one spacecraft to alter the orbital parameters or orientation of another spacecraft. The purpose of relocation can be to move operational spacecraft to a new orbit, move space debris or retired spacecraft to a decay or graveyard orbit, or extend the life of a satellite with depleted fuel. The operation of the ISS has required relocation services on multiple occasions since its installation, including boosting by visiting vehicles to maintain orbit. The Space Shuttle was also responsible for many in space relocation activities, such as delivery of satellites to orbit, reorientation of satellites prior to deployment from the Space Shuttle cargo bay, or orbit raising of spacecraft such as HST.

Due to the increasing number of space debris and debris generating events, many debris removal technologies and spacecraft are currently under development. Astroscale's ELSA-d mission, launched in 2016, demonstrated technologies critical to debris removal and end-of-life services through completing

RPO and capture activities with a piece of simulated space debris within LEO. Similarly, the Aolong-1 mission, launched in 2016, demonstrated capture and re-entry of a simulated piece of space debris from LEO. Astroscale plans to launch the ELSA-M spacecraft in 2026, which will be capable of removing several pieces of debris from LEO. In 2028, ESA, OHB, and ClearSpace plan to fly the ClearSpace-1 mission to demonstrate space debris remediation by grappling and removing the PROBA-1 satellite from LEO and reentering both vehicles through Earth's atmosphere. Interest in removing debris or defunct spacecraft from GEO is also prevalent, with solutions often involving moving the debris or spacecraft to a GEO graveyard orbit. In 2022, the Shijian-21 spacecraft demonstrated relocation of a Beidou-2 G2 spacecraft from GEO to the GEO graveyard orbit. The RISE mission, commissioned by ESA and being developed by D-Orbit, will demonstrate relocation of multiple GEO clients to the GEO graveyard orbit in 2028.

In addition to the development of space debris removal technologies, relocation technologies have also been advanced through docked life extension missions. Northrop Grumman's MEV spacecraft currently provide docked life extension services to commercial payloads. Planned mission extension spacecraft include Astroscale's LEXI, Northrop Grumman's MRV and MEP, and Starfish Space's Otter. These life-extension servicing spacecraft are ideal in situations where a client space object is still functional but has lost the ability to modify or maintain its orbit due to propellant exhaustion or thruster failure. Instead of full satellite replacement, customers may extend the operational life of the satellite through the services of an on-orbit, docked, life-extension spacecraft. While MEV-1 and MEV-2 are both currently operating on orbit, MEP is currently in development and will be deployed by the MRV spacecraft, which is scheduled to launch in 2026. LEXI, MEV, MRV, MEP, and Otter are designed to offer satellite mission extension in GEO. Otter will also provide end-of-life deorbiting services and life extension to satellites in LEO.

Current development in this capability area is also ongoing for space tugs and rideshare upper stages. Space tugs offer orbital relocation for satellites which may not have the capability to perform large orbital changes, and rideshare upper stages deliver clients to multiple orbits after launch. Demonstrated or currently available commercial space tugs include D-Orbit's ION Satellite Carrier, Impulse Space's Mira, Spaceflight's Sherpa, and Exotrail's Spacevan, and Momentus' Vigoride. Future relocation capabilities include Blue Origin's Blue Ring, Firefly's Elytra, and MOOG's Orbital Maneuvering Vehicle, all of which offer ESPA-based hosting capabilities. Figure 6 shows the operational orbits of each relocation technology. As shown in the figure, the current activities are heavily focused on relocation capabilities within LEO and GEO. Future missions are expanding relocation capabilities towards operations beyond GEO and into xGEO or cislunar orbits.

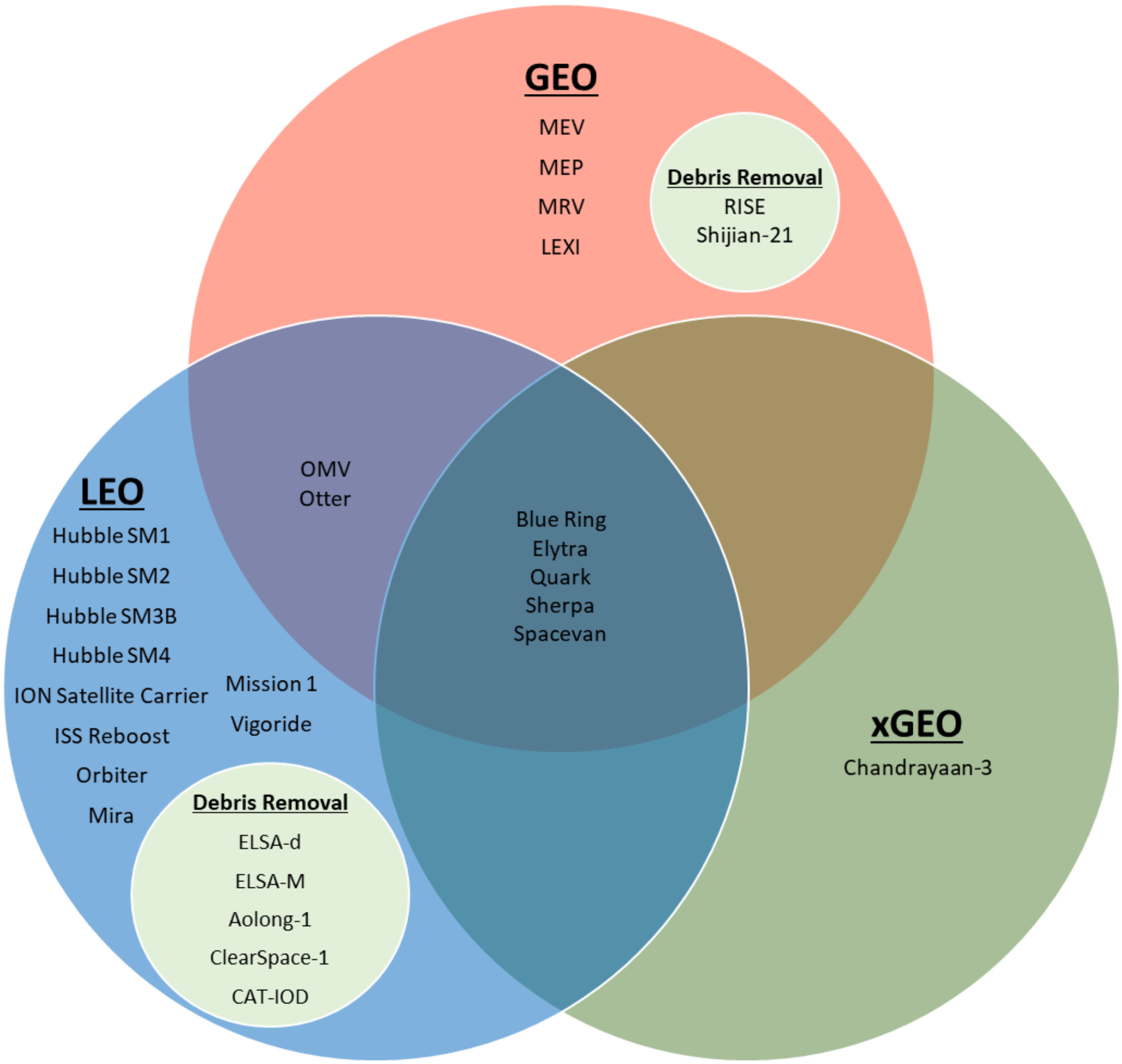

Figure 6: Relocation capabilities are currently heavily focused on LEO and GEO orbital regimes, and on commercial spacecraft targets. Of the technologies included in this figure, Aolong-1, Chandrayaan-3, ELSA-d, the Hubble Servicing Missions, ION Satellite Carrier, ISS Reboost, MEV, Mira, Orbiter, SHERPA, Shijian-21, Spacevan, and Vigoride have been successfully demonstrated on orbit.

3.4 Prepared Repair, Maintenance, Upgrade, and Installation

Prepared Repair, Upgrade, Maintenance, and Installation refers to the capability to service or augment an existing spacecraft that is designed to be serviced. Unlike legacy systems that are not expected to be visited again once on orbit, a prepared spacecraft is designed with the servicer or assembly agent in mind before launch. This is the center of an ISAM ecosystem where the client spacecraft and servicing spacecraft are co-designed to operate together and enable new missions and capabilities in the future. Key to prepared repair, upgrade, maintenance, and installation are standardized, interoperable interfaces for power and data connections within a spacecraft, between a hosting spacecraft and a payload, or between a servicing spacecraft and client spacecraft. These interfaces may be used for activities such as payload hosting, assembly of modular spacecraft in-space, deployment of modular spacecraft, and spacecraft servicing.

Modular interfaces are core to the function of NASA's ISS, which has enabled scientific research and continuous human presence in LEO since 2000. On board the ISS, external payload platforms with standard interfaces, such as the ELC, the JEM Exposed Facility, and Bartolomeo, have enabled experiments and payloads to be robotically attached to and removed from the ISS to take advantage of the unique space environment. Standard interfaces on the ISS also enable robotic systems, such as Canadarm2 and Dextre, to reposition on the exterior of the station and expand the overall workspace of the manipulators. The docking interfaces on each of the ISS modules provided means of assembly of the modules, and currently undocked interfaces serve as a means for visiting spacecraft to attach to the space station, resupply consumables, and exchange crew.

Another flagship NASA mission, HST, also heavily leveraged modular interfaces to enable prepared servicing activities. The standard interfaces of HST provided means for rapid replacement of modular subsystems during the five servicing missions conducted by astronauts aboard the Space Shuttle. The servicing activities corrected an initial fault in observation capabilities and extended the lifetime of the science platform.

Similarly, the MMS platform integrated into the Solar Maximum Mission satellite ensured the spacecraft could be serviced during STS-49C to correct the initial attitude control system failure. More recently, modularity was demonstrated on the Athena spacecraft through the NovaWurks SLEGO interface, which highlighted the utility of modularity for rapid deployment of spacecraft.

Beyond NASA efforts, industry is currently investing in technologies to advance uncrewed spacecraft servicing using autonomous, robotic systems. All-in-one modular interfaces which provide multiple utilities in the same interface (e.g., mechanical, power, and data) are currently being developed by companies such as Sierra Space (SPDP interface), iBOSS (iSSI), and SpaceWorks (FuseBlox). These modular interfaces, if deployed on a potential client spacecraft, will enable a future servicer to dock and provide services through a known interface, thus reducing the required complexity of the mission. Figure 7 provides a timeline of planned servicing missions, the first use of modular spacecraft, and the first use of servicing interfaces.

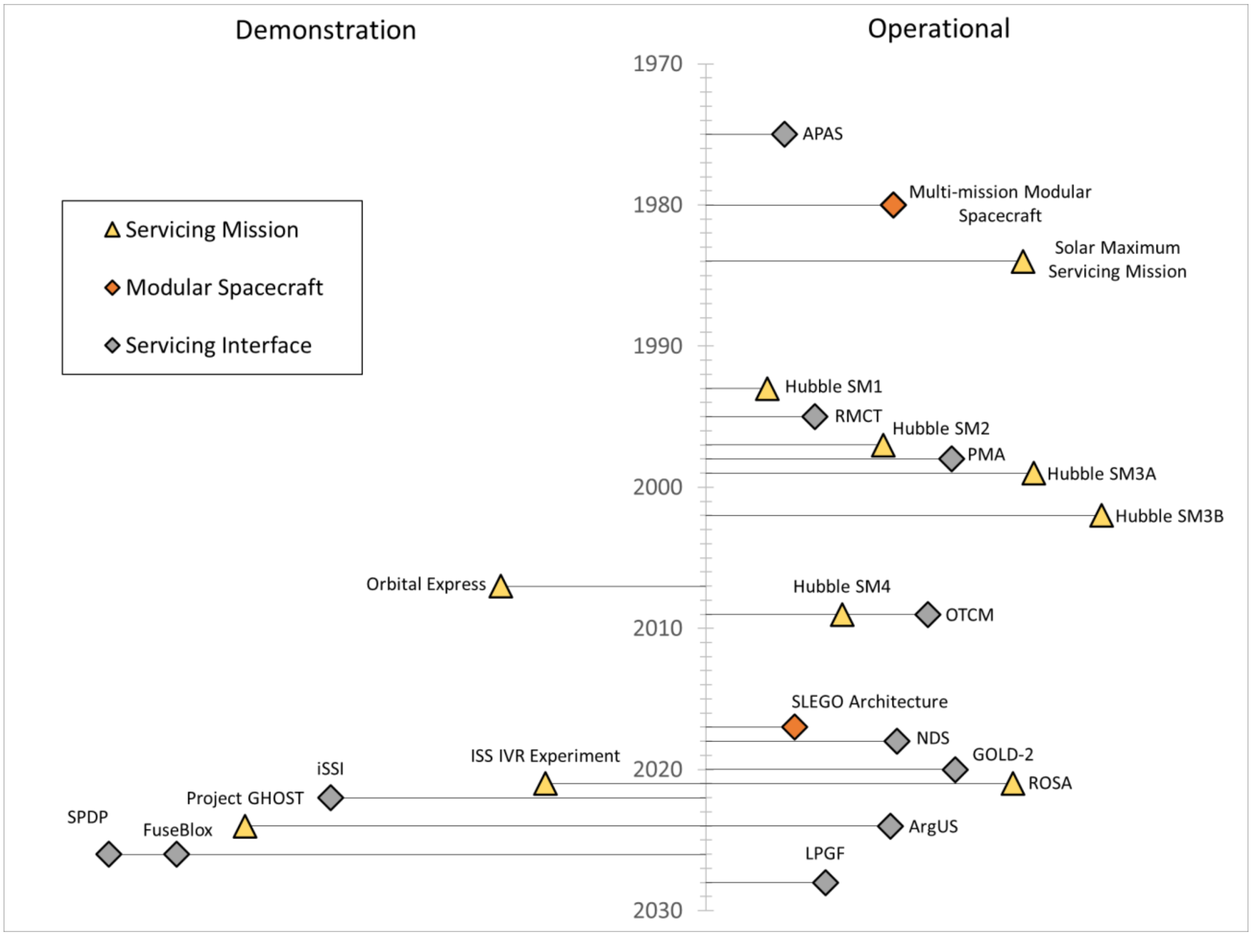

Figure 7: The planned servicing entries captured in this document include servicing missions, servicing spacecraft, and servicing interfaces. Provided is a timeline of these missions or the first use of the spacecraft or interface divided by demonstration or operational use. Demonstration relates to a mission or use of a spacecraft or interface to advance the readiness level of a technology. Operational relates to a mission or use of a spacecraft or interface with the intent of providing planned services.

3.5 Unprepared Repair, Maintenance, Upgrade, and Installation

Unprepared Repair, Maintenance, Upgrade, and Installation is the capability to service existing, or legacy, spacecraft that were not designed to take advantage of ISAM capabilities. Unprepared services include refueling, module repair and/or replacement, or augmentation of the spacecraft. This capability can help revive or expand the capability of spacecraft, allowing them to achieve operational goals and properly execute spacecraft disposal plans, potentially reducing the generation of space debris. Unprepared servicing is distinct from prepared servicing as the services being provided may need mission-specific functionality that could require unique capabilities to access, remove, or install parts or modules. These capabilities are also important for missions like debris removal, scavenging, and manipulating defunct or damaged satellites whose cooperative functionality is compromised.

Human spaceflight has often provided the means for conducting unprepared servicing due to the ability of astronauts to adapt and carry out a variety of repair and maintenance tasks. Unprepared servicing operations were conducted during each of the HST servicing missions, which required extensive planning and training prior to the mission and, at times, used available interfaces for installation of new components. The Shuttle crew conducted similar servicing missions for high-value satellites such as Intelsat-603 and Leasat-3. Unprepared servicing has also become common on the ISS due to unexpected system failures, such as the 2019 AMS cooling failure and the 2025 NICER payload “light leak.”

While the future vision of an ISAM ecosystem relies on robotic servicing and co-design between the servicing spacecraft and the client spacecraft to take full advantage of ISAM capabilities, near-term servicing activities must adapt to interact with legacy, unprepared spacecraft. Between 2011 to 2015, the RRM-1 and RRM-2 payloads on the ISS used Dextre and custom robotic tools to demonstrate the capability to interface with legacy spacecraft components not designed for in-space servicing. OSAM-1 intended to demonstrate these capabilities by inspecting, refueling, and relocating the unprepared Landsat 7 spacecraft. The unprepared nature of the Landsat 7 client spacecraft increased complexity of the mission due to operations such as RPO without fiducials on the client spacecraft, grapple without existing grapple features on the client spacecraft, and access to the closed-out fluid fill valves on the client spacecraft.

Similarly, MRV will begin offering services to unprepared clients beginning in 2026. MRV, developed through DARPA’s RSGS public-private partnership with Northrop Grumman’s SpaceLogistics, will inspect and service satellites in GEO using its dual robotic servicing arms. MRV will also install MEPs, which are attached to the apogee engine of the client spacecraft, to provide clients with depleted propellant or inoperable propulsion systems with up to six years of life extension through electric propulsion. A timeline of unprepared servicing activities, the servicing method, and the orbital regime of the servicing is provided in Figure 8.

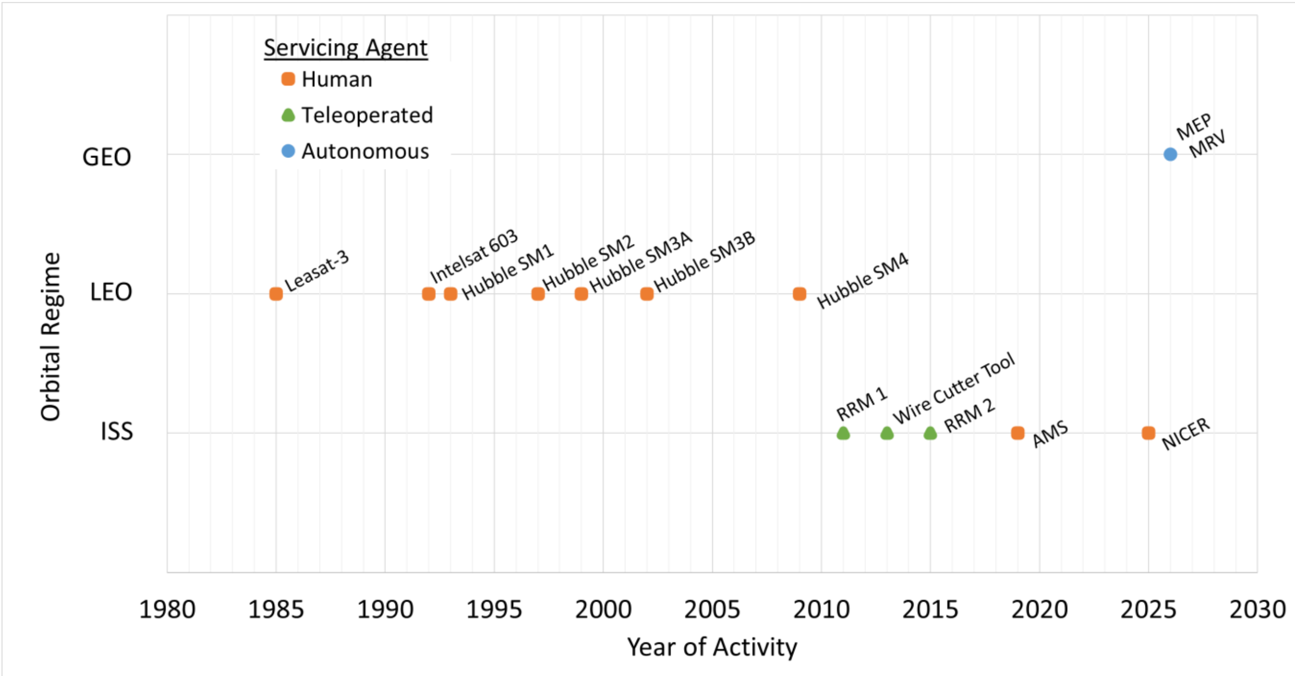

Figure 8: Unprepared repair, maintenance, upgrade, and installation has been historically implemented through use of human operators. More recent developments in this capability area have shifted towards teleoperated and autonomous servicing, which reduces the need for crew in space and the corresponding risks and complexities associated with human spaceflight.

3.6 Refueling and Fluid Transfer

Refueling and Fluid Transfer is the capability to move a fluid between spacecraft. This can be done to extend the life of a system, augment its capability beyond what a single launch can deliver, and/or enable reusable transportation systems. The most mature fluid transfer capability is that of storable fluids which do not require active cooling to remain liquid. Examples of storable fluids include water, hydrazine, MMH, and NTO MON-3. Cryogenic fluids, such as liquid oxygen, hydrogen, or methane, provide performance benefits as a propellant and are often used in large human-scale exploration system design concepts. Technologies used for storable fluids are not necessarily extensible to cryogenic fluids but can be with minor hardware modifications and additional qualification testing. The least mature in-space fluid transfer is that of high pressure pneumatic and supercritical fluids such as gaseous helium, gaseous nitrogen, gaseous oxygen, carbon dioxide, xenon, and krypton.

Several fluid storage and transfer demonstrations with storable fluids occurred on Space Shuttle missions (e.g., ORS, SFMD, FARE) in the 1980s and 1990s. Among other ISAM achievements, the Orbital Express flight demonstration transferred hydrazine between spacecraft. The most prolific refueling capability comes from the Russian Progress vehicle which first refueled Salyut 6 in 1978 and has been used to refuel the ISS with a hydrazine derivative, NTO MON-25, and water since 2000. In 2012, RRM-1 on the ISS demonstrated the capability to interface to legacy spacecraft components and perform a fluid (ethanol) fill into a mock spacecraft fuel tank.

Historically, little has been demonstrated for in-space cryogenic fluid management and transfer. However, because future missions will rely on cryogenic propellants, multiple flight demonstrations are currently in development. The SHOOT flight demonstration on STS-57 transferred a cryogenic fluid (superfluid helium) between tanks using some special properties of that fluid. Therefore, the techniques used are not necessarily applicable to other cryogenic fluids such as liquid oxygen, liquid hydrogen, or liquid methane. In 2019, RRM-3 demonstrated cryogenic zero boil-off fluid storage (using liquid methane) and robotic manipulation of the cryogenic tools, fittings, and hoses to enable the transfer, but a system failure inhibited the fluid transfer demonstration. In addition to the contributions for cryogenic fluid management, RRM-3 and its predecessors demonstrated tool change technologies critical to a wide variety of ISAM operations. In 2020, NASA awarded four Tipping Point awards to demonstrate cryogenic fluid management, storage, and transfer of liquid oxygen and liquid hydrogen in space to support large missions of the future (e.g., human lunar missions). In 2024, as part of one of those Tipping Point awards, SpaceX demonstrated the transfer of approximately 10 t of liquid oxygen on board the third demonstration flight of Starship. Eta Space, another Tipping point awardee, plans to demonstrate cryogenic fluid management through its Liquid Oxygen Satellite (LOXSAT-1) mission in 2026.

The future of this capability area appears to be heading toward commercial propellant resupply services. In 2021, Orbit Fab launched the first propellant depot with its Tanker-001 Tenzing, storing HTP propellant. Orbit Fab is currently developing its Kamino fuel depot, expecting to offer refueling services in 2026. Upcoming missions in GEO, such as Astroscale's APS-R and the United States Space Force's Tetra-5, will demonstrate operationally relevant refueling capabilities. A summary of the various completed and planned activities in refueling and fluid transfer are presented in Figure 9.

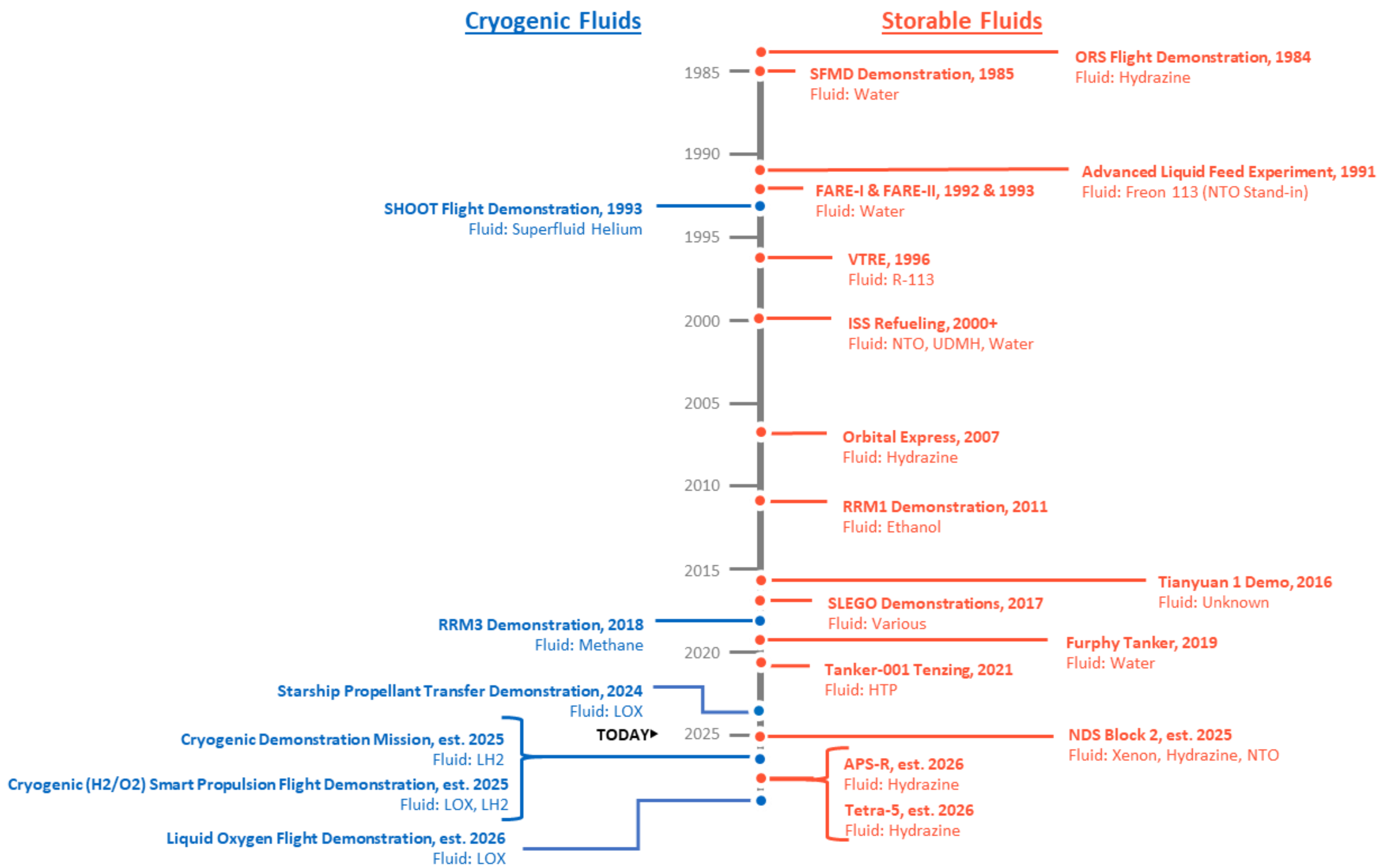

Figure 9: Storable fluid transfer has been demonstrated many times, including in operational missions like the ISS. The future is heading toward commercial refueling services (especially for storable fluids) and demonstrations are planned to test large-scale cryogenic fluid transfer in space.

3.7 Structural Manufacturing and Assembly

Structural Manufacturing and Assembly is the capability to produce structures and assemblies in space out of components delivered from Earth or produced in space. A major use case of this capability area is the production of structures which exceed the typical payload volume constraint of launch vehicles. Technologies which contribute to this capability area are wide ranging due to the complexity of positioning and joining structural elements in space. In contrast with deployable space structures, which can also produce in-space structures larger than launch volume constraints, structural manufacturing and assembly enables the ability to launch standard structural components, reduces the need for intricate deployable designs, and allows for in-space structural reconfigurability.

Although current developments within the realm of structural manufacturing and assembly involve the use of robotics, NASA initially explored the possibility of astronaut-assisted structural manufacturing and assembly through the EASE/ACCESS Space Shuttle flight experiments in 1985. The EASE/ACCESS flight experiments studied astronaut efficiency, fatigue, and construction techniques for assembling space structures. The construction of the ISS began in 1998 and included extensive use of structural assembly, which was completed using robotics and human construction. The first resident crew arrived at the ISS in November of 2000, two years after assembly began. More recently, DARPA selected Caltech and UIUC to participate in their NOM4D program. The Robotic Assembly Mission, which is being developed by Caltech, plans to launch to LEO in 2026 and construct truss structures to simulate an assembled antenna aperture. The Materials Process Mission, which is being developed by UIUC, will demonstrate an in-space composite-forming process using carbon fiber. NASA Marshall Space Flight Center has also partnered with the DARPA NOM4D program to support the University of Florida in their development of in-space laser forming of sheet metal.

Multiple welding experiments have also been conducted in space by astronauts. The first demonstration of welding in space was during the Vulkan experiment on the 1969 Soyuz-6 flight, which tested three methods of welding a variety of metals. EBW in space was further advanced through the Skylab materials processing facility experiments which began in 1973 and investigated EBW parameters within the vacuum of space. During the Soyuz T-12 flight to the Salyut-7 station in 1984, the first use of a handheld electron beam welder in an exposed space environment was demonstrated. NASA Marshall Space Flight Center is currently leading multiple parabolic flight experiments and thermal vacuum tests to demonstrate laser welding techniques in space-relevant environments.

Recent demonstrations of assembly in relevant space environments have been made possible through use of the ISS. The SIMPL mission in 2017 demonstrated the assembly of a satellite using the SLEGO architecture. In 2021, GITAI's S2 robotic arm demonstrated the assembly of a four-panel solar array within the Nanoracks Bishop Airlock pressurized volume. Two of the same robotic arms were used during GITAI's Project GHOST mission which was hosted externally on the Nanoracks Bishop Airlock in 2024. Project GHOST involved assembly tasks such as tool changing, installing and removing fasteners, and mating and demating of connectors.

Progress in the structural manufacturing and assembly capability area has also been made through recent assembly ground demonstrations, including NINJAR, SAMURAI, Assemblers, TLT, and PASS at NASA Langley Research Center and ARMADAS at NASA Ames Research Center. These demonstrations were focused on the robotic and autonomous positioning and joining of standard structural elements. These technologies are applicable to assembly in a variety of environments, including assembly on orbit and vertical and horizontal construction on the surface of the Moon or other planets. Figure 10 presents technologies that contribute to the capability of structural manufacturing and assembly.

COMPLETED Completed In-Space Demonstration SCHEDULED Scheduled In-Space Demonstration DEVELOPING In Development	Robotic Arm	Robotic Arm Joint	Structural Joint	Human Assembly	Robotic Assembly
ARMADAS *Incl. Androgynous Fasteners*	DEVELOPING		DEVELOPING		DEVELOPING
Assemblers	DEVELOPING				
DARPA NOM4D Programs *Incl. CalTech Robotic Assembly, UIUC Materials Process*					DEVELOPING
EASE/ACCESS				COMPLETE	
GITAI ISS Experiments *Incl. Project Ghost, ISS IVR Experiment*	COMPLETE				COMPLETE
ISS Assembly *Incl. CAS, MRTAS, RTAS, SSAS, ITS assembly*			COMPLETE	COMPLETE	COMPLETE
Laser Welding Experiments *Incl. 3-DOF Experiment, Parabolic Flight Tests*			DEVELOPING		
Lunar Communication Tower Construction Demonstration (GITAI)					DEVELOPING
NINJAR and SAMURAI					DEVELOPING
PASS					DEVELOPING
Replicator Mission			COMPLETE		
SAGE III					COMPLETE
Salyut-7 Welding Experiment					COMPLETE
Self-Aligning Nut Plate			DEVELOPING		
Skylab Materials Processing Facility Experiments			COMPLETE		
SLEGO Architecture				COMPLETE	COMPLETE
SO-WARM					DEVELOPING
Tall Lunar Tower					DEVELOPING
TCAM Soft Robotic Actuator					DEVELOPING
ThinkOrbital Flight-1			COMPLETE		
TVAC Laser Bending Experiment			DEVELOPING		
Vulkan Experiment			COMPLETE		

Figure 10: The technologies that contribute to the capability of structural manufacturing and assembly are wide ranging, due to the complexity of the process. Current advancement in this capability area focuses on robotic structural manufacturing and assembly.

3.8 Recycling, Reuse, and Repurposing

Recycling, Reuse, and Repurposing is the capability to use spacecraft parts and materials already in space for a new purpose. This includes breaking down materials like polymers and metals for use in in-space manufacturing, reforming existing components into shapes that perform a different function, repurposing full spacecraft components (e.g., tanks, structural members, electronics) in new ways, and choosing materials with recyclability in mind. Recycling, reuse, and repurposing results in reduced strain on the space logistics supply chain and reframes spacecraft components and materials as part of the "native" resources available for sustained presence in space.

Recycling polymer parts into filament is a current area of research which could enable purpose-built parts to be created on an as-needed basis and then recycled for use later in the mission, reducing the need for transportation of single-use parts or an excess of stock materials. The first polymer recycling facility, the ReFabricator, was installed on the ISS in 2019 and was intended to have the capability to recycle 3D-printed polymer parts into filament feedstock for further manufacturing. However, upon startup, an anomaly in the recycling system occurred, and it was unable to achieve all of its objectives.

The future in this nascent capability area is in expanding the materials that can be reused in space, tailoring the performance of those materials for use in the space environment, reducing the power required to process materials, exploring new manufacturing methods, and understanding the mission implications of this capability. On-orbit demonstrations for recycling processes have recently advanced this capability area. Recent developments include the 2022 Outpost Mars Demo - 1, which demonstrated the use of friction milling to cut metal coupons in space, and the Modular Space Foundry, which started demonstrating microgravity metal processing systems on parabolic flights in 2024.

3.9 Parts and Goods Manufacturing

Parts and Goods Manufacturing is the capability of producing items in space that have been traditionally delivered from Earth. Parts, which refers to spacecraft components, and goods, which refers to items astronauts would use in space, are traditionally delivered from Earth to space for spacecraft repair or astronaut use. This capability area also includes goods produced in space for use on Earth, potentially delivering items of higher quality than those produced on Earth. A major benefit of parts and goods manufacturing in space is the ability to quickly produce a component when needed, thus reducing the timeline for delivery and quantity of launched spare components. With the ability to produce, inspect, and verify parts and goods at a consistent quality, this capability may prove crucial in time sensitive situations or in situations where delivery of a component from Earth is unrealistic, such as a human mission to Mars. Technologies which have been demonstrated in space thus far rely on delivery of stock material from Earth, but technologies are in development which would allow for the use of in-situ resources.

The first demonstration of parts and goods manufacturing in space was in 2014 using an FDM 3D printer developed by Made In Space, now a Redwire company, and operated in an MSG on the ISS. Made In Space next developed the AMF, which was sent to the ISS in 2016 and remains a current installation. Both 3D printers created products using plastic materials. Redwire is currently developing the Multimaterial Fabrication Laboratory, which will demonstrate production of electronic components on the ISS.

Development is currently underway to explore the use of in-situ materials to produce parts and goods. Certain raw materials, such as regolith, basalt, sulfur, and waste products, can be used in polymer synthesis to produce items for sustainable presence. The use of regolith in 3D printing is applicable to future human missions to the Moon or Mars, where delivery of stock material from Earth is costly. Redwire Regolith Print, a 3D printer based on the AMF design, used a regolith simulant feedstock blend to provide a proof of concept for future ISRU-based feedstock 3D printing. Blue Origin's Blue Alchemist project has demonstrated the production of solar cells on Earth using only lunar simulant and a molten regolith electrolysis process, with the expectation that similar technologies could be adapted on the Moon for Earth-independent operations.

Technologies for in-space manufacturing of products intended to be returned and used on Earth are also currently being developed. Production of certain goods in space is advantageous due to environmental factors such as vacuum and microgravity. Recent in-space demonstrations of these technologies include production of pharmaceuticals (PIL-BOX, W-1), fiber optics (External Material Processing Platform, ORFOM, SpaceFiber), and semiconductors (MSTIC).

Figure 11 provides an overview of demonstrated and in-development technologies in this capability area and categorizes each technology according to manufacturing-specific technology areas.

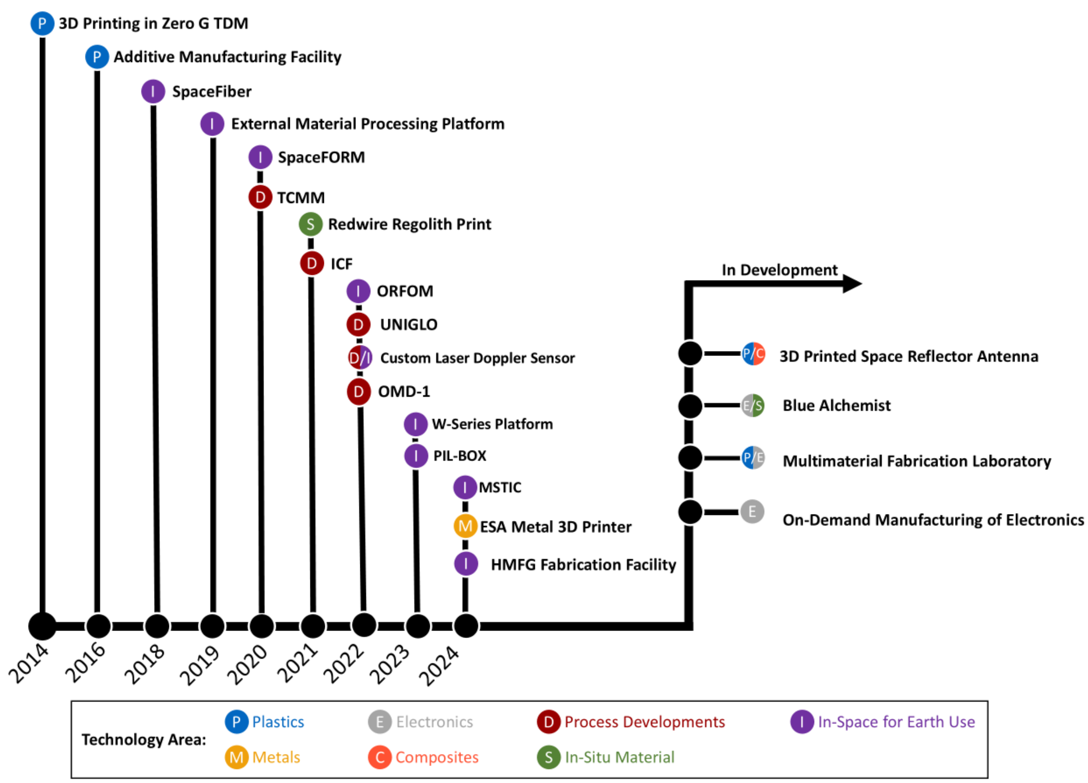

Figure 11: The first flight demonstrations of parts and goods manufacturing in space began in 2014 with the use of 3D printed plastics. Current production techniques in development aim to expand the production capabilities to metals, electronics, and in-space production for Earth use.

3.10 Surface Infrastructure

Surface Infrastructure involves the capability to construct structures and operate on non-terrestrial surfaces. Construction capabilities include the excavation, site preparation, assembly, ISRU-based construction, and outfitting of infrastructure elements such as landing pads, roads, unpressurized shelters, habitats, and power and communications systems, which are necessary to sustain and expand human and robotic presence on non-terrestrial surfaces. In addition to these construction capabilities, surface infrastructure also includes the logistics and mobility capabilities which will support surface operations, such as payload offloading, commodity storage and transfer, and astronaut transport.

Surface construction methods that provide infrastructure on the lunar and Mars surfaces are currently under development through NASA and industry projects. There are two primary areas of development for surface construction methods: (1) deployable and assembled structures and (2) in-situ ISRU-based construction. TLT is a NASA Langley Research Center project that demonstrated technologies necessary to assemble a 50 m tall truss-based tower on the lunar surface, including the development of autonomous robotic assembly and structural joining methods. ARMADAS is a NASA Ames Research Center project that demonstrated the autonomous assembly of various structures including a small shelter using unit cells called voxels. Wire routing and functional module outfitting capabilities were also demonstrated. Similarly, the GITAI Lunar Communication Tower Construction Demonstration utilized their R1 rover and IN1 robotic arms to demonstrate assembly of a 5 m tall modular communications tower. These assembly technologies will enable the construction of critical infrastructure and enhance operations for exploration of the lunar and Mars surfaces. Applications of interest include improved launch/landing surfaces, unpressurized shelters for crew and asset protection, PSI ejecta shields around landing areas, operational surfaces, and tall towers.

Due to the expense and time required to send construction materials to non-terrestrial bodies, surface infrastructure technologies often leverage the in-situ resources as construction material. The GaLORE project, for example, developed technologies to separate oxygen and metallics from lunar regolith, both of which could be useful for future fabrication processes. SO-WARM is a system being developed to enable welding and joining of metals and non-metals using concentrated solar-thermal power. Other projects, such as Blue Origin's Blue Alchemist, the NASA 3D Printed Habitat Challenge, and MMPACT, have explored direct use of lunar regolith to construct components of the lunar infrastructure. Blue Alchemist is developing technologies for the production of silicon solar cells and aluminum wire for power generation and distribution exclusively using lunar regolith simulant. The NASA 3D Printed Habitat Challenge was designed to advance construction technologies needed to create habitats and shelters.

MMPACT and Redwire's Mason project are focused on the construction of large-scale horizontal infrastructure such as landing pads and roads. MMPACT, led by NASA Marshall Space Flight Center, has pursued the development of laser-based regolith melting processes to construct landing pad and road surfaces, with possible extensibility to blast shields and walls. MMPACT also developed geopolymer, sulfur, and other unique construction materials and processes with numerous partners. The Mason project is developing a suite of tools for the construction of landing pads and roads, including site preparation implements for grading and compacting of regolith and microwave sintering capability to consolidate regolith into a durable surface. The REACT project, in partnership with AI SpaceFactory, demonstrated regolith-polymer composite construction technologies in thermal vacuum environments for the construction of an unpressurized protective shelter.

Construction of large-scale infrastructure will require equipment for site preparation and regolith manipulation. Site preparation includes clearing, grading, and compacting of regolith surfaces. Bulk regolith can be used for berms or overburden for PSI ejecta shielding, FSP radiation attenuation, meteoroid protection, and thermal stability. Some of these same site preparation technologies may also be used to supply ISRU-based manufacturing facilities with the required regolith feedstock materials. In addition to the site preparation implements developed by the Redwire Mason project, projects such as LANCE and IPEx, both at NASA Kennedy Space Center, focus on systems for site preparation and excavation of regolith, respectively. LANCE is a lightweight bulldozer blade designed to attach to a lunar rover, and IPEx is an extraction and mobility platform which uses rotating drums to collect and move regolith. Additionally, the STOMP project led out of NASA Kennedy Space Center is developing roller compactor implements for modular attachment to construction mobility platforms.

Operations support for surface infrastructure is currently focused on logistics-related elements, such as cranes and rovers. LSMS, a scalable-tendon-actuated crane system, will enable offloading of payloads from lunar landers. Customizable mobility platforms like ATHLETE and, more recently, FLEX fulfill a variety of logistics and mobility needs. In 2023, Astrolab announced Mission-1, which is planning for the first lunar demonstration mission of FLEX in 2026 via a SpaceX Starship HLS.

Figure 12 provides an overview of the surface infrastructure technologies categorized into four technology areas of excavation and site preparation, regolith processing, logistics, and construction.

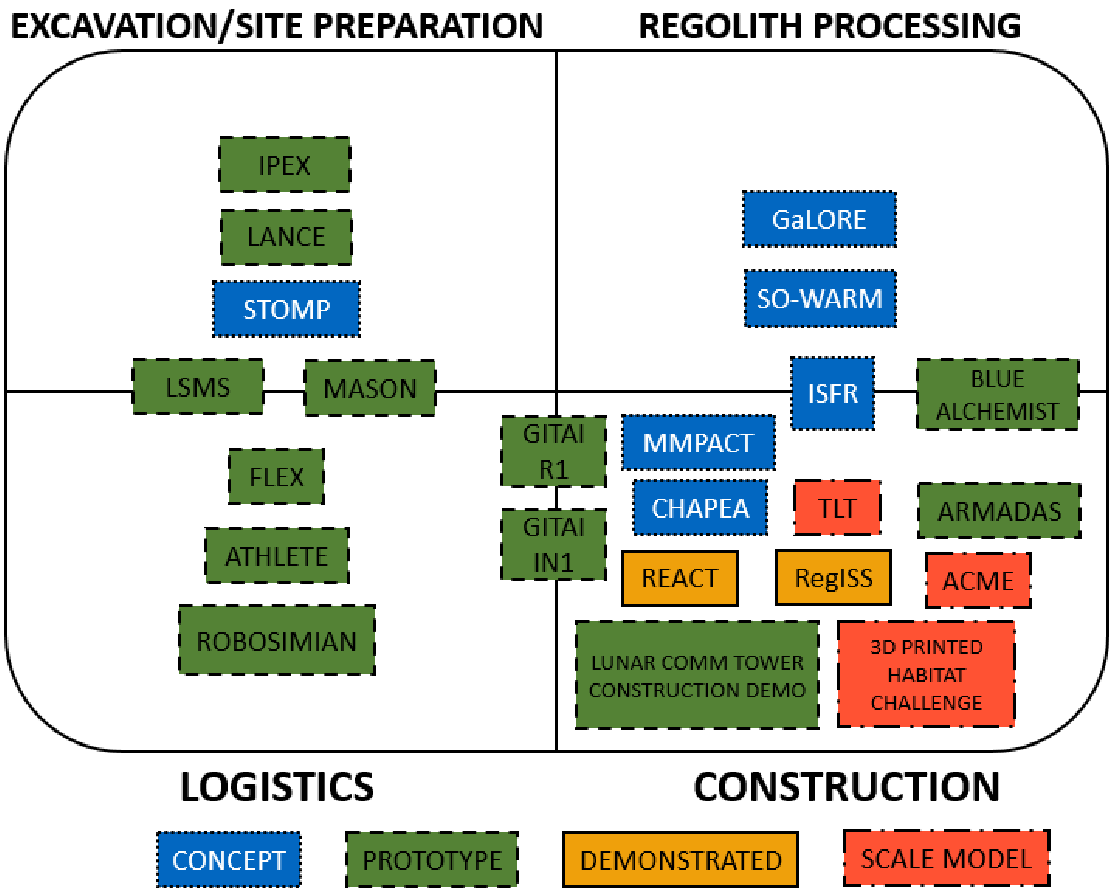

Figure 12: Surface infrastructure technologies, sorted into four main categories: Excavation and Site Preparation, Regolith Processing, Logistics, and Construction.

3.11 Inspection and Metrology

Inspection and Metrology involves the observation of in-space systems to survey and analyze their location, configuration, size and shape, state of repair, and other features of interest. The scope of inspection and metrology includes activities such as space situational awareness, free-flyer inspection, non-destructive evaluation, and close (robotic) inspection. These observations can also include inspection of assembly and manufacturing processes, such as shapes of assembled antennas or accuracy of 3D printed parts. Spacecraft can suffer unexpected damage during their lifetimes from subsystem failures or impacts from other vehicles, micrometeoroids, or space debris. Observation can help to track and predict the position of orbital objects (space situational awareness) or assess the threat of collisions and possibly avoid them. In the event of damage or defect, inspection can evaluate the state of an asset and provide information to determine whether the mission is a loss or if the problem can be repaired or accommodated. Inspection vehicles are often designed to navigate autonomously and send the collected data to Earth for off-board analysis. Inspection may be carried out via high-definition cameras processing standard visual images, although other sensors, such as ultrasound or multispectral sensors, are also implemented depending on the mission. The sensors are deployed from a variety of platforms, such as anchored to a structure or robotic arm or free flying on a dedicated spacecraft.

Anchored inspection payloads have been prevalent tenants of the ISS, which has historically provided a platform for technology demonstration and often employs inspection techniques for safe operation. Inspection payloads hosted on the ISS include NASA's VIPIR, RELL, and Sonatest Veo PAUT. NASA's VIPIR robotic multi-capability inspection tools were used on the ISS-based RRM payloads to provide detailed close-up component inspections using a deployable, snake-like flexible hose with articulation capability. Real-time imagery was downloaded to Earth-based robotic operators. RELL is a robotic tool used along with the SSRMS to inspect various areas of the ISS for signs of pressure increases that are indicative of ammonia leakage. This versatile tool has an integral mass spectrometer used to differentiate molecules within a pressure source and an ion gauge used as a general pressure gauge. For external inspection, RELL is stowed in the RiTS, a storage unit for tools which provides protection from thermal extremes and micrometeoroid strikes. RELL can be used to support additional in-space servicing needs as well as validating the integrity of existing fluid systems during ISS refueling operations. The Sonatest Veo PAUT, which was installed on the ISS in 2013, uses ultrasonic inspection techniques to assess the structure of the ISS following micrometeoroid strikes and provides information important for determining the best methods of repair.

Free-flying inspection payloads have been under development since the deployment of the XSS satellites launched in 2003 and 2005. The AFRL XSS satellites were designed without a permanent target, instead performing proximity inspections on derelict or inactive space objects near each satellite's orbit. Free-flying inspection satellites have since been demonstrated on orbit through the ANGELS and AeroCube missions. ANGELS, also developed by AFRL, evaluated situational awareness techniques around a Delta-IV upper stage while Aerospace Corporation's AeroCube-10B satellite, one of a pair of 1.5U CubeSats deployed in concert, was designed to orbit around its dedicated partner AeroCube-10A and record images with an onboard camera during operation. In February 2024, the ADRAS-J successfully approached and inspected an H-IIA rocket body which had been in orbit since 2009. The mission concluded in November of 2024, with the inspection spacecraft maneuvering within 15 feet of the client object. In the future follow-on mission, titled ADRAS-J2, Astroscale is planning to relocate the H-IIA rocket body to a safe orbit to avoid collisions with other objects. Meanwhile, the United States Space Force led Tetra-5 mission is set to launch in 2026. In 2024, Orion Space Solutions completed a CDR for the Tetra-5 program, which will demonstrate multi-agent autonomous RPO, inspection, docking, and on-orbit servicing, leveraging technologies developed by Orbit Fab, Northrop Grumman, and Astroscale. Figure 13 provides an overview of inspection entries and classifies the inspection platforms according to their mission types.

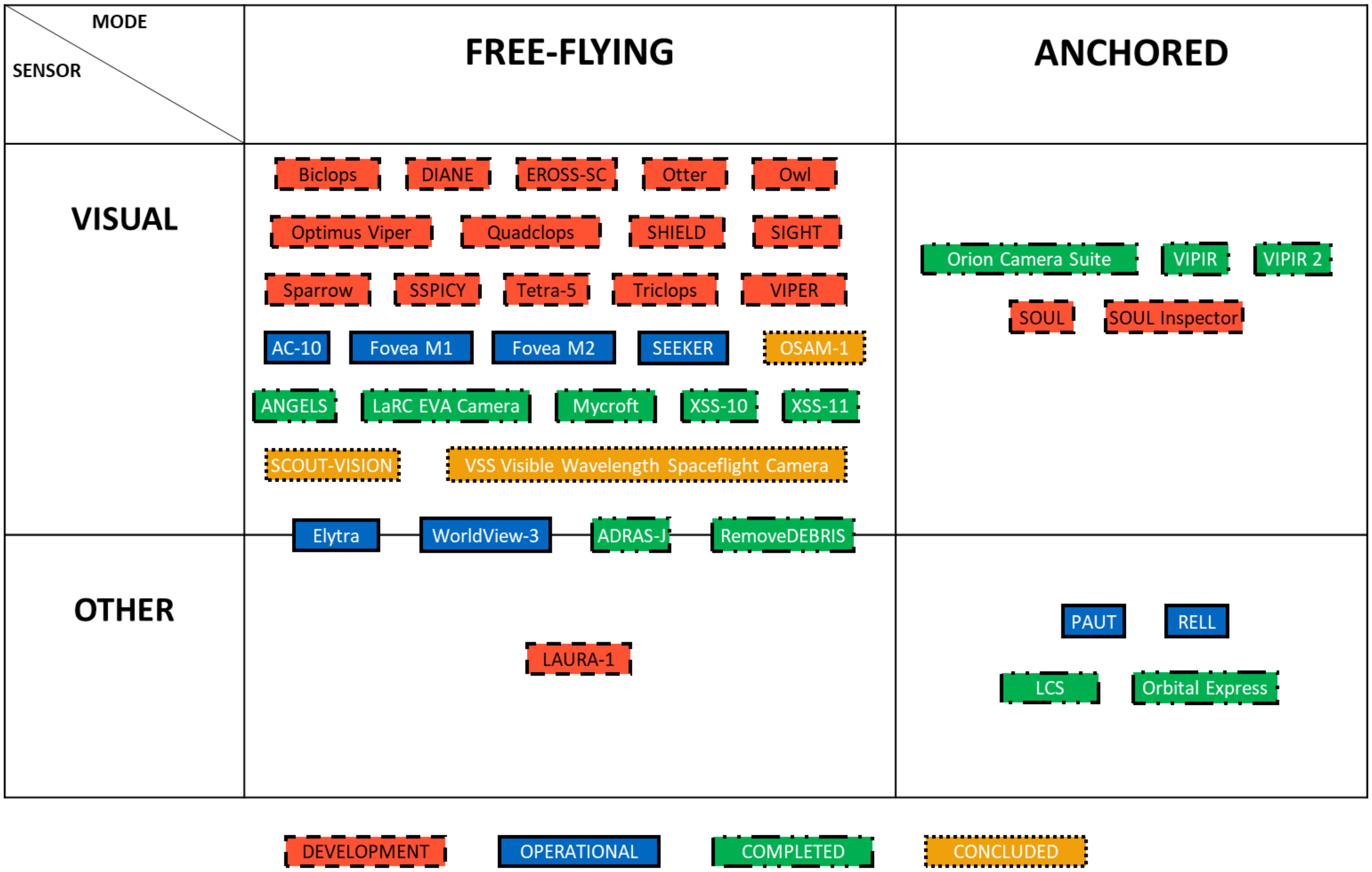

Figure 13: Inspection and metrology technologies, sorted into four main categories. Free-flying visual platforms command by far the highest in-demand application of this technology area.

4 ISAM CROSS-CUTTING CAPABILITY AREAS

This section outlines a series of cross-cutting capability areas identified as the hardware, software, services, and regulations which serve to support the 11 functional capability areas defined in the previous sections. These cross-cutting capability areas do not perform an ISAM function by themselves but instead support the types of in-space operations outlined in the functional capability areas. The scopes of the three cross-cutting capability areas discussed in this report are defined below.

- **Software and Algorithms:** Involves a range of software, programs, and algorithms that are specifically designed to support ISAM systems.
- **Management, Logistics, and Operations:** Involves the methods, infrastructure, and consumables required to facilitate sustained crewed and uncrewed space operations.
- **Laws, Policies, and Standards:** Involves the high-level government policies to include international treaties, widely used international standards, and country-specific regulations relevant to ISAM systems.

Like the 11 functional capability areas, each cross-cutting capability area section contains an overview and current state while also forecasting future developments based on the current direction of the ISAM and greater space community. Additional details on the entries for each cross-cutting capability area can be found in Appendix 9.

4.1 SOFTWARE AND ALGORITHMS

In the early days of spaceflight, computer data was processed on the ground and sent to the spacecraft for execution. This worked well initially; however, as spaceflight progressed, issues with communication black out zones, jamming threats, and time-delays drove the need to implement onboard computers on spacecraft. The first onboard computer was the Gemini Guidance Computer, which was introduced in 1965. It assisted astronauts with rendezvous operations without the need for ground-based tracking systems, and it regulated heating and attitude control during re-entry. While relatively simple compared to today's standards, both tasks marked large steps forward for human spaceflight and set the new standard for spacecraft design.

Following the Gemini program, NASA programs continued to advance the state-of-the-art for in-space software and algorithms. With an increased need for onboard computing during the Apollo Program, NASA selected the MIT Instrumentation Lab to design the Apollo Guidance System software. This software was responsible for guidance, navigation, control, and rendezvous operations in scenarios where the time-delay made ground processing infeasible. During the development of the Space Shuttle, NASA selected an off-the-shelf computer system to provide fly-by-wire avionics and main engine optimization. An off-the-shelf option reduced the development time and maintenance burden after the system was implemented. Software engineering then took another leap forward with the ISS by providing the capability to monitor environmental control and life support systems and facilitate communication with other spacecraft and ground-based systems, among many other complex tasks.

Recent ISAM-related software developments are generally focused in five major areas, including:

1. RPO
2. Multi-Agent Frameworks
3. Modeling and Simulation
4. Robotics
5. Autonomy

A distribution of the collected software releases broken out into the capability area(s) they support is displayed in Figure 14, and more information on each software entry is captured in Appendix 9.

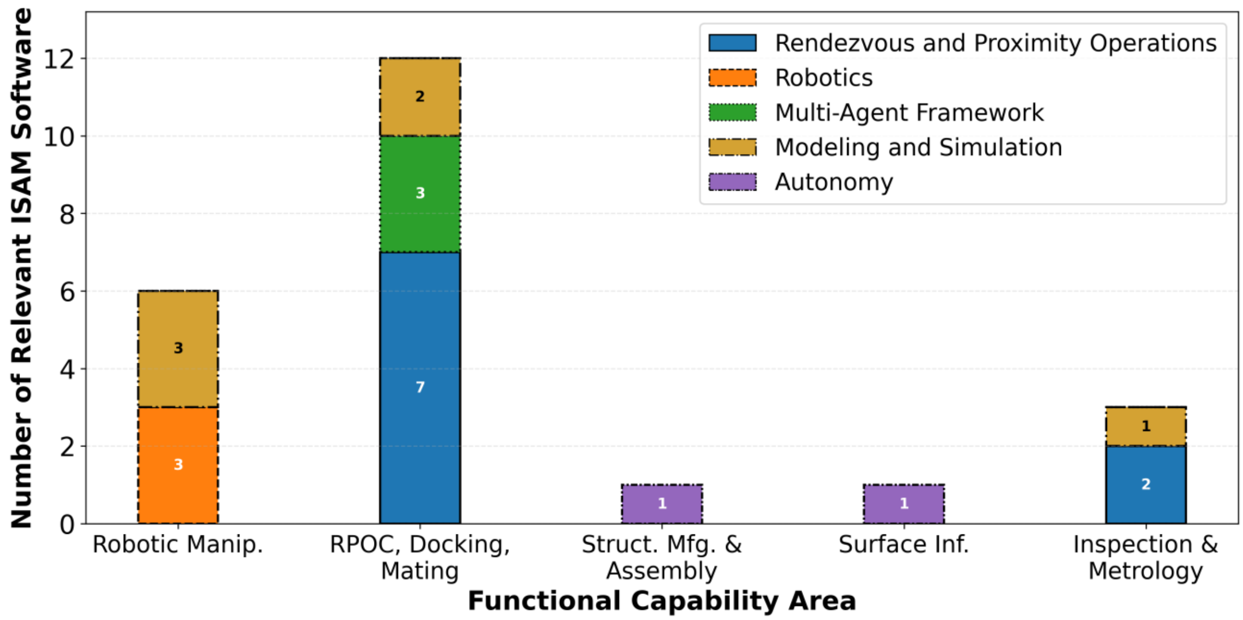

Figure 14: ISAM software is heavily focused on advancing robotic manipulation and RPO, capture, docking, and mating capability areas.

RPO, Capture, Docking, and Mating is the area with the highest ISAM flight software focus as many ISAM missions require this capability in some capacity. The ULTOR Passive Pose and Positioning Engine was utilized by the Space Shuttle program to service the HST. Additionally, the ANGELS software was demonstrated by the United States Air Force in 2014, and it enables increased autonomous navigation for smaller satellites. Some examples for today's ISAM RPO programs include Northrop Grumman's MEV and Starfish Space's Cephalopod software platform. The MEV-1 software was demonstrated on orbit in 2020, and Cephalopod first flew on board Orbit Fab's Tanker-001 Tenzing LEO refueling demo mission in 2021.

Multi-agent frameworks are another area of software and algorithms undergoing development, focusing on integrating multiple intelligent agents to solve problems that a common monolithic system could not. For example, in an on-orbit logistics network, client satellites could request service from a servicing satellite which could then interact with a logistics depot to acquire the commodities needed. This could all happen autonomously, requiring each system to make independent decisions based on the information provided from other systems, therefore, creating a multi-agent network. This has applications to surface operations as there will be a demand to operate autonomously on the lunar surface once a more permanent human presence on the Moon has been established.

Due to the high cost of demonstration in space, there is a strong interest in modeling and simulating systems to test and validate performance on the ground. Open Robotics' Gazebo, ROS, and Google Deepmind's MuJoCo are examples of open-source software environments that are available to ISAM developers to create modeling and simulation environments for their systems. NASA has also developed multi-use modeling and simulation platforms, including LaSRS++, AEON, and BEAM, that have been or could be used for ISAM modeling.

4.2 Management, Logistics, and Operations

Whether it is sending consumables to a crewed space station, refueling a satellite at the end of its service life, or assembling modular components into a new spacecraft, ISAM space activities require management, logistics, and operations to achieve mission success. Logistics enable ISAM operations in space, and ISAM provides key capabilities to the logistics network. This section captures the current practices associated with space management, logistics, and operations, and how those practices support ISAM systems and activities. It also highlights how ISAM is currently utilized in the field of space logistics and how ISAM could provide critical infrastructure for future space operations.

In 1998, the first component of the ISS was launched into orbit. The assembly and operation of the ISS requires a robust logistics network to ensure its success, and that logistics network was initially made possible by NASA's Space Shuttle Program and Russia's Soyuz and Progress spacecraft. In 2000, a Soyuz spacecraft delivered the first crew to the ISS. Two weeks later, the first uncrewed logistics mission to the ISS was completed by a Progress spacecraft. The first logistics mission by the Space Shuttle to the ISS was STS-102 in 2001, which provided crew supplies and facilitated a crew rotation.

This rotation of mixed Space Shuttle, Soyuz, and Progress logistics missions continued until 2011 when the Space Shuttle completed its final mission. Today, Progress still resupplies the ISS, and the NASA CRS program handles the United States' uncrewed resupply responsibilities. The JAXA HTV and the ESA ATV have also provided resupply services to the ISS with nine and five missions, respectively. The Soyuz spacecraft continues to facilitate crew rotations along with SpaceX's Crew Dragon and Boeing's Starliner through NASA's Commercial Crew Program. Figure 15 provides a timeline of logsitics missions to the ISS, categorized by country.

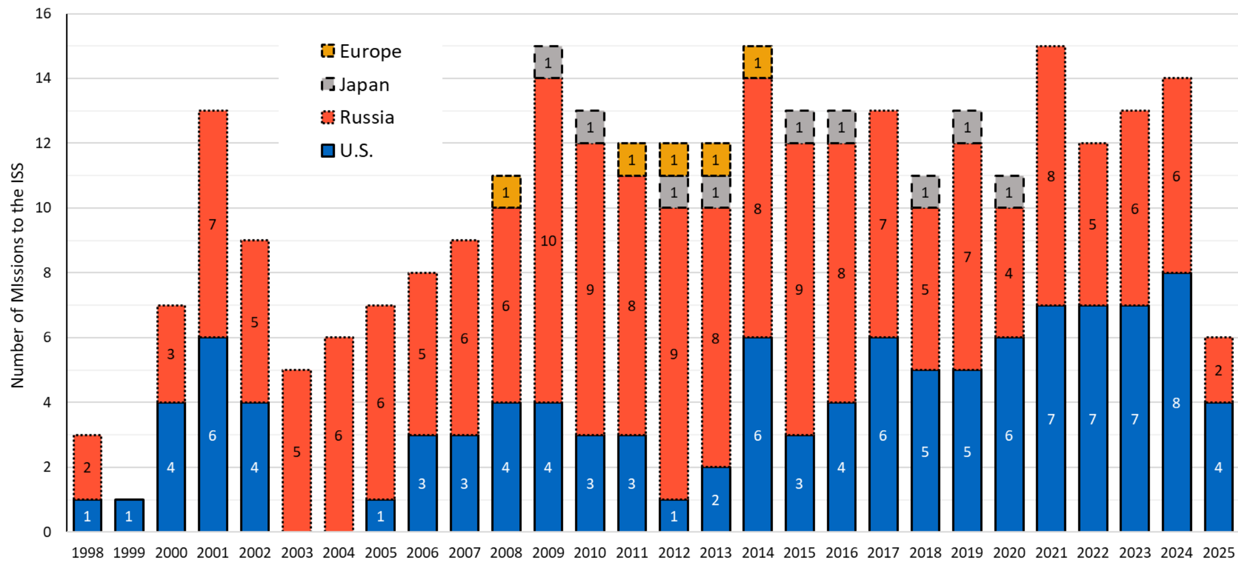

Figure 15: Distribution of logistics missions to the ISS from 2000 to 2023. Russia's Progress and the U.S.'s Space Shuttle program handled the bulk of logistics missions until NASA's CRS program began in 2012. Data Source: "Uncrewed spaceflights to the International Space Station," Wikipedia, "List of human spaceflights to the International Space Station," Wikipedia.

Currently, there are nine active spacecraft providing logistics to support human exploration provided by the following countries:

- United States (SpaceX's Dragon, Boeing's Starliner, Northrop Grumman's Cygnus)
- China (Shenzhou, Tianzhou)
- Russia (Soyuz, Progress)
- Japan (HTV)
- Europe (ATV)

Additionally, there are three logistics spacecraft in development to support future exploration (Orion, Sierra Space's Dream Chaser, and SpaceX's Dragon XL).

Crewed missions to the ISS are typically divided into 6-month stays that include spacewalks, supply missions, and research. These missions are planned years in advance so that crew members can practice their mission's operations and supply manifests can be built. Flight planners must account for the needed commodities, commodity use rate, and cargo vehicle availability when developing the flight manifests. The manifests must also account for contingency situations, such as unsuccessful cargo delivery missions or extensive flight delays. Once manifests are complete and items are approved for flight, the items are then distributed to the re-suppliers and their respective launch sites (e.g., Mid-Atlantic Regional Spaceport, Kennedy Space Center, Cape Canaveral Space Force Station, Baikonur Cosmodrome, Tanegashima Space Center) where they utilize the previously discussed logistics spacecraft. If supplies need to be removed from the ISS, those items can be placed on a Progress, Cygnus, HTV, or ATV spacecraft to burn up in the atmosphere or placed on a Cargo Dragon or crewed mission for return to Earth in the pressurized cabin. A simplified depiction of a logistics network is shown in Figure 16 which demonstrates how materials flow from suppliers to the launch provider to the user in LEO.

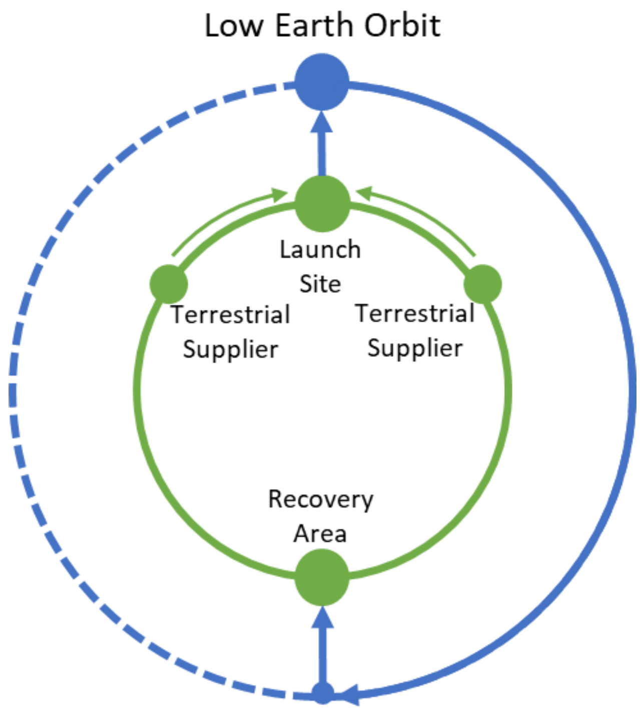

Figure 16: A generalized depiction of how cargo is moved from ground suppliers to LEO and back to Earth, if necessary.

Under the current logistics network for crewed space stations, ISAM capabilities leverage the logistics delivered to achieve ISAM functions, and ISAM capabilities are used to enable the logistics network. ISAM functional capability areas related to ISS logistics are as follows:

- Robotic Manipulation: Canadarm2 is utilized to berth resupply missions with the ISS.
- RPO Capture, Mating, and Docking: Resupply spacecraft must rendezvous and berth/dock with the ISS to transfer their payloads.
- Relocation: Resupply spacecraft provide thrust for ISS station-keeping.
- Prepared Repair, Maintenance, Upgrade, and Installation: There have been several missions to upgrade existing modules or install new instruments on the ISS using prepared interfaces.
- Unprepared Repair, Maintenance, Upgrade, and Installation: Examples include the repair of damaged solar arrays or replacing a failed part in the ECLSS system.
- Refueling and Fluid Transfer: Russia’s Progress transfers propellant to the ISS for the station’s independent station-keeping.
- Structural Manufacturing and Assembly: Much of the ISS was assembled through astronaut EVAs, particularly the integrated truss structure, relying on the logistics flights to deliver parts and tools.

- Inspection and Metrology: Inspection through instruments such as RELL and Sonatest Veo PAUT provide data critical to safety of the astronauts onboard the ISS.

More details and space logistics references can be found in Appendix 9.

In 2017, NASA announced the Artemis Program, which includes missions to return to the Moon and set the foundation for travel to Mars. The architecture is still being defined, but the future logistics network could become significantly more complex than the model presented in Figure 16. With the introduction of Gateway and lunar surface operations, the space logistics network of the future could have multiple launch sites, lunar surface locations, and orbital aggregation locations. Figure 17 presents a notional diagram of an Earth-to-Moon logistics network.

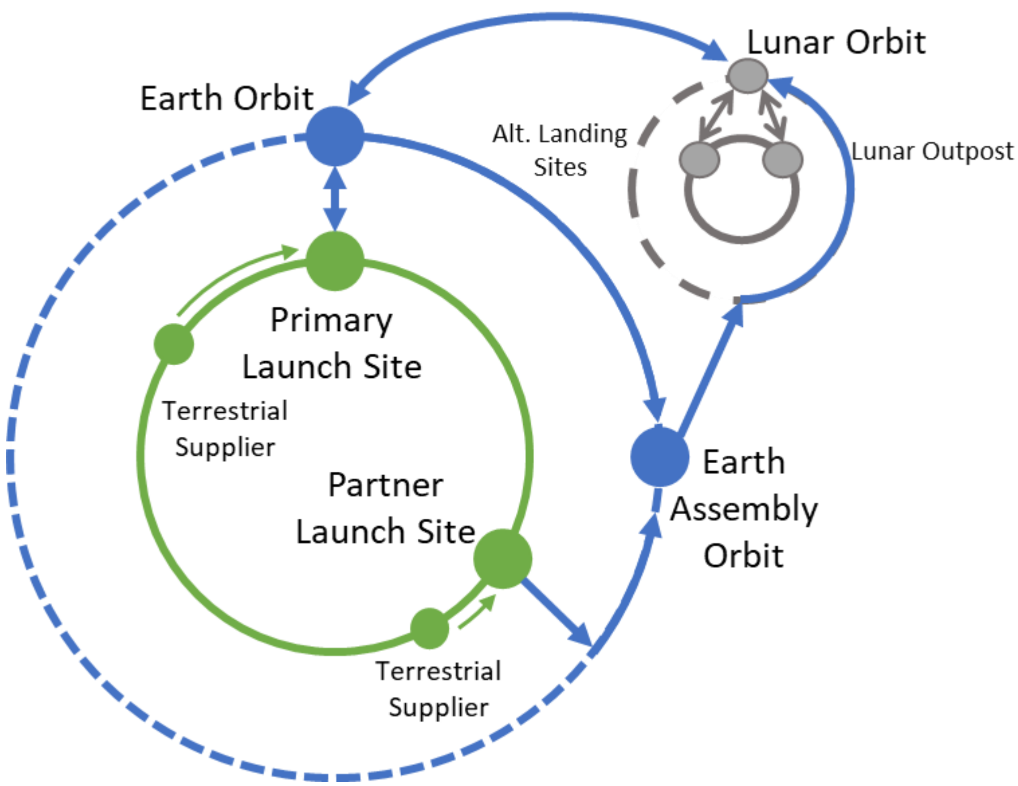

Figure 17: A notional diagram of an Earth-to-Moon logistics network that could potentially contain multiple launch sites, orbital aggregation locations around the Earth and Moon, and diverse activities on the lunar surface.

Within this notional network, ISAM capabilities leverage the products available in the network and play a crucial role in enabling space logistics. For example, assembling Gateway in a similar method to the ISS would require RPO and docking maneuvers. Other ISAM capabilities to support Gateway operations could include robotic manipulation, prepared and unprepared servicing, relocation, station-keeping, and refueling. Additionally, in a similar program to the CRS, SpaceX has been awarded the Gateway Logistics Services contract by NASA to provide cargo, science experiments, and other supplies to Gateway in lunar orbit. The requirements for the network are still being defined, and technical papers that document and analyze the logistics requirements for missions beyond LEO are listed in Appendix 9.

Advancements in space logistics also contribute to uncrewed systems, where instead of delivering consumables such as clothing and food on a recurring basis, resupply missions focus on activities such as refueling, repair, and upgrade. Uncrewed logistics can support ISAM activities such as relocation, mission extension, repair, and refueling by providing parts and consumables. As discussed in the Relocation capability area, servicing spacecraft, such as MEV, could provide life extension services, and there is increasing interest in end-of-life and debris removal missions. The prepared and unprepared servicing capability areas include repair of uncrewed systems such as the HST, and OSAM-1 and RSGS/MRV plan to demonstrate servicing with robotic systems rather than astronauts. Finally, several potential refueling services, from commercial entities such as Northrop Grumman and Orbit Fab, are under development, which may utilize a logistics network to distribute propellant to depots, clients, or reusable servicing vehicles.

4.3 Laws, Policies, and Standards

Every economic industry has some level of government oversight to ensure safety, protect consumers, and facilitate a fair market. Within the ISAM community, this oversight is executed through the policies, standards, and regulations that each government puts forth. As defined below, this section elaborates on these forms of government oversight and how they need to be considered during ISAM system development and operation. While this section attempts to capture the breadth of laws, policies, and standards as they pertain to ISAM activities, the authors recognize that the characterization is not exhaustive.

- Laws: The treaties, statutes, regulations, and procedures that ISAM operators must account for prior to placing their spacecraft into operation in space.
- Policies: International, national, and agency documents, procedures, and norms of behavior to facilitate and encourage ISAM activities.
- Standards: The published standards for spacecraft design that ISAM developers may utilize.

In addition to the three forms of oversight listed above, best practices are developed by the community over time, and they inform the laws, policies, and standards that are eventually formalized. A summary of the United States' laws, policies, and standards is presented in Figure 18. Each of the 11 functional capability areas is connected to their associated standards. The laws and policies listed govern activities in all the capability areas, as denoted by the brackets. These items are further explored in the following sections.

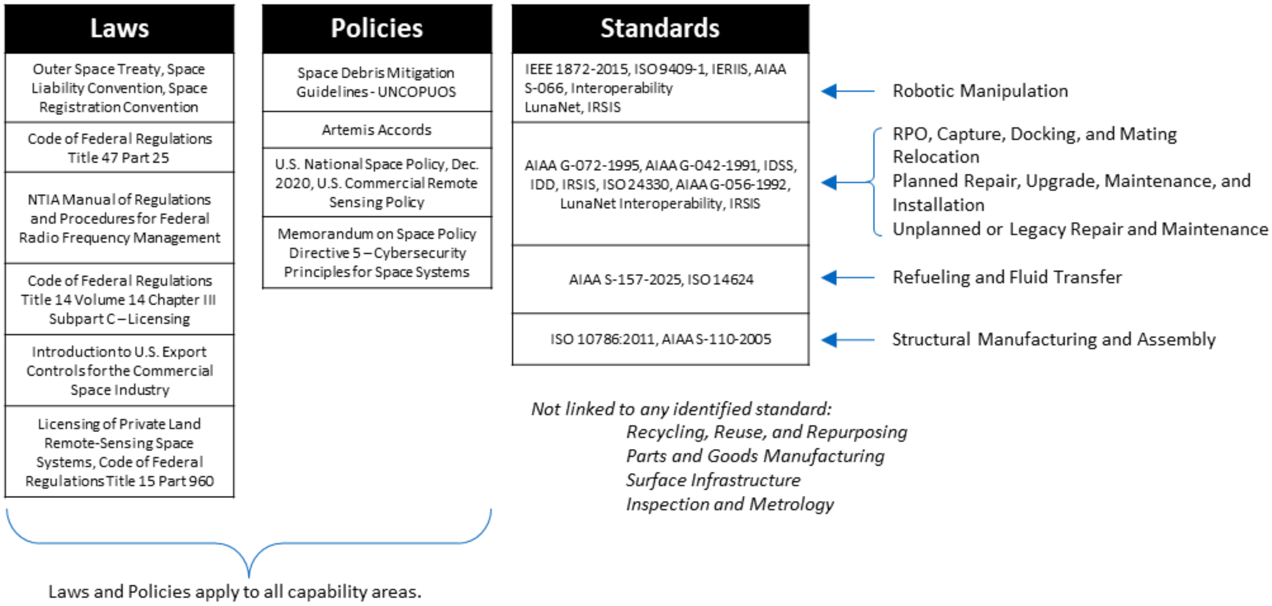

Figure 18: Snapshot of the laws, policies, and standards that are relevant for each capability area from a U.S. perspective. The bracket associated with laws and policies denote that they govern all 11 capability areas.

In 1967, the *Outer Space Treaty* entered into force, which established the basic legal framework on international space law for the peaceful exploration and use of space. While the *Outer Space Treaty* does not explicitly reference ISAM, Articles VI and XI are most applicable to ISAM operations. Article VI states that State Parties to the treaty shall bear international responsibility for national activities in space, whether such activities are carried on by governmental agencies or non-governmental entities. Article XI requires State Parties to the treaty conducting activities in outer space "to inform the Secretary-General of the United Nations as well as the public and the international scientific community…of the nature, conduct, locations, and results of such activities." The *Artemis Accords*, which opened for signature in 2020, provide a set of principles for cooperation in the civil exploration and use of the Moon, Mars, comets, and asteroids for peaceful purposes. Section 10 of the *Artemis Accords* provides guidance on space resource extraction and utilization, which may have implications on the surface infrastructure and parts and goods manufacturing capability areas. This section also emphasizes compliance with the *Outer Space Treaty*. Section 11 of the *Artemis Accords* discusses principles for deconfliction of space activities, which are relevant to ISAM activities such as acknowledging principles of due regard, harmful interference, and the establishment of safety zones for activities on the lunar surface and the sharing of information regarding such activities.

Among the many internationally recognized standards organizations, four main organizations have issued ISAM-related standards, including the American Institute of Aeronautics and Astronautics (AIAA), the International Organization for Standardization (ISO), the Institute of Electrical and Electronics Engineers (IEEE), and the National Aeronautics and Space Administration (NASA). AIAA has published standards in robotics, RPO, prepared and unprepared servicing, fluid transfer, and structural assembly. The Consortium for Execution of Rendezvous and Servicing Operations (CONFERS), an industry-led ISAM trade organization, is working with AIAA and ISO to develop industry-consensus standards focused on ISAM activities. CONFERS, through those standards organizations, has developed two standards that pertain to RPO and refueling and is in the process of developing more. Figure 19 illustrates the number of published standards by ISAM capability area. It is important to note that capability areas 7 through 11 lack well-documented standards, likely due to the lack of completed space demonstrations or planned missions. As ISAM concepts continue to be developed and implemented, these capability areas can expect more standards to be developed.

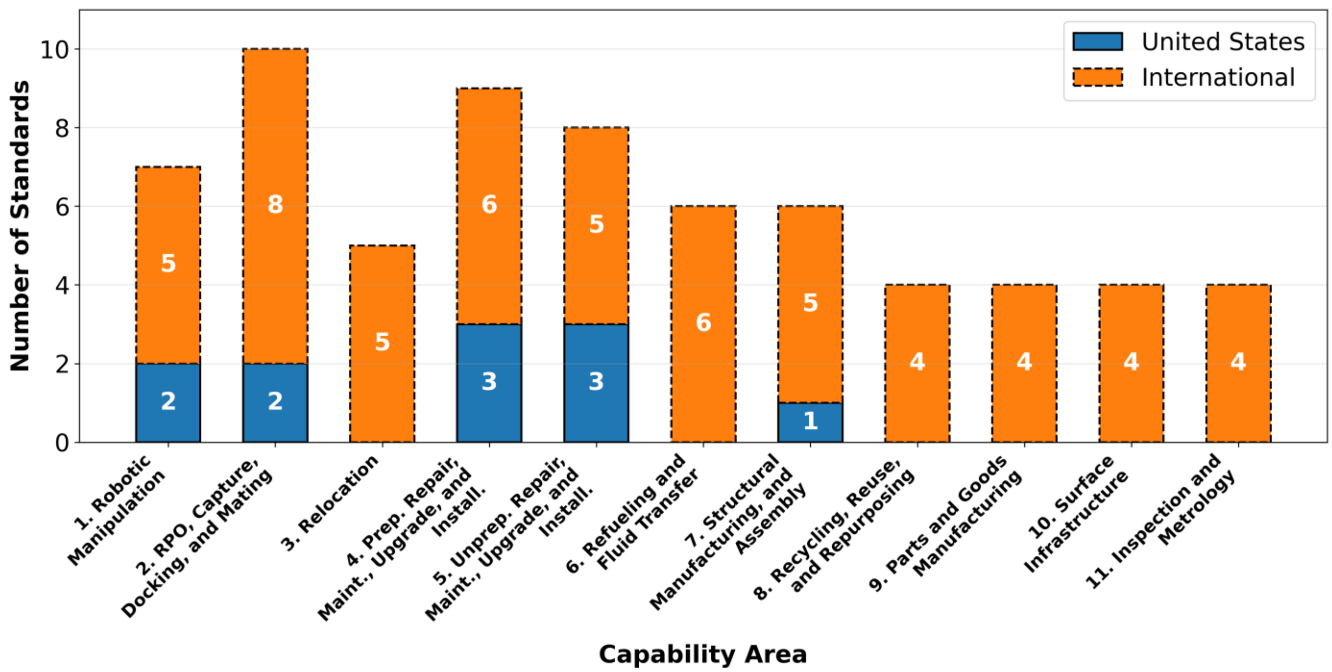

Figure 19: The capability areas with the most standards are RPO, Capture, Docking, and Mating; Prepared Repair, Upgrade, Maintenance, and Installation; and Unprepared Repair, Upgrade, Maintenance, and Installation.

ISAM-related regulations provide requirements for licensing, operation, and end-of-service procedures for non-federal spacecraft. In the United States, these regulations are put forth by four main bodies:

1. The Federal Communications Commission (FCC)
2. The National Telecommunications and Information Administration (NTIA)
3. The Federal Aviation Administration (FAA)
4. The Department of Commerce (DOC)

The FCC's *Code of Federal Regulations Title 47 Chapter I Subchapter B Part 25 – Satellite Communications* is the FCC's regulation that covers the licensing process for all space systems. The FCC 100 series sections relate to licensing requirements and the 200 series sections outline technical regulations. The FCC published a Notice of Proposed Rulemaking to address some ambiguities with licensing pertaining to ISAM systems, ISAM's role in orbital debris mitigation and remediation, radiofrequency spectrum to support ISAM, and digital equity and inclusion for ISAM. The NTIA's *Manual of Regulations and Procedures for Federal Radio Frequency Management* has two relevant ISAM sections, Section 5.6 on Space Services and Section 7.7 on the Use of Frequencies by Manned Spacecraft. Additionally, the FAA's *Code of Federal Regulations Title 14 Chapter III Subpart C – Licensing* discusses properly acquiring authorization to launch, operate a launch site, reenter, and operate a reentry site in the United States. Subpart C also includes payload review and determination requirements. However, Subpart C generally does not apply to activities that occur after launch and before reentry. The DOC's *Introduction to U.S. Export Controls for the Commercial Space Industry* provides basic information to help commercial space organizations, especially emerging entrepreneurial firms, considering business in the international space market. Also applicable to U.S. space operations, the ITU allocates global radio spectrum and spacecraft orbits and develops standards to ensure interconnectivity across the network. Appendix 9 has more information on the documents mentioned above and includes some regulations for other countries such as the EU, Japan, United Kingdom, and New Zealand.

5 ISAM Developers and Facilities

The previously discussed ISAM capability areas and corresponding entries are supported by a thriving and expanding community of developers across government, commercial, and academic sectors. The 145 cataloged ISAM developers range in size from government agencies to corporations of fewer than 10 employees and represent 21 countries around the world. The developers presented are those who made contributions towards activities recorded in the functional capability areas and the Software and Algorithms cross-cutting capability area. Developers are not recorded for the remaining cross-cutting capability areas (Management, Logistics, and Operations and Laws, Policies, and Standards) as these capability areas typically contain documents with authorship by individuals or countries, as opposed to organizations or companies. More information on each of these developers can be found in Section 10. Figure 20 presents the number of ISAM developments and organizations by distinct associations.

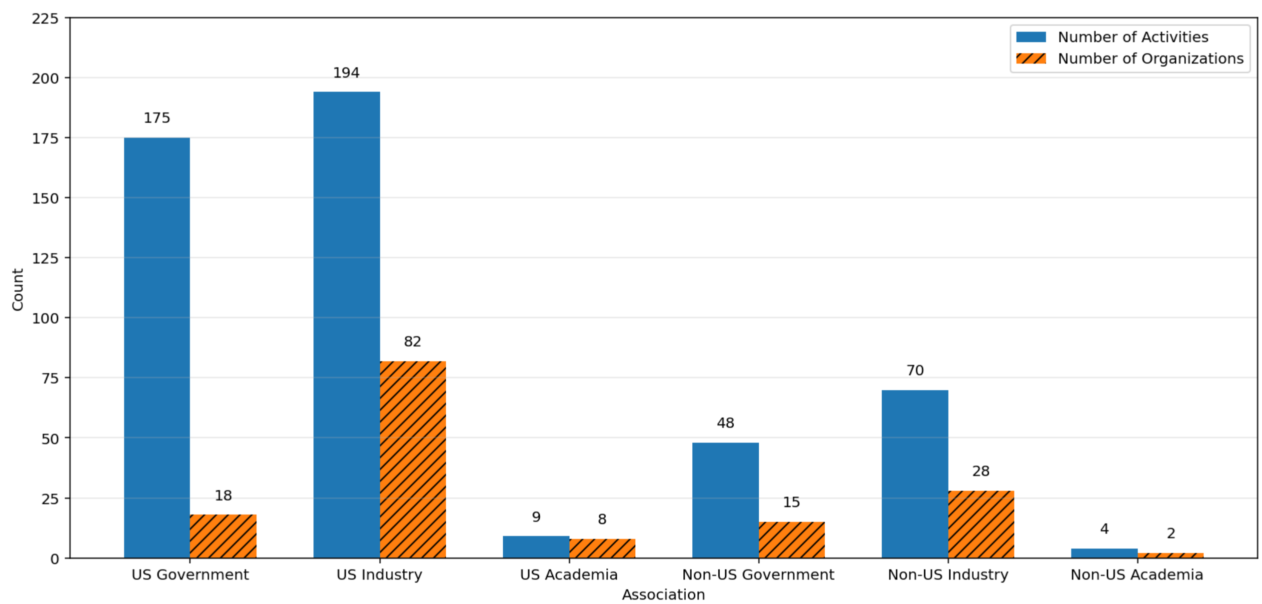

Figure 20: Number of activities and organizations by developer association. The number of activities represents the sum of all capability area activities completed by the developers within that association from the functional capability areas and the Software and Algorithms cross-cutting capability area.

Facilities provide an important resource in advancing ISAM capabilities, and Figure 21 presents a summary of these facilities. While not exhaustive, the facilities operated by the DoD, supporting FFRDCs, NASA (including the ISS), and academia are vital to advancing the capability areas discussed in this document and will continue to be a centerpiece for future ISAM development. A collection of ISAM facilities is further detailed in Section 11.

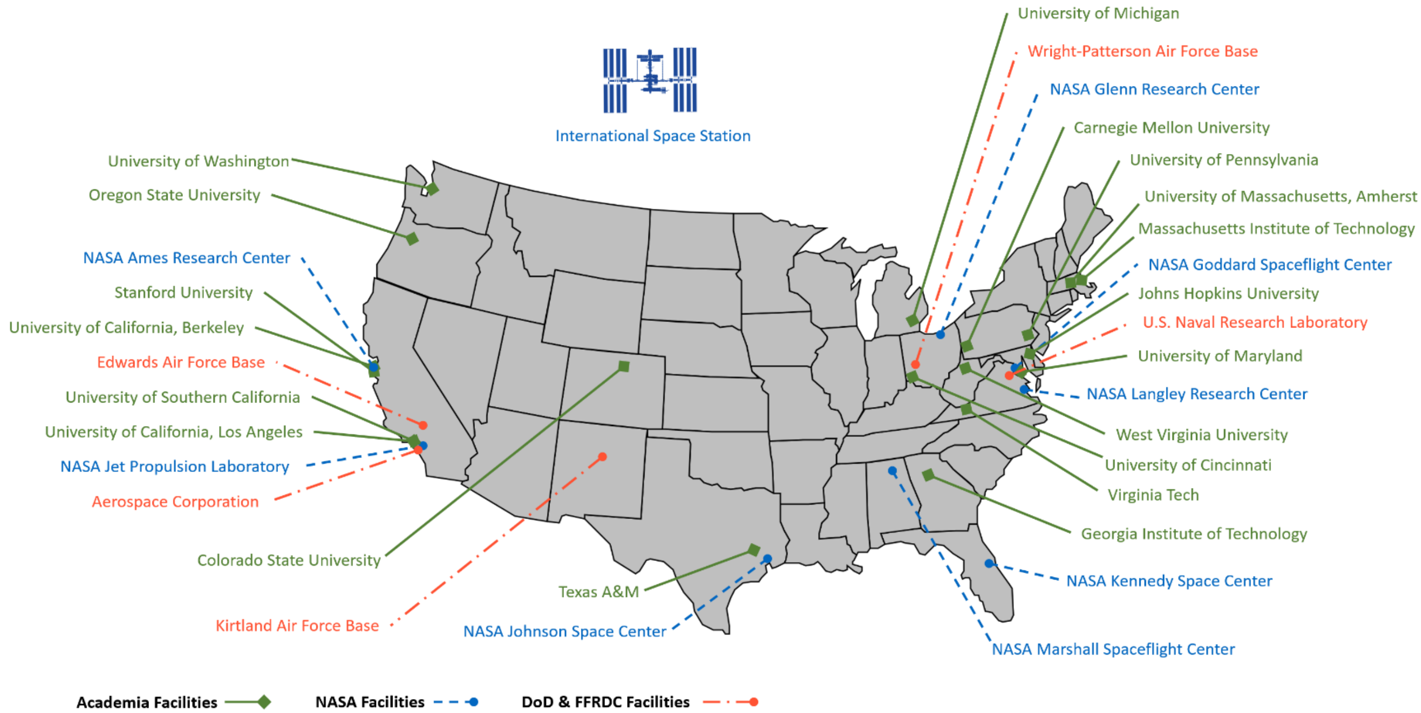

Figure 21: Facilities that have been advancing ISAM capabilities exist across the country and in space aboard the ISS. This figure presents a summary of the facilities captured in this document, with DoD and supporting FFRDC facilities in orange, NASA facilities in blue, and academic facilities in green. More information on each facility is in Section 11.

6 KEY ISAM MISSIONS

Several of the ISAM activities and technologies included in this document contribute to larger missions, programs, or projects. These higher-level activities, which are discussed in Section 2 and displayed in Figure 1, have led the space industry in ISAM technology development and have highlighted the utility of these technologies. Table 1 lists the entries that are mapped to each of these key ISAM missions. Due to their historical significance, technical advancement, and reach into several capability areas, these missions have been designated as "Key ISAM Missions." Descriptions of these missions are as follows:

- ETS-VII: ETS-VII (or Kiku7) was a JAXA (formerly NASDA) technology demonstration satellite which performed space robotic experiments and demonstrated its utility for uncrewed orbital operation and servicing tasks. The satellite completed operation in 1998.

- HST: Launched in 1990, the HST is an optical space telescope positioned in low Earth orbit. To maintain operations, the HST was serviced by shuttle crews on multiple occasions, performing both prepared and unprepared servicing activities. After initial launch, the HST was retrofitted with additional ORU Swap capabilities to ease future servicing missions.

- ISM: The NASA ISM Project incorporates a portfolio of technologies focused on in-space on-demand fabrication, repair, and recycling capabilities. The Project adapts terrestrial manufacturing technologies to in-space environments, often demonstrating these technologies on the ISS. ISM offer the ability to reduce costs through minimizing launch mass and reduce risk through less reliance on spares and overdesign for reliability.

- ISS: The ISS is a crewed space laboratory in Earth's Low Earth Orbit (LEO). During the ISS assembly process, which began in 1998, many in-space assembly, RPO, and docking technologies were required to piece together the modular structure. The ISS is host to many ISAM-related technology demonstrations.

- MEV: Developed by Northrop Grumman, MEV is the industry's first satellite life extension vehicle, designed to dock to geostationary satellites whose fuel is nearly depleted. Once connected to its client satellite, MEV uses its own thrusters and fuel supply to extend the satellite's lifetime. When the customer no longer desires MEV's service, the spacecraft will undock and move on to the next client satellite.

- Orbital Express: Launched March 8, 2007 as part of the United States Air Force STP, Orbital Express demonstrated automated rendezvous and capture of two spacecraft (ASTRO and NEXTSat), transfer of propellant, and transfer of a modular spacecraft component. Flow sensors demonstrated 5 to 10 percent flow rate error on N2H4 transfer with no significant issues. The mission demonstrated 9 mate/demate cycles on orbit and demonstrated robotic ORU transfer and installation.

- OSAM-1: OSAM-1 was a robotic spacecraft equipped with the tools, technologies and techniques needed to extend satellites' lifespans - even if they were not designed to be serviced on orbit. During its mission, the OSAM-1 servicer planned to rendezvous with, grasp, refuel, and relocate a government-owned satellite to extend its life. The capabilities developed through OSAM-1 may provide satellite operators new ways to manage their fleets more efficiently and derive more value from their initial investment. These capabilities may also help mitigate the looming problem of orbital debris.

- RRM: The RRM missions were a set of three servicing and refueling technology demonstration missions which were hosted by the ISS and completed in 2011, 2015, and 2018. The focus of RRM1 was servicing of heritage spacecraft without standard interfaces. RRM2 demonstrated use of new inspection and manipulation tools for servicing and refuel. RRM3 focused on cryogenic propellant storage, gauging, and transfer. Each of these missions was developed through the NExIS projects division of NASA GSFC.

- RSGS: The DARPA RSGS program will demonstrate robotic servicing within GEO through use of a robotic servicing vehicle. The commercially owned and operated servicing vehicle will be comprised of a DARPA-developed toolkit and MRV, a spacecraft under development by Northrop Grumman. The RSGS program intends to demonstrate robotic servicing, on-orbit mission flexibility, and commercial and government collaboration through a multi-year, multi-mission campaign.

Table 1: This table breaks down the larger missions into the entries in the appendix and identifies the applicable capability area(s).

Activity	Area
ETS-VII	
ETS-VII	1, 2
HST	
Hubble SM1	2, 3, 4, 5
Hubble SM2	2, 3, 4, 5
Hubble SM3A	2, 4, 5
Hubble SM3B	2, 3, 4, 5
Hubble SM4	2, 3, 4, 5
ULTOR P3E	12
ISM	
2024 Laser Welding Parabolic Flight Test	7
3D Printing in Zero G TDM	9
3-DOF Laser Welding Experiment	7
AMF	9
Custom Laser Doppler Sensor	9

ISM (Continued)	
DISCMAN	7
External Material Processing Platform	9
FabLab	9
LASAR	7
MAMBA	8
ODME	9
ORFOM	9
Recyclable Packaging Materials	8
ReFabricator	8
RegISS	9, 10
SIMPLE	9
SpaceFiber	9
TVAC Laser Bending Experiment	7
Vulcan	9
ISS	
AMS-02 Servicing	5
APAS	2, 4
ArgUS	2, 4
CAS	7
Dextre	1
ERA	1
FRAM	2, 4
GOLD-2	4
H-Fixture	2, 4
IBDM	2, 4
ISS ITS	7
ISS Reboost	3
JEM SFA	1
JEM-RMS	1
LGF	2
MCF	2
Micro-Fixture	2, 4
MRTAS	7
NDS	2, 4, 6
NICER Servicing	5
OTCM	2, 4
PDGF	4
PMA	2, 4
Progress Vehicle and ATV Refueling of the ISS	6
PVGF	4
R1	1
R2	1
RELL	11

ISS (Continued)	
RMCT	2, 4
ROSA	4
RTAS	7
Sonatest Veo PAUT	11
SSAS	7
SSRMS	1
Strela Cargo Cranes	1
MEV	
MEV	2,3
MEV-1 RPO Imager	12
Orbital Express	
Orbital Express	4, 6, 11
Orbital Express Capture System	2
OEDMS	1
OSAM-1	
ATDS	4
NASA Servicing Arm	1
OSAM-1	2, 5, 6
Robotically Compatible Erectable Joint with Square Cross-Section	7
SPIDER	1, 7
RRM	
CST	6
MFT	6
MFT2	6
Nozzle Tool	6
RROxiTT	6
RRM1	5, 6
RRM2	5
RRM3	6
Safety Cap Tool	6
VIPIR	11
VIPIR2	11
Wire Cutter Tool	5
RSGS	
FREND	1
MRV	2, 3, 5
SPDP	2, 4

7 CONTRIBUTORS

The 2025 edition of the *ISAM State of Play* was prepared by:

- Dr. Dale Arney (NASA Langley Research Center)
- John Mulvaney (NASA Langley Research Center)
- Jose Morel (NASA Langley Research Center)
- Christina Williams (NASA Langley Research Center)
- Christopher Stockdale (Analytical Mechanics Associates, Inc.)
- Christopher Whitlock (NASA Intern, University of Kansas)
- Vishruth Balaji (NASA Intern, Texas A&M University)

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- Andrew O’Connor (NASA Marshall Space Flight Center)
- Andrew Owens (NASA Langley Research Center)
- Luc Riesbeck (NASA SMD)
- Benjamin Rupp (NASA Marshall Space Flight Center)
- Russell Snyder (NASA Goddard Space Flight Center)

8 Appendix – ISAM Functional Capability Area Activities

This appendix presents more details on the ISAM development activities and technologies that define the current state of ISAM. For the use of the table found in this appendix, the capability areas are numbered from 1 to 11, as follows:

1. Robotic Manipulation (RM)
2. RPO, Capture, Docking, and Mating (RCDM)
3. Relocation (R)
4. Prepared Repair, Maintenance, Upgrade, and Installation (PRMUI)
5. Unprepared Repair, Maintenance, Upgrade, and Installation (URMUI)
6. Refueling and Fluid Transfer (RFT)
7. Structural Manufacturing and Assembly (SMA)
8. Recycling, Reuse, and Repurposing (RRR)
9. Parts and Goods Manufacturing (PGM)
10. Surface Infrastructure (SI)
11. Inspection and Metrology (IM)

Table 2 presents all the entries listed in the *ISAM State of Play* and highlights applicable capability area(s). Note that many of the entries are detailed in multiple capability areas due to the broad scope or impact of an activity. After the table, more information about the use/demonstration date, developing organization, country of origin, and select performance parameters are provided for each entry, organized by capability area. For the detailed entries, the “Status” and “First Use Date” information have specific lexicons. These definitions are listed below for “Status”:

- In Development: ongoing development project
- Operational: ongoing flight project or mission
- Concluded: project ended or was canceled
- Completed: project had an operational flight or similar and has been completed

The definitions for “First Use Date” are listed below:

- N/A: concluded without technology used in space
- Unavailable: unable to find the use date
- TBD: project in development without scheduled future use in space
- Scheduled for 20XX: scheduled future use in space

Table 2: This table lists all the entries within the ISAM State of Play Functional Capability Areas mapped to the applicable capability area(s). The text in the columns of this table are unique identifiers for each entry detailed in the appendix.

Activity	1	2	3	4	5	6	7	8	9	10	11
1989 Laser Welding Parabolic Flight Tests							SMA01				
2024 Laser Welding Parabolic Flight Test							SMA02				
3D Printed Habitat Challenge										SI01	
3D Printed Space Reflector Antenna									PGM01		
3D Printing in Zero G TDM									PGM02		
3-DOF Laser Welding Experiment							SMA03				
ACME										SI02	
ADRAS-J		RCDM001									IM01
AeroCube-10		RCDM002									IM02
ALFE						RFT01					
AMF									PGM03		
AMS-02 Servicing					URMUI01						
Androgynous Fasteners							SMA04				
ANGELS		RCDM013									IM03
Aolong-1		RCDM004	R01								
APAS		RCDM003		PRMUI02							
APS-R		RCDM011				RFT02					
Argon AR&D Sensor		RCDM006									
ArgUS		RCDM007		PRMUI03							
ARMADAS							SMA06			SI04	
ASPIN		RCDM012		PRMUI04							
Assemblers	RM02						SMA05				
ASSIST Pro		RCDM008									
Asteria		RCDM009									
ASTP-DM		RCDM005									
Astroscale Docking Plate		RCDM010									
ATDS				PRMUI01							
ATHLETE	RM01									SI03	
AVANTI		RCDM014									
AXON/Dactylus		RCDM015		PRMUI05							
Biclops		RCDM016									IM04
Blue Alchemist									PGM04	SI05	
Blue Ring			R02								
CAESAR	RM07										
Caltech NOM4D Robotic Assembly Mission							SMA07				
Canadarm3	RM06										
Canadarm3 - XDA	RM05										
CAS							SMA08				

Activity	1	2	3	4	5	6	7	8	9	10	11
CAT-IOD		RCDM017	R03								
CDM						RFT05					
Chandrayaan-3			R04								
CHAPEA										SI06	
ClearSpace-1		RCDM018	R05								
CMM	RM08										
Composite Joint Connector							SMA09				
CPOD		RCDM019									
CrossLink	RM09										
Cryogenic (H2/O2) Smart Propulsion Flight Demonstration						RFT04					
CST						RFT06					
CSV						RFT03					
Custom Laser Doppler Sensor									PGM05		
DART		RCDM021									
Dextre	RM10										
DFT Port		RCDM022		PRMUI06		RFT07					
DIANE		RCDM020									IM05
DISCMAN							SMA10				
DogTag		RCDM023									
EASE/ACCESS							SMA13				
EBW Joint							SMA22				
Elixir						RFT08					
ELSA-d		RCDM026	R08								
ELSA-M		RCDM025	R07								
Elytra		RCDM024	R06								IM06
EMM	RM13										
End Effector for In-Space Autonomous Fastener Installation							SMA11				
Enduralock Satellite Connector		RCDM027		PRMUI07		RFT09					
ERA	RM12										
EROSS-SC		RCDM029				RFT10					IM07
ESA Metal 3D Printer									PGM06		
ESA Replicator 1							SMA12				
ESAMM							SMA14				
ESPRIT						RFT11					
ETS-VII	RM11	RCDM028									
EVA IR Camera											IM10
External Material Processing Platform									PGM07		
FabLab									PGM11		
FARE-I						RFT12					
FARE-II						RFT13					
FLEX	RM14									SI07	
Flight-1							SMA15				

Activity	1	2	3	4	5	6	7	8	9	10	11
Fovea M1											IM11
Fovea M2											IM12
FRAM		RCDM032		PRMUI08							
FREND	RM15										
FRGF		RCDM033									
Furphy Prototype Tanker						RFT14					
FuseBlox		RCDM034		PRMUI09							
GaLORE										SI08	
Gecko Gripper					URMUI02						
GOLD-2				PRMUI10							
GRASP		RCDM037		PRMUI12							
Green Propellant Micropump						RFT16					
GRIP		RCDM036				RFT15					
GSSAP		RCDM035									
HelioSwarm		RCDM038									
Helium Compressor						RFT17					
H-Fixture		RCDM039		PRMUI13							
High Accuracy Coriolis Mass Flow Meter						RFT18					
Hinge for Use in a Tension Stiffened and Tendon Actuated Manipulator							SMA17				
HMA						RFT19					
HMFG Fabrication Facility									PGM08		
HOTDOCK		RCDM040		PRMUI14							
HRT						RFT20					
Hubble SM1		RCDM041	R09	PRMUI15	URMUI03						
Hubble SM2		RCDM042	R10	PRMUI16	URMUI04						
Hubble SM3A		RCDM043		PRMUI17	URMUI05						
Hubble SM3B		RCDM044	R11	PRMUI18	URMUI06						
Hubble SM4		RCDM045	R12	PRMUI19	URMUI07						
IBDM		RCDM047		PRMUI21							
ICF									PGM09		
IN1	RM16										
IN2	RM17										
Instrument Deployment Arm (Insight)	RM18										
Intelsat 603 Servicing Mission					URMUI08						
ION Satellite Carrier			R14								
IPEx										SI10	
ISFR										SI09	
ISS ITS							SMA18				
ISS IVR Experiment				PRMUI22			SMA19				
ISS Reboost			R13								
iSSI		RCDM046		PRMUI20							
ISWE							SMA20				
Jackal		RCDM048									

Activity	1	2	3	4	5	6	7	8	9	10	11
JEM SFA	RM20										
JEM-RMS	RM19										
JOINS							SMA21				
K Program		RCDM049				RFT22					
Kamino						RFT21					
KRAKEN	RM21										
LANCE										SI12	
LASAR							SMA23				
Laura-1											IM14
LCS											IM13
LDDM		RCDM051									
Leasat-3 Servicing Mission					URMUI09						
LEXI		RCDM052	R15								
LGF		RCDM050									
LINUSS		RCDM053									
LOXSAT-1						RFT23					
LPGF		RCDM054		PRMUI39							
LSMS	RM22									SI11	
Lunar Communication Tower Construction Demonstration							SMA24			SI13	
Lunar Outpost LTVS MDA SKYMAKER™ Manipulator Arm	RM23										
MagTag		RCDM055									
MakerSat							SMA25				
MAMBA								RRR01			
Mars Surveyor 2001 Robotic Arm	RM26										
MCF		RCDM057									
Mengtian Indexing Robotic Arm	RM28										
MEP			R18		URMUI10						
MER IDD	RM24										
MEV		RCDM060	R19								
MFT						RFT25					
MFT2						RFT26					
MICE		RCDM056									
Micro-Fixture		RCDM058		PRMUI23							
Mira			R16								
Mission 1		RCDM059	R17			RFT24					
MMIC-I	RM29										
MMPACT										SI15	
Modulink				PRMUI24							
MRTAS							SMA26				
MRV		RCDM061	R20		URMUI11						
MSF								RRR02			
MSL Robotic Arm	RM25										
MSTIC									PGM10		

Activity	1	2	3	4	5	6	7	8	9	10	11
Multi-mission Modular Spacecraft				PRMUI25							
MVACS	RM27										
Mycroft		RCDM062									IM15
NASA Servicing Arm	RM30										
Nautilus		RCDM064									
NDS		RCDM063		PRMUI26		RFT27					
NICER Servicing					URMUI12						
NINJAR							SMA27				
Nozzle Tool						RFT28					
ODME									PGM12		
OEDMS	RM31										
OMD-1								RRR03	PGM15		
OMV			R21								
Optimus Viper											IM16
Orbital Express				PRMUI27		RFT31					IM17
Orbital Express Capture System		RCDM066									
Orbiter			R22								
OrbitGuard 1		RCDM067									
ORFOM									PGM14		
Orion Camera Suite		RCDM068									IM18
ORS Flight Demonstration						RFT32					
OSAM-1		RCDM065			URMUI13	RFT30					
OSAM-2							SMA28				
OTCM		RCDM069		PRMUI28							
Otter		RCDM070	R23								IM19
Otter Pup		RCDM071									
Otter Pup 2		RCDM072									
Owl											IM20
PASS							SMA29				
PDGF				PRMUI29							
Phoenix Mars Lander Robotic Arm	RM33										
PIL-BOX									PGM16		
PMA		RCDM075		PRMUI31							
Podracer		RCDM074									
PRISMA		RCDM076									
PRM		RCDM073				RFT33					
Proba-3		RCDM077									
Progress Vehicle and ATV Refueling of the ISS						RFT34					
Project GHOST				PRMUI11			SMA16				
PUMA						RFT35					
PVGF				PRMUI30							
Quadclops		RCDM078									IM21
Quark		RCDM079	R24			RFT36					
R1	RM35										

Activity	1	2	3	4	5	6	7	8	9	10	11
R1.5										SI14	
R2	RM36										
RAFTI		RCDM080				RFT38					
Rancor						RFT37					
Ranger	RM34										
Raven		RCDM081									
REACCH		RCDM082									
REACT										SI18	
Recyclable Packaging Materials								RRR04			
RED-EYE		RCDM083									
Redwire Mason										SI16	
ReFabricator								RRR05			
RegISS									PGM17	SI17	
RELL											IM23
REMORA CubeSat					URMUI14						
RemoveDEBRIS		RCDM084									IM22
RISE		RCDM086	R25								
RMCT		RCDM087		PRMUI32							
RoboSimian	RM37									SI19	
Robotically Compatible Erectable Joint with Square Cross-Section							SMA30				
ROSA				PRMUI33							
RPOD Kit		RCDM085									
RRM1					URMUI15	RFT40					
RRM2					URMUI16						
RRM3						RFT41					
RROxiTT						RFT39					
RSat	RM38										
RTAS							SMA31				
S1	RM39										
S10	RM40										
S2	RM41										
Safety Cap Tool						RFT42					
SAGE III							SMA39				
Salyut-7 Welding Experiment							SMA32				
SAMURAI							SMA40				
SCOUT-Vision		RCDM088									IM24
Seal-Less Mechanically Compliant Fluid Adapter						RFT43					
Seeker											IM25
Self-Aligning Nut Plate							SMA34				
SFMD						RFT45					
SHA	RM32										
Sherpa			R26								
SHIELD		RCDM089			URMUI17						IM26
SHOOT Flight Demonstration						RFT46					

Activity	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
SIGHT					URMUI18						IM27
SIMPLE									PGM18		
SIROM		RCDM099		PRMUI37							
SJ-17		RCDM090									
SJ-21		RCDM091	R27								
Skylab Materials Processing Facility Experiments							SMA35				
SLAC1	RM43										
SLEGO Architecture		RCDM094		PRMUI34		RFT44	SMA36				
Solar Maximum Servicing Mission				PRMUI35							
SOLL-E	RM42										
Sonatest Veo PAUT											IM29
SOUL		RCDM097		PRMUI36							IM30
SOUL Inspector											IM31
SO-WARM							SMA37			SI21	
SpaceFiber									PGM13		
SpaceFORM									PGM19		
Spacevan			R28								
SpaDeX		RCDM096									
Sparrow											IM32
SPDP		RCDM102		PRMUI38							
Spectre		RCDM098									
SPIDER	RM44						SMA38				
SRMS	RM03										
SSAS							SMA33				
SSPICY		RCDM095									IM28
SSRMS	RM04										
SSVP		RCDM093									
STAARK	RM45										
Starling		RCDM100									
Starship HLS Docking System		RCDM101									
Starship Propellant Transfer Demonstration						RFT29					
STOMP										SI20	
Strela Cargo Cranes	RM46										
SunRISE		RCDM103									
SY-7		RCDM092									
TALISMAN	RM47										
Tanker-001 Tenzing		RCDM104				RFT48					
TCAM Soft Robotic Actuator							SMA46				
TCMM									PGM20		
TDEA							SMA44				
TESSERAE							SMA42				
Tetra-5		RCDM105				RFT49					IM33
Tetra-6		RCDM106				RFT50					
TG-2 Space Robot	RM48										

Activity	1	2	3	4	5	6	7	8	9	10	11
Thermally Reversible Polymers for AM Feedstock								RRR07			
Tianyuan 1 Refueling Demonstration						RFT51					
TLT							SMA41			SI22	
TPCE/TP						RFT47					
Triclops		RCDM107									IM34
TriDAR		RCDM108									
TSCM							SMA45				
TuFF Reformability Demonstration								RRR06			
TVAC Laser Bending Experiment							SMA43				
UIUC NOM4D Materials Process Mission							SMA47				
UNIGLO									PGM21		
Variable Output Regulator						RFT52					
VICTUS NOX		RCDM109									
Vigoride			R29								
VIPIR											IM36
VIPIR2											IM37
VisCam		RCDM110									
VSS Visible Wavelength Spaceflight Camera											IM35
VTRE						RFT53					
Vulcan									PGM22		
Vulkan Experiment							SMA48				
Wire Cutter Tool					URMUI19						
WM	RM49										
WorldView-3											IM38
W-Series Platform									PGM23		
Xenon Compressor						RFT54					
xLink Robotic Arm	RM50										
XSS-10		RCDM030									IM08
XSS-11		RCDM031									IM09

8.1 Robotic Manipulation

8.1.1 RM01: All-Terrain Hex-Limbed Extra-Terrestrial Explorer (ATHLETE)

Description: The All-Terrain Hex-Limbed Extra-Terrestrial Explorer (ATHLETE) vehicle, developed at JPL, is a vehicle intended to support human exploration on the lunar surface. The vehicle includes a habitable volume mounted on six 6-degree-of-freedom robotic arms, each with a 1-degree-of-freedom wheel attached. The robotic arms and wheels are able to traverse stable terrain in a standard rover-like configuration. For more difficult terrain, the wheels can be locked, and the robotic arms can act as legs.
Developer: NASA Jet Propulsion Laboratory (JPL)
Country: United States
First Use Date: 2005
Status: In Development
Reach (m): 6
Degrees of Freedom: Each of the 6 legs has 6 DOF
Grapple Type/Interface: Wheel
Cross Listing: SI03

8.1.2 RM02: Assemblers

Description: Assemblers is a technology development for a modular robotic manipulator that consists of a variable number of stacked Stewart platforms. The goals of this project are to increase the technology readiness level for modular robots and autonomous in-space assembly and to develop a robotic prototype for ground testing.
Developer: NASA Langley Research Center (LaRC)
Country: United States
Status: Concluded
Reach (m): 1.01
Degrees of Freedom: 6
Grapple Type/Interface: End effectors, grip, lift, weld, join
Cross Listing: SMA05

8.1.3 RM03: Canadarm / Shuttle Remote Manipulator System (SRMS)

Description: Canadarm or Canadarm1 (officially Shuttle Remote Manipulator System or SRMS) is a series of robotic arms that were used on the Space Shuttle orbiters to deploy, maneuver, and capture payloads. After the Space Shuttle Columbia disaster, the Canadarm was always paired with the Orbiter Boom Sensor System (OBSS), which was used to inspect the exterior of the Shuttle for damage to the thermal protection system.
Developer: Spar Aerospace
Country: Canada
First Use Date: 1981
Status: Completed
Reach (m): 15
Degrees of Freedom: 6
Grapple Type/Interface: Snare End Effector

8.1.4 RM04: Canadarm2 / Space Station Remote Manipulator System (SSRMS)

Description: Officially known as the Space Station Remote Manipulator System (SSRMS), Canadarm2 supports a wide array of ISS operations. Launched on STS-100 in April 2001, this second-generation arm is a larger, more advanced version of the Space Shuttle's original Canadarm.
Developer: Canadian Space Agency (CSA), MDA Space
Country: Canada
First Use Date: 2001
Status: Operational
Reach (m): 17.6
Degrees of Freedom: 7
Grapple Type/Interface: Snare End Effector, Latches, Umbilicals

8.1.5 RM05: Canadarm3 - eXploration Dexterous Arm (Canadarm3 - XDA)

Description: The Canadarm3 XDA is a robotic manipulator used for dexterous handling operations such as On-Orbit Replaceable Unit/Payload replacement, handling and inspection activities similar to the Dextre robot on the ISS. This arm, along with the Canadarm3 XLA will be the contribution of the Canadian Space Agency (CSA) to the Lunar Gateway. CSA contracted MDA Space to build the arm. MDA Space previously built Canadarm2, while its former subsidiary, Spar Aerospace, built Canadarm.
Developer: Canadian Space Agency (CSA), MDA Space
Country: Canada
First Use Date: Scheduled for 2028
Status: In Development
Reach (m): 3
Degrees of Freedom: 7
Grapple Type/Interface: Dexterous End Effector, Umbilical

8.1.6 RM06: Canadarm3 - eXploration Large Arm (Canadarm3)

Description: The Canadarm3 XLA is a robotic remote manipulator arm similar to the Space Shuttle Canadarm and International Space Station Canadarm2. Canadarm3 will be used for berthing the modules and inspecting the Lunar Gateway. The arm is to be the contribution of the Canadian Space Agency (CSA) to this international endeavor. CSA contracted MDA Space to build the arm. MDA Space previously built Canadarm2, while its former subsidiary, Spar Aerospace, built Canadarm.
Developer: Canadian Space Agency (CSA), MDA Space
Country: Canada
First Use Date: Scheduled for 2028
Status: In Development
Reach (m): 8.5
Degrees of Freedom: 7
Grapple Type/Interface: Low Profile End Effector, Latches, Umbilicals

8.1.7 RM07: Compliant Assistance and Exploration SpAce Robot (CAESAR)

Description: The Compliant Assistance and Exploration SpAce (CAESAR) robotic arm is being developed to catch satellites in LEO/GEO, even ones that are tumbling and/or in non-cooperative states. CAESAR's seven DOF will enable it to assemble, perform maintenance, and repair satellites.
Developer: German Space Agency (DLR)
Country: Germany
First Use Date: TBD
Status: In Development
Reach (m): 3
Degrees of Freedom: 7
Grapple Type/Interface: Unavailable

8.1.8 RM08: Core Module Manipulator (CMM)

Description: The Core Module Manipulator (CMM) is a 10 m, 7-degree-of-freedom robotic arm mounted on the Tianhe core module of the Chinese Tiangong space station. The arm has a maximum capacity of 25 tons and can act cooperatively with the Experimental Module Manipulator (EMM) to increase utility or expand work area. The arm is primarily used for element transfer, cargo transfer, capture of visiting spacecraft, and EVA support.
Developer: China Academy of Space Technology (CAST), Harbin Institute of Technology (HIT)
Country: China
First Use Date: 2021
Status: Completed
Reach (m): 10
Degrees of Freedom: 7
Grapple Type/Interface: Unavailable

8.1.9 RM09: CrossLink

Description: The CrossLink is a robotic system developed by Motiv Space Systems for use in ISAM activities. Created by fusing technologies from Motiv's xLink, Mantis, and end effector robotic systems, CrossLink is a walking robot created to support in-space assembly and servicing operations.
Developer: Motiv Space Systems
Country: United States
First Use Date: TBD
Status: In Development
Reach (m): Unavailable
Degrees of Freedom: Unavailable
Grapple Type/Interface: Grappling end effector

8.1.10 RM10: Dextre

Description: The Special Purpose Dexterous Manipulator, or "Dextre," is a smaller two-armed robot that can attach to Canadarm2, the ISS or the Mobile Base System. The arms and its power tools are capable of handling the delicate assembly tasks and changing Orbital Replacement Units (ORUs) previously handled by astronauts during space walks. Although Canadarm2 can move around the station in an "inchworm motion," it is unable to carry anything with it unless Dextre is attached.
Developer: Canadian Space Agency (CSA), MDA Space
Country: Canada
First Use Date: 2008
Status: Operational
Reach (m): 3.51
Degrees of Freedom: 7
Grapple Type/Interface: Latching End Effector, Robotic Micro Conical Tools, RMM Tools

8.1.11 RM11: Engineering Test Satellite VII (ETS-VII)

Description: Engineering Test Satellite VII (ETS-VII, Japanese nickname Kiku7) was a NASDA (which is now part of JAXA) technology demonstration satellite. The overall mission objectives were to conduct space robotic experiments with an onboard 2-meter arm and to demonstrate its utility for uncrewed orbital operation and servicing tasks (e.g., rendezvous-docking techniques).
Developer: National Space Development Agency of Japan (NASDA)
Country: Japan
First Use Date: 1998
Status: Completed
Reach (m): 2
Degrees of Freedom: 6
Grapple Type/Interface: Grapple
Cross Listing: RCDM028

8.1.12 RM12: European Robotic Arm (ERA)

Description: The European Robotic Arm (ERA) is a robotic manipulator attached to the Russian Orbital Segment of the International Space Station (ISS). The manipulator transfers small payloads directly from inside to outside the International Space Station, which reduces the number and duration of EVAs.
Developer: European Space Agency (ESA), Airbus
Country: European Union
First Use Date: 2021
Status: Operational
Reach (m): 9.2
Degrees of Freedom: 7
Grapple Type/Interface: Grapple Integrated Tools

8.1.13 RM13: Experimental Module Manipulator (EMM)

Description: The Experimental Module Manipulator (EMM) is a 5 m, 7-degree-of-freedom robotic arm mounted on the Gentian experiment module of the Chinese Tiangong space station. The arm has a maximum capacity of 3 tons and can act cooperatively with the Core Module Manipulator (CMM) to increase utility or expand work area. The arm is primarily used for small cargo maneuvering, maintenance, and EVA support.
Developer: China Academy of Space Technology (CAST), Harbin Institute of Technology (HIT)
Country: China
First Use Date: 2022
Status: Completed
Reach (m): 5
Degrees of Freedom: 7
Grapple Type/Interface: Unavailable

8.1.14 RM14: FLEX

Description: The Astrolab FLEX rover will be capable of carrying science payloads, logistics payloads, and crew on planetary and lunar surfaces. The rover is currently under development and expected to launch to the Moon in 2026 on the SpaceX Starship with 1500 kg of commercial customer cargo. The rover is equipped with a steerable high-gain antenna, adaptable suspension, remote science mast, crew interfaces, and a 2-meter, 6-degree-of-freedom robotic arm.
Developer: Astrolab
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Reach (m): 2
Degrees of Freedom: 6
Grapple Type/Interface: Modular Interface
Cross Listing: SI07

8.1.15 RM15: Front-end Robotic Enabling Near-term Demonstration (FREND)

Description: The Front-end Robotic Enabling Near-term Demonstration (FREND) robotic arm was developed by DARPA to demonstrate a 7-degree-of-freedom arm capable of autonomous grapple and manipulation. The design is being leveraged by OSAM-1 and RSGS. The arm is driven by the MOOG Rikishi Electronics Unit, which is designed to drive up to nine separate robotic arm joints.
Developer: Defense Advanced Research Projects Agency (DARPA), Naval Research Laboratory (NRL), MDA Space, Maxar Technologies, MOOG
Country: United States
First Use Date: 2007
Status: Completed
Reach (m): 1.8
Degrees of Freedom: 7
Grapple Type/Interface: Grapple

8.1.16 RM16: IN1

Description: The IN1, in development by Japanese startup GITAI, is an inchworm-type robotic arm equipped with grapple end-effectors on both ends of the arm. This unique feature increases “capability,” which enables it to connect to various tools to perform multiple tasks, and “mobility,” which enables it to move in any direction. It can also connect/disconnect itself among different vehicles, such as rovers, landers, lunar base, etc. In March 2023, a demonstration of cooperative lunar base construction using two GITAI inchworm-type robotic arms and two GITAI lunar robotic rovers in a simulated lunar environment was successfully completed.
Developer: GITAI
Country: Japan
Status: Concluded
Reach (m): 1.5
Degrees of Freedom: Unavailable
Grapple Type/Interface: Internal Proprietary Interface, Camera, Tool Change Capability

8.1.17 RM17: IN2

Description: The IN2 robotic arm developed by GITAI is a 2 m long, 7-degree-of-freedom robotic arm capable of performing inch-worm maneuvers through use of the 2-degree-of-freedom grappling end effectors mounted on each end of the robotic arm. The inch-worming capability enlarges the work envelope for the robotic arm and enables transition between vehicles, such lunar landers and rovers. Three of these robotic arms were used in GITAI's 2024 demonstration of constructing a 5 m lunar tower.
Developer: GITAI
Country: Japan
First Use Date: TBD
Status: In Development
Reach (m): 2
Degrees of Freedom: 7
Grapple Type/Interface: Internal Proprietary Interface, Camera, Tool Change Capability

8.1.18 RM18: Instrument Deployment Arm (Instrument Deployment Arm (Insight))

Description: The Instrument Deployment Arm (IDA) originated as the robotic arm built for the Jet Propulsion Laboratory (JPL) for the cancelled Mars 2001 Surveyor mission in 1998. It was later used on the InSight Mars lander to deploy instruments on the surface and orient the deployment camera.
Developer: Maxar Technologies, MDA Space
Country: United States
First Use Date: 2018
Status: Completed
Reach (m): 1.9
Degrees of Freedom: 4
Grapple Type/Interface: Scoop, Grapple, Camera

8.1.19 RM19: Japanese Experiment Module Remote Manipulator System (JEM-RMS)
Description: Kibo's robotic arm, Japanese Experiment Module Remote Manipulator System (JEM-RMS), is a robotic manipulator system intended for supporting experiments to be conducted on Kibo's Exposed Facility or for supporting Kibo's maintenance tasks.
Developer: Japan Aerospace Exploration Agency (JAXA)
Country: Japan
First Use Date: 2008
Status: Operational
Reach (m): 10
Degrees of Freedom: 6
Grapple Type/Interface: Grapple, JEM SFA Connection

8.1.20 RM20: Japanese Experiment Module Small Fine Arm (JEM SFA)
Description: The Small Fine Arm (SFA) consists of electronics, booms, joints, effectors called "tools," and cameras. The SFA attaches to the end of the JEM-RMS when operated.
Developer: Japan Aerospace Exploration Agency (JAXA)
Country: Japan
First Use Date: 2008
Status: Operational
Reach (m): 2.2
Degrees of Freedom: 6
Grapple Type/Interface: 3 Fingers, Torque Driver, Electric Connectors

8.1.21 RM21: KRAKEN
Description: Tethers Unlimited Inc. was developing the KRAKEN robotic arm to provide the space industry with a compact, high-performance, and cost-effective manipulator to enable small spacecraft to perform in-space assembly, manufacturing, and servicing missions.
Developer: Tethers Unlimited Inc
Country: United States
Status: Concluded
Reach (m): 1
Degrees of Freedom: 7
Grapple Type/Interface: Swappable, Tool-Change Interface, Power/Data Interface

8.1.22 RM22: Lightweight Surface Manipulator System (LSMS)

Description: Lightweight Surface Manipulation System (LSMS) is a crane with multiple end effectors being developed at NASA Langley. LSMS is designed to be scalable to a wide range of reach and tip mass requirements, with 12 years of design heritage and testing on 1000 kg (lunar) tip mass capable prototype unit. The LSMS allows for fine positioning of a payload in both the translational and rotational directions. Attachments include buckets, pallet forks, grappling devices, sensors, and robotic arms.
Developer: NASA Langley Research Center (LaRC)
Country: United States
First Use Date: TBD
Status: In Development
Reach (m): 7.5
Degrees of Freedom: 3
Grapple Type/Interface: Unavailable
Cross Listing: SI11

8.1.23 RM23: Lunar Outpost LTVS MDA SKYMAKER Manipulator Arm

Description: The LTVS MDA SKYMAKER™ lunar manipulator arm is being developed for Lunar Outpost's Lunar Dawn LTVS rover. It is a 4-degree of freedom, 3-meter manipulator designed to operate on the lunar surface with a 70 kg payload capability. It includes a lunar regolith tolerant end effector capable of providing power and data to a series of tools and payloads.
Developer: MDA Space
Country: Canada
First Use Date: TBD
Status: In Development
Reach (m): 2.5
Degrees of Freedom: 6
Grapple Type/Interface: CLAMP latching end effector, regolith tolerant power and data transfer

8.1.24 RM24: Mars Exploration Rover Robotic Arm (MER IDD)

Description: The Instrument Deployment Device (IDD) is a 5-degree-of-freedom robotic arm designed to give the Mars Exploration Rover (MER) the ability to gain physical access to the rocks and soil in the Martian environment. The IDD accurately positions each of the four separate instruments attached to its end effector against and near geological specimens selected for scientific investigation. This robotic arm was used on both Spirit and Opportunity.
Developer: National Aeronautics and Space Administration (NASA), Maxar Technologies, MDA Space
Country: United States
First Use Date: 2004
Status: Completed
Reach (m): 1
Degrees of Freedom: 5
Grapple Type/Interface: Abrasion Tool, Spectrometer, Camera

8.1.25 RM25: Mars Science Laboratory Robotic Arm (MSL Robotic Arm)

Description: The Mars Science Laboratory (also known as Curiosity) mission incorporates many lessons learned from the Pathfinder mission and Sojourner rover, the Mars Exploration Rovers, and the Phoenix

Lander to explore Mars and help understand if it ever had the conditions to support life. Curiosity's robotic arm maneuvers instruments close to the surface. These instruments and tools are housed in a "turret" that can switch to the appropriate tool at the time.
Developer: Maxar Technologies, MDA Space
Country: United States
First Use Date: 2012
Status: Operational
Reach (m): 2.2
Degrees of Freedom: 5
Grapple Type/Interface: 5 Scientific Instruments, Drill

8.1.26 RM26: Mars Surveyor 2001 Robotic Arm

Description: The Mars Surveyor 2001 Lander was scheduled to carry both a robotic arm and rover to support various science and technology experiments. This mission was cancelled, but the lander and robotic arm were eventually repurposed as the Phoenix lander in 2007.
Developer: NASA Jet Propulsion Laboratory (JPL)
Country: United States
First Use Date: 2001
Status: Concluded
Reach (m): 2
Degrees of Freedom: 4
Grapple Type/Interface: Scoop, Scraping Blades, Electrometer

8.1.27 RM27: Mars Volatiles and Climate Surveyor Robotic Arm (MVACS)

Description: The Mars Volatiles and Climate Surveyor (MVACS) suite of instruments was intended to land on Mars aboard the Mars Polar Lander in 1999. The primary purpose of the MVACS Robotic Arm was to support the other MVACS science instruments by digging trenches in the Martian soil, acquiring and dumping soil samples into the Thermal Evolved Gas Analyzer, and other support functions. The Mars Polar Lander mission failed before use of the robotic arm.
Developer: National Aeronautics and Space Administration (NASA), University of Arizona
Country: United States
First Use Date: 1999
Status: Completed
Reach (m): 2.2
Degrees of Freedom: 4
Grapple Type/Interface: Scoop, Temp probe, Camera

8.1.28 RM28: Mengtian Indexing Robotic Arm

Description: The Mengtian Indexing Robotic Arm is a robotic arm mounted on the Tiangong space station Mengtian module. The robotic arm, which is similar in design to the Lyappa arm of the Mir space station, was designed to move the Mengtian module to the portside port of the Tianhe Core Module. The robotic arm provides additional services such as cargo transfer, payload release, microsatellite launch, and EVA assist.
Developer: Unavailable
Country: China
First Use Date: 2022
Status: Completed
Reach (m): 0.8
Degrees of Freedom: Unavailable
Grapple Type/Interface: Unavailable

8.1.29 RM29: Mobile Metamaterial Internal Co-Integrator (MMIC-I)

Description: The Mobile Metamaterial Internal Co-Integrator (MMIC-I) serves as the ARMADAS integration robot. It is used for internal climbing and completing inter-voxel connections using bolts.
Developer: NASA Ames Research Center (ARC)
Country: United States
First Use Date: TBD
Status: In Development
Reach (m): 0.3
Degrees of Freedom: 5 locomotion +16 end effector
Grapple Type/Interface: Internal framework gripping interface

8.1.30 RM30: NASA Servicing Arm

Description: The Robotic Servicing Arm has extensive heritage from arms used in past Mars rover missions. The system design heavily leverages the flight-qualified robotic arm developed for DARPA's Spacecraft for the Universal Modification of Orbits and Front-end Robotics Enabling Near-term Demonstration (FREND) programs in the mid-2000s. In particular, it builds off of previous NASA and DARPA investments in motion control, robotic software frameworks, flex harnesses, force-torque sensor, joint design, and flight operations experience.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
Status: Concluded
Reach (m): 2.46
Degrees of Freedom: 7
Grapple Type/Interface: Six-Axis Force/Torque Sensor

8.1.31 RM31: Orbital Express Demonstration Manipulator System (OEDMS)

Description: Using a robotic arm on orbit, the Orbital Express mission demonstrated autonomous capture of a fully unconstrained free-flying client satellite, autonomous transfer of a functional battery On-Orbit Replaceable Unit (ORU) between two spacecraft, and autonomous transfer of a functional computer ORU.
Developer: Defense Advanced Research Projects Agency (DARPA), MDA Space
Country: United States
First Use Date: 2007
Status: Completed
Reach (m): 2.8
Degrees of Freedom: 6
Grapple Type/Interface: Mouse Trap, Cone, Probe

8.1.32 RM32: Perseverance Sample Handling Assembly (SHA)

Description: The Perseverance rover uses a 2.1-meter arm to support sample handling and science collection. The turret at the end of the arm contains multiple instruments and tools to extract and store core samples, drill into regolith and rocks, and to take images and analyze the Martian environment.
Developer: Maxar Technologies, MDA Space
Country: United States
First Use Date: 2020
Status: Operational
Reach (m): 2.1
Degrees of Freedom: 5
Grapple Type/Interface: Tool Turret, SHERLOC, WATSON, PIXL, GDRT, Drill

8.1.33 RM33: Phoenix Mars Lander Robotic Arm

Description: The robotic arm on the Phoenix lander was an essential system for achieving the scientific goals of the Phoenix mission by providing support to the other science instruments and conducting specific soil mechanics experiments.
Developer: Maxar Technologies, MDA Space
Country: United States
First Use Date: 2008
Status: Completed
Reach (m): 2
Degrees of Freedom: 4
Grapple Type/Interface: Scoop, Camera

8.1.34 RM34: Ranger

Description: Ranger, a four-armed repair robot, is currently being testing at the University of Maryland in their Space Systems Laboratory. This robot was proposed for Hubble Servicing Missions but was eventually defunded by NASA. First use of robot control of "hazardous" payload, leveraged by Robonaut and Restore.
Developer: University of Maryland Space Systems Laboratory (UMD SSL)
Country: United States
First Use Date: 1995
Status: Operational
Reach (m): 1.35
Degrees of Freedom: 8
Grapple Type/Interface: Bolt and Angle Drives, Jaw Gripper

8.1.35 RM35: Robonaut (R1)

Description: NASA, in a collaborative effort with DARPA, designed the first generation Robonaut. It was developed to assist astronauts in space with extra-vehicular activities. With 43 degrees of freedom, the human-like robot could perform a wide variety of maintenance tasks.
Developer: National Aeronautics and Space Administration (NASA), Defense Advanced Research Projects Agency (DARPA)
Country: United States
First Use Date: 2010
Status: Concluded
Reach (m): 0.203
Degrees of Freedom: 43
Grapple Type/Interface: 2 Single-DOF Fingers and Palm DOF Grasp, API Interface, EVA Crew Interface

8.1.36 RM36: Robonaut 2 (R2)

Description: Robonaut 2 (R2) was jointly developed by NASA and General Motors under a cooperative agreement to develop a robotic assistant that can work alongside humans, whether they are astronauts in space or workers at General Motors manufacturing plants on Earth.
Developer: National Aeronautics and Space Administration (NASA), General Motors
Country: United States
First Use Date: 2011
Status: Operational
Reach (m): 0.812
Degrees of Freedom: 42
Grapple Type/Interface: 12-DOF Hands

8.1.37 RM37: RoboSimian

Description: The RoboSimian traverse vehicle out of NASA's Jet Propulsion Laboratory (JPL) is a robot with four wheels mounted on the end of 7-degree-of-freedom robotic arms. The robot was constructed in response to a Defense Advanced Research Projects Agency (DARPA) challenge to advance the use of robots in disaster situations. The vehicle can carry 20 kg and is capable of traversing complex environments through use of the four independent limbs, seven sets of stereo cameras, and a LiDAR mapping device.
Developer: NASA Jet Propulsion Laboratory (JPL)
Country: United States
First Use Date: 2014
Status: Completed
Reach (m): 1
Degrees of Freedom: Each of the four legs has 7 degrees of freedom
Grapple Type/Interface: Wheel/Claw
Cross Listing: SI19

8.1.38 RM38: Robotic Repair Satellite Mission (RSat)

Description: The Robotic Repair Satellite (RSat) Mission, developed by the United States Naval Academy, is a 3U CubeSat with two extendable robotic arms. RSat launched to the ISS in 2022 and remained in stowage until 2024. ISS crew installed the RSAT inside the microgravity science glovebox (MSG). RSat successfully demonstrated on-orbit capabilities using remote robotic arm operations within the confines of the MSG.
Developer: U.S. Naval Academy
Country: United States
First Use Date: 2024
Status: Completed
Reach (m): 0.6
Degrees of Freedom: 6
Grapple Type/Interface: Dual robot arms with grasping end-effectors, includes cameras

8.1.39 RM39: S1

Description: The S1, developed by GITAI, is a semi-autonomous, semi-teleoperated robotic arm capable of operating internal or external to on-orbit or lunar facilities. The S1 is able to excel in general purpose tasks often difficult for industrial robots, such as switch actuation, tool use, and soft object manipulation. In October of 2021, the robotic arm autonomously completed a number of common crew IVA tasks within the NanoRacks Bishop pressurized volume of the ISS.
Developer: GITAI
Country: Japan
First Use Date: 2021
Status: Completed
Reach (m): 1
Degrees of Freedom: 8 + 1
Grapple Type/Interface: Two Finger Gripper, Camera

8.1.40 RM40: S10

Description: The S10, in development by GITAI, is an autonomous robotic arm intended for commercial space station applications. This robotic arm is capable of manipulating large objects, such as spacecraft or payloads, autonomously or through teleoperation. Also, autonomous traverse of the arm itself is available by using grapple end effectors at both ends of the arm. Demonstration of the S10 within a simulated microgravity environment in an underwater experimental facility was completed in 2023.
Developer: GITAI
Country: Japan
First Use Date: TBD
Status: In Development
Reach (m): 10
Degrees of Freedom: 7
Grapple Type/Interface: Internal Proprietary Interface, Camera, Tool Change Capability

8.1.41 RM41: S2

Description: The S2, developed by GITAI, is a dual autonomous robotic arm system that completed demonstrations outside of the NanoRacks Bishop airlock of the ISS in 2024 through Project GHOST. The S2 has 7+1 degrees of freedom and a tool change capability, allowing for various mounted end effectors. The S2 arrived at the ISS on February 1st, 2024.
Developer: GITAI
Country: Japan
First Use Date: 2024
Status: Completed
Reach (m): 1.5
Degrees of Freedom: 7 + 1
Grapple Type/Interface: Two Finger Gripper, Camera, Tool Change Capability

8.1.42 RM42: Scaling Omnidirectional Lattice Locomoting Explorer (SOLL-E)

Description: The Scaling Omnidirectional Lattice Locomoting Explorer (SOLL-E) serves as the ARMADAS cargo robot. It is used for material transport and placement through an inchworming process on the exterior of the structure.
Developer: NASA Ames Research Center (ARC)
Country: United States
First Use Date: TBD
Status: In Development
Reach (m): 0.7
Degrees of Freedom: 5 locomotion + 8 end effector
Grapple Type/Interface: External Framework Gripping Interface

8.1.43 RM43: Sierra Lobo Arm Compact 1 (SLAC1)

Description: Sierra Lobo has developed a robot arm called Sierra Lobo Arm Compact one (SLAC1) for use inside volumes as small as a CubeSat. SLAC1 has 3-degrees of freedom, excluding the end effector, and simple kinematics which can support autonomous or direct human control tasks.
Developer: Sierra Lobo
Country: United States
Status: In Development
Reach (m): 0.1
Degrees of Freedom: 3
Grapple Type/Interface: Three-finger claw end effector

8.1.44 RM44: Space Infrastructure Dexterous Robot (SPIDER)

Description: The OSAM-1 spacecraft intended to include an attached payload called Space Infrastructure Dexterous Robot (SPIDER). SPIDER contains a lightweight 16-foot (5-meter) robotic arm, bringing the total number of robotic arms on OSAM-1 to three. Previously known as Dragonfly during the ground demonstration phase of a NASA Tipping Point partnership, SPIDER planned to assemble seven elements to form a functional 9-foot (3-meter) communications antenna.
Developer: Maxar Technologies
Country: United States
Status: Concluded
Reach (m): 5
Degrees of Freedom: 7
Grapple Type/Interface: MDA-Provided Dexterous End Effector
Cross Listing: SMA38

8.1.45 RM45: STAARK

Description: STAARK is a modular, customizable robotic system developed by Redwire. It has a standardized tool interface to accommodate multiple end-effectors, including Redwire's own grippers. A vision system supports object tracking and provides grasping knowledge for grappling operations. The software enables teleoperation, assisted operation, and supervised autonomous operations. STAARK has two configurations: a 1 m length variant and a 2 m length variant.
Developer: Redwire Corporation
Country: United States
First Use Date: TBD
Status: In Development
Reach (m): 1.92
Degrees of Freedom: 6
Grapple Type/Interface: Multiple

8.1.46 RM46: Strela Cargo Cranes

Description: Strela is a class of four Russian built cargo cranes used during EVAs to move cosmonauts and components around the exterior of the Soviet/Russian space station Mir and the Russian Orbital Segment of the International Space Station. Both telescoping booms extend like fishing rods and are used to move massive components outside the station.
Developer: Russia
Country: Russia
First Use Date: 1986
Status: Operational
Reach (m): 14
Degrees of Freedom: Unavailable
Grapple Type/Interface: Unavailable

8.1.47 RM47: Tendon-Actuated Lightweight In-Space MANipulator (TALISMAN)

Description: The Tendon-Actuated Lightweight In-Space MANipulator (TALISMAN) is a long reach manipulator arm that can be used for satellite servicing, small payload delivery, and large space observatory assembly. TALISMAN uses a series of tension members for stiffening so that it can actively change the geometry of the components during operation.
Developer: NASA Langley Research Center (LaRC)
Country: United States
Status: Concluded
Reach (m): 20
Degrees of Freedom: 5
Grapple Type/Interface: Swappable End effector

8.1.48 RM48: Tiangong-2 Space Robot (TG-2 Space Robot)

Description: The TG-2 Space Robot is a 6-degree-of-freedom robotic arm installed on the Tiangong-2 Chinese space station. The robot is equipped with a five-finger humanoid end-effector which enables coordination with astronauts to perform activities such as grasping of floating objects, a handshake with an astronaut, on-orbit maintenance activities, and teleoperations. For simulated maintenance, the robot completed tasks such as tearing multilayer protection, using an electric tool to loosen a bolt, and screwing in an electrical connector.
Developer: Harbin Institute of Technology (HIT)
Country: China
First Use Date: 2016
Status: Completed
Reach (m): Unavailable
Degrees of Freedom: 6
Grapple Type/Interface: Dexterous Robotic Hand

8.1.49 RM49: Walking Manipulator (WM)

Description: Space Applications Services developed a seven joint symmetrical robotic arm, equipped with standard interconnects as end effectors, called the Walking Manipulator (WM). The WM can move or carry payloads over large distances and offers a wide range of motion compared to a fixed or tracked manipulator systems. In July 2021, the Modular and Reconfigurable Spacecraft (MOSAR) project ended with a demonstration on Earth, showcasing WM's ability to organize and assemble square payloads.
Developer: Space Applications Services
Country: Belgium
Status: Concluded
Reach (m): 1.2
Degrees of Freedom: Unavailable
Grapple Type/Interface: HOTDOCK Interface, cameras on end-effector

8.1.50 RM50: xLink Robotic Arm

Description: The Motiv xLink robotic arm was initially developed for NASA's OSAM-2 mission to position 3D printed solar array elements, connect deployable solar arrays, and position the onboard 3D printer. The xLink system can perform on-orbit assembly and manipulation tasks and can be deployed across different platforms and use cases.
Developer: Motiv Space Systems
Country: United States
Status: In Development
Reach (m): 1-3
Degrees of Freedom: 4-7
Grapple Type/Interface: Unavailable

8.2 RPO, Capture, Docking, and Mating

8.2.1 RCDM001: Active Debris Removal by Astroscale - Japan (ADRAS-J)

Description: Active Debris Removal by Astroscale - Japan (ADRAS-J) was a mission to safely approach and characterize an existing piece of large debris. The ADRAS-J spacecraft was selected by JAXA for Phase I of its Commercial Removal of Debris Demonstration (CRD2) Project and was launched in February 2024 from New Zealand on a Rocket Lab Electron. The spacecraft successfully approached and inspected an H2A rocket body which was launched in 2009. The position of the uncooperative rocket body was initially communicated to the ADRAS-J spacecraft through ground-based observations, after which onboard systems executed closer RPO activities. At its final approach, the spacecraft maneuvered within 15 meters of the client object, a historic feat in RPO. In August of 2024, Astroscale Japan announced it had been selected by JAXA for a second mission titled ADRAS-J2, in which another spacecraft would travel to the H2A rocket body, grapple it, and lower its orbit for eventual disposal.
Developer: Astroscale, Japan Aerospace Exploration Agency (JAXA)
Country: Japan
First Use Date: 2024
Status: Completed
Contact vs. Non-contact: Non-Contact
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Non-Cooperative
Cross Listing: IM01

8.2.2 RCDM002: AeroCube-10

Description: The AeroCube-10 demonstration mission was a pair of 1.5U CubeSats (one with 28 deployable atmospheric probes and a laser beacon, another with a camera and propulsion system). AC-10B entered "orbit" around AC-10A and used its onboard camera to take resolved images of AC-10A. AC-10B took photos from 22 meters away.
Developer: The Aerospace Corporation
Country: United States
First Use Date: 2019
Status: Completed
Contact vs. Non-contact: Non-Contact
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Unavailable
Cross Listing: IM02

8.2.3 RCDM003: Androgynous Peripheral Attachment System (APAS)

Description: The Androgynous Peripheral Attachment System (APAS) is an androgynous docking mechanism used on the ISS. The system was first used on the ISS between the United States Pressurized Mating Adapter 1 and the Russian Functional Cargo Block (FGB, also known as Zarya).
Developer: RKK Energiya
Country: United States, USSR
First Use Date: 1975
Status: Operational
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: PRMUI02

8.2.4 RCDM004: Aolong-1

Description: Aolong-1 is a Chinese developed satellite which demonstrated the removal of a simulated space debris object from orbit. The satellite captured the space debris and altered the trajectory to de-orbit in Earth's atmosphere.
Developer: National University of Defense Technology (NUDT), People's Liberation Army (PLA)
Country: China
First Use Date: 2016
Status: Completed
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Non-Cooperative
Cross Listing: R01

8.2.5 RCDM005: Apollo-Soyuz Test Project Docking Module (ASTP-DM)

Description: The Apollo-Soyuz Test Project Docking Module (ASTP-DM) was a modification made to the Apollo Command and Service Module to allow for mating with the Soyuz spacecraft. The module was designed jointly by the United States and USSR, but it was constructed in the United States.
Developer: North American Rockwell
Country: United States, USSR
First Use Date: 1975
Status: Completed
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative

8.2.6 RCDM006: Argon Autonomous Rendezvous and Docking Sensor (Argon AR&D Sensor)

Description: Argon was a ground-based demonstration module created to test technologies needed to perform rendezvous and proximity operations (RPO) in space. The integrated system consisted of a LIDAR sensor, a group of optical cameras, and a situational awareness camera to verify analyses. Although Argon was not designed to fly in space, the algorithms and capabilities tested will be used in future flight-ready RPO systems.
Developer: NASA Goddard Space Flight Center (GSFC)
Country: United States
First Use Date: 2012
Status: Completed
Contact vs. Non-contact: Non-Contact
Max RPO Initiation Distance (m): 90
Cooperative vs. Non-cooperative client: Non-cooperative

8.2.7 RCDM007: ArgUS Multi-Payload Adapter (ArgUS)

Description: The ArgUS Multi-Payload Adapter is a payload platform developed to increase the utility of the Bartolomeo Platform System. It is able to host up to 5 smaller payloads while only using a single Bartolomeo slot. Depending on the configuration, the ArgUS can accommodate payloads ranging from 1U all the way to 200U. Onboard interfaces add power and data capabilities to the adapter as well, with up to 760 W of power available to share amongst 5 payloads.
Developer: Airbus
Country: United States
First Use Date: 2024
Status: Operational
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: PRMUI03

8.2.8 RCDM008: ASSIST Pro

Description: An element in ESA's In-Space Proof-of-Concepts (InSPoC) Initiative, GMV's ASSIST Pro docking system provides soft capture capabilities to spacecraft. It is currently undergoing ground testing at ESA's Orbital Robotics Laboratory, where the system is performing docking operations in a simulated weightless environment. With InSPoC being a initiative under the Future Launcher Preparatory Programme (FLPP), the ASSIST Pro system design phase will conclude in an In-Orbit Demonstration.
Developer: GMV, European Space Agency (ESA)
Country: Spain, ESA
First Use Date: TBD
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative

8.2.9 RCDM009: Asteria

Description: Asteria is an adhesive technology allowing for payload attachment to an unprepared client. The technology functions without continuous power input and provides attachment to a wide range of materials.
Developer: Kall Morris Inc
Country: United States
First Use Date: TBD
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Cooperative vs. Non-cooperative client: Both

8.2.10 RCDM010: Astroscale Docking Plate (Astroscale Docking Plate)

Description: Astroscale developed a docking plate grapple interface to "future-proof" satellites. This plate, complete with fiducial markers and retroreflectors, is made to allow servicing spacecraft to connect to it for servicing and relocation. It was developed with the consideration of several sustainability-based standards/practices in mind, including the Space Safety Coalition's Best Practices for Sustainability of Space Operations, the Space Sustainability Rating, and CONFERS. In 2025, Astroscale UK announced the first large-scale order of their docking plates to Airbus Defence and Space.
Developer: Astroscale
Country: United States
First Use Date: 2021
Status: Operational
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative

8.2.11 RCDM011: Astroscale Prototype Servicer for Refueling (APS-R)

Description: Astroscale Prototype Servicer for Refueling (APS-R) is a propellant delivery vehicle which will operate in GEO. The vehicle will collect hydrazine from the DIU RAPIDS Kamino fuel depot and deliver the propellant to a client within GEO, such as the Astroscale LEXI vehicle. The vehicle will be ESPA class and will be constructed at the Southwest Research Institute's facility in San Antonio, Texas.
Developer: Astroscale
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: RFT02

8.2.12 RCDM012: Augmentation System Port Interface (ASPIN)

Description: The Augmentation System Port Interface (ASPIN) is a spacecraft interface based on the Mission Augmentation Port (MAP), an open-source docking standard also developed by Lockheed Martin. This interface is capable of providing a mechanical, data, and electrical connection between spacecraft.
Developer: Lockheed Martin
Country: United States
First Use Date: TBD
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: PRMUI04

8.2.13 RCDM013: Automated Navigation and Guidance Experiment for Local Space (ANGELS)

Description: Automated Navigation and Guidance Experiment for Local Space (ANGELS) evaluated space situational awareness techniques in the region around its Delta IV launch vehicle upper stage. The mission began with experiments approximately 50 km away from the upper stage and progressed to within several kilometers using ground-commanded authorization to proceed at points throughout the experiment.
Developer: Air Force Research Laboratory (AFRL)
Country: United States
First Use Date: 2014
Status: Completed
Contact vs. Non-contact: Non-Contact
Max RPO Initiation Distance (m): 50000
Cooperative vs. Non-cooperative client: Non-cooperative
Cross Listing: IM03

8.2.14 RCDM014: Autonomous Vision Approach Navigation and Target Identification (AVANTI)

Description: The Autonomous Vision Approach Navigation and Target Identification (AVANTI) mission was an autonomous rendezvous and proximity operations demonstration mission performed in 2018. The demonstrations included autonomous vision-based rendezvous with a passive target and closer proximity operations supported by a more extensive sensor suite. The small satellite BIROS was used to approach the noncooperative BEESAT-4 CubeSat to a distance of 50 m.
Developer: German Space Agency (DLR)
Country: Germany
First Use Date: 2018
Status: Completed
Contact vs. Non-contact: Non-Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Non-Cooperative

8.2.15 RCDM015: AXON/Dactylus

Description: Tethers Unlimited's AXON connector was a low-profile soft capture end effector that could be used to connect two spacecraft together in orbit. The Dactylus servicing tool was a robotic tool that could be used for in-space servicing of satellites. The Dactylus tool was designed to be used with the KRAKEN robotic arm and the AXON connector to enable small robotic systems to perform complex servicing tasks on large space systems.
Developer: Tethers Unlimited Inc
Country: United States
Status: Concluded
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: PRMUI05

8.2.16 RCDM016: Biclops

Description: Biclops utilizes the stereo-camera pair of the Triclops system as a separate product offering depth-sensing, spatial object detection, and 3D mapping. The cameras can be programmed to operate asynchronously, offering different fields of view or orthogonal camera directions. The entire system is housed in a 1U CubeSat footprint.
Developer: TRL11
Country: United States
First Use Date: TBD
Status: In Development
Contact vs. Non-contact: Non-Contact
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Both
Cross Listing: IM04

8.2.17 RCDM017: Capture Bay for Active Debris Removal In-Orbit Demonstration (CAT-IOD)

Description: This mission, developed by GMV and AVS under ESA guidance, will test several ISAM systems in the context of an Active Debris Removal mission. Developed under the guidelines of ESA's Design for Removal (D4R) Standards, the mission intends to test technologies such as the Capture Bay for Active Debris Removal (CAT) and the Mechanical Interface for Capture and Extraction (MICE). The mission will use the ELSA-M platform from Astroscale as the spacecraft platform. The mission will use close-proximity navigation aids to align itself with debris and a robotic arm with the MICE system to capture the debris. The target is AVS's LUR-1 satellite.
Developer: GMV, AVS, European Space Agency (ESA), Astroscale
Country: Spain, ESA
First Use Date: TBD
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): <50 m for mid-range relative navigation, potential systems for large range
Cooperative vs. Non-cooperative client: Both
Cross Listing: R03

8.2.18 RCDM018: ClearSpace-1

Description: ClearSpace-1 is a planned orbital debris remediation mission developed by ClearSpace and funded by ESA. The mission is to use a spacecraft with a 4-pronged capture system to grab ESA's PROBA-1 satellite in LEO. The mission will conclude with both objects being destroyed while re-entering the Earth's atmosphere.
Developer: ClearSpace, OHB
Country: Switzerland, Germany, ESA
First Use Date: Scheduled for 2028
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Non-cooperative
Cross Listing: R05

8.2.19 RCDM019: CubeSat Proximity Operations Demonstration (CPOD)

Description: The CubeSat Proximity Operations Demonstration (CPOD) project was a NASA project intending to demonstrate rendezvous, proximity operations, and docking between two spacecraft. The spacecraft, each a 3-unit CubeSat, were equipped with docking mechanisms, cold gas thrusters, and sensor suites to support rendezvous and proximity operations. The mission ended before completion of mission goals due to anomalies in the guidance, navigation, and control systems.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2022
Status: Concluded
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative

8.2.20 RCDM020: Démonstration d'Inspection et Amarrage Novatrice Embarquée (DIANE)

Description: The DIANE mission, led by Thales Alenia Space, is a demonstration of rendezvous, capture and inspection capabilities. Supported by the French space agency CNES, the mission will use a pair of spacecraft which are a part of the European Robotic Orbital Support Services (EROSS) program. EROSS intends to use two spacecraft to test rendezvous and servicing using a robot arm. After the EROSS demonstration, DIANE will spin the client satellite in order to represent loss of attitude and orbit control. From there, the mission will demonstrate the ability to capture and inspect a now uncontrolled spacecraft. The two spacecraft are slated to launch before the end of 2028.
Developer: Thales Alenia Space
Country: France, Italy, European Union
First Use Date: Scheduled for 2028
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Non-Cooperative
Cross Listing: IM05

8.2.21 RCDM021: Demonstration for Autonomous Rendezvous Technology (DART)

Description: Demonstration for Autonomous Rendezvous Technology (DART) was a spacecraft launched in April of 2005 intended to demonstrate autonomous rendezvous and proximity operations with the Multiple Paths, Beyond-Line-of-Sight Communications (MUBLCOM) satellite. DART performed expected operations through the rendezvous phase of the mission, but anomalies during the close proximity phase of the mission led to a collision with the MUBLCOM spacecraft and an early conclusion of the mission.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2005
Status: Concluded
Contact vs. Non-contact: Non-Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Non-Cooperative

8.2.22 RCDM022: Docking and Fluid Transfer Port (DFT Port)

Description: The Docking and Fluid Transfer Port is an in-space interface that provides mechanical, data, and refueling connections for satellite servicing operations. The docking port may be used for missions such as life extension, relocation, and active debris removal.
Developer: Dawn Aerospace
Country: Netherlands/New Zealand
First Use Date: TBD
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: PRMUI06, RFT07

8.2.23 RCDM023: DogTag

Description: DogTag is a mechanical grapple fixture with fiducials that is compatible with magnetic, electroadhesive, gecko grip, or mechanical pinch grasping. As of February 2022, over 300 DogTags have been launched into space aboard OneWeb satellites.
Developer: Altius Space Machines Inc
Country: United States
First Use Date: 2021
Status: Operational
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): 5
Cooperative vs. Non-cooperative client: Cooperative

8.2.24 RCDM024: Elytra

Description: Elytra is an ESPA-based electric space tug system designed to launch with Firefly Aerospace's Alpha launch vehicle, Medium Launch Vehicle (MLV), and potentially other launch vehicles. The three classes of Elytra vehicles, Dawn, Dusk, and Dark, provide expanding capabilities to clients, including payload hosting, final orbit delivery, LEO to GEO transfer, and lunar orbit transfer. Elytra is expected to perform demonstrations on orbit no earlier than 2025 and a variant will serve as a transfer vehicle for Firefly's Blue Ghost Mission 2 to the lunar surface in 2026. The vehicle can deliver 2,700 kg of payload capacity to lunar orbit with the ability to provide on-orbit services for up to 5 years. It also has sufficient propellant reserve to enable a variety of advanced mission opportunities, such as lunar sample return to Earth and further exploration to nearby planets like Mars and Venus.
Developer: Firefly Aerospace
Country: United States
First Use Date: Scheduled for 2025
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: R06, IM06

8.2.25 RCDM025: End-of-Life Service by Astroscale - Multiple (ELSA-M)

Description: The End-of-Life Service by Astroscale - Multiple (ELSA-M) servicer spacecraft is intended to provide end-of-life services to satellites with a compatible magnetic capture mechanism, such as the Astroscale Docking Plate. The spacecraft will use chemical and electric propulsion and will be capable of approaching non-compliant or tumbling clients.
Developer: Astroscale
Country: Japan
First Use Date: Scheduled for 2026
Status: In Development
Contact vs. Non-contact: Contact
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Non-Cooperative
Cross Listing: R07

8.2.26 RCDM026: End-of-Life Services by Astroscale - demonstration (ELSA-d)

Description: The End-of-Life Services by Astroscale - demonstration (ELSA-d) mission consists of a servicer satellite and a client satellite launched together. The servicer satellite was developed to safely remove debris objects from orbit, equipped with proximity rendezvous technologies and a magnetic docking mechanism. The client satellite simulated a piece of debris fitted with a ferromagnetic plate to enable docking with the servicer satellite.
Developer: Astroscale
Country: Japan
First Use Date: 2021
Status: Completed
Contact vs. Non-contact: Contact
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: R08

8.2.27 RCDM027: Enduralock Satellite Connector

Description: Enduralock is a small satellite interface which provides mechanical, data/power, and fuel transfer connection between spacecraft. The interface is intended to occupy a 1 cm cubic volume and incorporates features to allow for the misalignment expected during autonomous docking between spacecraft.
Developer: Enduralock
Country: United States
First Use Date: TBD
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: 4/5 degrees +/- pitch/yaw/roll
4 mm +/- Radial
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: PRMUI07, RFT09

8.2.28 RCDM028: Engineering Test Satellite VII (ETS-VII)

Description: Engineering Test Satellite VII (ETS-VII, Japanese nickname Kiku7) was a NASDA (which is now part of JAXA) technology demonstration satellite. The overall mission objectives were to conduct space robotic experiments with an onboard 2-meter arm and to demonstrate its utility for uncrewed orbital operation and servicing tasks (e.g., rendezvous-docking techniques).
Developer: National Space Development Agency of Japan (NASDA)
Country: Japan
First Use Date: 1998
Status: Completed
Contact vs. Non-contact: Contact
Misalignment Tolerance: 1.3 mm arm tolerance
Max RPO Initiation Distance (m): 10000
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: RM11

8.2.29 RCDM029: European Robotic Orbital Support Services - Servicing Component (EROSS-SC)

Description: The European Robotic Orbital Support Services (EROSS) project is focused on developing technologies to support orbital operations in LEO and GEO. It has evolved through several phases and is now scoped to develop an operational mission demonstrating docking, rendezvous, inspection, and other servicing capabilities. Funded through the European Commission and led by Thales Alenia Space, the EROSS-SC mission is scheduled for an In-Orbit Demonstration (IOD) in 2026, followed by an operational mission in 2027-2028.
Developer: Thales Alenia Space, European Commission (EC)
Country: European Union
First Use Date: Scheduled for 2028
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: RFT10, IM07

8.2.30 RCDM030: eXperimental Small Satellite 10 (XSS-10)

Description: eXperimental Small Satellite 10 (XSS-10) was a micro-satellite with objectives to demonstrate autonomous navigation, proximity operations, and inspection of another space object. The satellite was launched and completed operations, including the imaging of a Delta II upper stage, in 2003.
Developer: Air Force Research Laboratory (AFRL)
Country: United States
First Use Date: 2003
Status: Completed
Contact vs. Non-contact: Non-Contact
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Non-cooperative
Cross Listing: IM08

8.2.31 RCDM031: eXperimental Small Satellite 11 (XSS-11)

Description: eXperimental Small Satellite 11 (XSS-11) was a micro-satellite demonstrating rendezvous and proximity operations with an expended rocket body. XSS-11 demonstrated technologies necessary to plan and evaluate autonomous rendezvous and proximity operations with an expended rocket body and other space objects near its orbit.
Developer: Air Force Research Laboratory (AFRL)
Country: United States
First Use Date: 2005
Status: Completed
Contact vs. Non-contact: Non-Contact
Max RPO Initiation Distance (m): 5000
Cooperative vs. Non-cooperative client: Non-cooperative
Cross Listing: IM09

8.2.32 RCDM032: Flight Releasable Attachment Mechanism (FRAM)

Description: The Flight Releasable Attachment Mechanism (FRAM) is a system used for hosting payloads aboard the ISS, specifically externally at locations such as the Expedite the Processing of Experiments to Space Station (ExPRESS) Logistics Carrier (ELC). ELCs provide unpressurized areas for payload attachment, allowing for mechanical attachment, as well as power and data connections. FRAMs are used to connect payloads to these locations, primarily through robotic systems on the ISS such as Dextre. FRAMs consist of a passive half located on the ELC, and an active half on the payload itself.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: Unavailable
Status: Operational
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: PRMUI08

8.2.33 RCDM033: Flight Releasable Grapple Fixture (FRGF)

Description: The Flight Releasable Grapple Fixture is an interface utilized by Canadarm2 (aka the Space Station Remote Manipulator System) on the ISS. It is one of several interfaces used by the SSRMS to berth and stow payloads, as well as to move around the ISS. The FRGF is the simplest grapple fixture variant, consisting solely of a grapple shaft for the Canadarm2's Latching End Effector to ensnare.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1984
Status: Operational
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative

8.2.34 RCDM034: FuseBlox

Description: FuseBlox is an androgynous interface providing mechanical, electrical, and data connections. It received Phase II SBIR funding from AFRL. In 2025, SpaceWorks announced the Fuseblox system will be hosted on Rogue Space Systems Corporation's Orbital Test Platform 3 (OTP-3) mission. Stated to launch in 2026, OTP-3 will use Fuseblox to enable docking, power/data transfer, and eventual refueling capabilities to the spacecraft.
Developer: SpaceWorks Enterprises Inc
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Unavailable
Cross Listing: PRMUI09

8.2.35 RCDM035: Geosynchronous Space Situational Awareness Program (GSSAP)

Description: Geosynchronous Space Situational Awareness Program (GSSAP) is a program out of the United States Space Force which involves the use of satellites near geosynchronous orbit to perform space surveillance operations. The space surveillance operations performed include rendezvous and proximity operations with resident space objects to characterize anomalies and provide data to enhance knowledge of the environment.
Developer: United States Space Force
Country: United States
First Use Date: 2014
Status: Operational
Contact vs. Non-contact: Non-Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Non-Cooperative

8.2.36 RCDM036: Grappling Resupply Interface for Products (GRIP)

Description: The Grappling Resupply Interface for Products (GRIP) is the active mating component to the RAFTI refueling interface. The GRIP interface is mounted on the servicing spacecraft and provides mechanical connection and refueling to the client. GRIP will be used in conjunction with RAFTI ports on the two Tetra-5 satellites projected to launch in 2026. Astroscale will also be using RAFTI and GRIP in a servicing vehicle being developed for the U.S. Space Force in 2026.
Developer: Orbit Fab
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: +/- 12.5 mm in X/Y Axes
+/- 30 mm in Z Axis
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: RFT15

8.2.37 RCDM037: Guideless Resilient Androgynous Serial Port (GRASP)

Description: The GRASP modular interface, developed by Champaign-Urbana Aerospace, provides mechanical, power, and data transfer between spacecraft during in-space operations. The interface has been terrestrially demonstrated for use cases such as modular assembly, free-flier capture, and mismatched capture scenarios.
Developer: Champaign-Urbana Aerospace
Country: USA
First Use Date: TBD
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Tested at 2 degrees Pitch & Roll mismatch
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Unavailable
Cross Listing: PRMUI12

8.2.38 RCDM038: HelioSwarm

Description: The HelioSwarm mission is a constellation of nine spacecraft that will capture multiple in-space measurements of solar wind and magnetic field fluctuations from different points in space. HelioSwarm will consist of one hub spacecraft and eight co-orbiting small satellites that range in distance from each other and the hub spacecraft.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: Scheduled for 2028
Status: In Development
Contact vs. Non-contact: Non-Contact
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative

8.2.39 RCDM039: H-Fixture

Description: The H-Fixture is an interface compatible with the Special Purpose Dexterous Manipulator (SPDM) robotic system, also known as Dextre. Using the ORU Tool Changeout Mechanism (OCTM), Dextre can directly grasp the H-fixture. This interface is specifically used in high-load or high-mass payload cases. Like other Dextre interfaces, the H-Fixture allows for umbilical connection to provide power, data, and video to payloads.
Developer: Canadian Space Agency (CSA), MDA Space
Country: Canada
First Use Date: Unavailable
Status: Operational
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: PRMUI13

8.2.40 RCDM040: HOTDOCK

Description: HOTDOCK is an androgynous standard interface supporting mechanical, electrical, data, and (optionally) thermal interconnect. It is used especially for robotic arm interfacing. The MOSAR-WM walking robotic arm, developed by Space Application Services and DLR, used this as the standard interface.
Developer: Space Applications Services
Country: Belgium
First Use Date: TBD
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: +/- 15mm translational on 3 axes
+/- 10 degrees angular on 3 axes
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Unavailable
Cross Listing: PRMUI14

8.2.41 RCDM041: Hubble Servicing Mission 1 (Hubble SM1)

Description: The crew of STS-61 (Servicing Mission 1, SM1) addressed the Hubble's primary mirror spherical aberration by installing the Corrective Optics Space Telescope Axial Replacement (COSTAR) Orbital Replacement Unit (ORU) and performed upgrades and replacements to address other issues during five total EVAs. The upgrades and replacements included installing new magnetometers in place of degrading units, a new pair of solar arrays and solar array drive electronics to mitigate a mechanical oscillation caused by thermal expansion, an upgraded Wide Field & Planetary Camera (WFPC2) instrument, a coprocessor for the DF-224 computer to mitigate failure of two memory units, two Rate Sensor Units (RSU) each containing two gyros, and other minor components. A 7 km re-boost was performed at the end of the mission and an improvised temporary solution to capture debris coming from flaked-off coating from the old magnetometers was constructed by the crew with onboard materials.

Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1993
Status: Completed
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: R09, PRMUI15, URMUI03

8.2.42 RCDM042: Hubble Servicing Mission 2 (Hubble SM2)

Description: STS-82 (Servicing Mission 2, SM2) was the second planned Hubble servicing mission. It focused on increasing the telescope's productivity with the installation of new instruments that extended Hubble's wavelength range into the near infrared for imaging and spectroscopy. Through four planned EVAs, failed and degraded components were replaced, and some upgrades were performed to older equipment. The tasks included replacement of the outdated Goddard High Resolution Spectrograph (GHRS) and Faint Object Spectrometer (FOS) by the Space Telescope Imaging Spectrograph (STIS) and Near-Infrared Camera and Multi-Object Spectrometer (NICMOS) instruments, respectively, to increase spectral range of the telescope, upgrade of tape recorder #1 from a reel-to-reel recorder to a Solid State Recorder which could store 10 times more data, direct replacement of the degraded tape recorder #2 by a spare unit, replacement of the degraded Fine Guidance Sensor #1 (FGS-1) by an upgraded unit with the added capability of ground-controlled alignment corrections, replacement of the degraded Reaction Wheel Assembly #1 (RWA-1), covering worn MLI at the top of the telescope's tube with Patch Kit Thermal Insulation Blankets, installing permanent magnetometer covers over the temporary ones installed in SM-1, and replacement of the Solar Array Drive Electronics #1 (SADE-1) with a refurbished unit. Since damage to the MLI was greater than anticipated, a fifth EVA was conducted to cover degraded MLI with sheets manufactured by the crew with onboard materials. A re-boost was performed to raise Hubble's orbit by 16 km.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1997
Status: Completed
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: R10, PRMUI16, URMUI04

8.2.43 RCDM043: Hubble Servicing Mission 3A (Hubble SM3A)

Description: STS-103 (Servicing Mission 3A, SM3A) was originally scheduled for June 2000 as the third planned Hubble servicing mission for preventive maintenance but became more urgent after four of the six gyros on the telescope failed, with the HST requiring at least 3 to operate. It was divided into two parts, the first of which was SM3A. The telescope was placed in safe mode on November 13, 1999, when the fourth gyro failed until the launch and arrival of SM3A on December 19, 1999. Tasks performed during three EVAs included replacement of all three Rate Sensor Units (each containing two gyros), replacement of the Fine Guidance Sensor #2 (FGS-2) by an upgraded and refurbished unit, replacement of the faulty S-Band Single Access Transmitter #2 (SSAT-2), replacement the DF-224 main computer by the more capable Advanced Computer, installation of Battery Voltage/Temperature Improvement Kits (VIKs) for increased interoperability between the batteries and solar arrays by preventing overcharging and overheating, upgrade of tape recorder #3 to Solid State Recorder (SSR), and installation of handrail covers made to prevent possible contamination from flaking paint. The New Outer Blanket Layer (NOBL) and Shell/Shield Replacement (SSR) fabric MLI kits were used to cover MLI which had been greatly degraded by embrittlement and cracks caused by exposure to charged particles, thermal cycling, and other environmental effects.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1999
Status: Completed
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: PRMUI17, URMUI05

8.2.44 RCDM044: Hubble Servicing Mission 3B (Hubble SM3B)

Description: STS-109 (Servicing Mission 3B, SM3B) was the fourth servicing mission for the Hubble in 2002 and the continuation to the third servicing mission (SM3A) in 1999, as SM3 was split into two parts. With five total EVAs, replacement and upgrade tasks in this mission included direct replacement of the Reaction Wheel Assembly #1 (RWA), replacement of the Faint Object Camera (FOC) for the Advanced Camera for Surveys (ACS), upgrade of the Solar Arrays 2 (SA-2) to the rigid, smaller, and more efficient SA-3, upgrade of the Power Control Unit (PCU) to eliminate intermittent issues and handle the extra power generated by the new solar arrays, installation of the Near Infrared Camera and Multi-Object Spectrometer (NICMOS) Cryocooler and its supporting electronics to revive the NICMOS instrument and extend its lifetime by providing necessary cooling, and installation of New Outer Blanket Layer (NOBL) sheets over damaged MLI on bays 5, 6, 7, and 8. At the end of this mission, a 6.3 km re-boost took place to extend Hubble's mission lifetime, being the last re-boost performed on Hubble servicing missions.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2002
Status: Completed
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: R11, PRMUI18, URMUI06

8.2.45 RCDM045: Hubble Servicing Mission 4 (Hubble SM4)

Description: STS-125 (Servicing Mission 4, SM4) was the fifth and currently final servicing mission to the HST in May of 2009. This mission focused on performing basic maintenance replacements, upgrades to instruments, and the addition of some new components through five EVAs. Direct maintenance replacements included three Rate Sensor Units (RSUs) which had degraded, all six battery modules which had not been replaced/serviced since launch, a Fine Guidance Sensor (FGS) to replace the degraded FGS-2, repairs for the Advanced Camera for Surveys (ACS) which included the external installation of a Low Voltage Power Supply (LVPS) in conjunction with the replacement of the four Wide Field Channel (WFC) control boxes by the Charged Couple Device (CCD) Electronics Box to restore functionality to the ACS's WFC which was out of service due to a serious power failure, and a Science Instrument Control and Data Handling (SIC&DH) unit due to failed electronics on the original one. For upgrades, the Wide Field and Planetary Camera 2 (WFPC-2) was replaced for the Wide Field Camera 3 (WFC-3) to increase spectral range, the STIS Low Voltage Power Supply (LVPS) card #2 was replaced by a new version, and the COSTAR , which was added during SM1, was replaced by a new instrument called the Cosmic Origins Spectrograph (COS), which is the most powerful UV spectrograph ever flown on Hubble. Components added included NOBL sheets placed over damaged MLI on bays 5, 7, and 8 and a new Soft Capture Mechanism (SCM) for potential future RPOC operations including deorbiting.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2009
Status: Completed
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: R12, PRMUI19, URMUI07

8.2.46 RCDM046: intelligent Space System Interface (iSSI)

Description: The intelligent Space System Interface (iSSI) is a standardized modular interface which allows for the possibility of on-orbit servicing and the in-orbit replacement of common infrastructure elements. The modularity approach focuses on a 4-in-1 interface for mechanical coupling as well as power, data, and thermal interconnection. The interface was successfully tested on orbit in 2022 during the iSSI-FQE (Flight Qualification Experiment) while attached to the Kibo external platform on the ISS.
Developer: iBOSS, German Space Agency (DLR)
Country: Germany
First Use Date: 2022
Status: Operational
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Unavailable
Cross Listing: PRMUI20

8.2.47 RCDM047: International Berthing and Docking Mechanism (IBDM)

Description: The International Berthing & Docking Mechanism (IBDM) is a docking mechanism being developed by the ESA which is composed of a soft docking system to facilitate spacecraft alignment, mechanical latches to achieve soft capture, and a hard docking system to create a sealed interface. The androgynous docking system is contact-force sensing, magnetically latched for capture, low impact, and capable of docking and berthing large and small vehicles. This docking system may be used on the Dream Chaser spacecraft to support docking to the ISS.
Developer: European Space Agency (ESA), QinetiQ Space, Sierra Nevada Corporation, SENER, RUAG, Maxon Group
Country: ESA
First Use Date: TBD
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Both
Cross Listing: PRMUI21

8.2.48 RCDM048: Jackal

Description: Jackal is a new class of space vehicle, purpose-built for national security space missions. The first two Jackal spacecraft launched in March 2024. The mission intended one Jackal spacecraft to capture high-resolution images and full motion video of the other while maneuvering in close proximity; however, the mission ended prematurely due to communications issues with the spacecraft. In December of 2024, another Jackal spacecraft was launched into orbit and is currently in space evaluating critical orbital maneuvering capabilities. Future iterations of the Jackal spacecraft will conduct orbital operations in GEO.
Developer: True Anomaly
Country: United States
First Use Date: 2024
Status: Operational
Contact vs. Non-contact: Non-Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative

8.2.49 RCDM049: Key and Advanced Technology R&D through Cross Community Collaboration Program (K Program)

Description: The K Program was established by Astroscale Japan in incentivizing Rendezvous Proximity Operational Technologies to further demonstrate on-orbit chemical refueling services in LEO orbit as well as ground verification for GEO orbit refueling services for electric propulsion systems. The goal of this is to lead the in-space market for satellite servicing and long-term orbital sustainability. The program will span five years with a total budget of $77 million.
Developer: Astroscale
Country: Japan
First Use Date: TBD
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Non-cooperative
Cross Listing: RFT22

8.2.50 RCDM050: Latchable Grapple Fixture (LGF)

Description: The Latchable Grapple Fixture is an interface used in robotic operations on the ISS. Similar to the Flight Releasable Grapple Fixture, the LGF allows for grappling between payloads and Canadarm2. Where the LGF differs is that it's designed for payloads to be stowed on the Payload ORU Accommodation Unit (PAO), typically for greater than 3 weeks.
Developer: Canadian Space Agency (CSA), MDA Space
Country: Canada
First Use Date: Unavailable
Status: Operational
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative

8.2.51 RCDM051: Launch-Hardened Deploy and Docking Mechanism (LDDM)

Description: The Launch-Hardened Deploy and Docking Mechanism (LDDM) is a reusable satellite docking mechanism currently being developed through a NASA SBIR Phase II. The mechanism is capable of reuse and provides sufficient capture strength to allow spacecraft to launch in a docked configuration. The mechanism utilizes a soft and hard capture system to allow for large misalignment tolerances.
Developer: Apech Labs
Country: United States
First Use Date: TBD
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative

8.2.52 RCDM052: Life Extension In-Orbit (LEXI)

Description: Life Extension In-Orbit (LEXI) is a life extension servicer which will provide station keeping, pointing, and relocation services to satellites throughout GEO. These services include movement to new GEO orbital slots, correction of inclination, and relocation to graveyard orbit. The servicer will use electric propulsion and will dock to the client spacecraft using four robotic arms.
Developer: Astroscale
Country: Japan
First Use Date: Scheduled for 2026
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Both
Cross Listing: R15

8.2.53 RCDM053: Lockheed Martin's In-space Upgrade Satellite System (LINUSS)

Description: Lockheed Martin's In-space Upgrade Satellite System (LINUSS) is a pair of 12U CubeSats within geosynchronous orbit. Launched in 2022, the satellites demonstrated maneuvering technologies for future servicing missions and space domain awareness capabilities. Beyond orbital maneuvering, the LINUSS mission also demonstrated various other capabilities such as machine vision, onboard high-performance processing, and low toxicity-propulsion.
Developer: Lockheed Martin
Country: United States
First Use Date: 2022
Status: Completed
Contact vs. Non-contact: Non-Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Unavailable

8.2.54 RCDM054: Low Profile Grapple Fixture (LPGF)

Description: The Low Profile Grapple Fixture is an interface compatible with MDA's Low Profile End Effector, which will be mounted on the Canadarm3 eXploration Large Arm (XLA) of Gateway. The interface allows for the XLA to capture and manipulate payloads in space. The interface provides a mechanical, power, and data interface between the manipulator and the payload.
Developer: MDA Space
Country: Canada
First Use Date: Scheduled for 2028
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: PRMUI39

8.2.55 RCDM055: MagTag

Description: MagTag is an EPM-based latching connector for enabling repair, fluid transfer, modular upgrades, and payload swapping.
Developer: Altius Space Machines Inc
Country: United States
First Use Date: TBD
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative

8.2.56 RCDM056: Mechanical Interface for Capture and Extraction (MICE)

Description: The MICE interface is a system aiming to be tested on the CAT-IOD ESA-guided mission. It has been built using ESA's Space Debris Mitigation Standard and will aid in the capturing of AVS's LUR-1 microsatellite.
Developer: GMV, AVS, European Space Agency (ESA)
Country: Spain, ESA
First Use Date: TBD
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): <50 m for mid-range relative navigation, potential systems for large range
Cooperative vs. Non-cooperative client: Both

8.2.57 RCDM057: Micro-Conical Fitting (MCF)

Description: First demonstrated on the Space Shuttle in 1995, the Micro-Conical Fitting (MCF) is the passive interface component of the larger Micro-Conical System designed to manipulate payloads on the ISS. It is compatible with the Special Purpose Dexterous Manipulator (SPDM), specifically for when payloads do not have the adequate clearance envelope for the ORU Tool Changeout Mechanism (OTCM). The MCF is directly grasped by the SPDM's Robot Micro-Conical Tool, which has a much smaller clearance envelope when compared to the OTCM.
Developer: Oceaneering International Inc
Country: USA
First Use Date: 1995
Status: Operational
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative

8.2.58 RCDM058: Micro-Fixture

Description: The Micro-Fixture is the standard interface of the Special Purpose Dexterous Manipulator (SPDM) on the ISS. Also known as a Micro-Square, this interface allows for direct grasp with the SPDM, so long as the payload has an adequate clearance envelope around the fixture for the SPDM to operate. The Micro-Fixture also allows for an umbilical connection to provide power, data, and video to the payload.
Developer: Canadian Space Agency (CSA), MDA Space
Country: Canada
First Use Date: Unavailable
Status: Operational
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: PRMUI23

8.2.59 RCDM059: Mission 1

Description: The Atomos Space Mission 1 (colloquially the Singing Astronomer Mission) was an RPO, refueling, and orbital transfer mission which used Atomos' Quark and Gluon spacecraft. The Quark and Gluon spacecraft were launched in a joined state on SpaceX's Falcon 9 Transporter 10 mission. The mission intended for the Quark spacecraft to autonomously RPO and dock to Gluon, Quark to refuel from Gluon, and combined vehicle orbital transfer demonstrations. Due to anomalies experienced during mission initiation, the intended multi-vehicle operations were not performed.
Developer: Atomos Space
Country: United States
First Use Date: 2024
Status: Concluded
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): >100 km for capture in any orbit
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: R17, RFT24

8.2.60 RCDM060: Mission Extension Vehicle (MEV)

Description: The Mission Extension Vehicle (MEV) is the first commercial satellite life extension vehicle, designed to provide relocation services to geostationary satellites. Once connected to its client satellite, MEV uses its own thrusters and propellant supply to extend the satellite's lifetime. When the customer no longer desires MEV's service, the spacecraft undocks and moves on to the next client satellite.
Developer: Northrop Grumman
Country: United States
First Use Date: 2020
Status: Operational
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): 80
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: R19

8.2.61 RCDM061: Mission Robotic Vehicle (MRV)

Description: The Mission Robotic Vehicle (MRV) is a future on-orbit servicing bus developed using technologies and lessons from the Mission Extension Vehicle. The robotic payload will be supplied by DARPA and developed by the United States Naval Research Laboratory as part of the Robotic Servicing of Geosynchronous Satellites (RSGS) mission.
Developer: Northrop Grumman
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Both
Cross Listing: R20, URMUI11

8.2.62 RCDM062: Mycroft

Description: Mycroft is a Space Situational Awareness (SSA) spacecraft that builds upon technology developed for the XSS-10, XSS-11, and ANGELS missions. The spacecraft was launched on the AFRL's ESPA Augmented Geosynchronous Laboratory Environment (EAGLE) to test characterization and navigation capabilities in the surrounding region. Mycroft was also dispatched to inspect AFRL's defunct S5 satellite in GEO.
Developer: Air Force Research Laboratory (AFRL)
Country: United States
First Use Date: 2018
Status: Completed
Contact vs. Non-contact: Non-Contact
Max RPO Initiation Distance (m): 3500
Cooperative vs. Non-cooperative client: Unavailable
Cross Listing: IM15

8.2.63 RCDM063: NASA Docking System (NDS)

Description: The NASA Docking System (NDS) is an androgynous docking system installed on the ISS which meets the International Docking System Standard. This docking system allows for vehicles such as the Orion, Dragon, or Starliner spacecraft to visit the ISS. The Linear Actuator System (LAS), designed and built by MOOG, provides multi-axis independent load control for soft capture docking without a robotic arm. The NDS Block 1 is intended for use with ISS and the Block 2 is intended to be used on Gateway. The Block 2 variant will support fluid transfer through the MOOG fluid transfer coupling, which is capable of transferring xenon, hydrazine, and NTO. A variant of this coupler capable of transferring cryogenic propellants is under development.
Developer: National Aeronautics and Space Administration (NASA), MOOG
Country: United States
First Use Date: 2018
Status: Operational
Contact vs. Non-contact: Contact
Misalignment Tolerance: 0.1 m, 5 degrees in one axis
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: PRMUI26, RFT27

8.2.64 RCDM064: Nautilus

Description: Developed by Starfish Space, the Nautilus capture mechanism attaches to satellites for docking and manipulation. It is reusable and can adhere to multiple capture surfaces, even those not designed for docking. The mechanism can also provide dynamic damping between the servicer and client spacecraft. As a part of the Otter Pup 2 mission launching in June of 2025, the Nautilus system will test electrostatic adherence capabilities on the D-Orbit ION spacecraft client.
Developer: Starfish Space
Country: United States
First Use Date: Scheduled for 2025
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Non-Cooperative

8.2.65 RCDM065: On-orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1)

Description: On-orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) was a spacecraft under development by NASA and Maxar to demonstrate activities required for unplanned satellite mission extension. OSAM-1 was planned to rendezvous with and refuel Landsat 7, which required activities such as cutting insulation, unscrewing bolts and caps, and attaching propellant lines. After completing refuel of Landsat 7, the hosted SPIDER payload would have assembled a communications antenna.
Developer: National Aeronautics and Space Administration (NASA), Maxar Technologies
Country: United States
Status: Concluded
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Non-cooperative
Cross Listing: URMUI13, RFT30

8.2.66 RCDM066: Orbital Express Capture System

Description: Launched March 8, 2007, as part of the United States Air Force Space Test Program (STP), Orbital Express demonstrated automated rendezvous and capture of two spacecraft (ASTRO and NEXTSat), transfer of propellant, and transfer of a modular spacecraft component. Flow sensors demonstrated 5 to 10 percent flow rate error on N2H4 transfer with no significant issues. The mission demonstrated 9 mate/demate cycles on orbit and demonstrated robotic Orbital Replacement Unit (ORU) transfer and installation.
Developer: Sierra Space, Defense Advanced Research Projects Agency (DARPA), National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2007
Status: Completed
Contact vs. Non-contact: Contact
Misalignment Tolerance: 5 degrees +/- pitch/yaw/roll
2 inch +/- lateral
Max RPO Initiation Distance (m): 6-inch axial capture distance
Cooperative vs. Non-cooperative client: Cooperative

8.2.67 RCDM067: OrbitGuard 1

Description: The OrbitGuard 1 satellite is a nanosatellite designed for inspection within geostationary orbit. The satellite can use its autonomous navigation systems and sensor suite to provide customers with space situational awareness or inspection of customer assets.
Developer: Infinite Orbits
Country: Singapore
First Use Date: 2023
Status: Operational
Contact vs. Non-contact: Non-Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Non-Cooperative

8.2.68 RCDM068: Orion Camera Suite

Description: The Orion camera suite, which was first used in space during the Artemis I mission in 2022, is a suite of 11 cameras integrated into the Orion spacecraft to provide inspection and navigation capabilities. The camera suite includes four cameras mounted to the end of each of the four Orion solar arrays to provide inspection, one optical navigation camera to determine the spacecraft's relative position and velocity, and six additional internally and externally mounted cameras to provide in-flight video recording of events.
Developer: Redwire Corporation, Lockheed Martin, National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2022
Status: Completed
Contact vs. Non-contact: Non-Contact
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Both
Cross Listing: IM18

8.2.69 RCDM069: ORU Tool Changeout Mechanism (OTCM)

Description: The ORU Tool Changeout Mechanism (OTCM) is a robotic manipulator system used by the Special Purpose Dexterous Manipulator (SPDM) on the ISS. It is used to grasp a variety of different payload fixtures, including the H-Fixture and Micro-Fixture. It is equipped with lights to align itself with targets, as well as a gripper mechanism to directly grasp the fixtures. It is able to provide power, data, and video to payloads through an umbilical connector.
Developer: Canadian Space Agency (CSA), MDA Space
Country: Canada
First Use Date: 2009
Status: Operational
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: PRMUI28

8.2.70 RCDM070: Otter

Description: Otter, from Starfish Space, is a low cost, rapidly deployable satellite servicing vehicle which will perform inspection, life extension, and end-of-life satellite services in LEO and GEO. Otter will leverage Starfish Space's Cephalopod software to perform autonomous rendezvous and proximity operations, CETACEAN software to provide relative navigation, Nautilus capture mechanism to provide docking without standardized, pre-installed interfaces on client satellites, and Manta articulating boom to provide tunable thrusting capabilities while docked to a client. Starfish Space has agreements to provide Otter vehicles for customers including Intelsat, USSF, and NASA.
Developer: Starfish Space
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Unavailable
Cross Listing: R23, IM19

8.2.71 RCDM071: Otter Pup

Description: Otter Pup was a demonstration mission to test RPOD and docking with another spacecraft on orbit. The mission planned to use Starfish Space's technologies to rendezvous and capture the Launcher Space's Orbiter spacecraft (which also delivered Otter Pup to orbit). On June 12, 2023, the Launcher OTV experienced a thruster anomaly during deployment (due to the quantity of xenon remaining, Starfish suspected a software issue), which put the completion of the demonstration's objectives in jeopardy. In August 2023 Starfish was able to regain control over the satellite, though the original rendezvous demonstrations were scrubbed due to the anomaly. In April of 2024, the Otter Pup spacecraft successfully rendezvoused to within 1 km and captured images of the D-Orbit ION spacecraft.
Developer: Starfish Space
Country: United States
First Use Date: 2023
Status: Completed
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Non-Cooperative

8.2.72 RCDM072: Otter Pup 2

Description: Otter Pup 2 is a demonstration mission seeking to build upon the flight heritage of Starfish Space's Otter Pup 1 mission. It is intending to validate various RPOD systems on a client spacecraft developed by D-Orbit. Several key technologies include Starfish's Nautilus docking mechanism, as well as the CEPHALOPOD guidance and control software and CETACEAN navigation software.
Developer: Starfish Space
Country: United States
First Use Date: 2025
Status: Operational
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Non-Cooperative

8.2.73 RCDM073: Passive Refueling Module (PRM)

Description: The Passive Refueling Module (PRM) is a satellite refueling interface developed by Northrop Grumman and being implemented on U.S. Space Force satellites. The PRM includes elements to successfully dock and transfer fuel, as well as a refueling payload that handles fuel transfer. It will be used as part of the Elixir mission to demonstrate on orbit refueling for the United States Space Force.
Developer: United States Space Force, Northrop Grumman
Country: United States
First Use Date: Scheduled for 2027
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: RFT33

8.2.74 RCDM074: Podracer

Description: Orbit Fab's Podracer mission seeks to demonstrate Rendezvous and Proximity Operations (RPO) on a client satellite as a precursor for future in-space refueling missions. The spacecraft will be equipped with a RAFTI interface and will test a variety of RPO capabilities.
Developer: Orbit Fab
Country: USA
First Use Date: TBD
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative

8.2.75 RCDM075: Pressurized Mating Adapter (PMA)

Description: A Pressurized Mating Adapter (PMA) converts common berthing mechanisms on the ISS to APAS-95 docking ports. These are comprised of a passive common berthing mechanism port and a passive APAS port.
Developer: The Boeing Company
Country: United States
First Use Date: 1998
Status: Operational
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Non-cooperative
Cross Listing: PRMUI31

8.2.76 RCDM076: PRISMA

Description: PRISMA was a Swedish satellite project involving two free flying spacecraft intended to demonstrate technologies for guidance, navigation, rendezvous, and formation flying. The spacecraft included Mango, a satellite with a variety of rendezvous sensors and multiple propulsion systems, and Tango, a satellite with basic attitude control systems intended to be the target spacecraft for Mango. The project successfully completed many rendezvous and proximity operations demonstrations.
Developer: Swedish Space Corporation
Country: Sweden
First Use Date: 2010
Status: Completed
Contact vs. Non-contact: Non-Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative

8.2.77 RCDM077: Proba-3

Description: The Proba-3 mission is a science and technology demonstration mission which will use two small satellites to perform coronagraph inspection. The satellites, the coronagraph satellite and the Occulter spacecraft, will fly 144 m apart and will use precise pointing to allow the Occulter spacecraft to block the bright disk of the sun from the view of the coronagraph satellite. After launching in 2024, the Proba-3 spacecraft has successfully completed two formation flying orbits, including tests of various navigation systems.
Developer: European Space Agency (ESA)
Country: ESA
First Use Date: 2024
Status: Operational
Contact vs. Non-contact: Non-Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative

8.2.78 RCDM078: Quadclops

Description: Rated for GEO and designed for use in RPOD applications, the Quadclops is a four-camera system that combines two stereoscopic imagers, a center long-distance imager, and a fourth wide-angle situational awareness camera into a single integrated system. The system can be combined with a SDK for integrating gathered image data into user applications.
Developer: TRL11
Country: United States
First Use Date: TBD
Status: In Development
Contact vs. Non-contact: Non-Contact
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Both
Cross Listing: IM21

8.2.79 RCDM079: Quark

Description: Quark is an ESPA-Grande class system that can be launched as a secondary payload or on a dedicated small launch. Quark-Alpha combines solar electric propulsion and robotics to provide relocation, life extension, orbit raising, and payload delivery for missions from LEO through to cislunar space. Other Quark variants have specialized functions including high thrust for tactically responsive missions (Quark-Gamma), refueling (Quark-Beta), and deep space missions (Quark-Delta). During Quark's first mission in 2024, Atomos Space also launched a Gluon spacecraft, which housed additional propellant and hosted a customer payload. The Gluon spacecraft can be configured to house propellant for Quark's refueling, store or host customer payloads, or aggregate multiple small spacecraft for easy launch. The first launch of the Quark-Alpha vehicle is set for 2025, planning to provide inclination reduction and life extension services.
Developer: Atomos Space
Country: United States
First Use Date: Scheduled for 2025
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): 100000
Cooperative vs. Non-cooperative client: Non-Cooperative
Cross Listing: R24, RFT36

8.2.80 RCDM080: Rapidly Attachable Fluid Transfer Interface (RAFTI)

Description: Rapidly Attachable Fluid Transfer Interface (RAFTI) is a docking and refueling interface produced by Orbit Fab which replaces a spacecraft's fill and drain valve. RAFTI can be used for on-orbit and ground refueling, and it is a passive refueling interface for the client, which is captured by GRIP, an active refueling interface on the refueling spacecraft.
Developer: Orbit Fab
Country: United States
First Use Date: 2019
Status: Operational
Contact vs. Non-contact: Contact
Misalignment Tolerance: +/- 12.5 mm in X/Y Axes
+/- 30 mm in Z Axis
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: RFT38

8.2.81 RCDM081: Raven

Description: Raven is a technology demonstration module on the ISS that tests key elements of a new autonomous RPO system. Raven contains sensors, algorithms, and a high-speed processor to advance the capability to detect and track objects in space.
Developer: NASA Goddard Space Flight Center (GSFC)
Country: United States
First Use Date: 2017
Status: Operational
Contact vs. Non-contact: Non-Contact
Max RPO Initiation Distance (m): 100
Cooperative vs. Non-cooperative client: Both

8.2.82 RCDM082: REACCH

Description: REACCH is a soft robotic gripper that enables universal on-orbit docking without preparation of the docking target. The gripper uses eight arms which use electrostatic and mechanical adhesion to grapple targets up to 6.5 m in width. The REACCH gripper was demonstrated on the ISS in 2024.
Developer: Kall Morris Inc
Country: United States
First Use Date: 2024
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Cooperative vs. Non-cooperative client: Both

8.2.83 RCDM083: RED-EYE

Description: The RED-EYE satellite constellation, funded by DARPA, was launched from the ISS in 2019 to demonstrate multi-path communications on orbit. The satellite constellation orbital spacing was controlled through aerodynamic drag modulation, which was, at times, dictated through ground-based automation. The satellites began to decommission in June of 2022.
Developer: Millennium Space Systems, Defense Advanced Research Projects Agency (DARPA)
Country: United States
First Use Date: 2019
Status: Completed
Contact vs. Non-contact: Non-Contact
Cooperative vs. Non-cooperative client: Cooperative

8.2.84 RCDM084: RemoveDEBRIS

Description: The RemoveDEBRIS mission was a small satellite mission which was launched from the ISS in 2018 to demonstrate in-orbit debris removal technologies. The technologies tested include a space debris harpoon, which captured a target from 1.5 m, a space debris net, which captured a free-flying CubeSat, and a visual-based navigation system, which used laser and visual sensors to track a free-flying CubeSat.
Developer: Airbus, University of Surrey
Country: European Union
First Use Date: 2018
Status: Completed
Contact vs. Non-contact: Both
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Non-Cooperative
Cross Listing: IM22

8.2.85 RCDM085: Rendezvous, Proximity Operations, and Docking Kit (RPOD Kit)

Description: The Rendezvous, Proximity Operations, and Docking (RPOD) Kit is a turnkey solution for spacecraft to autonomously dock in space, offering services like asset inspection, refueling, and satellite life-extension. It is designed for cooperative docking missions, featuring low mass, low power consumption, and compatibility with various docking interfaces and propulsion systems, with fleet performance improvement through software updates after each mission. For uncooperative missions or robotic arm usage, specific mission needs can be discussed with the company.
Developer: Obruta Space Solutions
Country: Canada
First Use Date: TBD
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative

8.2.86 RCDM086: RISE

Description: RISE is a mission commissioned by the European Space Agency (ESA)'s Space Safety Programme and being developed by D-Orbit to demonstrate spacecraft life extension and end-of-life services in GEO. As part of the mission, the RISE spacecraft will move a GEO spacecraft into a graveyard orbit 100 km higher than the spacecraft's original altitude, through RPO, docking, and relocation operations. The spacecraft will loiter between GEO and the graveyard orbit while it awaits a subsequent client.
Developer: D-Orbit, European Space Agency (ESA)
Country: ESA
First Use Date: Scheduled for 2028
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: R25

8.2.87 RCDM087: Robot Micro-Conical Tool (RMCT)

Description: The Robot Micro-Conical Tool (RMCT) is a manipulator system used by the Special Purpose Dexterous Manipulator (SPDM) on the ISS for handling payloads. It is made to grasp the Micro-Conical Fixture and needs a small clearance envelope around the fixture to successfully grasp the payload. Because of this, the RMCT is used to grasp payloads that have clearance envelopes too small for the ORU Tool Changeout Mechanism to grasp.
Developer: Oceaneering International Inc
Country: USA
First Use Date: 1995
Status: Operational
Contact vs. Non-contact: Contact
Misalignment Tolerance: +/- 7 degrees w.r.t vertical axis
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: PRMUI32

8.2.88 RCDM088: SCOUT-Vision

Description: SCOUT-Vision was a space situational awareness payload that provides data to support identification and tracking of objects in its vicinity. The payload uses the company's software suite to enable on-demand, on-site inspections for space assets. The first SCOUT-Vision payload was launched in 2021 on Orbit Fab's Tenzing spacecraft.
Developer: Scout Space Inc
Country: United States
First Use Date: 2021
Status: Concluded
Contact vs. Non-contact: Non-Contact
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Both
Cross Listing: IM24

8.2.89 RCDM089: SHIELD

Description: SHIELD is a modular upgrade system featuring a base station and deployable scouting units designed to provide dynamic inspection, space domain awareness data collection, and defensive maneuvering capabilities when installed on commercial satellites.
Developer: Katalyst Space Technologies
Country: United States
First Use Date: TBD
Status: In Development
Contact vs. Non-contact: Both
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: URMUI17, IM26

8.2.90 RCDM090: Shijian-17 (SJ-17)

Description: Shijian-17 is a Chinese satellite which conducted a series of space rendezvous and proximity operations in geosynchronous orbit. The satellite was notable due to its relocation within GEO.
Developer: China Academy of Space Technology (CAST)
Country: China
First Use Date: 2016
Status: Operational
Contact vs. Non-contact: Non-Contact
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Unavailable

8.2.91 RCDM091: Shijian-21 (SJ-21)

Description: Shijian-21 was a Chinese debris mitigation technology satellite which actively docked with a defunct Beidou-2 G2 navigation satellite and relocated it to a graveyard orbit.
Developer: China Academy of Space Technology (CAST)
Country: China
First Use Date: 2022
Status: Completed
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Unavailable
Cross Listing: R27

8.2.92 RCDM092: Shiyan-7 (SY-7)

Description: Shiyan-7 was a Chinese technology demonstration satellite launched in 2013. From 6–9 August 2013, Shiyan-7 performed rendezvous proximity operations with the Chuangxin-3 satellite.
Developer: China Academy of Space Technology (CAST)
Country: China
First Use Date: 2013
Status: Completed
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Unavailable

8.2.93 RCDM093: Sistema Stykivki I Vnutrennego Perekhoda (SSVP)

Description: Sistema Stykivki I Vnutrennego Perekhoda (SSVP) is the docking standard used by Soviet and Russian spacecraft such as the Soyuz, Progress, and Mir. It is sometimes called the Russian Docking System.
Developer: TsKBEM
Country: Russia
First Use Date: 1971
Status: Operational
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Unavailable

8.2.94 RCDM094: SLEGO Architecture

Description: The SLEGO block is a high performance, modular spacecraft bus which is capable of interfacing with payloads attached to a SLEGO interface or with other SLEGO building blocks. Each SLEGO block manages power, provides basic sensing and metrology, processes and manages data, provides basic attitude adjustments, and manages thermal control. Fluids for thermal or refueling purposes can be transmitted through the modular interface. This interface has been tested through the eXCITe (eXperiment for Cellular Integration Technology) mission launched to LEO in 2018, the Satlet Initial-Mission Proofs and Lessons (SIMPL) mission on the ISS in 2017, and the PODSat-1 mission launched within DARPA's Hosted POD Assembly in GEO. The SLEGO architecture is also integrated into the Athena satellite, which will measure solar energy that Earth reflects and absorbs, gathered via a small telescope attached to a NovaWurks Payload Accommodation Configuration (PAC).
Developer: NovaWurks
Country: United States
First Use Date: 2017
Status: Operational
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Unavailable
Cross Listing: PRMUI34, RFT44, SMA36

8.2.95 RCDM095: Small Spacecraft Propulsion and Inspection Capability (SSPICY)

Description: The Small Spacecraft Propulsion and Inspection Capability (SSPICY) mission is a NASA-funded, Starfish-led Phase III SBIR mission during which the Starfish Otter spacecraft will inspect multiple defunct U.S.-owned spacecraft. The Otter spacecraft will operate within low Earth orbit (LEO) and will approach the defunct spacecraft within hundreds of meters.
Developer: Starfish Space, National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Contact vs. Non-contact: Non-Contact
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Non-cooperative
Cross Listing: IM28

8.2.96 RCDM096: Space Docking Experiment (SpaDeX)

Description: The Space Docking Experiment (SpaDeX), developed by the Indian Space Research Organisation (ISRO) and launched in 2024, was a demonstration of RPO and docking capabilities performed between two co-manifested spacecraft. The two 220 kg spacecraft were launched to LEO, separated by ~20 km, and then began RPO and capture operations. The docking interface between the spacecraft was also used to demonstrate power distribution from one spacecraft to another.
Developer: Indian Space Research Organisation (ISRO), Ananth Technologies
Country: India
First Use Date: 2024
Status: Operational
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): 20000
Cooperative vs. Non-cooperative client: Cooperative

8.2.97 RCDM097: Spacecraft on Umbilical Line (SOUL)

Description: Spacecraft on Umbilical Line (SOUL) is a tethered robotic spacecraft that is designed to provide self-inspection and self-servicing. SOUL is a small (<10 kg) robotic, self-propelled, self-navigating, autonomous vehicle that receives power and commands from the host spacecraft. It acts as a robotic arm with essentially infinite degrees of freedom and very long reach, allowing it to access parts of the spacecraft inaccessible by a traditional robotic arm.
Developer: Busek Co. Inc
Country: United States
First Use Date: TBD
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): 30
Cooperative vs. Non-cooperative client: Both
Cross Listing: PRMUI36, IM30

8.2.98 RCDM098: Spectre

Description: Spectre is a satellite capable of precision RPO and close-proximity operations. The satellite is currently being developed through Sierra Space's Axelerator program and is expected to perform on-orbit demonstrations in 2025 or 2026.
Developer: Sierra Space
Country: United States
First Use Date: Scheduled for 2025
Status: In Development
Contact vs. Non-contact: Non-Contact
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Both

8.2.99 RCDM099: Standard Interface for Robotic Manipulation of Payloads in Future Space Missions (SIROM)

Description: SIROM offers three configurations of a standardized interface (Active-Passive, Active, and Passive) with distinct features for mating, alignment, and data/power transmission. It enables direct interaction with cooperative structures for servicing and standardizes interfaces for mechanical, data, electrical, and fluid connections. Notably, SIROM finds applications in satellite payload upgrades or replacements.

Developer: SENER, European Commission (EC)

Country: Spain, European Union

First Use Date: TBD

Status: In Development

Contact vs. Non-contact: Contact

Misalignment Tolerance: 10 mm Axial, 5 mm all other axes

1.5 degrees X/Y/Z axes

Max RPO Initiation Distance (m): Unavailable

Cooperative vs. Non-cooperative client: Unavailable

Cross Listing: PRMUI37

8.2.100 RCDM100: Starling

Description: The NASA Starling mission involves the launch of four CubeSats to demonstrate technologies critical to future swarm missions. The spacecraft will operate autonomously and advance swarm maneuver planning and execution, communications between spacecraft, relative navigation, and autonomous coordination. The Stanford Space Rendezvous Laboratory will operate the Starling Formation-flying Optical eXperiment (StarFOX), which will use onboard star trackers to determine the orientation and track other spacecraft within the swarm.

Developer: National Aeronautics and Space Administration (NASA), Stanford Space Rendezvous Laboratory

Country: United States

First Use Date: 2023

Status: Operational

Contact vs. Non-contact: Non-Contact

Cooperative vs. Non-cooperative client: Cooperative

8.2.101 RCDM101: Starship HLS Docking System

Description: The Starship Human Landing System (HLS) docking system is based on the Dragon 2 docking system used for missions to the International Space Station. This new docking system will mate with Orion in lunar orbit during Artemis III and then with Gateway in subsequent missions. A full-scale docking system was tested during a 10-day testing campaign at NASA's Johnson Space Center. During these trials the docking system underwent over 200 docking scenarios which included different approach angles and speeds and a "soft capture" capability where Starship assumes the active docking role. The test results will help validate computer models of the Starship HLS docking system.
Developer: SpaceX
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative

8.2.102 RCDM102: Structural, Power, and Data Port (SPDP)

Description: The SPDP is a modular connector which provides mechanical and electrical connection between satellites. The connector was initially designed as a tool holder for robotic servicing satellites. The SPDP supports payloads up to 8.25 kg through launch and is designed to mate and demate up to 400 times on orbit. Consisting of both an active and passive unit, the SPDP system is designed to support robotics applications, satellite docking, and other on-orbit operations.
Developer: Sierra Space
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Unavailable
Cross Listing: PRMUI38

8.2.103 RCDM103: Sun Radio Interferometer Space Experiment (SunRISE)

Description: Sun Radio Interferometer Space Experiment (SunRISE) is a NASA project intending to study solar activity through a cluster of six cooperatively operating 6-unit CubeSats. The CubeSats will be located 10 km from each other and will effectively act as a large aperture radio telescope. The satellites are located at a higher altitude than geosynchronous orbit to avoid effects from the Earth's ionosphere.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: Scheduled for 2025
Status: In Development
Contact vs. Non-contact: Non-Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative

8.2.104 RCDM104: Tanker-001 Tenzing

Description: Tanker-001 Tenzing is a fuel depot storing High-Test Peroxide green propellant. The tanker is outfitted with the Rapidly Attachable Fluid Transfer Interface (RAFTI) service valve for fill and drain. It also includes high- and low-pressure variants of RAFTI compatible with common propellants. The tanker supports both primary docking and secondary attachment of two spacecraft.
Developer: Orbit Fab
Country: United States
First Use Date: 2021
Status: Operational
Contact vs. Non-contact: Contact
Misalignment Tolerance: +/- 12.5 mm X/Y, 30 mm Z
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: RFT48

8.2.105 RCDM105: Tetra-5

Description: Tetra-5 is a program within the United States Space Force (USSF) to demonstrate capabilities required for on-orbit refueling. The program, which was awarded to Orion Space Systems in 2022, involves the construction of two satellites which will perform RPO, docking, inspection, and refueling operations to demonstrate the utility of commercial refueling operations. One of the two Tetra-5 satellites will receive 50 kg of hydrazine from an Orbit Fab Kamino Fuel Depot, funded through the DIU RAPIDS program. The satellite will receive propellant through the Orbit Fab RAFTI interface. The second spacecraft will demonstrate compatibility with the APS-R propellant shuttle developed by Astroscale.
Developer: United States Space Force, Orion Space Solutions
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: RFT49, IM33

8.2.106 RCDM106: Tetra-6

Description: Tetra-6 is a program within the United States Space Force (USSF) to demonstrate capabilities required for on-orbit refueling. The program, which was awarded to Orion Space Systems, involves the deployment of a small satellite which will perform RPO, docking, and refueling operations with Northrop Grumman's Elixir payload, hosted on the ROOSTER-5 spacecraft. The refueling operations will be performed using Northrop Grumman's Passive Refueling Module (PRM), hosted on the Tetra-6 spacecraft, and Active Refueling Module (ARM), hosted on the Elixir payload.
Developer: United States Space Force, Orion Space Solutions
Country: United States
First Use Date: Scheduled for 2027
Status: In Development
Contact vs. Non-contact: Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Cooperative
Cross Listing: RFT50

8.2.107 RCDM107: Triclops
Description: Triclops is a three-camera system designed for in-space inspection and RPO activities. The system combines the Biclops stereo-camera's operational capabilities with an added center camera with wide-field-of-view to enhance object acquisition.
Developer: TRL11
Country: United States
First Use Date: TBD
Status: In Development
Contact vs. Non-contact: Non-Contact
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Both
Cross Listing: IM34

8.2.108 RCDM108: TriDAR
Description: TriDAR, developed by Neptec, was a LIDAR based system intended to support Rendezvous and Proximity Operations in space. The system was tested during STS-128, STS-131, and STS-135 to demonstrate capability of the system to generate a target point cloud and range and bearing solutions for docking.
Developer: Neptec Design Group Ltd
Country: Canada
First Use Date: 2009
Status: Completed
Contact vs. Non-contact: Non-Contact
Max RPO Initiation Distance (m): 2000
Cooperative vs. Non-cooperative client: Both

8.2.109 RCDM109: VICTUS NOX
Description: VICTUS NOX is a small satellite built by Millennium Space Systems and launched by Firefly Aerospace for the United States Space Force. The mission is part of the Tactically Responsive Space (TacRS) efforts as it demonstrated an end-to-end capability to rapidly respond to adversary aggression. The small satellite was equipped with a Space Domain Awareness (SDA) payload and imaged a resident space object and conducted rendezvous and proximity operations.
Developer: Millennium Space Systems, Firefly Aerospace, United States Space Force
Country: United States
First Use Date: 2023
Status: Completed
Contact vs. Non-contact: Non-Contact
Misalignment Tolerance: Unavailable
Max RPO Initiation Distance (m): Unavailable
Cooperative vs. Non-cooperative client: Unavailable

8.2.110 RCDM110: Visible Wavelength Camera (VisCam)

Description: The Visible Wavelength Camera (VisCam) developed by Neptec is a visible light camera intended to support RPO activities. The camera, which was planned to be used on the OSAM-1 mission, was developed in a wide field of view and narrow field of view configuration.

Developer: Neptec Design Group Ltd, National Aeronautics and Space Administration (NASA)

Country: Canada

Status: Concluded

Contact vs. Non-contact: Non-Contact

Max RPO Initiation Distance (m): Unavailable

Cooperative vs. Non-cooperative client: Both

8.3 Relocation

8.3.1 R01: Aolong-1

Description: Aolong-1 is a Chinese developed satellite which demonstrated the removal of a simulated space debris object from orbit. The satellite captured the space debris and altered the trajectory to de-orbit in Earth's atmosphere.
Developer: National University of Defense Technology (NUDT), People's Liberation Army (PLA)
Country: China
First Use Date: 2016
Status: Completed
Intended Transit: Unavailable
Max. Client Mass: Unavailable
Thruster / Propellant Type: Unavailable
Cross Listing: RCDM004

8.3.2 R02: Blue Ring

Description: Blue Ring is a multi-orbit space tug capable of hosting or deploying up to twelve 500 kg payloads with a 3,000 m/s delta-V capability. The first demonstration mission for Blue Ring, known as the Blue Ring Pathfinder and partially funded through the DIU DarkSky-1 Mission, launched on the maiden flight of Blue Origin's New Glenn launch vehicle in January of 2025. Blue Ring is considered a heavy utility m-OLV by DIU, which indicates the capability to transport or host a mechanically coupled spacecraft or payload with masses greater than 500 kg.
Developer: Blue Origin, Defense Innovation Unit (DIU)
Country: United States
First Use Date: TBD
Status: In Development
Intended Transit: Multiple orbits
Max. Client Mass: Up to twelve 500 kg payloads
Thruster / Propellant Type: Unavailable

8.3.3 R03: Capture Bay for Active Debris Removal In-Orbit Demonstration (CAT-IOD)

Description: This mission, developed by GMV and AVS under ESA guidance, will test several ISAM systems in the context of an Active Debris Removal mission. Developed under the guidelines of ESA's Design for Removal (D4R) Standards, the mission intends to test technologies such as the Capture Bay for Active Debris Removal (CAT) and the Mechanical Interface for Capture and Extraction (MICE). The mission will use the ELSA-M platform from Astroscale as the spacecraft platform. The mission will use close-proximity navigation aids to align itself with debris and a robotic arm with the MICE system to capture the debris. The target is AVS's LUR-1 satellite.
Developer: GMV, AVS, European Space Agency (ESA), Astroscale
Country: Spain, ESA
First Use Date: TBD
Status: In Development
Intended Transit: LEO
Max. Client Mass: Target is 57 kg wet mass
Thruster / Propellant Type: Chemical and Electric
Cross Listing: RCDM017

8.3.4 R04: Chandrayaan-3

Description: Chandrayaan-3, developed by the Indian Space Research Organisation (ISRO), was a lunar lander mission launched in 2023. During the mission, the propulsion module delivered the Vikram lander to lunar orbit. After separation, the Vikram lander touched down near the lunar south pole, while the propulsion module began a transfer back to Earth orbit. Once in Earth orbit, the propulsion module continued to host payloads until it ended operations in August of 2024.
Developer: Indian Space Research Organisation (ISRO)
Country: India
First Use Date: 2023
Status: Completed
Intended Transit: Trans-lunar injection orbit to lunar-orbit insertion, lunar-orbit insertion to circularization into low-lunar orbit, low lunar orbit to trans-Earth injection, trans-Earth injection to high-Earth orbit
Max. Client Mass: 1752 kg
Thruster / Propellant Type: Bi-Propellant Propulsion System (MMH + MON3)

8.3.5 R05: ClearSpace-1

Description: ClearSpace-1 is a planned orbital debris remediation mission developed by ClearSpace and funded by ESA. The mission is to use a spacecraft with a 4-pronged capture system to grab ESA's PROBA-1 satellite in LEO. The mission will conclude with both objects being destroyed while re-entering the Earth's atmosphere.
Developer: ClearSpace, OHB
Country: Switzerland, Germany, ESA
First Use Date: Scheduled for 2028
Status: In Development
Intended Transit: Orbit to atmosphere for end of life
Max. Client Mass: 112 kg
Thruster / Propellant Type: Unavailable
Cross Listing: RCDM018

8.3.6 R06: Elytra

Description: Elytra is an ESPA-based electric space tug system designed to launch with Firefly Aerospace's Alpha launch vehicle, Medium Launch Vehicle (MLV), and potentially other launch vehicles. The three classes of Elytra vehicles, Dawn, Dusk, and Dark, provide expanding capabilities to clients, including payload hosting, final orbit delivery, LEO to GEO transfer, and lunar orbit transfer. Elytra is expected to perform demonstrations on orbit no earlier than 2025 and a variant will serve as a transfer vehicle for Firefly's Blue Ghost Mission 2 to the lunar surface in 2026. The vehicle can deliver 2,700 kg of payload capacity to lunar orbit with the ability to provide on-orbit services for up to 5 years. It also has sufficient propellant reserve to enable a variety of advanced mission opportunities, such as lunar sample return to Earth and further exploration to nearby planets like Mars and Venus.
Developer: Firefly Aerospace
Country: United States
First Use Date: Scheduled for 2025
Status: In Development
Intended Transit: Payload hosting, final orbit delivery, LEO to GEO transfer, and lunar orbit transfer
Max. Client Mass: Dawn: 12U
Dusk: ESPA Class
Dark: ESPA Grande Class (2,700 kg)
Thruster / Propellant Type: Unavailable
Cross Listing: RCDM024, IM06

8.3.7 R07: End-of-Life Service by Astroscale - Multiple (ELSA-M)

Description: The End-of-Life Service by Astroscale - Multiple (ELSA-M) servicer spacecraft is intended to provide end-of-life services to satellites with a compatible magnetic capture mechanism, such as the Astroscale Docking Plate. The spacecraft will use chemical and electric propulsion and will be capable of approaching non-compliant or tumbling clients.
Developer: Astroscale
Country: Japan
First Use Date: Scheduled for 2026
Status: In Development
Intended Transit: Debris removal
Max. Client Mass: Unavailable
Thruster / Propellant Type: Chemical and Electric
Cross Listing: RCDM025

8.3.8 R08: End-of-Life Services by Astroscale - demonstration (ELSA-d)

Description: The End-of-Life Services by Astroscale - demonstration (ELSA-d) mission consists of a servicer satellite and a client satellite launched together. The servicer satellite was developed to safely remove debris objects from orbit, equipped with proximity rendezvous technologies and a magnetic docking mechanism. The client satellite simulated a piece of debris fitted with a ferromagnetic plate to enable docking with the servicer satellite.
Developer: Astroscale
Country: Japan
First Use Date: 2021
Status: Completed
Intended Transit: Debris removal
Max. Client Mass: 20 kg
Thruster / Propellant Type: green chemical
Cross Listing: RCDM026

8.3.9 R09: Hubble Servicing Mission 1 (Hubble SM1)

Description: The crew of STS-61 (Servicing Mission 1, SM1) addressed the Hubble's primary mirror spherical aberration by installing the Corrective Optics Space Telescope Axial Replacement (COSTAR) Orbital Replacement Unit (ORU) and performed upgrades and replacements to address other issues during five total EVAs. The upgrades and replacements included installing new magnetometers in place of degrading units, a new pair of solar arrays and solar array drive electronics to mitigate a mechanical oscillation caused by thermal expansion, an upgraded Wide Field & Planetary Camera (WFPC2) instrument, a coprocessor for the DF-224 computer to mitigate failure of two memory units, two Rate Sensor Units (RSU) each containing two gyros, and other minor components. A 7 km re-boost was performed at the end of the mission and an improvised temporary solution to capture debris coming from flaked-off coating from the old magnetometers was constructed by the crew with onboard materials.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1993
Status: Completed
Intended Transit: Orbit raising
Thruster / Propellant Type: Chemical
Cross Listing: RCDM041, PRMUI15, URMUI03

8.3.10 R10: Hubble Servicing Mission 2 (Hubble SM2)

Description: STS-82 (Servicing Mission 2, SM2) was the second planned Hubble servicing mission. It focused on increasing the telescope's productivity with the installation of new instruments that extended Hubble's wavelength range into the near infrared for imaging and spectroscopy. Through four planned EVAs, failed and degraded components were replaced, and some upgrades were performed to older equipment. The tasks included replacement of the outdated Goddard High Resolution Spectrograph (GHRS) and Faint Object Spectrometer (FOS) by the Space Telescope Imaging Spectrograph (STIS) and Near-Infrared Camera and Multi-Object Spectrometer (NICMOS) instruments, respectively, to increase spectral range of the telescope, upgrade of tape recorder #1 from a reel-to-reel recorder to a Solid State Recorder which could store 10 times more data, direct replacement of the degraded tape recorder #2 by a spare unit, replacement of the degraded Fine Guidance Sensor #1 (FGS-1) by an upgraded unit with the added capability of ground-controlled alignment corrections, replacement of the degraded Reaction Wheel Assembly #1 (RWA-1), covering worn MLI at the top of the telescope's tube with Patch Kit Thermal Insulation Blankets, installing permanent magnetometer covers over the temporary ones installed in SM-1, and replacement of the Solar Array Drive Electronics #1 (SADE-1) with a refurbished unit. Since damage to the MLI was greater than anticipated, a fifth EVA was conducted to cover degraded MLI with sheets manufactured by the crew with onboard materials. A re-boost was performed to raise Hubble's orbit by 16 km.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1997
Status: Completed
Intended Transit: Orbit raising
Thruster / Propellant Type: Chemical
Cross Listing: RCDM042, PRMUI16, URMUI04

8.3.11 R11: Hubble Servicing Mission 3B (Hubble SM3B)

Description: STS-109 (Servicing Mission 3B, SM3B) was the fourth servicing mission for the Hubble in 2002 and the continuation to the third servicing mission (SM3A) in 1999, as SM3 was split into two parts. With five total EVAs, replacement and upgrade tasks in this mission included direct replacement of the Reaction Wheel Assembly #1 (RWA), replacement of the Faint Object Camera (FOC) for the Advanced Camera for Surveys (ACS), upgrade of the Solar Arrays 2 (SA-2) to the rigid, smaller, and more efficient SA-3, upgrade of the Power Control Unit (PCU) to eliminate intermittent issues and handle the extra power generated by the new solar arrays, installation of the Near Infrared Camera and Multi-Object Spectrometer (NICMOS) Cryocooler and its supporting electronics to revive the NICMOS instrument and extend its lifetime by providing necessary cooling, and installation of New Outer Blanket Layer (NOBL) sheets over damaged MLI on bays 5, 6, 7, and 8. At the end of this mission, a 6.3 km re-boost took place to extend Hubble's mission lifetime, being the last re-boost performed on Hubble servicing missions.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2002
Status: Completed
Intended Transit: Orbit raising
Thruster / Propellant Type: Chemical
Cross Listing: RCDM044, PRMUI18, URMUI06

8.3.12 R12: Hubble Servicing Mission 4 (Hubble SM4)

Description: STS-125 (Servicing Mission 4, SM4) was the fifth and currently final servicing mission to the HST in May of 2009. This mission focused on performing basic maintenance replacements, upgrades to instruments, and the addition of some new components through five EVAs. Direct maintenance replacements included three Rate Sensor Units (RSUs) which had degraded, all six battery modules which had not been replaced/serviced since launch, a Fine Guidance Sensor (FGS) to replace the degraded FGS-2, repairs for the Advanced Camera for Surveys (ACS) which included the external installation of a Low Voltage Power Supply (LVPS) in conjunction with the replacement of the four Wide Field Channel (WFC) control boxes by the Charged Couple Device (CCD) Electronics Box to restore functionality to the ACS's WFC which was out of service due to a serious power failure, and a Science Instrument Control and Data Handling (SIC&DH) unit due to failed electronics on the original one. For upgrades, the Wide Field and Planetary Camera 2 (WFPC-2) was replaced for the Wide Field Camera 3 (WFC-3) to increase spectral range, the STIS Low Voltage Power Supply (LVPS) card #2 was replaced by a new version, and the COSTAR , which was added during SM1, was replaced by a new instrument called the Cosmic Origins Spectrograph (COS), which is the most powerful UV spectrograph ever flown on Hubble. Components added included NOBL sheets placed over damaged MLI on bays 5, 7, and 8 and a new Soft Capture Mechanism (SCM) for potential future RPOC operations including deorbiting.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2009
Status: Completed
Intended Transit: Orbit raising
Thruster / Propellant Type: Chemical
Cross Listing: RCDM045, PRMUI19, URMUI07

8.3.13 R13: International Space Station Reboost (ISS Reboost)

Description: Throughout the lifetime of the ISS, reboost operations have been performed by visiting spacecraft, such as Progress, Shuttle, Ariane Transfer Vehicle, and most recently Cygnus. The station itself can adjust its altitude through operations of the Zvezda module. These boosting operations were used on an as-needed basis in order to maintain orbit.
Developer: National Aeronautics and Space Administration (NASA), Roscosmos
Country: United States, Russia
First Use Date: 1998
Status: Operational
Intended Transit: LEO
Thruster / Propellant Type: Chemical

8.3.14 R14: ION Satellite Carrier

Description: The ION Satellite Carrier is a satellite dispenser platform that can deliver a range of different sized payloads to LEO. The configurable payload bay can carry a combination of launch dispensers, CubeSat-sized payloads, microsatellites, and other instruments. The platform is able to perform orbital maneuvers between payload deployments.
Developer: D-Orbit
Country: Italy
First Use Date: 2020
Status: Operational
Intended Transit: change of altitude and inclination, true anomaly phasing, RAAN shift
Max. Client Mass: 160 kg
Thruster / Propellant Type: Unavailable

8.3.15 R15: Life Extension In-Orbit (LEXI)

Description: Life Extension In-Orbit (LEXI) is a life extension servicer which will provide station keeping, pointing, and relocation services to satellites throughout GEO. These services include movement to new GEO orbital slots, correction of inclination, and relocation to graveyard orbit. The servicer will use electric propulsion and will dock to the client spacecraft using four robotic arms.
Developer: Astroscale
Country: Japan
First Use Date: Scheduled for 2026
Status: In Development
Intended Transit: Attitude control in GEO, move to GEO graveyard orbit, move between orbital slots in GEO
Max. Client Mass: Unavailable
Thruster / Propellant Type: Electric, hydrazine
Cross Listing: RCDM052

8.3.16 R16: Mira

Description: The Mira orbital transfer vehicle uses a nontoxic, high-impulse chemical propulsion system to offer orbital transport, constellation deployment, and precision reentry services to customers throughout LEO. Two Mira spacecraft have successfully launched to LEO and a mission to GEO is scheduled for 2026.
Developer: Impulse Space
Country: United States
First Use Date: 2023
Status: Operational
Intended Transit: LEO
Max. Client Mass: 300 kg
Thruster / Propellant Type: Chemical (Saiph), bipropellant (nitrous oxide and ethane)

8.3.17 R17: Mission 1

Description: The Atomos Space Mission 1 (colloquially the Singing Astronomer Mission) was an RPO, refueling, and orbital transfer mission which used Atomos' Quark and Gluon spacecraft. The Quark and Gluon spacecraft were launched in a joined state on SpaceX's Falcon 9 Transporter 10 mission. The mission intended for the Quark spacecraft to autonomously RPO and dock to Gluon, Quark to refuel from Gluon, and combined vehicle orbital transfer demonstrations. Due to anomalies experienced during mission initiation, the intended multi-vehicle operations were not performed.
Developer: Atomos Space
Country: United States
First Use Date: 2024
Status: Concluded
Intended Transit: Orbit raising and lowering within LEO
Max. Client Mass: Unavailable
Thruster / Propellant Type: Electric
Cross Listing: RCDM059, RFT24

8.3.18 R18: Mission Extension Pods (MEP)

Description: Mission Extension Pods (MEP) are Northrop Grumman's next generation of servicing vehicles. MEPs will extend the life of hosting spacecraft by providing orbit control services for up to six years. They will be installed by a Mission Robotic Vehicle which can carry several pods to multiple client spacecraft.
Developer: Northrop Grumman
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Intended Transit: Attitude control in GEO
Max. Client Mass: Unavailable
Thruster / Propellant Type: Electric
Cross Listing: URMUI10

8.3.19 R19: Mission Extension Vehicle (MEV)

Description: The Mission Extension Vehicle (MEV) is the first commercial satellite life extension vehicle, designed to provide relocation services to geostationary satellites. Once connected to its client satellite, MEV uses its own thrusters and propellant supply to extend the satellite's lifetime. When the customer no longer desires MEV's service, the spacecraft undocks and moves on to the next client satellite.
Developer: Northrop Grumman
Country: United States
First Use Date: 2020
Status: Operational
Intended Transit: GEO
Max. Client Mass: Unavailable
Thruster / Propellant Type: Electric
Cross Listing: RCDM060

8.3.20 R20: Mission Robotic Vehicle (MRV)

Description: The Mission Robotic Vehicle (MRV) is a future on-orbit servicing bus developed using technologies and lessons from the Mission Extension Vehicle. The robotic payload will be supplied by DARPA and developed by the United States Naval Research Laboratory as part of the Robotic Servicing of Geosynchronous Satellites (RSGS) mission.
Developer: Northrop Grumman
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Intended Transit: GEO
Max. Client Mass: Unavailable
Thruster / Propellant Type: Electric
Cross Listing: RCDM061, URMUI11

8.3.21 R21: Orbital Maneuvering Vehicle (OMV)

Description: The Orbital Maneuvering Vehicle (OMV) is an ESPA-based space tug used for orbital relocation of secondary payloads. OMV offers a variety of sizes and configurations, and it aims to perform orbital adjustments and insertions in LEO and GEO.
Developer: MOOG
Country: United States
First Use Date: TBD
Status: In Development
Intended Transit: Orbit raising and lowering, plane changes, phasing
Max. Client Mass: Assorted
Thruster / Propellant Type: Green, Hydrazine

8.3.22 R22: Orbiter

Description: Orbiter was a space tug and payload delivery system developed by Launcher Space for use in LEO. Orbiter was designed to operate as part of a rideshare or a dedicated launch. The first launch of this system occurred in March of 2023 to deliver satellites to orbit, but an anomaly forced an early deployment of its payloads. The final launch in December of 2023, which hosted Starfish Space's Otter Pup spacecraft and was an intended docking target for Starfish Space's spacecraft, also encountered an anomaly after release from the launch vehicle and fell into an uncontrolled rotation.
Developer: Launcher Space
Country: United States
First Use Date: 2023
Status: Completed
Intended Transit: Orbit raising, lowering, plane changes, phasing, and inclination change in LEO
Max. Client Mass: 400 kg
Thruster / Propellant Type: Ethane and N20 chemical propulsion capable of up to 500 m/s delta-V

8.3.23 R23: Otter

Description: Otter, from Starfish Space, is a low cost, rapidly deployable satellite servicing vehicle which will perform inspection, life extension, and end-of-life satellite services in LEO and GEO. Otter will leverage Starfish Space's Cephalopod software to perform autonomous rendezvous and proximity operations, CETACEAN software to provide relative navigation, Nautilus capture mechanism to provide docking without standardized, pre-installed interfaces on client satellites, and Manta articulating boom to provide tunable thrusting capabilities while docked to a client. Starfish Space has agreements to provide Otter vehicles for customers including Intelsat, USSF, and NASA.
Developer: Starfish Space
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Intended Transit: Orbit maintenance in GEO, de-orbit of satellites in LEO
Max. Client Mass: Unavailable
Thruster / Propellant Type: Chemical and Electric
Cross Listing: RCDM070, IM19

8.3.24 R24: Quark

Description: Quark is an ESPA-Grande class system that can be launched as a secondary payload or on a dedicated small launch. Quark-Alpha combines solar electric propulsion and robotics to provide relocation, life extension, orbit raising, and payload delivery for missions from LEO through to cislunar space. Other Quark variants have specialized functions including high thrust for tactically responsive missions (Quark-Gamma), refueling (Quark-Beta), and deep space missions (Quark-Delta). During Quark's first mission in 2024, Atomos Space also launched a Gluon spacecraft, which housed additional propellant and hosted a customer payload. The Gluon spacecraft can be configured to house propellant for Quark's refueling, store or host customer payloads, or aggregate multiple small spacecraft for easy launch. The first launch of the Quark-Alpha vehicle is set for 2025, planning to provide inclination reduction and life extension services.
Developer: Atomos Space
Country: United States
First Use Date: Scheduled for 2025
Status: In Development
Intended Transit: Orbit raising and lowering from low earth to interplanetary
Max. Client Mass: Unavailable
Thruster / Propellant Type: Electric
Cross Listing: RCDM079, RFT36

8.3.25 R25: RISE

Description: RISE is a mission commissioned by the European Space Agency (ESA)'s Space Safety Programme and being developed by D-Orbit to demonstrate spacecraft life extension and end-of-life services in GEO. As part of the mission, the RISE spacecraft will move a GEO spacecraft into a graveyard orbit 100 km higher than the spacecraft's original altitude, through RPO, docking, and relocation operations. The spacecraft will loiter between GEO and the graveyard orbit while it awaits a subsequent client.
Developer: D-Orbit, European Space Agency (ESA)
Country: ESA
First Use Date: Scheduled for 2028
Status: In Development
Intended Transit: GEO Station Keeping, GEO to GEO Graveyard
Max. Client Mass: Unavailable
Thruster / Propellant Type: Unavailable
Cross Listing: RCDM086

8.3.26 R26: Sherpa

Description: Spaceflight's Sherpa family of spacecraft were orbital transfer vehicles based on a ESPA-class deployment system. The spacecraft were capable of hosting multiple payloads, providing telemetry, and deploying payloads at different timings during the mission. Multiple Sherpa variants conducted five successful missions between 2021 and 2022. The Sherpa line of spacecraft was discontinued after Spaceflight's acquisition by Firefly Aerospace.
Developer: Spaceflight
Country: United States
First Use Date: 2021
Status: Completed
Intended Transit: Orbit raising and lowering, in-plane phasing, LTAN change
Max. Client Mass: Unavailable
Thruster / Propellant Type: Bi-propellant, green propulsion, Chemical Propulsion, electric propulsion, Xenon propellant

8.3.27 R27: Shijian-21 (SJ-21)

Description: Shijian-21 was a Chinese debris mitigation technology satellite which actively docked with a defunct Beidou-2 G2 navigation satellite and relocated it to a graveyard orbit.
Developer: China Academy of Space Technology (CAST)
Country: China
First Use Date: 2022
Status: Completed
Intended Transit: GEO Debris Removal
Max. Client Mass: Unavailable
Thruster / Propellant Type: Unavailable
Cross Listing: RCDM091

8.3.28 R28: Spacevan

Description: Spacevan is an electric propulsion orbital transfer vehicle developed by the French company Exotrail. The vehicle was first demonstrated with Spacevan-001, which launched on the SpaceX Transporter-9 mission in 2024. Spacevan uses Exotrail's spaceware electric propulsion system to offer access to orbits with high inclinations or altitudes.
Developer: Exotrail
Country: France
First Use Date: 2024
Status: Operational
Intended Transit: LEO, SSO, GTO, GEO
Max. Client Mass: 200 kg (LEO V2), 50 kg (GEO Gen 1), 150 kg (GEO Gen 2)
Thruster / Propellant Type: Electric

8.3.29 R29: Vigoride

Description: Vigoride is a space tug from Momentus, Inc., that is compatible with the ESPA Grande and designed for orbital plane changes, inclination adjustments, and payload delivery while also providing power, communications, and station keeping while attached to the tug. Momentus launched its third Vigoride mission, Vigoride-6, in April 2023 aboard the SpaceX Transporter-7 mission. Vigoride-6 successfully deployed all of its customer payloads.
Developer: Momentus Inc
Country: United States
First Use Date: 2022
Status: Operational
Intended Transit: Orbit raising and lowering mainly in low earth orbits
Max. Client Mass: 750 kg
Thruster / Propellant Type: water plasma engines

8.4 Prepared Repair, Maintenance, Upgrade, and Installation

8.4.1 PRMUI01: Advanced Tool Drive System (ATDS)

Description: The Advanced Tool Drive System is a system of interfaces and sensors made to support the servicing operations of the OSAM-1 Servicing Payload (SP). The SP included two Robotic Systems (RS) capable of performing a variety of operations through various tools. Attaching to the end of a Robot Arm Assembly (RAA), each ATDS included three rotary torque interfaces, as well as electrical interfaces, actuators, and two cameras meant for precision views. This system enables the use of custom tools for specific ISAM tasks.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
Status: Concluded
Operation Type: Servicing Interface
ORU SWaP: Unavailable
Standard Interface Type: Mechanical, Electrical

8.4.2 PRMUI02: Androgynous Peripheral Attachment System (APAS)

Description: The Androgynous Peripheral Attachment System (APAS) is an androgynous docking mechanism used on the ISS. The system was first used on the ISS between the United States Pressurized Mating Adapter 1 and the Russian Functional Cargo Block (FGB, also known as Zarya).
Developer: RKK Energiya
Country: United States, USSR
First Use Date: 1975
Status: Operational
Operation Type: Servicing Interface
ORU SWaP: Unavailable
Standard Interface Type: Mechanical, Power, Data, Video
Cross Listing: RCDM003

8.4.3 PRMUI03: ArgUS Multi-Payload Adapter (ArgUS)

Description: The ArgUS Multi-Payload Adapter is a payload platform developed to increase the utility of the Bartolomeo Platform System. It is able to host up to 5 smaller payloads while only using a single Bartolomeo slot. Depending on the configuration, the ArgUS can accommodate payloads ranging from 1U all the way to 200U. Onboard interfaces add power and data capabilities to the adapter as well, with up to 760 W of power available to share amongst 5 payloads.
Developer: Airbus
Country: United States
First Use Date: 2024
Status: Operational
Operation Type: Servicing Interface
ORU SWaP: Mass: 200 kg total cargo capability, shared between payloads
Power: 28 VDC, 100-150 W nominal per payload (760 W total between all payloads)
Data Rate: 2-8 Mbps
Standard Interface Type: Mechanical, Power, Data
Cross Listing: RCDM007

8.4.4 PRMUI04: Augmentation System Port Interface (ASPIN)

Description: The Augmentation System Port Interface (ASPIN) is a spacecraft interface based on the Mission Augmentation Port (MAP), an open-source docking standard also developed by Lockheed Martin. This interface is capable of providing a mechanical, data, and electrical connection between spacecraft.
Developer: Lockheed Martin
Country: United States
First Use Date: TBD
Status: In Development
Operation Type: Servicing Interface
ORU SWaP: Unavailable
Standard Interface Type: Mechanical, Power, and Data
Cross Listing: RCDM012

8.4.5 PRMUI05: AXON/Dactylus

Description: Tethers Unlimited's AXON connector was a low-profile soft capture end effector that could be used to connect two spacecraft together in orbit. The Dactylus servicing tool was a robotic tool that could be used for in-space servicing of satellites. The Dactylus tool was designed to be used with the KRAKEN robotic arm and the AXON connector to enable small robotic systems to perform complex servicing tasks on large space systems.
Developer: Tethers Unlimited Inc
Country: United States
Status: Concluded
Operation Type: Servicing Interface
ORU SWaP: Unavailable
Standard Interface Type: Unavailable
Cross Listing: RCDM015

8.4.6 PRMUI06: Docking and Fluid Transfer Port (DFT Port)

Description: The Docking and Fluid Transfer Port is an in-space interface that provides mechanical, data, and refueling connections for satellite servicing operations. The docking port may be used for missions such as life extension, relocation, and active debris removal.
Developer: Dawn Aerospace
Country: Netherlands/New Zealand
First Use Date: TBD
Status: In Development
Operation Type: Servicing Interface
ORU SWaP: Unavailable
Standard Interface Type: Mechanical, Refueling, Power, Data
Cross Listing: RCDM022, RFT07

8.4.7 PRMUI07: Enduralock Satellite Connector

Description: Enduralock is a small satellite interface which provides mechanical, data/power, and fuel transfer connection between spacecraft. The interface is intended to occupy a 1 cm cubic volume and incorporates features to allow for the misalignment expected during autonomous docking between spacecraft.
Developer: Enduralock
Country: United States
First Use Date: TBD
Status: In Development
Operation Type: Servicing Interface
ORU SWaP: Type of Interface: Ethernet (faster) or Micro-USB protocol
# of Ports for Power Transfer: 4
Mass of Satellite Connector A: 3.75 lb (estimate)
Mass of Satellite Connector B: 2.20 lb (estimate)
Max. Permissible Tensile Load: 1100 lb (estimate)
Max. Permissible Compressive Load: 2100 lb (estimate)
Max. Static Bending Axial Load: 3000 lb (estimate)
Max. Torsional Load: 825 lb-in (estimate)
Standard Interface Type: Mechanical, Refueling, Power, Data
Cross Listing: RCDM027, RFT09

8.4.8 PRMUI08: Flight Releasable Attachment Mechanism (FRAM)

Description: The Flight Releasable Attachment Mechanism (FRAM) is a system used for hosting payloads aboard the ISS, specifically externally at locations such as the Expedite the Processing of Experiments to Space Station (ExPRESS) Logistics Carrier (ELC). ELCs provide unpressurized areas for payload attachment, allowing for mechanical attachment, as well as power and data connections. FRAMs are used to connect payloads to these locations, primarily through robotic systems on the ISS such as Dextre. FRAMs consist of a passive half located on the ELC, and an active half on the payload itself.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: Unavailable
Status: Operational
Operation Type: Servicing Interface
ORU SWaP: Unavailable
Standard Interface Type: Mechanical, Power, Data
Cross Listing: RCDM032

8.4.9 PRMUI09: FuseBlox

Description: FuseBlox is an androgynous interface providing mechanical, electrical, and data connections. It received Phase II SBIR funding from AFRL. In 2025, SpaceWorks announced the Fuseblox system will be hosted on Rogue Space Systems Corporation's Orbital Test Platform 3 (OTP-3) mission. Stated to launch in 2026, OTP-3 will use Fuseblox to enable docking, power/data transfer, and eventual refueling capabilities to the spacecraft.
Developer: SpaceWorks Enterprises Inc
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Operation Type: Servicing Interface
ORU SWaP: Mass: 3.2 kg
Max Lateral load: Unavailable
Power: 1.2 kW Nominal, 1.5 kW Max
Data Rate: MIL-STD-1553/Gigabit Ethernet
Standard Interface Type: Mechanical, Electrical, Data
Cross Listing: RCDM034

8.4.10 PRMUI10: General-purpose Oceaneering Latching Device 2 (GOLD-2)

Description: General-purpose Oceaneering Latching Device 2 (GOLD-2) is a general-purpose latching device suitable for mechanically connecting up to 454 kg payload with power and data connections. Options are available for custom fluid connections. The interface includes passive and active sides.
Developer: Oceaneering International Inc
Country: United States
First Use Date: 2020
Status: Operational
Operation Type: Servicing Interface
ORU SWaP: Mass: 7.8 kg
Max Lateral load: Unknown, sized for 125 kg nominal ops
Power: Up to 800 W
Data Rate: up to 1 Mb/s downlink
Heat: Not Available
Standard Interface Type: Mechanical, Power, Data

8.4.11 PRMUI11: GITAI S2's extraveHicular multi-Objective in-Space servicing Task demonstration (Project GHOST)

Description: Project GHOST (GITAI S2's extraveHicular multi-Objective in-Space servicing Task demonstration) was an on-orbit demonstration of ISAM operations by two GITAI S2 robotic arms installed externally to the ISS NanoRacks Bishop Airlock. The experiment included supervised autonomous ISAM operations by the S2 robotic arms, including ORU manipulation, tool changing, fastener tightening and removal, thermal blanket manipulation, connector mating and demating, and dual robotic arm cooperation.
Developer: GITAI
Country: Japan
First Use Date: 2024
Status: Completed
Operation Type: Robotic Servicing Demonstration
Standard Interface Type: General Gripper
Cross Listing: SMA16

8.4.12 PRMUI12: Guideless Resilient Androgynous Serial Port (GRASP)

Description: The GRASP modular interface, developed by Champaign-Urbana Aerospace, provides mechanical, power, and data transfer between spacecraft during in-space operations. The interface has been terrestrially demonstrated for use cases such as modular assembly, free-flier capture, and mismatched capture scenarios.
Developer: Champaign-Urbana Aerospace
Country: USA
First Use Date: TBD
Status: In Development
Operation Type: Servicing Interface
ORU SWaP: Preload: 2,500 N
Data Transfer: 100 Mbps
Power Transfer @ 115VAC: 1350 W
Power Transfer @ 32VDC: 627 W
Mass: 2 kg
Volume: 35 cm x 25 cm x 5 cm
Lifespan: 10 years
Standard Interface Type: Mechanical, Power, Data
Cross Listing: RCDM037

8.4.13 PRMUI13: H-Fixture

Description: The H-Fixture is an interface compatible with the Special Purpose Dexterous Manipulator (SPDM) robotic system, also known as Dextre. Using the ORU Tool Changeout Mechanism (OCTM), Dextre can directly grasp the H-fixture. This interface is specifically used in high-load or high-mass payload cases. Like other Dextre interfaces, the H-Fixture allows for umbilical connection to provide power, data, and video to payloads.
Developer: Canadian Space Agency (CSA), MDA Space
Country: Canada
First Use Date: Unavailable
Status: Operational
Operation Type: Servicing Interface
ORU SWaP: Unavailable
Standard Interface Type: Mechanical, Power, Data, Video
Cross Listing: RCDM039

8.4.14 PRMUI14: HOTDOCK

Description: HOTDOCK is an androgynous standard interface supporting mechanical, electrical, data, and (optionally) thermal interconnect. It is used especially for robotic arm interfacing. The MOSAR-WM walking robotic arm, developed by Space Application Services and DLR, used this as the standard interface.
Developer: Space Applications Services
Country: Belgium
First Use Date: TBD
Status: In Development
Operation Type: Servicing Interface
ORU SWaP: Mass: 2.6 kg
Max Lateral load: 600 Nm
Power: 4 kW
Data Rate: Spacewire/Ethernet
Heat: 20-50 W
Standard Interface Type: Mechanical, Power, Data, Thermal
Cross Listing: RCDM040

8.4.15 PRMUI15: Hubble Servicing Mission 1 (Hubble SM1)

Description: The crew of STS-61 (Servicing Mission 1, SM1) addressed the Hubble's primary mirror spherical aberration by installing the Corrective Optics Space Telescope Axial Replacement (COSTAR) Orbital Replacement Unit (ORU) and performed upgrades and replacements to address other issues during five total EVAs. The upgrades and replacements included installing new magnetometers in place of degrading units, a new pair of solar arrays and solar array drive electronics to mitigate a mechanical oscillation caused by thermal expansion, an upgraded Wide Field & Planetary Camera (WFPC2) instrument, a coprocessor for the DF-224 computer to mitigate failure of two memory units, two Rate Sensor Units (RSU) each containing two gyros, and other minor components. A 7 km re-boost was performed at the end of the mission and an improvised temporary solution to capture debris coming from flaked-off coating from the old magnetometers was constructed by the crew with onboard materials.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1993
Status: Completed
Operation Type: Servicing Mission
ORU SWaP: Unavailable
Standard Interface Type: Mechanical, Power, Data
Cross Listing: RCDM041, R09, URMUI03

8.4.16 PRMUI16: Hubble Servicing Mission 2 (Hubble SM2)

Description: STS-82 (Servicing Mission 2, SM2) was the second planned Hubble servicing mission. It focused on increasing the telescope's productivity with the installation of new instruments that extended Hubble's wavelength range into the near infrared for imaging and spectroscopy. Through four planned EVAs, failed and degraded components were replaced, and some upgrades were performed to older equipment. The tasks included replacement of the outdated Goddard High Resolution Spectrograph (GHRS) and Faint Object Spectrometer (FOS) by the Space Telescope Imaging Spectrograph (STIS) and Near-Infrared Camera and Multi-Object Spectrometer (NICMOS) instruments, respectively, to increase spectral range of the telescope, upgrade of tape recorder #1 from a reel-to-reel recorder to a Solid State Recorder which could store 10 times more data, direct replacement of the degraded tape recorder #2 by a spare unit, replacement of the degraded Fine Guidance Sensor #1 (FGS-1) by an upgraded unit with the added capability of ground-controlled alignment corrections, replacement of the degraded Reaction Wheel Assembly #1 (RWA-1), covering worn MLI at the top of the telescope's tube with Patch Kit Thermal Insulation Blankets, installing permanent magnetometer covers over the temporary ones installed in SM-1, and replacement of the Solar Array Drive Electronics #1 (SADE-1) with a refurbished unit. Since damage to the MLI was greater than anticipated, a fifth EVA was conducted to cover degraded MLI with sheets manufactured by the crew with onboard materials. A re-boost was performed to raise Hubble's orbit by 16 km.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1997
Status: Completed
Operation Type: Servicing Mission
ORU SWaP: Unavailable
Standard Interface Type: Mechanical, Power, Data
Cross Listing: RCDM042, R10, URMUI04

8.4.17 PRMUI17: Hubble Servicing Mission 3A (Hubble SM3A)

Description: STS-103 (Servicing Mission 3A, SM3A) was originally scheduled for June 2000 as the third planned Hubble servicing mission for preventive maintenance but became more urgent after four of the six gyros on the telescope failed, with the HST requiring at least 3 to operate. It was divided into two parts, the first of which was SM3A. The telescope was placed in safe mode on November 13, 1999, when the fourth gyro failed until the launch and arrival of SM3A on December 19, 1999. Tasks performed during three EVAs included replacement of all three Rate Sensor Units (each containing two gyros), replacement of the Fine Guidance Sensor #2 (FGS-2) by an upgraded and refurbished unit, replacement of the faulty S-Band Single Access Transmitter #2 (SSAT-2), replacement the DF-224 main computer by the more capable Advanced Computer, installation of Battery Voltage/Temperature Improvement Kits (VIKs) for increased interoperability between the batteries and solar arrays by preventing overcharging and overheating, upgrade of tape recorder #3 to Solid State Recorder (SSR), and installation of handrail covers made to prevent possible contamination from flaking paint. The New Outer Blanket Layer (NOBL) and Shell/Shield Replacement (SSR) fabric MLI kits were used to cover MLI which had been greatly degraded by embrittlement and cracks caused by exposure to charged particles, thermal cycling, and other environmental effects.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1999
Status: Completed
Operation Type: Servicing Mission
ORU SWaP: Unavailable
Standard Interface Type: Mechanical, Power, Data
Cross Listing: RCDM043, URMUI05

8.4.18 PRMUI18: Hubble Servicing Mission 3B (Hubble SM3B)

Description: STS-109 (Servicing Mission 3B, SM3B) was the fourth servicing mission for the Hubble in 2002 and the continuation to the third servicing mission (SM3A) in 1999, as SM3 was split into two parts. With five total EVAs, replacement and upgrade tasks in this mission included direct replacement of the Reaction Wheel Assembly #1 (RWA), replacement of the Faint Object Camera (FOC) for the Advanced Camera for Surveys (ACS), upgrade of the Solar Arrays 2 (SA-2) to the rigid, smaller, and more efficient SA-3, upgrade of the Power Control Unit (PCU) to eliminate intermittent issues and handle the extra power generated by the new solar arrays, installation of the Near Infrared Camera and Multi-Object Spectrometer (NICMOS) Cryocooler and its supporting electronics to revive the NICMOS instrument and extend its lifetime by providing necessary cooling, and installation of New Outer Blanket Layer (NOBL) sheets over damaged MLI on bays 5, 6, 7, and 8. At the end of this mission, a 6.3 km re-boost took place to extend Hubble's mission lifetime, being the last re-boost performed on Hubble servicing missions.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2002
Status: Completed
Operation Type: Servicing Mission
ORU SWaP: Unavailable
Standard Interface Type: Mechanical, Power, Data, Fluid
Cross Listing: RCDM044, R11, URMUI06

8.4.19 PRMUI19: Hubble Servicing Mission 4 (Hubble SM4)

Description: STS-125 (Servicing Mission 4, SM4) was the fifth and currently final servicing mission to the HST in May of 2009. This mission focused on performing basic maintenance replacements, upgrades to instruments, and the addition of some new components through five EVAs. Direct maintenance replacements included three Rate Sensor Units (RSUs) which had degraded, all six battery modules which had not been replaced/serviced since launch, a Fine Guidance Sensor (FGS) to replace the degraded FGS-2, repairs for the Advanced Camera for Surveys (ACS) which included the external installation of a Low Voltage Power Supply (LVPS) in conjunction with the replacement of the four Wide Field Channel (WFC) control boxes by the Charged Couple Device (CCD) Electronics Box to restore functionality to the ACS's WFC which was out of service due to a serious power failure, and a Science Instrument Control and Data Handling (SIC&DH) unit due to failed electronics on the original one. For upgrades, the Wide Field and Planetary Camera 2 (WFPC-2) was replaced for the Wide Field Camera 3 (WFC-3) to increase spectral range, the STIS Low Voltage Power Supply (LVPS) card #2 was replaced by a new version, and the COSTAR , which was added during SM1, was replaced by a new instrument called the Cosmic Origins Spectrograph (COS), which is the most powerful UV spectrograph ever flown on Hubble. Components added included NOBL sheets placed over damaged MLI on bays 5, 7, and 8 and a new Soft Capture Mechanism (SCM) for potential future RPOC operations including deorbiting.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2009
Status: Completed
Operation Type: Servicing Mission
ORU SWaP: Unavailable
Standard Interface Type: Mechanical, Power, Data
Cross Listing: RCDM045, R12, URMUI07

8.4.20 PRMUI20: intelligent Space System Interface (iSSI)

Description: The intelligent Space System Interface (iSSI) is a standardized modular interface which allows for the possibility of on-orbit servicing and the in-orbit replacement of common infrastructure elements. The modularity approach focuses on a 4-in-1 interface for mechanical coupling as well as power, data, and thermal interconnection. The interface was successfully tested on orbit in 2022 during the iSSI-FQE (Flight Qualification Experiment) while attached to the Kibo external platform on the ISS.
Developer: iBOSS, German Space Agency (DLR)
Country: Germany
First Use Date: 2022
Status: Operational
Operation Type: Servicing Interface
ORU SWaP: Max Lateral load: 400 N
Max Axial load: 6,000 N
Power: 0.05 kW/V
Data Rate: 1 Gb/s
Heat: 5 W/K
Mass: 1 kg
Standard Interface Type: Mechanical, Power, Data, Thermal
Cross Listing: RCDM046

8.4.21 PRMUI21: International Berthing and Docking Mechanism (IBDM)

Description: The International Berthing & Docking Mechanism (IBDM) is a docking mechanism being developed by the ESA which is composed of a soft docking system to facilitate spacecraft alignment, mechanical latches to achieve soft capture, and a hard docking system to create a sealed interface. The androgynous docking system is contact-force sensing, magnetically latched for capture, low impact, and capable of docking and berthing large and small vehicles. This docking system may be used on the Dream Chaser spacecraft to support docking to the ISS.
Developer: European Space Agency (ESA), QinetiQ Space, Sierra Nevada Corporation, SENER, RUAG, Maxon Group
Country: ESA
First Use Date: TBD
Status: In Development
Operation Type: Servicing Interface
ORU SWaP: Unavailable
Standard Interface Type: Mechanical, Power, Data, Video, Fluid (coolant/air)
Cross Listing: RCDM047

8.4.22 PRMUI22: International Space Station Intravehicular Activity Experiment (ISS IVR Experiment)

Description: During the GITAI International Space Station (ISS) Intravehicular Activity (IVA) Experiment, an S1 robotic arm completed a number of operations within the Nanoracks Bishop Airlock pressurized volume of the ISS. This experiment involved the robotic arm assembling a four-panel solar array mockup and completing a number of IVA tasks on a task board with standard IVA operations. The robot completed these operations autonomously and through teleoperations from a ground station in Houston.
Developer: GITAI
Country: Japan
First Use Date: 2021
Status: Completed
Operation Type: Robotic Servicing Demonstration
Standard Interface Type: General Gripper
Cross Listing: SMA19

8.4.23 PRMUI23: Micro-Fixture

Description: The Micro-Fixture is the standard interface of the Special Purpose Dexterous Manipulator (SPDM) on the ISS. Also known as a Micro-Square, this interface allows for direct grasp with the SPDM, so long as the payload has an adequate clearance envelope around the fixture for the SPDM to operate. The Micro-Fixture also allows for an umbilical connection to provide power, data, and video to the payload.
Developer: Canadian Space Agency (CSA), MDA Space
Country: Canada
First Use Date: Unavailable
Status: Operational
Operation Type: Servicing Interface
ORU SWaP: Unavailable
Standard Interface Type: Mechanical, Power, Data, Video
Cross Listing: RCDM058

8.4.24 PRMUI24: Modulink

Description: Modulink, developed by Motiv Space Systems, is self-contained for a variety of configurations conducive to integration with host spacecraft bus types. The hardware foundation includes dual robotic arms, separable interfaces to manipulate payload modules, and one payload module with an interface for attachment (client satellite). Additional applications include satellite servicing, refueling, assembly, and manufacturing.
Developer: Motiv Space Systems
Country: United States
First Use Date: Unavailable
Status: In Development
Operation Type: Servicer Spacecraft
Standard Interface Type: Two robotic arms, capable of hosting a variety of interfaces

8.4.25 PRMUI25: Multi-mission Modular Spacecraft

Description: The Multi-mission Modular Spacecraft was a modular spacecraft bus designed by NASA in the 1970s. This spacecraft bus was comprised of modular, standard subsystems to reduce the cost of satellite design and construction. In addition, the spacecraft bus was designed to be launched and captured by the Space Shuttle and serviceable on orbit. This spacecraft bus was used on six NASA satellites, one of which was serviced on orbit.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1980
Status: Completed
Operation Type: Modular Spacecraft

8.4.26 PRMUI26: NASA Docking System (NDS)

Description: The NASA Docking System (NDS) is an androgynous docking system installed on the ISS which meets the International Docking System Standard. This docking system allows for vehicles such as the Orion, Dragon, or Starliner spacecraft to visit the ISS. The Linear Actuator System (LAS), designed and built by MOOG, provides multi-axis independent load control for soft capture docking without a robotic arm. The NDS Block 1 is intended for use with ISS and the Block 2 is intended to be used on Gateway. The Block 2 variant will support fluid transfer through the MOOG fluid transfer coupling, which is capable of transferring xenon, hydrazine, and NTO. A variant of this coupler capable of transferring cryogenic propellants is under development.
Developer: National Aeronautics and Space Administration (NASA), MOOG
Country: United States
First Use Date: 2018
Status: Operational
Operation Type: Servicing Interface
ORU SWaP: Unavailable
Standard Interface Type: Mechanical, Power, Data, Refueling
Cross Listing: RCDM063, RFT27

8.4.27 PRMUI27: Orbital Express

Description: Launched March 8, 2007, as part of the United States Air Force Space Test Program (STP), Orbital Express demonstrated automated rendezvous and capture of two spacecraft (ASTRO and NEXTSat), transfer of propellant, tank venting, and transfer of a modular spacecraft component. Flow sensors demonstrated 5 to 10 percent flow rate error on N2H4 transfer with no significant issues. The mission demonstrated 9 mate/demate cycles on orbit and demonstrated robotic Orbital Replacement Unit (ORU) transfer and installation.
Developer: Defense Advanced Research Projects Agency (DARPA), National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2007
Status: Completed
Operation Type: Servicing Mission, Robotic Servicing Demonstration
ORU SWaP: Unavailable
Standard Interface Type: Data, Power, Mechanical
Cross Listing: RFT31, IM17

8.4.28 PRMUI28: ORU Tool Changeout Mechanism (OTCM)

Description: The ORU Tool Changeout Mechanism (OTCM) is a robotic manipulator system used by the Special Purpose Dexterous Manipulator (SPDM) on the ISS. It is used to grasp a variety of different payload fixtures, including the H-Fixture and Micro-Fixture. It is equipped with lights to align itself with targets, as well as a gripper mechanism to directly grasp the fixtures. It is able to provide power, data, and video to payloads through an umbilical connector.
Developer: Canadian Space Agency (CSA), MDA Space
Country: Canada
First Use Date: 2009
Status: Operational
Operation Type: Servicing Interface
ORU SWaP: Unavailable
Standard Interface Type: Mechanical, Power, Data, Video
Cross Listing: RCDM069

8.4.29 PRMUI29: Power and Data Grapple Fixture (PDGF)

Description: The Power and Data Grapple Fixture (PDGF) is an interface utilized by Canadarm2 on the International Space Station. They are placed throughout the outer surface of the ISS in order to facilitate the movement of Canadarm2 around the station. The interface is able to provide power, data, and video to Canadarm2, as well as an anchor point to grapple/latch on to. The fixture is an On-orbit Replaceable Unit (ORU), meaning it can be replaced once it fails or exceeds its design lifetime.
Developer: Canadian Space Agency (CSA), MDA Space
Country: Canada
First Use Date: Unavailable
Status: Operational
Operation Type: Servicing Interface
ORU SWaP: Unavailable
Standard Interface Type: Mechanical, Power, Data

8.4.30 PRMUI30: Power and Video Grapple Fixture (PVGF)

Description: The Power and Video Grapple Fixture (PVGF) is an interface compatible with the Canadarm2, made for use on the ISS. It can provide power, video, and data to the arm, as well as an anchor point to latch/grapple on to.
Developer: Canadian Space Agency (CSA), MDA Space
Country: Canada
First Use Date: Unavailable
Status: Operational
Operation Type: Servicing Interface
ORU SWaP: Unavailable
Standard Interface Type: Mechanical, Power, Data

8.4.31 PRMUI31: Pressurized Mating Adapter (PMA)

Description: A Pressurized Mating Adapter (PMA) converts common berthing mechanisms on the ISS to APAS-95 docking ports. These are comprised of a passive common berthing mechanism port and a passive APAS port.
Developer: The Boeing Company
Country: United States
First Use Date: 1998
Status: Operational
Operation Type: Servicing Interface
ORU SWaP: Unavailable
Standard Interface Type: Mechanical, Power, Data, Video
Cross Listing: RCDM075

8.4.32 PRMUI32: Robot Micro-Conical Tool (RMCT)

Description: The Robot Micro-Conical Tool (RMCT) is a manipulator system used by the Special Purpose Dexterous Manipulator (SPDM) on the ISS for handling payloads. It is made to grasp the Micro-Conical Fixture and needs a small clearance envelope around the fixture to successfully grasp the payload. Because of this, the RMCT is used to grasp payloads that have clearance envelopes too small for the ORU Tool Changeout Mechanism to grasp.
Developer: Oceaneering International Inc
Country: USA
First Use Date: 1995
Status: Operational
Operation Type: Servicing Interface
ORU SWaP: Unavailable
Standard Interface Type: Mechanical, Power, Data, Video
Cross Listing: RCDM087

8.4.33 PRMUI33: Roll-Out Solar Array (ROSA)

Description: The Roll-Out Solar Array (ROSA) is a NASA-developed, flexible, rollable solar panel technology for space applications, offering a more compact design compared to traditional rigid panels. The ROSA investigation evaluates deployment, retraction, shape changes during solar obstruction, and other physical challenges to assess the array's strength and durability. It was first tested on the International Space Station in 2017.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2021
Status: Operational
Operation Type: Servicing Mission
ORU SWaP: Unavailable
Standard Interface Type: Mechanical, Power, Data

8.4.34 PRMUI34: SLEGO Architecture

Description: The SLEGO block is a high performance, modular spacecraft bus which is capable of interfacing with payloads attached to a SLEGO interface or with other SLEGO building blocks. Each SLEGO block manages power, provides basic sensing and metrology, processes and manages data, provides basic attitude adjustments, and manages thermal control. Fluids for thermal or refueling purposes can be transmitted through the modular interface. This interface has been tested through the eXCITe (eXperiment for Cellular Integration Technology) mission launched to LEO in 2018, the Satlet Initial-Mission Proofs and Lessons (SIMPL) mission on the ISS in 2017, and the PODSat-1 mission launched within DARPA's Hosted POD Assembly in GEO. The SLEGO architecture is also integrated into the Athena satellite, which will measure solar energy that Earth reflects and absorbs, gathered via a small telescope attached to a NovaWurks Payload Accommodation Configuration (PAC).
Developer: NovaWurks
Country: United States
First Use Date: 2017
Status: Operational
Operation Type: Modular Spacecraft
ORU SWaP: Unavailable
Standard Interface Type: Mechanical, Fluid, Power, Data
Cross Listing: RCDM094, RFT44, SMA36

8.4.35 PRMUI35: Solar Maximum Servicing Mission

Description: During STS-41-C, astronauts from Space Shuttle Challenger captured, repaired, and re-deployed the Solar Maximum Mission satellite. The satellite experienced a failure with the attitude control system after launch in 1980 and was held in a passive state until serviced. During the repair, attitude control components and the electronics for the coronagraph instrument were replaced. This mission marks the first Shuttle rendezvous and capture of another, uncooperative spacecraft and the first Shuttle supported spacecraft and instrument repair.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1984
Status: Completed
Operation Type: Servicing Mission
ORU SWaP: Unavailable

8.4.36 PRMUI36: Spacecraft on Umbilical Line (SOUL)

Description: Spacecraft on Umbilical Line (SOUL) is a tethered robotic spacecraft that is designed to provide self-inspection and self-servicing. SOUL is a small (<10 kg) robotic, self-propelled, self-navigating, autonomous vehicle that receives power and commands from the host spacecraft. It acts as a robotic arm with essentially infinite degrees of freedom and very long reach, allowing it to access parts of the spacecraft inaccessible by a traditional robotic arm.
Developer: Busek Co. Inc
Country: United States
First Use Date: TBD
Status: In Development
Operation Type: Servicer Spacecraft
ORU SWaP: SOUL unit stows in 6U container. Mass <10 kg. Peak Power <100 W.
Cross Listing: RCDM097, IM30

8.4.37 PRMUI37: Standard Interface for Robotic Manipulation of Payloads in Future Space Missions (SIROM)

Description: SIROM offers three configurations of a standardized interface (Active-Passive, Active, and Passive) with distinct features for mating, alignment, and data/power transmission. It enables direct interaction with cooperative structures for servicing and standardizes interfaces for mechanical, data, electrical, and fluid connections. Notably, SIROM finds applications in satellite payload upgrades or replacements.
Developer: SENER, European Commission (EC)
Country: Spain, European Union
First Use Date: TBD
Status: In Development
Operation Type: Servicing Interface
ORU SWaP: Interface Mass: 1.5 kg
Max Lateral load: Unavailable
Power: 3000 W
Data: 1 Mbps (CAN), 100 Mbps (SpW)
Fluid Rate: 0.3 L/min @ 1 bar
Thermal: 2-2.5 kW
Standard Interface Type: Mechanical, Fluid (Thermal), Power, Data
Cross Listing: RCDM099

8.4.38 PRMUI38: Structural, Power, and Data Port (SPDP)

Description: The SPDP is a modular connector which provides mechanical and electrical connection between satellites. The connector was initially designed as a tool holder for robotic servicing satellites. The SPDP supports payloads up to 8.25 kg through launch and is designed to mate and demate up to 400 times on orbit. Consisting of both an active and passive unit, the SPDP system is designed to support robotics applications, satellite docking, and other on-orbit operations.
Developer: Sierra Space
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Operation Type: Servicing Interface
ORU SWaP: 8.25 kg through launch environment. Additional detail available upon request.
Pass-through harness: 29 connections, including 6 power pairs, 4 digital signal pairs, 3 analog signal pairs
Standard Interface Type: Mechanical, Power, Data
Cross Listing: RCDM102

8.4.39 PRMUI39: Low Profile Grapple Fixture (LPGF)

Description: The Low Profile Grapple Fixture is an interface compatible with MDA's Low Profile End Effector, which will be mounted on the Canadarm3 eXploration Large Arm (XLA) of Gateway. The interface allows for the XLA to capture and manipulate payloads in space. The interface provides a mechanical, power, and data interface between the manipulator and the payload.
Developer: MDA Space
Country: Canada
First Use Date: Scheduled for 2028
Status: In Development
Operation Type: Servicing Interface
ORU SWaP: Interface Mass: 11.3 kg
Power: 2000 W
Data: Gigabit Ethernet
Standard Interface Type: Mechanical, Power, Data, Video
Cross Listing: RCDM054

8.5 Unprepared Repair, Maintenance, Upgrade, and Installation

8.5.1 URMUI01: Alpha Magnetic Spectrometer Servicing (AMS-02 Servicing)

Description: The AMS-02 is a particle physics detector designed to operate as an external module on the ISS. It uses the unique environment of space to study the universe and its origin by searching for antimatter and dark matter while performing precision measurements of cosmic ray composition and flux. The instrument was repaired on orbit in 2019.
Developer: United States Department of Energy (DOE), National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2011
Status: Operational
Repairable Subsystems / Components: Debris cover, handrails, cooling system, support beams
Repair Tools: Unavailable
Grapple Types: Unavailable

8.5.2 URMUI02: Gecko Gripper

Description: The Gecko Gripper is an evolution of Altius' patent-pending StickyBoom enabled by JPL's space-rated gecko adhesive. Because the adhesive relies on van der Waals forces to adhere to surfaces, it is insensitive to temperature, pressure, and radiation. Like the gecko, the directional asymmetry of the synthetic adhesive allows the sticking power to be turned ON and OFF using a shear force. Gecko Gripper can grip objects that are difficult or impossible to manipulate with conventional grippers.
Developer: NASA Jet Propulsion Laboratory (JPL), Altius Space Machines Inc
Country: United States
Status: Concluded
Repairable Subsystems / Components: Tumbling object capture, stabilization, object manipulation
Repair Tools: Gripper
Grapple Types: Gecko gripper end effector

8.5.3 URMUI03: Hubble Servicing Mission 1 (Hubble SM1)

Description: The crew of STS-61 (Servicing Mission 1, SM1) addressed the Hubble's primary mirror spherical aberration by installing the Corrective Optics Space Telescope Axial Replacement (COSTAR) Orbital Replacement Unit (ORU) and performed upgrades and replacements to address other issues during five total EVAs. The upgrades and replacements included installing new magnetometers in place of degrading units, a new pair of solar arrays and solar array drive electronics to mitigate a mechanical oscillation caused by thermal expansion, an upgraded Wide Field & Planetary Camera (WFPC2) instrument, a coprocessor for the DF-224 computer to mitigate failure of two memory units, two Rate Sensor Units (RSU) each containing two gyros, and other minor components. A 7 km re-boost was performed at the end of the mission and an improvised temporary solution to capture debris coming from flaked-off coating from the old magnetometers was constructed by the crew with onboard materials.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1993
Status: Completed
Repairable Subsystems / Components: Instrument swap, instrument upgrade, hardware swap, hardware upgrade, new hardware installation, relocation, sensor replacement
Repair Tools: Canadarm, HST Servicing EVA tools, Manipulator Foot Restraint and Grapple Fixture
Grapple Types: Canadarm
Cross Listing: RCDM041, R09, PRMUI15

8.5.4 URMUI04: Hubble Servicing Mission 2 (Hubble SM2)

Description: STS-82 (Servicing Mission 2, SM2) was the second planned Hubble servicing mission. It focused on increasing the telescope's productivity with the installation of new instruments that extended Hubble's wavelength range into the near infrared for imaging and spectroscopy. Through four planned EVAs, failed and degraded components were replaced, and some upgrades were performed to older equipment. The tasks included replacement of the outdated Goddard High Resolution Spectrograph (GHRS) and Faint Object Spectrometer (FOS) by the Space Telescope Imaging Spectrograph (STIS) and Near-Infrared Camera and Multi-Object Spectrometer (NICMOS) instruments, respectively, to increase spectral range of the telescope, upgrade of tape recorder #1 from a reel-to-reel recorder to a Solid State Recorder which could store 10 times more data, direct replacement of the degraded tape recorder #2 by a spare unit, replacement of the degraded Fine Guidance Sensor #1 (FGS-1) by an upgraded unit with the added capability of ground-controlled alignment corrections, replacement of the degraded Reaction Wheel Assembly #1 (RWA-1), covering worn MLI at the top of the telescope's tube with Patch Kit Thermal Insulation Blankets, installing permanent magnetometer covers over the temporary ones installed in SM-1, and replacement of the Solar Array Drive Electronics #1 (SADE-1) with a refurbished unit. Since damage to the MLI was greater than anticipated, a fifth EVA was conducted to cover degraded MLI with sheets manufactured by the crew with onboard materials. A re-boost was performed to raise Hubble's orbit by 16 km.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1997
Status: Completed
Repairable Subsystems / Components: Instrument swap, instrument upgrade, hardware swap, hardware upgrade, new hardware installation, relocation, sensor replacement
Repair Tools: Canadarm, HST Servicing EVA tools, Manipulator Foot Restraint and Grapple Fixture
Grapple Types: Canadarm
Cross Listing: RCDM042, R10, PRMUI16

8.5.5 URMUI05: Hubble Servicing Mission 3A (Hubble SM3A)

Description: STS-103 (Servicing Mission 3A, SM3A) was originally scheduled for June 2000 as the third planned Hubble servicing mission for preventive maintenance but became more urgent after four of the six gyros on the telescope failed, with the HST requiring at least 3 to operate. It was divided into two parts, the first of which was SM3A. The telescope was placed in safe mode on November 13, 1999, when the fourth gyro failed until the launch and arrival of SM3A on December 19, 1999. Tasks performed during three EVAs included replacement of all three Rate Sensor Units (each containing two gyros), replacement of the Fine Guidance Sensor #2 (FGS-2) by an upgraded and refurbished unit, replacement of the faulty S-Band Single Access Transmitter #2 (SSAT-2), replacement the DF-224 main computer by the more capable Advanced Computer, installation of Battery Voltage/Temperature Improvement Kits (VIKs) for increased interoperability between the batteries and solar arrays by preventing overcharging and overheating, upgrade of tape recorder #3 to Solid State Recorder (SSR), and installation of handrail covers made to prevent possible contamination from flaking paint. The New Outer Blanket Layer (NOBL) and Shell/Shield Replacement (SSR) fabric MLI kits were used to cover MLI which had been greatly degraded by embrittlement and cracks caused by exposure to charged particles, thermal cycling, and other environmental effects.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1999
Status: Completed
Repairable Subsystems / Components: Instrument swap, instrument upgrade, hardware swap, hardware upgrade, new hardware installation, sensor replacement
Repair Tools: Canadarm, HST Servicing EVA tools, Manipulator Foot Restraint and Grapple Fixture
Grapple Types: Canadarm
Cross Listing: RCDM043, PRMUI17

8.5.6 URMUI06: Hubble Servicing Mission 3B (Hubble SM3B)

Description: STS-109 (Servicing Mission 3B, SM3B) was the fourth servicing mission for the Hubble in 2002 and the continuation to the third servicing mission (SM3A) in 1999, as SM3 was split into two parts. With five total EVAs, replacement and upgrade tasks in this mission included direct replacement of the Reaction Wheel Assembly #1 (RWA), replacement of the Faint Object Camera (FOC) for the Advanced Camera for Surveys (ACS), upgrade of the Solar Arrays 2 (SA-2) to the rigid, smaller, and more efficient SA-3, upgrade of the Power Control Unit (PCU) to eliminate intermittent issues and handle the extra power generated by the new solar arrays, installation of the Near Infrared Camera and Multi-Object Spectrometer (NICMOS) Cryocooler and its supporting electronics to revive the NICMOS instrument and extend its lifetime by providing necessary cooling, and installation of New Outer Blanket Layer (NOBL) sheets over damaged MLI on bays 5, 6, 7, and 8. At the end of this mission, a 6.3 km re-boost took place to extend Hubble's mission lifetime, being the last re-boost performed on Hubble servicing missions.

Developer: National Aeronautics and Space Administration (NASA)

Country: United States

First Use Date: 2002

Status: Completed

Repairable Subsystems / Components: Instrument swap, instrument upgrade, hardware swap, hardware upgrade, new hardware installation, relocation, sensor replacement

Repair Tools: Canadarm, HST Servicing EVA tools, Manipulator Foot Restraint and Grapple Fixture

Grapple Types: Canadarm

Cross Listing: RCDM044, R11, PRMUI18

8.5.7 URMUI07: Hubble Servicing Mission 4 (Hubble SM4)

Description: STS-125 (Servicing Mission 4, SM4) was the fifth and currently final servicing mission to the HST in May of 2009. This mission focused on performing basic maintenance replacements, upgrades to instruments, and the addition of some new components through five EVAs. Direct maintenance replacements included three Rate Sensor Units (RSUs) which had degraded, all six battery modules which had not been replaced/serviced since launch, a Fine Guidance Sensor (FGS) to replace the degraded FGS-2, repairs for the Advanced Camera for Surveys (ACS) which included the external installation of a Low Voltage Power Supply (LVPS) in conjunction with the replacement of the four Wide Field Channel (WFC) control boxes by the Charged Couple Device (CCD) Electronics Box to restore functionality to the ACS's WFC which was out of service due to a serious power failure, and a Science Instrument Control and Data Handling (SIC&DH) unit due to failed electronics on the original one. For upgrades, the Wide Field and Planetary Camera 2 (WFPC-2) was replaced for the Wide Field Camera 3 (WFC-3) to increase spectral range, the STIS Low Voltage Power Supply (LVPS) card #2 was replaced by a new version, and the COSTAR , which was added during SM1, was replaced by a new instrument called the Cosmic Origins Spectrograph (COS), which is the most powerful UV spectrograph ever flown on Hubble. Components added included NOBL sheets placed over damaged MLI on bays 5, 7, and 8 and a new Soft Capture Mechanism (SCM) for potential future RPOC operations including deorbiting.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2009
Status: Completed
Repairable Subsystems / Components: Instrument swap, instrument upgrade, hardware swap, hardware upgrade, new hardware installation, sensor replacement
Repair Tools: Canadarm, HST Servicing EVA tools, Manipulator Foot Restraint and Grapple Fixture
Grapple Types: Canadarm
Cross Listing: RCDM045, R12, PRMUI19

8.5.8 URMUI08: Intelsat 603 Servicing Mission

Description: During STS-49, astronauts aboard Space Shuttle Endeavour installed a new perigee kick motor to Intelsat 603, allowing the satellite to transfer to geostationary orbit as originally intended. The capture of Intelsat 603 required 3 EVAs, the last of which included the only 3-person EVA in spaceflight history during which the shuttle was navigated within feet of the communications satellite and the satellite was grasped by hand.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1992
Status: Completed
Repairable Subsystems / Components: Satellite Repair
Repair Tools: Canadarm, EVA Tools
Grapple Types: Canadarm

8.5.9 URMUI09: Leasat-3 Servicing Mission

Description: During STS-51-I, astronauts from Space Shuttle Discovery repaired the Leasat-3 satellite, also known as Syncom IV-4. The satellite was stranded in Low Earth Orbit after a faulty timing mechanism prevented satellite activation. After repair, commands from the ground were able to activate the satellite and perform operations to send the satellite to its intended destination in geosynchronous orbit.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1985
Status: Completed
Repairable Subsystems / Components: Satellite Repair
Repair Tools: Canadarm, EVA Tools
Grapple Types: Canadarm

8.5.10 URMUI10: Mission Extension Pods (MEP)

Description: Mission Extension Pods (MEP) are Northrop Grumman's next generation of servicing vehicles. MEPs will extend the life of hosting spacecraft by providing orbit control services for up to six years. They will be installed by a Mission Robotic Vehicle which can carry several pods to multiple client spacecraft.
Developer: Northrop Grumman
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Repairable Subsystems / Components: Unavailable
Repair Tools: None in current design (planned for future)
Grapple Types: Unavailable
Cross Listing: R18

8.5.11 URMUI11: Mission Robotic Vehicle (MRV)

Description: The Mission Robotic Vehicle (MRV) is a future on-orbit servicing bus developed using technologies and lessons from the Mission Extension Vehicle. The robotic payload will be supplied by DARPA and developed by the United States Naval Research Laboratory as part of the Robotic Servicing of Geosynchronous Satellites (RSGS) mission.
Developer: Northrop Grumman
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Repairable Subsystems / Components: Unavailable
Repair Tools: DARPA's two dexterous robotic manipulator arms, several tools and sensors
Grapple Types: Unavailable
Cross Listing: RCDM061, R20

8.5.12 URMUI12: Neutron star Interior Composition Explorer Servicing (NICER Servicing)

Description: The NICER payload is a space telescope currently operating on the exterior of the ISS. Its purpose is to study phenomena such as black holes and neutron stars. In 2025, it was repaired by astronauts due to a "light leak" condition where sunlight entered the payload and interfered with onboard detectors.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2017
Status: Operational
Repairable Subsystems / Components: Interior instrument components
Repair Tools: Unavailable
Grapple Types: Unavailable

8.5.13 URMUI13: On-orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1)

Description: On-orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) was a spacecraft under development by NASA and Maxar to demonstrate activities required for unplanned satellite mission extension. OSAM-1 was planned to rendezvous with and refuel Landsat 7, which required activities such as cutting insulation, unscrewing bolts and caps, and attaching propellant lines. After completing refuel of Landsat 7, the hosted SPIDER payload would have assembled a communications antenna.
Developer: National Aeronautics and Space Administration (NASA), Maxar Technologies
Country: United States
Status: Concluded
Repairable Subsystems / Components: Refueling, others unavailable
Repair Tools: Dexterous Robotic Arms (2), Space Infrastructure Dexterous Robot (SPIDER), Autonomous Real-time Relative Navigation System, Servicing Avionics, Advanced Tool Drive and Tools, Propellant Transfer System
Grapple Types: 2 robotic arms, SPIDER arm
Cross Listing: RCDM065, RFT30

8.5.14 URMUI14: REMORA CubeSat

Description: Jet Propulsion Laboratory (JPL) has developed a concept called REMORA that would use a 6U CubeSat to capture space debris or be used to assemble payloads in space. The CubeSat is designed to use one or dual robotic manipulators, also designed by JPL. In addition to space debris and assembly applications, the spacecraft may be used to track debris locations and potentially prevent collision between objects.
Developer: NASA Jet Propulsion Laboratory (JPL)
Country: United States
Status: Concluded
Repairable Subsystems / Components: Large Orbital Debris Removal
Repair Tools: Robotic arm

8.5.15 URMUI15: Robotic Refueling Mission 1 (RRM1)

Description: The Robotic Refueling Mission (RRM) was a multi-phased ISS technology demonstration that tested tools and techniques to refuel and repair satellites not designed to be tested in orbit. RRM was mounted to an external payload of the ISS to demonstrate fluid transfer. There were four tools stowed in the module which were used by Dextre, which was controlled remotely by mission operators at Johnson Space Center, to perform various servicing tasks.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2011
Status: Completed
Repairable Subsystems / Components: Repair Demo, Refueling Demo
Repair Tools: cameras and LEDs, Canadian Dextre Robot (Wire Cutter and Blanket Manipulation Tool, Multifunction Tool, Safety Cap Tool, Nozzle Tool), robotic fueling hose, Visual Inspection Poseable Invertebrate Robot (VIPIR)
Grapple Types: 2 Dextre Arms
Cross Listing: RFT40

8.5.16 URMUI16: Robotic Refueling Mission 2 (RRM2)

Description: RRM2 (phase 2) began in 2015 with the help of Dextre, transferring new RRM hardware to the module. RRM tested a new inspection tool, tested electrical connections for space instruments, and practiced steps to support coolant replenishment. VIPIR tested its camera capabilities by capturing images of various satellite parts on the RRM module.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2015
Status: Completed
Repairable Subsystems / Components: Coolant replenishment, testing electrical connections, working with machine vision indicators.
Repair Tools: Dextre, VIPIR, Wire Cutter and Blanket Manipulation Tool, Multifunction Tool, Safety Cap Tool, and Nozzle Tool
Grapple Types: Dextre

8.5.17 URMUI17: SHIELD

Description: SHIELD is a modular upgrade system featuring a base station and deployable scouting units designed to provide dynamic inspection, space domain awareness data collection, and defensive maneuvering capabilities when installed on commercial satellites.
Developer: Katalyst Space Technologies
Country: United States
First Use Date: TBD
Status: In Development
Repairable Subsystems / Components: Instrument Upgrade with Space Domain Awareness capabilities
Repair Tools: Katalyst Launch Adapter Ring Attachment
Grapple Types: Launch Adapter Ring
Cross Listing: RCDM089, IM26

8.5.18 URMUI18: SIGHT

Description: SIGHT is a modular imaging sensor package designed to retrofit existing satellites with space domain awareness capabilities by attaching to an orbiting spacecraft's launch adapter ring.
Developer: Katalyst Space Technologies
Country: United States
First Use Date: TBD
Status: In Development
Repairable Subsystems / Components: Instrument Upgrade with Space Domain Awareness capabilities
Repair Tools: MRV's robotic arms, Katalyst Launch Adapter Ring Attachment
Grapple Types: Launch Adapter Ring
Cross Listing: IM27

8.5.19 URMUI19: Wire Cutter Tool

Description: The Wire Cutter tool was one of the four RRM tools used to perform servicing tasks in space. Mission controllers remotely commanded Dextre to perform tasks such as grabbing, snipping, manipulating, and slicing using the wire cutter tool on the RRM module.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2013
Status: Completed
Grapple Types: Small sniper, slicer, and manipulator

8.6 Refueling and Fluid Transfer

8.6.1 RFT01: Advanced Liquid Feed Experiment (ALFE)

Description: The Advanced Liquid Feed Experiment (ALFE) was an in-space demonstration flown on STS-39 in 1991. The main objectives of the experiment were to evaluate the performance and operations of electronic pressure regulators, flowmeters, sensors, and tank fluid refilling in low gravity. The experiment utilized commercial off the shelf (COTS) parts as well as the Hitchhiker carrier system on the Space Shuttle in order to maintain a low-cost, reliable mission. Freon 113 was used as a test fluid representation of Nitrogen Tetroxide.
Developer: McDonnell Douglas Astronautics Company
Country: USA
First Use Date: 1991
Status: Completed
Propellant / Fluid Type: Freon 113
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable

8.6.2 RFT02: Astroscale Prototype Servicer for Refueling (APS-R)

Description: Astroscale Prototype Servicer for Refueling (APS-R) is a propellant delivery vehicle which will operate in GEO. The vehicle will collect hydrazine from the DIU RAPIDS Kamino fuel depot and deliver the propellant to a client within GEO, such as the Astroscale LEXI vehicle. The vehicle will be ESPA class and will be constructed at the Southwest Research Institute's facility in San Antonio, Texas.
Developer: Astroscale
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Propellant / Fluid Type: Hydrazine
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable
Cross Listing: RCDM011

8.6.3 RFT03: Cooperative Service Valve (CSV)

Description: The Cooperative Service Valve (CSV) is a spacecraft fill and drain valve for cooperative servicing, featuring a robotic interface, three individually actuated seals, a self-contained anti-back drive system, and built-in thermal isolation. It transfers loads to the mounting structure, prevents accidental actuation, and has four fluid configurations with unchanged geometry. Unique keying and color-coding prevent media mixing and operator error. The CSV is currently licensable through NASA's Technology Transfer Program.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: TBD
Status: In Development
Propellant / Fluid Type: Pressurant / Hydrazine / MMH / NTO
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable

8.6.4 RFT04: Cryogenic (H2/O2) Smart Propulsion Flight Demonstration

Description: ULA was selected for one of four contracts under the 2020 NASA Tipping Point solicitation for cryogenic fluid management technology demonstrations. Totaling 86.2 million dollars, the contract tasked ULA with developing and demonstrating a small propulsion cryogenic system. Scheduled for a 2025 launch, ULA is aiming to demonstrate the transfer of liquid hydrogen between tanks on orbit, pressure control of liquid tanks, and the performance of NASA Kennedy's Solar White passive thermal control technology.
Developer: United Launch Alliance (ULA)
Country: USA
First Use Date: Scheduled for 2025
Status: In Development
Propellant / Fluid Type: Liquid Hydrogen
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable

8.6.5 RFT05: Cryogenic Demonstration Mission (CDM)

Description: Lockheed Martin's Cryogenic Demonstration Mission (CDM) is an awardee of the NASA 2020 Tipping Point Selection for Cryogenic Fluid Management. It was awarded 89.7 million dollars to demonstrate the storage and transfer of liquid hydrogen, often deemed the most challenging of cryogenic propellants. The entire mission is comprised of up to 17 technologies combined into a single system capable of storing, transferring, and controlling the pressure of cryogenic propellant.
Developer: Lockheed Martin
Country: USA
First Use Date: Scheduled for 2025
Status: In Development
Propellant / Fluid Type: Liquid Hydrogen
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable

8.6.6 RFT06: Cryogenic Servicing Tool (CST)

Description: A robotic servicing tool designed to grab a flexible cryogen transfer hose. Used on RRM 3, which demonstrated the storage of cryogenic fluid for four months with zero boil-off. The CST was an integral component to RRM3's objectives of connecting, sealing, and managing hoses enabling in-space cryogenic fuel transfer.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2018
Status: Completed
Propellant / Fluid Type: Methane
Fluid Volume / Mass: 42 liters
Boil-Off Rate: ~Zero

8.6.7 RFT07: Docking and Fluid Transfer Port (DFT Port)

Description: The Docking and Fluid Transfer Port is an in-space interface that provides mechanical, data, and refueling connections for satellite servicing operations. The docking port may be used for missions such as life extension, relocation, and active debris removal.
Developer: Dawn Aerospace
Country: Netherlands/New Zealand
First Use Date: TBD
Status: In Development
Propellant / Fluid Type: Fuel: Propene, Ethane
Oxidizer: Nitrous oxide
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable
Cross Listing: RCDM022, PRMUI06

8.6.8 RFT08: Elixir

Description: The Elixir program is a refueling demonstration program funded through Space Systems Command and developed by Northrop Grumman. Through the program, Northrop Grumman will design and deploy a payload equipped with Northrop Grumman's Active Refueling Module (ARM). The payload will be installed on the ROOSTER-5 spacecraft and will provide propellant to the Tetra-6 spacecraft as part of the demonstration.
Developer: Northrop Grumman, United States Space Force
Country: United States
First Use Date: Scheduled for 2027
Status: In Development
Propellant / Fluid Type: Unavailable
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable

8.6.9 RFT09: Enduralock Satellite Connector

Description: Enduralock is a small satellite interface which provides mechanical, data/power, and fuel transfer connection between spacecraft. The interface is intended to occupy a 1 cm cubic volume and incorporates features to allow for the misalignment expected during autonomous docking between spacecraft.
Developer: Enduralock
Country: United States
First Use Date: TBD
Status: In Development
Propellant / Fluid Type: Unavailable
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable
Cross Listing: RCDM027, PRMUI07

8.6.10 RFT10: European Robotic Orbital Support Services - Servicing Component (EROSS-SC)

Description: The European Robotic Orbital Support Services (EROSS) project is focused on developing technologies to support orbital operations in LEO and GEO. It has evolved through several phases and is now scoped to develop an operational mission demonstrating docking, rendezvous, inspection, and other servicing capabilities. Funded through the European Commission and led by Thales Alenia Space, the EROSS-SC mission is scheduled for an In-Orbit Demonstration (IOD) in 2026, followed by an operational mission in 2027-2028.
Developer: Thales Alenia Space, European Commission (EC)
Country: European Union
First Use Date: Scheduled for 2028
Status: In Development
Propellant / Fluid Type: Unavailable
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable
Cross Listing: RCDM029, IM07

8.6.11 RFT11: European System Providing Refueling Infrastructure and Telecommunications (ESPRIT)

Description: The ESPRIT module is a refueling and communications component of NASA's Gateway lunar space station. This module is being developed by Thales Alenia Space and funded through a contract with the European Space Agency (ESA). ESPRIT consists of two elements: the communications component known as Lunar Link and the refueling and storage component known as Lunar View. Lunar Link will focus on communications between Gateway and the Moon, while Lunar View is a logistics area and viewing deck that will also be capable of supplying Gateway with propellant.
Developer: European Space Agency (ESA), Thales Alenia Space
Country: ESA
First Use Date: Scheduled for 2028
Status: In Development
Propellant / Fluid Type: Xenon
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable

8.6.12 RFT12: Fluid Acquisition & Resupply Experiment I (FARE-I)

Description: Flown aboard STS-53 in 1992, the Fluid Acquisition & Resupply Experiment I (FARE-1) demonstrated an upgraded fluid management system over the SFMD, again with colored water. The screen-type system was tested 8 times and filled up to 70 percent without liquid venting.
Developer: NASA Marshall Space Flight Center (MSFC)
Country: United States
First Use Date: 1992
Status: Completed
Propellant / Fluid Type: Water
Fluid Volume / Mass: Approx. 15 liters

8.6.13 RFT13: Fluid Acquisition & Resupply Experiment II (FARE-II)

Description: Flown aboard STS-57 in 1993, the Fluid Acquisition & Resupply Experiment II (FARE-II) demonstration followed SFMD and FARE-I. The demonstration used a vane fluid management system. It demonstrated fill to 95 percent without liquid venting at a maximum flow rate of 0.35 gallons per minute. FARE-II, like FARE-I, used colored water.
Developer: NASA Marshall Space Flight Center (MSFC)
Country: United States
First Use Date: 1993
Status: Completed
Propellant / Fluid Type: Water
Fluid Volume / Mass: 16.8 liters

8.6.14 RFT14: Furphy Prototype Tanker

Description: Orbit Fab's Furphy experiment transferred water between two tanks on ISS, then transferred that water to the ISS water supply. This demonstration advanced Orbit Fab's propellant feed system to TRL 8.
Developer: Orbit Fab
Country: United States
First Use Date: 2019
Status: Completed
Propellant / Fluid Type: Water
Fluid Volume / Mass: 15 liters

8.6.15 RFT15: Grappling Resupply Interface for Products (GRIP)

Description: The Grappling Resupply Interface for Products (GRIP) is the active mating component to the RAFTI refueling interface. The GRIP interface is mounted on the servicing spacecraft and provides mechanical connection and refueling to the client. GRIP will be used in conjunction with RAFTI ports on the two Tetra-5 satellites projected to launch in 2026. Astroscale will also be using RAFTI and GRIP in a servicing vehicle being developed for the U.S. Space Force in 2026.
Developer: Orbit Fab
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Propellant / Fluid Type: Hydrazine, Gaseous Helium, Deionized Water, Isopropyl Alcohol, Gaseous Nitrogen, MMH
Cross Listing: RCDM036

8.6.16 RFT16: Green Propellant Micropump

Description: As part of the Lunar Flashlight mission, a lunar CubeSat mission focused on locating ice deposits, Flight Works Inc developed and qualified a small pump for fluid transfer. Known as the Lunar Flashlight Propulsion System, the micropumps were made to transfer ASCENT propellant, also known as AF-M315E. These pumps were flight-qualified and able to provide suitable delta-V for maneuvers. The pumps could potentially be used for refueling applications.
Developer: Flight Works Inc
Country: United States
First Use Date: 2022
Status: Operational
Propellant / Fluid Type: ASCENT
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable

8.6.17 RFT17: Helium Compressor

Description: Filling the need for an on-orbit, mass efficient, gaseous helium transfer capability, the Advancement of Exploration Components for In-Space Servicing (AXCIS) Early Career Initiative project at NASA is developing a compressor system compatible with both helium and xenon. Building off of an SBIR Phase I project by Flight Works Incorporated, the AXCIS team will use an SBIR Phase III contract to procure a flight-like EDU. AXCIS plans to use expertise and lessons learned in the development of OSAM-1, as well as detailed environmental testing, to advance the Technology Readiness Level of these components.
Developer: Flight Works Inc, National Aeronautics and Space Administration (NASA)
Country: USA
First Use Date: TBD
Status: In Development
Propellant / Fluid Type: Helium, Xenon
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable

8.6.18 RFT18: High Accuracy Coriolis Mass Flow Meter

Description: A component of the Advancement of Exploration Components for In-Space Servicing (AXCIS) Early Career Initiative project at NASA, the Coriolis Mass Flow Meter is a highly accurate flow meter, with components like transmitter electronics and sensors designed for space applications. Originally developed at Kennedy Space Center alongside Chase Defense Partners, the flow meter prototype was created to measure mass flow using motion mechanics. Although the initial project ended in 2023, AXCIS is advancing the technology to a higher Technology Readiness Level.
Developer: Chase Defense Partners, National Aeronautics and Space Administration (NASA)
Country: USA
First Use Date: TBD
Status: In Development
Propellant / Fluid Type: Unavailable
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable

8.6.19 RFT19: Hose Management Assembly (HMA)

Description: The Hose Management Assembly (HMA) was a pivotal component of the OSAM-1 Propellant Transfer Subsystem (PTS). Made up of several smaller subsystems, the HMA was planned to be used for transferring hydrazine to client satellites. The HMA was also planned to be used for maintaining fuel temperature through different levels of shadow coverage, operating a retractable refueling hose system, and interfacing with other tools such as the Hypergol Refueling Tool.
Developer: National Aeronautics and Space Administration (NASA)
Country: USA
First Use Date: N/A
Status: Concluded
Propellant / Fluid Type: Hydrazine
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable

8.6.20 RFT20: Hypergol Refueling Tool (HRT)

Description: The Hypergol Refueling Tool is a technology developed to interface with in-orbit propulsion systems. It was designed with a Quick Disconnect (QD) and mainly used for Fill and Drain Valves on satellites. It is a component that was planned to be used on NASA's OSAM-1 mission, meaning the primary propellant used would be hydrazine. However, the technologies can be augmented and changed to work with other hypergolic propellants. The HRT is licensable through NASA's Technology Transfer Program.
Developer: National Aeronautics and Space Administration (NASA)
Country: USA
First Use Date: N/A
Status: Concluded
Propellant / Fluid Type: Hydrazine
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable

8.6.21 RFT21: Kamino

Description: Starting in 2026, Orbit Fab will offer customers in GEO the opportunity to replenish hydrazine through use of Orbit Fab Kamino fuel depots and propellant shuttles. Development of the Kamino is supported by the Defense Innovation Unit's RAPIDS contract, as well as commercial agreements with ClearSpace and Astroscale. The initial DIU RAPIDS vehicle will be hosted on an Impulse Space Mira orbital service vehicle and will deliver 50 kg of hydrazine to the Tetra-5 spacecraft and APS-R servicer.
Developer: Orbit Fab
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Propellant / Fluid Type: Hydrazine
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable

8.6.22 RFT22: Key and Advanced Technology R&D through Cross Community Collaboration Program (K Program)

Description: The K Program was established by Astroscale Japan in incentivizing Rendezvous Proximity Operational Technologies to further demonstrate on-orbit chemical refueling services in LEO orbit as well as ground verification for GEO orbit refueling services for electric propulsion systems. The goal of this is to lead the in-space market for satellite servicing and long-term orbital sustainability. The program will span five years with a total budget of $77 million.
Developer: Astroscale
Country: Japan
First Use Date: TBD
Status: In Development
Propellant / Fluid Type: Chemical Propellant
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable
Cross Listing: RCDM049

8.6.23 RFT23: Liquid Oxygen Flight Demonstration (LOXSAT-1)

Description: LOXSAT-1 is a demonstration satellite developed by Eta Space and set to launch in 2026. Selected in 2020 for a NASA Tipping Point award, Eta Space was given 27 million dollars to develop a demonstration of a cryogenic fluid management system. The LOXSAT will demonstrate several key technologies for refueling in space, such as zero-loss storage/transfer and cryogenic pressure control. The LOXSAT system will be hosted on a Rocket Lab Photon satellite bus and will be launched in a Rocket Lab Electron Launch Vehicle.
Developer: Eta Space
Country: USA
First Use Date: Scheduled for 2026
Status: In Development
Propellant / Fluid Type: Liquid Oxygen
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable

8.6.24 RFT24: Mission 1

Description: The Atomos Space Mission 1 (colloquially the Singing Astronomer Mission) was an RPO, refueling, and orbital transfer mission which used Atomos' Quark and Gluon spacecraft. The Quark and Gluon spacecraft were launched in a joined state on SpaceX's Falcon 9 Transporter 10 mission. The mission intended for the Quark spacecraft to autonomously RPO and dock to Gluon, Quark to refuel from Gluon, and combined vehicle orbital transfer demonstrations. Due to anomalies experienced during mission initiation, the intended multi-vehicle operations were not performed.
Developer: Atomos Space
Country: United States
First Use Date: 2024
Status: Concluded
Propellant / Fluid Type: Unavailable
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable
Cross Listing: RCDM059, R17

8.6.25 RFT25: Multifunction Tool (MFT)

Description: The Multifunction Tool, part of the RRM 1 tool suite, effectively does the work of four tools. It is able to lock onto four separate tool adapters: the Tertiary Cap Adapter, T-Valve Adapter, Plug Manipulator Adapter, and Ambient Cap Adapter. These adapters perform different tasks relating to moving and stowage of various caps and gas plugs.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2011
Status: Completed

8.6.26 RFT26: Multi-Function Tool 2 (MFT2)

Description: A component of RRM3, the Multi-function Tool 2 is a drive tool used to facilitate the transfer of cryogenic fuel. On RRM3, the MFT2 was responsible for unstowing the cryogen coupler adapter and inserting it into its associated adapter port. The tool is comprised of a dual rotary system, enabling the connection of custom hoses to fill ports.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2018
Status: Completed

8.6.27 RFT27: NASA Docking System (NDS)

Description: The NASA Docking System (NDS) is an androgynous docking system installed on the ISS which meets the International Docking System Standard. This docking system allows for vehicles such as the Orion, Dragon, or Starliner spacecraft to visit the ISS. The Linear Actuator System (LAS), designed and built by MOOG, provides multi-axis independent load control for soft capture docking without a robotic arm. The NDS Block 1 is intended for use with ISS and the Block 2 is intended to be used on Gateway. The Block 2 variant will support fluid transfer through the MOOG fluid transfer coupling, which is capable of transferring xenon, hydrazine, and NTO. A variant of this coupler capable of transferring cryogenic propellants is under development.
Developer: National Aeronautics and Space Administration (NASA), MOOG
Country: United States
First Use Date: 2018
Status: Operational
Propellant / Fluid Type: Xenon and bipropellant
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable
Cross Listing: RCDM063, PRMUI26

8.6.28 RFT28: Nozzle Tool

Description: The Nozzle Tool connects to, opens, and ultimately closes a satellite fuel valve. Using an attached hose, it transfers a representative satellite fuel in a continuous loop to simulate the refueling of a satellite. The Nozzle Tool has an anti-cross-threading feature that ensures it cannot damage the satellite fuel valve by screwing the fuel cap on the wrong way. The fuel cap that the tool leaves behind has a quick disconnect fitting that gives operators easy future access to the valve, should it be needed. This tool is part of the RRM 1 tool suite.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2011
Status: Completed

8.6.29 RFT29: On-Orbit Large-Scale Cryogenic Propellant Management and Transfer Demonstration (Starship Propellant Transfer Demonstration)

Description: An awardee of a 2020 NASA Tipping Point contract, SpaceX was tasked with demonstrating a large-scale cryogenic fluid transfer system. On March 14, 2024, SpaceX's Starship conducted its third test flight, succeeding in transferring cryogenic fluid between two tanks inside the vehicle while in space. This milestone has paved the way for future SpaceX demonstrations, including a planned test in 2025 of cryogenic fluid transfer between two Starships in orbit.
Developer: SpaceX
Country: USA
First Use Date: 2024
Status: Completed
Propellant / Fluid Type: Liquid Oxygen
Fluid Volume / Mass: 10 t (approx.)
Boil-Off Rate: Unavailable

8.6.30 RFT30: On-orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1)

Description: On-orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) was a spacecraft under development by NASA and Maxar to demonstrate activities required for unplanned satellite mission extension. OSAM-1 was planned to rendezvous with and refuel Landsat 7, which required activities such as cutting insulation, unscrewing bolts and caps, and attaching propellant lines. After completing refuel of Landsat 7, the hosted SPIDER payload would have assembled a communications antenna.
Developer: National Aeronautics and Space Administration (NASA), Maxar Technologies
Country: United States
Status: Concluded
Propellant / Fluid Type: Hydrazine
Fluid Volume / Mass: Unknown
Cross Listing: RCDM065, URMUI13

8.6.31 RFT31: Orbital Express

Description: Launched March 8, 2007, as part of the United States Air Force Space Test Program (STP), Orbital Express demonstrated automated rendezvous and capture of two spacecraft (ASTRO and NEXTSat), transfer of propellant, tank venting, and transfer of a modular spacecraft component. Flow sensors demonstrated 5 to 10 percent flow rate error on N2H4 transfer with no significant issues. The mission demonstrated 9 mate/demate cycles on orbit and demonstrated robotic Orbital Replacement Unit (ORU) transfer and installation.
Developer: Defense Advanced Research Projects Agency (DARPA), National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2007
Status: Completed
Propellant / Fluid Type: Hydrazine
Fluid Volume / Mass: Unknown
Cross Listing: PRMUI27, IM17

8.6.32 RFT32: Orbital Refueling System Flight Demonstration (ORS Flight Demonstration)

Description: Flown aboard STS-41G in 1984, the Orbital Refueling System (ORS) demonstrated the feasibility of refueling hydrazine. Housed in the Shuttle Payload Bay, an EVA connected two tanks (one simulating a tanker and another simulating a satellite to be refueled). The experiment involved transferring up to 142 kg of propellant 6 times between the tanks and using nitrogen to inflate a diaphragm tank.
Developer: NASA Johnson Space Center (JSC)
Country: United States
First Use Date: 1984
Status: Completed
Propellant / Fluid Type: Hydrazine
Fluid Volume / Mass: 142 kg

8.6.33 RFT33: Passive Refueling Module (PRM)

Description: The Passive Refueling Module (PRM) is a satellite refueling interface developed by Northrop Grumman and being implemented on U.S. Space Force satellites. The PRM includes elements to successfully dock and transfer fuel, as well as a refueling payload that handles fuel transfer. It will be used as part of the Elixir mission to demonstrate on orbit refueling for the United States Space Force.
Developer: United States Space Force, Northrop Grumman
Country: United States
First Use Date: Scheduled for 2027
Status: In Development
Propellant / Fluid Type: Unavailable
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable
Cross Listing: RCDM073

8.6.34 RFT34: Progress Vehicle and Automated Transfer Vehicle Refueling of the International Space Station (Progress Vehicle and ATV Refueling of the ISS)

Description: The Russian Progress vehicle is used to deliver cargo and fluids to the ISS. The Progress can transfer fuel (UDMH), oxidizer (NTO), and water using bellows-style tanks. The vehicle can hold up to 1740 kg depending on amount of cargo the Progress also carries to the ISS. The fluids can be transferred to ISS using the docking ring. This propellant can also be used by the Progress's thrusters to maneuver ISS. This spacecraft and propellant transfer system was first used on Salyut 6 in 1978, was used on the Mir space station, and has been used on ISS since 2000. ESA's Automated Transfer Vehicle (ATV) has also refueled ISS since 2011.
Developer: Roscosmos, European Space Agency (ESA)
Country: Russia, Europe
First Use Date: 2000
Status: Completed
Propellant / Fluid Type: NTO, UDMH, Water
Fluid Volume / Mass: up to 1740 kg

8.6.35 RFT35: Propulsion Unit with Modular Applications (PUMA)

Description: Flight Works Incorporated's Propulsion Unit with Modular Applications (PUMA) system is a propulsion unit designed to enable Dynamic Space Operations (DSO) on orbit. Building on previous technologies designed for deorbiting servicers, Orbital Maneuvering vehicles, and Lunar Transfer Stages, Flight Works is developing a modular propulsion system able to provide high pressure for high delta v maneuvers, as well as low pressure for scenarios like Rendezvous, Proximity Operations and Docking (RPOD). The PUMA is equipped with a refueling port to add extra capability, utilizing Advanced Spacecraft Energetic Non-Toxic (ASCENT) propellant. The PUMA project is funded through an AFRL contract worth $5.7 million.
Developer: Flight Works Inc
Country: USA
First Use Date: TBD
Status: In Development
Propellant / Fluid Type: ASCENT
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable

8.6.36 RFT36: Quark

Description: Quark is an ESPA-Grande class system that can be launched as a secondary payload or on a dedicated small launch. Quark-Alpha combines solar electric propulsion and robotics to provide relocation, life extension, orbit raising, and payload delivery for missions from LEO through to cislunar space. Other Quark variants have specialized functions including high thrust for tactically responsive missions (Quark-Gamma), refueling (Quark-Beta), and deep space missions (Quark-Delta). During Quark's first mission in 2024, Atomos Space also launched a Gluon spacecraft, which housed additional propellant and hosted a customer payload. The Gluon spacecraft can be configured to house propellant for Quark's refueling, store or host customer payloads, or aggregate multiple small spacecraft for easy launch. The first launch of the Quark-Alpha vehicle is set for 2025, planning to provide inclination reduction and life extension services.
Developer: Atomos Space
Country: United States
First Use Date: Scheduled for 2025
Status: In Development
Propellant / Fluid Type: Solar Electric Propellant
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable
Cross Listing: RCDM079, R24

8.6.37 RFT37: Rancor

Description: Rancor is a refueling demonstration spacecraft developed by Orbit Fab which is intended to provide hydrazine to the Tetra-5 spacecraft and APS-R servicer. The spacecraft will be hosted on the ROOSTER-5 spacecraft and will be equipped with the Orbit Fab GRIP interface.
Developer: Orbit Fab
Country: United States
First Use Date: Scheduled for 2027
Status: In Development
Propellant / Fluid Type: Hydrazine
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable

8.6.38 RFT38: Rapidly Attachable Fluid Transfer Interface (RAFTI)

Description: Rapidly Attachable Fluid Transfer Interface (RAFTI) is a docking and refueling interface produced by Orbit Fab which replaces a spacecraft's fill and drain valve. RAFTI can be used for on-orbit and ground refueling, and it is a passive refueling interface for the client, which is captured by GRIP, an active refueling interface on the refueling spacecraft.
Developer: Orbit Fab
Country: United States
First Use Date: 2019
Status: Operational
Propellant / Fluid Type: Hydrazine, Gaseous Helium, Deionized Water, Isopropyl Alcohol, Gaseous Nitrogen, MMH
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable
Cross Listing: RCDM080

8.6.39 RFT39: Remote Robotic Oxidizer Transfer Test (RROxiTT)

Description: The Remote Robotic Oxidizer Transfer Test (RROxiTT) was a multi-center, remotely operated test of novel technologies designed to enable future space robots to safely transfer hazardous and corrosive satellite oxidizers into spacecraft propellant tanks already in orbit. The test was conducted at NASA's Goddard Space Flight Center and Kennedy Space Center. To simulate mission conditions, oxidizer transfer occurred at flight-representative pressures and flow rates.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2014
Status: Completed
Propellant / Fluid Type: NTO MON-3
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable

8.6.40 RFT40: Robotic Refueling Mission 1 (RRM1)

Description: The Robotic Refueling Mission (RRM) was a multi-phased ISS technology demonstration that tested tools and techniques to refuel and repair satellites not designed to be tested in orbit. RRM was mounted to an external payload of the ISS to demonstrate fluid transfer. There were four tools stowed in the module which were used by Dextre, which was controlled remotely by mission operators at Johnson Space Center, to perform various servicing tasks.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2011
Status: Completed
Propellant / Fluid Type: Ethanol
Fluid Volume / Mass: 1.7 liters
Boil-Off Rate: Unavailable
Cross Listing: URMUI15

8.6.41 RFT41: Robotic Refueling Mission 3 (RRM3)

Description: The Robotic Refueling Mission 3 (RRM3) stored liquid methane for 4 months on the ISS in 2018. Cryogenic mass gauging and zero boiloff was demonstrated. Cryocooler failure prevented the cryogenic propellant transfer demonstration that was planned. Gauging uncertainty was 2 percent.
Developer: NASA Goddard Space Flight Center (GSFC)
Country: United States
First Use Date: 2018
Status: Completed
Propellant / Fluid Type: Methane
Fluid Volume / Mass: 42 liters
Boil-Off Rate: ~Zero

8.6.42 RFT42: Safety Cap Tool

Description: The Safety Cap Tool is used on RRM 1. It removes and stows a typical fuel-valve safety cap and its seal. Small adapters allow it to also manipulate screws and remove caps on the RRM module. Each RRM tool's lobster-like appearance comes from the two integral cameras with built-in LEDs, which image and illuminate the tool's work during mission operations.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2011
Status: Completed

8.6.43 RFT43: Seal-Less Mechanically Compliant Fluid Adapter

Description: Quadrus Space is currently developing a prototype of a small footprint, dynamic seal-less fluid adapter to withstand nitrogen tetroxide. Initially funded through a Phase II SBIR award, the project will continue under a SBIR Phase II E as part of the Advancement of Exploration Components for In-Space Servicing (AXCIS) Early Career Initiative project at NASA. The adapter can be augmented for use with any flexible joint or fluid interface under 500 psig.
Developer: Quadrus Corporation, National Aeronautics and Space Administration (NASA)
Country: USA
First Use Date: TBD
Status: In Development
Propellant / Fluid Type: Nitrogen Tetroxide
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable

8.6.44 RFT44: SLEGO Architecture

Description: The SLEGO block is a high performance, modular spacecraft bus which is capable of interfacing with payloads attached to a SLEGO interface or with other SLEGO building blocks. Each SLEGO block manages power, provides basic sensing and metrology, processes and manages data, provides basic attitude adjustments, and manages thermal control. Fluids for thermal or refueling purposes can be transmitted through the modular interface. This interface has been tested through the eXCITe (eXperiment for Cellular Integration Technology) mission launched to LEO in 2018, the Satlet Initial-Mission Proofs and Lessons (SIMPL) mission on the ISS in 2017, and the PODSat-1 mission launched within DARPA's Hosted POD Assembly in GEO. The SLEGO architecture is also integrated into the Athena satellite, which will measure solar energy that Earth reflects and absorbs, gathered via a small telescope attached to a NovaWurks Payload Accommodation Configuration (PAC).
Developer: NovaWurks
Country: United States
First Use Date: 2017
Status: Operational
Propellant / Fluid Type: Inert Gasses, Green Fuels, Butane, Refrigerants
Cross Listing: RCDM094, PRMUI34, SMA36

8.6.45 RFT45: Storage Fluid Management Demonstration (SFMD)

Description: Flown aboard STS-51C in 1985, the Storage Fluid Management Demonstration (SFMD) tested a fluid acquisition device using colored water and air. In transferring water into the demonstration tank, a maximum of 85% fill was achieved at a maximum flow rate of 1 gallon per minute, but the system of baffles and screened liquid acquisition device was unsuccessful at orienting liquid away from the tank's vent port. Nine tests were performed.
Developer: Martin Marietta Corporation
Country: United States
First Use Date: 1985
Status: Completed
Propellant / Fluid Type: Water
Fluid Volume / Mass: 16.8 liters

8.6.46 RFT46: Superfluid Helium On-Orbit Transfer Flight Demonstration (SHOOT Flight Demonstration)

Description: Superfluid helium was transferred between tanks on the Superfluid Helium On-Orbit Transfer (SHOOT) flight demonstration on STS-57 in 1993. The experiment used the unique property of superfluid helium to move the fluid between two tanks. Some fluid boiled off with each transfer, and the unique properties of superfluid helium make the demonstration difficult to translate to other fluids.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1993
Status: Completed
Propellant / Fluid Type: Helium
Fluid Volume / Mass: 152 liters
Boil-Off Rate: > 0

8.6.47 RFT47: Tank Pressure Control Experiment/Thermal Phenomena (TPCE/TP)

Description: Flown on STS-52 in 1992, the Tank Pressure Control Experiment/Thermal Phenomena (TPCE/TP) was an in-space demonstration of fluid mixing and fluid management. TPCE/TP consisted of 21 tests, utilizing Freon 113 as a test fluid. Experimental and video data was collected on boiling, pressure decay, and flow pattern transition as a result of heat flux changes and jet-induced mixing. The data gathered from these tests supported the development of in-space cryogenic storage and resupply technologies.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1992
Status: Completed
Propellant / Fluid Type: Freon 113
Fluid Volume / Mass: Approx 11.7 liters
Boil-Off Rate: Unavailable

8.6.48 RFT48: Tanker-001 Tenzing

Description: Tanker-001 Tenzing is a fuel depot storing High-Test Peroxide green propellant. The tanker is outfitted with the Rapidly Attachable Fluid Transfer Interface (RAFTI) service valve for fill and drain. It also includes high- and low-pressure variants of RAFTI compatible with common propellants. The tanker supports both primary docking and secondary attachment of two spacecraft.
Developer: Orbit Fab
Country: United States
First Use Date: 2021
Status: Operational
Propellant / Fluid Type: High-Test Peroxide (HTP)
Fluid Volume / Mass: Unavailable
Cross Listing: RCDM104

8.6.49 RFT49: Tetra-5

Description: Tetra-5 is a program within the United States Space Force (USSF) to demonstrate capabilities required for on-orbit refueling. The program, which was awarded to Orion Space Systems in 2022, involves the construction of two satellites which will perform RPO, docking, inspection, and refueling operations to demonstrate the utility of commercial refueling operations. One of the two Tetra-5 satellites will receive 50 kg of hydrazine from an Orbit Fab Kamino Fuel Depot, funded through the DIU RAPIDS program. The satellite will receive propellant through the Orbit Fab RAFTI interface. The second spacecraft will demonstrate compatibility with the APS-R propellant shuttle developed by Astroscale.
Developer: United States Space Force, Orion Space Solutions
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Propellant / Fluid Type: Hydrazine
Fluid Volume / Mass: 50 kg
Boil-Off Rate: Unavailable
Cross Listing: RCDM105, IM33

8.6.50 RFT50: Tetra-6

Description: Tetra-6 is a program within the United States Space Force (USSF) to demonstrate capabilities required for on-orbit refueling. The program, which was awarded to Orion Space Systems, involves the deployment of a small satellite which will perform RPO, docking, and refueling operations with Northrop Grumman's Elixir payload, hosted on the ROOSTER-5 spacecraft. The refueling operations will be performed using Northrop Grumman's Passive Refueling Module (PRM), hosted on the Tetra-6 spacecraft, and Active Refueling Module (ARM), hosted on the Elixir payload.
Developer: United States Space Force, Orion Space Solutions
Country: United States
First Use Date: Scheduled for 2027
Status: In Development
Propellant / Fluid Type: Unavailable
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable
Cross Listing: RCDM106

8.6.51 RFT51: Tianyuan 1 Refueling Demonstration

Description: Launched in 2016 aboard a Long March-7, the Tianyuan 1 spacecraft demonstrated satellite refueling in orbit.
Developer: National University of Defense Technology (NUDT)
Country: China
First Use Date: 2016
Status: Completed
Propellant / Fluid Type: Unavailable
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable

8.6.52 RFT52: Variable Output Regulator

Description: In collaboration with Premier Industries, the Advancement of Exploration Components for In-Space Servicing (AXCIS) Early Career Initiative project at NASA will develop a variable output regulator for in-space applications. The purpose of a variable output regulator is the potential to service multiple clients, since the pressure is able to be adjusted in flight. This is a significant capability change, as current spacecraft regulators remain fixed for the duration of their missions.
Developer: Premier Industries, National Aeronautics and Space Administration (NASA)
Country: USA
First Use Date: TBD
Status: In Development
Propellant / Fluid Type: Unavailable
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable

8.6.53 RFT53: Vented Tank Resupply Experiment (VTRE)

Description: The Vented Tank Resupply Experiment (VTRE) Program, part of NASA's In-Space Technology Experiments Program (IN-STEP), was designed to develop and conduct a low-cost space experiment aimed at investigating and advancing capillary vane fluid management technologies. The program sought to acquire critical data to extend the application of these devices to scenarios requiring the direct venting of gas from tanks in low-gravity environments.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1996
Status: Completed
Propellant / Fluid Type: Refrigerant 113
Fluid Volume / Mass: 0.8 cubic ft.

8.6.54 RFT54: Xenon Compressor

Description: In addition to a helium compressor, the Advancement of Exploration Components for In-Space Servicing (AXCIS) Early Career Initiative project at NASA is also developing a xenon compressor system. Due to the increasing price of xenon, the project will also study the potential of krypton as a propellant for the compressor.
Developer: National Aeronautics and Space Administration (NASA)
Country: USA
First Use Date: TBD
Status: In Development
Propellant / Fluid Type: Xenon, Krypton
Fluid Volume / Mass: Unavailable
Boil-Off Rate: Unavailable

8.7 Structural Manufacturing and Assembly

8.7.1 SMA01: 1989 Laser Welding Parabolic Flight Tests

Description: The 1989 Laser Welding Parabolic Flight Tests were a series of more than 20 parabolic flight tests performed on board a KC-135 aircraft between September 1988 and June 1989. During the flight tests, the laser welding apparatus performed welding at conditions between 0.01 and 1.8 G. This experiment used a low-power Nd:YAG laser focused onto workpieces mounted in small vacuum canisters.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1989
Status: Completed
Material Types: SS304
Assembly Agent: Experiment Payload
Operation Regime: Parabolic Flight Test
Technology Area: Welding

8.7.2 SMA02: 2024 Laser Welding Parabolic Flight Test

Description: The NASA-OSU Laser Welding Parabolic Flight Test on board a Boeing 727 demonstrated laser welding technologies for AL 2219-T87, SS316L, and Ti64. The welding chamber from previous NASA Langley additive manufacturing parabolic flight tests was retrofitted for a laser welding system. The first flight in August 2024 successfully performed 69 out of 70 welds planned.
Developer: NASA Marshall Space Flight Center (MSFC)
Country: United States
First Use Date: Scheduled for 2024
Status: In Development
Material Types: Al2219-T87, SS316L, and Ti64
Assembly Agent: Experiment Payload
Operation Regime: Parabolic Flight Test
Technology Area: Welding

8.7.3 SMA03: 3-Degree-of-Freedom Laser Welding Experiment (3-DOF Laser Welding Experiment)

Description: The 3-Degree-of-Freedom (3-DOF) Laser Welding Experiment integrated a portable, handheld laser with a robotic arm on a 3-DOF space simulator. The experiment demonstrated the laser welding process for aluminum, stainless steel, and titanium in a lab setting. This demonstration system can identify welding challenges, including fit-up, weld quality, and the kinematics of welding recoil forces, while also providing a physical system to support the development of digital twin models.
Developer: NASA Marshall Space Flight Center (MSFC)
Country: United States
First Use Date: 2024
Status: Completed
Material Types: Al, SS, and Ti
Assembly Agent: Autonomous Operations
Operation Regime: Ground Test
Technology Area: Welding

8.7.4 SMA04: Androgynous Fasteners

Description: Androgynous fastener for autonomous robotic assembly of high-performance structures. The design prioritizes ease of assembly through simple actuation with large driver positioning tolerance requirements. The mechanical connection has high strength and stiffness per mass and is reversible.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: TBD
Status: In Development
Max Dimensions: Nominal 20 mm per fastener, 300 mm per modular interface (4 fasteners). System is material supply governed, demonstrated at 5.8 m
Material Types: Carbon-fiber-reinforced polymer, adaptable to metals
Assembly Agent: Robot
Operation Regime: On-Orbit, In-Space, Terrestrial
Technology Area: Structure Joint

8.7.5 SMA05: Assemblers

Description: Assemblers is a technology development for a modular robotic manipulator that consists of a variable number of stacked Stewart platforms. The goals of this project are to increase the technology readiness level for modular robots and autonomous in-space assembly and to develop a robotic prototype for ground testing.
Developer: NASA Langley Research Center (LaRC)
Country: United States
Status: Concluded
Max Dimensions: "Scalable"
Material Types: Metal Structure
Assembly Agent: Robot
Operation Regime: On-Orbit, In-Space, Terrestrial
Technology Area: Robotic Assembly
Cross Listing: RM02

8.7.6 SMA06: Automated Reconfigurable Mission Adaptive Digital Assembly Systems (ARMADAS)

Description: The Automated Reconfigurable Mission Adaptive Digital Assembly Systems (ARMADAS) project developed and demonstrated autonomous assembly of building-block-based "digital materials" and structures. The ARMADAS project seeks to provide integrated system design to address the full lifecycle of a persistent asset or surface structure. Project structural assembly systems and robots are specifically designed for energy efficient re-use, upgrade, recycling, reconfiguration, simplified robotic manipulation, inspection, and maintenance. Ground demonstration was completed showing autonomous robotic assembly of a 256-unit cell reconfigurable structure. Solar panel, wire routing, and functional module installation outfitting capabilities were also demonstrated. The technology is envisioned to be applied to sustainable and extensible orbital and surface space infrastructure construction.
Developer: NASA Ames Research Center (ARC)
Country: United States
First Use Date: TBD
Status: In Development
Max Dimensions: System is material supply governed, demonstrated at 5.8 m
Material Types: Demonstrated with carbon-fiber-reinforced polymer, adaptable to metals, ceramics, and ultralight/strong/self-programmable mechanical metamaterials
Assembly Agent: Robot
Operation Regime: On-Orbit, In-Space, Terrestrial
Technology Area: Robotic Assembly
Cross Listing: SI04

8.7.7 SMA07: Caltech NOM4D Robotic Assembly Mission

Description: DARPA selected Caltech to participate in developing a robotic technology for their Novel Orbital and Moon Manufacturing, Materials, and Mass-efficient Design (NOM4D) program. Caltech is developing a robotic technology to autonomously construct a compact truss structure using composite-fiber longerons that mimics the architectural structure of an antenna aperture. Caltech will demonstrate its technology aboard the Momentus Vigoride Orbital Services vehicle which is scheduled to launch in 2026.
Developer: Defense Advanced Research Projects Agency (DARPA), Caltech
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Max Dimensions: 1.4 m diameter
Material Types: Lightweight Carbon-Fiber Reinforced Composites
Assembly Agent: Free-Flying Autonomous System
Operation Regime: On-Orbit
Technology Area: Robotic Assembly

8.7.8 SMA08: Common Attachment System (CAS)

Description: The Common Attachment System (CAS) is a connection interface on the ISS with passive and active sides of the mechanism. The active CAS has three V-guides and a capture claw, while the passive CAS has three coarse alignment guide pins and a capture bar. The robotic arm brings the passive CAS into coarse alignment, and then the claw on the active side is closed, creating the structural attachment. The CAS was first used between the External Stowage Platform Three (ESP3) logistics carrier and the Port 3 (P3) zenith CAS site.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2009
Status: Operational
Max Dimensions: Contact
Material Types: Metal Structure
Assembly Agent: Robot / EVA
Operation Regime: On-Orbit
Technology Area: Structure Joint

8.7.9 SMA09: Composite Joint Connector

Description: A composite joint connector that is more structurally efficient than joints currently on the market. Traditionally, composite joints can bear heavy loads along their length but tend to fail when stress is applied along multiple axes. This joint is designed to minimize stress concentrations, leading to overall increased structural efficiency when compared to traditional joints.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
Status: Concluded
Material Types: Composite
Technology Area: Structure Joint

8.7.10 SMA10: DIsk-Shaped Configurable and Modular vAcuum uNit (DISCMAN)

Description: The DIsk-Shaped Configurable and Modular vAcuum uNit (DISCMAN) is a small, cylindrical vacuum chamber designed to support ground, parabolic, and suborbital flight testing. The DISCMAN payload has progressed to the maturation of a protoflight system and is in development for the final testing, flight, and post-flight analysis of the payload and test specimens.
Developer: NASA Marshall Space Flight Center (MSFC)
Country: United States
First Use Date: TBD
Status: In Development
Max Dimensions: Unavailable
Material Types: Glass
Assembly Agent: Unavailable
Operation Regime: In-Space
Technology Area: Welding

8.7.11 SMA11: End Effector for In-Space Autonomous Fastener Installation

Description: The End Effector for In-Space Autonomous Fastener Installation is an end effector which installs Enduralock Silver Lock fasteners. The end effector uses a retention system to capture the fastener within the tool until fastening operations are complete. The end effector also articulates the locking mechanisms of the Silver Lock fasteners to allow for installation or removal.
Developer: Enduralock
Country: United States
First Use Date: TBD
Status: In Development
Assembly Agent: Robot
Operation Regime: On-Orbit, In-Space, Terrestrial
Technology Area: Robotic End Effector

8.7.12 SMA12: ESA Replicator 1

Description: Orbital Matter developed technology for the Replicator Mission for an in-space demonstration on the Ariane 6. Their 3D printing method was designed to work in a vacuum, under microgravity, and without the need for heat, significantly speeding up the process of space construction. The 3U CubeSat mission intended to print a 50-centimeter-long beam while at an altitude of 580 km, out of a custom polymer material.
Developer: Orbital Matter, European Space Agency (ESA)
Country: Poland, Germany
First Use Date: 2024
Status: Completed
Max Dimensions: 50-centimeter-long beam
Material Types: Polymer Material
Assembly Agent: Robot
Operation Regime: On-Orbit
Technology Area: Manufacturing

8.7.13 SMA13: Experimental Assembly of Structures in Extravehicular Activity / Assembly Concept for Construction of Erectable Space Structures (EASE/ACCESS)

Description: The Experimental Assembly of Structures in Extravehicular Activity (EVA) (EASE) and Assembly Concept for Construction of Erectable Space Structures (ACCESS) Space Shuttle flight experiments studied astronaut efficiency, fatigue, and construction and maintenance techniques for EVA assembly of space structures. Both experiments were performed on STS-61-B in 1985.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1985
Status: Completed
Max Dimensions: 3.7 m tetrahedral truss
Material Types: Metal Structure
Assembly Agent: Human
Operation Regime: On-Orbit
Technology Area: Human Assembly

8.7.14 SMA14: Extended Structure Additive Manufacturing Machine (ESAMM)

Description: The Extended Structure Additive Manufacturing Machine (ESAMM) is the subsystem that would have additively manufactured the structural beams for OSAM-2. Multiple ground demonstrations of printed beams, including one with a length of 7 meters, were completed between 2017 and the conclusion of the project in 2023.
Developer: Redwire Corporation
Country: United States
Status: Concluded
Max Dimensions: 0.84 m
Material Types: Metal Structure
Assembly Agent: Robot
Operation Regime: On Orbit
Technology Area: Robotic Arm/Assembly

8.7.15 SMA15: Flight-1

Description: In May 2024, Think Orbital demonstrated the first-ever autonomous in-space weld using an electron beam welding system. The Flight-1 payload flew aboard a Falcon 9 booster and returned to Earth where the weld samples are being analyzed by NASA and ESA.
Developer: ThinkOrbital
Country: United States
First Use Date: 2024
Status: Completed
Material Types: Metal
Assembly Agent: Autonomous Operations
Operation Regime: On-Orbit
Technology Area: Welding

8.7.16 SMA16: GITAI S2's extraveHicular multi-Objective in-Space servicing Task demonstration (Project GHOST)

Description: Project GHOST (GITAI S2's extraveHicular multi-Objective in-Space servicing Task demonstration) was an on-orbit demonstration of ISAM operations by two GITAI S2 robotic arms installed externally to the ISS NanoRacks Bishop Airlock. The experiment included supervised autonomous ISAM operations by the S2 robotic arms, including ORU manipulation, tool changing, fastener tightening and removal, thermal blanket manipulation, connector mating and demating, and dual robotic arm cooperation.
Developer: GITAI
Country: Japan
First Use Date: 2024
Status: Completed
Assembly Agent: Robot
Operation Regime: On-Orbit, In-Space, Terrestrial
Technology Area: Robotic Assembly
Cross Listing: PRMUI11

8.7.17 SMA17: Hinge for Use in a Tension Stiffened and Tendon Actuated Manipulator

Description: The hinge connecting adjacent link arms together to allow the adjacent link arms to rotate relative to each other and a cable actuation and tensioning system provided between adjacent link arms; When in a stowed position, the centerlines of the first and second link arms and the central member are parallel to each other. Axis is offset from, but parallel to, the centerline of the central member.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
Status: Concluded
Max Dimensions: Approx. 360˚ rotation
Material Types: Metal Structure
Operation Regime: On-Orbit, In-Space
Technology Area: Robotic Arm Joint

8.7.18 SMA18: International Space Station Integrated Truss Structure (ISS ITS)

Description: The International Space Station (ISS) Integrated Truss Structure (ITS) is a structure that was assembled in space to support the operations of the ISS. The truss was assembled over multiple Space Shuttle missions between 2000 and 2009, and it contains equipment to support the power, thermal, communications, and logistics needs for the ISS.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1998
Status: Operational
Max Dimensions: 110 m
Material Types: Metal Structure
Assembly Agent: Robot / EVA
Operation Regime: On-Orbit
Technology Area: Robotic Arm/Assembly, Human Assembly, Deployable

8.7.19 SMA19: International Space Station Intravehicular Activity Experiment (ISS IVR Experiment)

Description: During the GITAI International Space Station (ISS) Intravehicular Activity (IVA) Experiment, an S1 robotic arm completed a number of operations within the Nanoracks Bishop Airlock pressurized volume of the ISS. This experiment involved the robotic arm assembling a four-panel solar array mockup and completing a number of IVA tasks on a task board with standard IVA operations. The robot completed these operations autonomously and through teleoperations from a ground station in Houston.
Developer: GITAI
Country: Japan
First Use Date: 2021
Status: Completed
Assembly Agent: Robot
Operation Regime: On-Orbit, In-Space, Terrestrial
Technology Area: Robotic Assembly
Cross Listing: PRMUI22

8.7.20 SMA20: International Space Welding Experiment (ISWE)

Description: The International Space Welding Experiment (ISWE) was an attempted demonstration mission for in-space welding intended to strengthen the cooperation between the United States and former Soviet states. The Paton Welding Institute in Ukraine, which previously designed the Universal Hand Tool (UHT), and Vulkan facility partnered with NASA to develop a modular, handheld welding tool with five different attachments that could be replaced depending on the welding task. In 1998, due to safety concerns of astronaut manual welding, the project was ended before a flight demonstration could take place.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1998
Status: Concluded
Material Types: Al2219, Al5356, SS304, and Ti-6AL-4V
Assembly Agent: Human
Operation Regime: On-Orbit
Technology Area: Welding

8.7.21 SMA21: JOining demonstrations IN Space (JOINS)

Description: JOINS is a Tipping Point awarded to Lockheed Martin to explore both laser and friction stir welding in space; currently scheduled for TVAC demo in 2025 and ISS (Bishop Airlock) demo in 2026. JOINS includes delivering an ISJ module payload to the ISS, integrating the payload within the Bishop Airlock, exposing the payload to the space environment while conducting joining demonstrations, and returning test articles to Earth for further study and analysis.
Developer: Lockheed Martin
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Max Dimensions: Unavailable
Material Types: Unavailable
Assembly Agent: Unavailable
Operation Regime: In-Space
Technology Area: Welding

8.7.22 SMA22: Joint Design Using Electron Beam Welding for Autonomous In-Space Truss Assembly (EBW Joint)

Description: EBW Joint is a metallic 3D printable joint system design for easy robotic handling and welding with room for adjustment. Although initially the joint was designed to be used with electronic beam welding, it can be configured to be used with other welding processes such as LASER or traditional welding.
Developer: NASA Langley Research Center (LaRC)
Country: United States
Status: Concluded
Assembly Agent: Robot/Human
Operation Regime: On-Orbit, In-Space
Technology Area: Structure Joint

8.7.23 SMA23: Lunar Assembly and Servicing by Autonomous Robotics (LASAR)

Description: Lunar Assembly and Servicing by Autonomous Robotics (LASAR) is a NASA Early Career Initiative project which intends to advance laser beam welding and repair capabilities through demonstration within a thermal vacuum chamber (TVAC). The project will certify laser optics for operation within TVAC and will integrate the laser welding device onto a robotic arm within TVAC to perform tests. This project is supported by NASA MSFC, NASA LaRC, and NASA JSC.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: TBD
Status: In Development
Max Dimensions: Unavailable
Material Types: Unavailable
Assembly Agent: Unavailable
Operation Regime: Ground Test
Technology Area: Welding

8.7.24 SMA24: Lunar Communication Tower Construction Demonstration

Description: The Lunar Communication Tower Construction Demonstration was a demonstration performed by GITAI in collaboration with KDDI Corporation of Japan. During this demonstration, a 5-meter-tall communications tower was constructed using stackable modules. The assembly agents include the GITAI R1 rover and three GITAI IN1 robotic arms. During the demonstration, the R1 delivered stackable modules to the worksite and the IN1 robotic arms iteratively translated the modules to the top of the tower and attached the new module, thus increasing the overall tower height.
Developer: GITAI
Country: United States
First Use Date: 2024
Status: Completed
Max Dimensions: 5 m
Material Types: Stackable Modules
Assembly Agent: Robot / semi-autonomous
Operation Regime: Terrestrial
Technology Area: Robotic Assembly
Cross Listing: SI13

8.7.25 SMA25: MakerSat

Description: MakerSat was a manufacturing payload intended to be flown on the OSAM-1 mission. MakerSat planned to manufacture a 10-meter, carbon fiber composite beam on board the spacecraft. MakerSat was descoped from the OSAM-1 mission in 2023.
Developer: Tethers Unlimited Inc
Country: United States
Status: Concluded
Max Dimensions: 10 m Truss Fabricated
Material Types: Carbon Fiber
Assembly Agent: Robot
Operation Regime: On-Orbit, In-Space
Technology Area: Robotic Assembly, manufacturing

8.7.26 SMA26: Modified Rocketdyne Truss Attachment Mechanism (MRTAS)

Description: The ISS Modified Rocketdyne Truss Attachment Mechanism (MRTAS) is a crucial docking system on the International Space Station, ensuring a secure and flexible connection between truss segments and other components, facilitating assembly and maintenance during spacewalks. It employs alignment cones and spring-loaded "stingers" for initial connection and fine-tuning with bolts for the final attachment.
Developer: The Boeing Company
Country: United States
First Use Date: 2006
Status: Operational
Max Dimensions: Contact
Assembly Agent: Robot
Operation Regime: On-Orbit, In-Space
Technology Area: Structure Joint

8.7.27 SMA27: NASA Intelligent Jigging and Assembly Robot (NINJAR)

Description: A Stewart Platform with 6 to 14 degrees of freedom; may be configured to use a smart jig for building trusses or similar structural system with alignment error correction capability; can also be attachment to a long reach manipulator to enhance precision and dexterity to aide fine precision operation.
Developer: NASA Langley Research Center (LaRC)
Country: United States
First Use Date: TBD
Status: In Development
Max Dimensions: 30 x 30 x 30 cube
Material Types: Metal Structure
Assembly Agent: Robot
Operation Regime: On-Orbit, In-Space, Terrestrial
Technology Area: Robotic Assembly

8.7.28 SMA28: On-orbit Servicing, Assembly, and Manufacturing 2 (OSAM-2)

Description: The technology demonstration OSAM-2, previously called Archinaut One, planned to manufacture and deploy one 10-meter beam and one 6-meter beam. During printing of the 10-meter beam, the system would have also deployed a surrogate solar array. The manufacturing would have been performed by Redwire's Extended Structure Additive Manufacturing Machine (ESAMM).
Developer: Redwire Corporation, NASA Marshall Space Flight Center (MSFC)
Country: United States
Status: Concluded
Max Dimensions: 10 m for ESPA class satellites
Material Types: PEI/PC
Assembly Agent: Robot
Operation Regime: On-Orbit, In-Space
Technology Area: Robotic Assembly, manufacturing

8.7.29 SMA29: Precision Assembled Space Structure (PASS)

Description: The Precision Assembled Space Structure (PASS) project is a modular assembly architecture to assemble a tri-truss system for applications such as large, assembled space telescopes. This design is intended to be scalable to 20-meter class telescopes. Ground demonstrations of subscale and full-scale robotic assembly operations have been completed.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: TBD
Status: In Development
Max Dimensions: "Scalable"
Material Types: Metal Structure
Assembly Agent: Robot
Operation Regime: On-Orbit, In-Space
Technology Area: Robotic Assembly

8.7.30 SMA30: Robotically Compatible Erectable Joint with Square Cross-Section

Description: This is an erectable joint design with a square cross-section at the interface to support robotic assembly that is functionally derived from the mechanical pre-load physics of LaRC's existing round erectable joint. It was intended to be used on the SPIDER demonstration of OSAM-1.
Developer: NASA Langley Research Center (LaRC)
Country: United States
Status: Concluded
Material Types: Metal Structure
Operation Regime: On-Orbit, In-Space, Terrestrial
Technology Area: Robotic Arm Joint

8.7.31 SMA31: Rocketdyne Truss Attachment System (RTAS)

Description: The Rocketdyne Truss Attachment System (RTAS) is an attachment mechanism for the ISS Integrated Truss Structure (ITS). It was first demonstrated connecting the P6 and Z1 segments on STS-97. The RTAS was later used to connect the P5 and P6 segments and the S5 and S6 segments. The mechanism has four cups and cones for coarse alignment and a capture claw and capture bar with fine alignment bolts. The truss segments are positioned robotically, and the capture claw closes to provide the initial connection. Then, an astronaut drives the fine alignment bolts to complete the structural connection.
Developer: The Boeing Company
Country: United States
First Use Date: 2000
Status: Operational
Max Dimensions: Contact
Material Types: Metal Structure
Assembly Agent: Robot / EVA
Operation Regime: On-Orbit
Technology Area: Structure Joint

8.7.32 SMA32: Salyut-7 Welding Experiment

Description: During the Salyut-7 mission, astronauts welded, brazed, coated, and cut metallics using a hand-held electron beam gun. This was the first demonstration of astronaut welding during extravehicular activity.
Developer: Union of Soviet Socialist Republics (USSR)
Country: USSR
First Use Date: 1984
Status: Completed
Material Types: Metal
Assembly Agent: Human
Operation Regime: On-Orbit
Technology Area: Welding

8.7.33 SMA33: Segment-to-Segment Attachment System (SSAS)

Description: The Segment-to-Segment Attachment System (SSAS) is an unpressurized device designed to securely link inboard truss components (such as truss P1 to S0). This fully automated mechanical system effectively aligns, captures, and subsequently fastens two truss elements together.
Developer: The Boeing Company
Country: United States
First Use Date: 2002
Status: Operational
Max Dimensions: Contact
Material Types: Metal Structure
Assembly Agent: Robot / EVA
Operation Regime: On-Orbit
Technology Area: Structure Joint

8.7.34 SMA34: Self-Aligning Nut Plate

Description: The Self-Aligning Nut Plate is a fastener nut assembly with an axially spring-loaded nut element to allow for radial float of 1 mm and axial tilt of up to 15 degrees. The assembly allows for engaging with an off-axis fastener and self-aligns during tightening, making the assembly ideal for autonomous assembly applications.
Developer: Enduralock
Country: United States
First Use Date: TBD
Status: In Development
Material Types: Metal
Operation Regime: On-Orbit, In-Space, Terrestrial
Technology Area: Structure Joint

8.7.35 SMA35: Skylab Materials Processing Facility Experiments

Description: This facility, developed by Westinghouse, was installed on Skylab and demonstrated electron beam welding. Welds were conducted in a chamber with variable access to the space environment. Welding was conducted on stainless steel, aluminum, and tantalum at various travel speeds and electron beam parameters.
Developer: National Aeronautics and Space Administration (NASA), Westinghouse Electric Company
Country: United States
First Use Date: 1973
Status: Completed
Max Dimensions: 40 cm welding chamber
Material Types: Metal
Assembly Agent: Human
Operation Regime: On-Orbit
Technology Area: Welding

8.7.36 SMA36: SLEGO Architecture

Description: The SLEGO block is a high performance, modular spacecraft bus which is capable of interfacing with payloads attached to a SLEGO interface or with other SLEGO building blocks. Each SLEGO block manages power, provides basic sensing and metrology, processes and manages data, provides basic attitude adjustments, and manages thermal control. Fluids for thermal or refueling purposes can be transmitted through the modular interface. This interface has been tested through the eXCITe (eXperiment for Cellular Integration Technology) mission launched to LEO in 2018, the Satlet Initial-Mission Proofs and Lessons (SIMPL) mission on the ISS in 2017, and the PODSat-1 mission launched within DARPA's Hosted POD Assembly in GEO. The SLEGO architecture is also integrated into the Athena satellite, which will measure solar energy that Earth reflects and absorbs, gathered via a small telescope attached to a NovaWurks Payload Accommodation Configuration (PAC).
Developer: NovaWurks
Country: United States
First Use Date: 2017
Status: Operational
Max Dimensions: "Scalable"
Material Types: Metal
Assembly Agent: Robot
Operation Regime: On-Orbit, In-Space
Technology Area: Robotic Assembly
Cross Listing: RCDM094, PRMUI34, RFT44

8.7.37 SMA37: Solar On-orbit Welder for Assembly, Repair, and Manufacturing (SO-WARM)

Description: The Solar On-Orbit Welder for Assembly, Repair, and Manufacturing (SO-WARM) system, developed by Outward Technologies, relies on direct solar-thermal heating of materials to weld metals (aluminum and titanium) and join non-metal materials. SO-WARM is a lightweight and versatile design that can weld parts, control the temperature, and be used as a cutting tool.
Developer: Outward Technologies
Country: United States
First Use Date: TBD
Status: In Development
Material Types: Thermoplastics, Metals
Assembly Agent: Robot
Operation Regime: In-Space
Technology Area: Solar Welding
Cross Listing: SI21

8.7.38 SMA38: Space Infrastructure Dexterous Robot (SPIDER)

Description: The OSAM-1 spacecraft intended to include an attached payload called Space Infrastructure Dexterous Robot (SPIDER). SPIDER contains a lightweight 16-foot (5-meter) robotic arm, bringing the total number of robotic arms on OSAM-1 to three. Previously known as Dragonfly during the ground demonstration phase of a NASA Tipping Point partnership, SPIDER planned to assemble seven elements to form a functional 9-foot (3-meter) communications antenna.
Developer: Maxar Technologies
Country: United States
Status: Concluded
Max Dimensions: 5 m
Material Types: Metal Structure
Assembly Agent: Robot
Operation Regime: On-Orbit
Technology Area: Robotic Arm
Cross Listing: RM44

8.7.39 SMA39: Stratospheric Aerosol and Gas Experiment III (SAGE III)

Description: The Stratospheric Aerosol and Gas Experiment III (SAGE III) was successfully assembled while attached to the ISS on March 7, 2017. Installation of the instrument included assembly of the truss structure to the ExPRESS Logistics Carrier platform and attachment of the instrument to the truss structure. The assembly was completed using the ISS Canadarm2.
Developer: NASA Langley Research Center (LaRC)
Country: United States
First Use Date: 2017
Status: Completed
Material Types: Metal Structure
Assembly Agent: Robot
Operation Regime: On-Orbit
Technology Area: Robotic Assembly

8.7.40 SMA40: Strut Attachment, Manipulation, and Utility Robotic Aide (SAMURAI)

Description: A scalable modular strut/component attachment handling system; may be configured into various forms to handle a variety of system components, such as structure elements, structure module, or other modules that need to be assembled. Its function includes but not limited to component retrieve and attachment.
Developer: NASA Langley Research Center (LaRC)
Country: United States
First Use Date: TBD
Status: In Development
Max Dimensions: 46 in.
Material Types: Metal Structure
Assembly Agent: Robot
Operation Regime: On-Orbit, In-Space, Terrestrial
Technology Area: Robotic Assembly

8.7.41 SMA41: Tall Lunar Tower (TLT)

Description: Tall Lunar Tower (TLT) is a Project Polaris activity from NASA's ESDMD to demonstrate assembly of a large truss-based tower. High performance truss-based towers could be assembled on planetary surfaces to support solar arrays, communications antenna, and navigation beacons. An assembly demonstration of an engineering development unit was completed in September 2023 at NASA Langley Research Center where a 4.5-meter-tall tower was assembled. A tower configuration utility was created based off the Euler buckling limitations allowing rapid scaling of the tower to support various payloads. The dimensions of the demonstration tower were scaled to support 1000 kg payloads at 50 meters height. The resulting structure, which would be assembled by 1.3-meter-reach robotic manipulators, would have a mass of 110 kg. The TLT process uses automated robotic assembly to construct towers to elevate payloads. Towers can be constructed by a variety of 6-DOF serial robotic manipulators fitted with specialized end effectors designed to hold, sense, and join struts into repeating truss bays. After each bay is constructed, a lifter system raises the completed bays and supported payload. TLT tower assembly concepts are compatible with various truss structures and using in-situ resources for truss components. In the future, TLT plans to demonstrate this scalable surface construction capability and utility outfitting, using the lessons learned from the initial demonstration.
Developer: NASA Langley Research Center (LaRC)
Country: United States
First Use Date: TBD
Status: In Development
Max Dimensions: 50-meter tower
Assembly Agent: Robot
Operation Regime: Terrestrial
Technology Area: Robotic Assembly
Cross Listing: SI22

8.7.42 SMA42: Tessellated Electromagnetic Space Structures for the Exploration of Reconfigurable, Adaptive Environments (TESSERAE)

Description: Tessellated Electromagnetic Space Structures for the Exploration of Reconfigurable, Adaptive Environments (TESSERAE) is a self-assembling, reconfigurable tile prototype that was flown on Ax-1, Axiom's research mission to the ISS on April 8, 2022. TESSERAE was among the 25 experiments on the 10-day private ISS mission that was flown in partnership with SpaceX. This was TESSERAE's second in-space test. A complete set of 32 fifth-generation TESSERAE tiles is scheduled to be delivered to the ISS in January 2026 for an on-orbit demonstration of the full buckyball assembly. An ISS crew member will set up the experiment in a section of the station, initiate the tiles' deployment, and document the tiles' autonomous connection in microgravity.
Developer: Aurelia Institute
Country: United States
First Use Date: 2022
Status: In Development
Max Dimensions: Unavailable
Material Types: Magnets
Assembly Agent: Autonomous Operations
Operation Regime: In-Space
Technology Area: Deployable

8.7.43 SMA43: Thermal Vacuum Laser Bending Experiment (TVAC Laser Bending Experiment)

Description: The Thermal Vacuum (TVAC) Laser Bending Experiment is a partnership between DARPA and NASA MSFC through DARPA's NOM4D program which intends to demonstrate laser bending of metals in a thermal vacuum chamber (TVAC).
Developer: NASA Marshall Space Flight Center (MSFC)
Country: United States
First Use Date: TBD
Status: In Development
Max Dimensions: Unavailable
Material Types: Unavailable
Assembly Agent: Unavailable
Operation Regime: Ground Test
Technology Area: Metal Bending

8.7.44 SMA44: Thermoplastics Development for Exploration Applications (TDEA)

Description: The Thermoplastics Development for Exploration Applications (TDEA) project is developing and maturing thermoplastic composite (TPC) materials for space structure joints. The TPC joints are being designed to create large monolithic structures that save on manufacturing time, part count, and weight, enabling in-space assembly and manufacturing of large monolithic space structures.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: TBD
Status: In Development
Material Types: Thermoplastic Composites (TPCs)
Assembly Agent: Human/Robot
Operation Regime: On-Orbit, In-Space
Technology Area: Structural Joint

8.7.45 SMA45: Turbine Superalloy Casting Module (TSCM)

Description: The Turbine Superalloy Casting Module (TSCM) is an in-space manufacturing device that will allow manufacturing of single-piece turbine blisks (blade + disk) for turbine engines. This demonstration investigated the microstructure and mechanical properties of polycrystal superalloy parts thermally processed in a microgravity environment.
Developer: Redwire Corporation
Country: United States
First Use Date: 2021
Status: Completed
Material Types: Polycrystalline Superalloy
Assembly Agent: Human
Operation Regime: In-Space
Technology Area: Deployable

8.7.46 SMA46: Twisted and Coiled Artificial Muscle Soft Robotic Actuator (TCAM Soft Robotic Actuator)

Description: The Twisted and Coiled Artificial Muscle (TCAM) Soft Robotic Actuator is a concept for an in-space end effector which uses Twisted and Coiled Artificial Muscles (TCAMs). This concept is intended to be used in the construction of bonded segments of a large in-space assembled structure. The end effector design allows for conforming to conical struts and meets all manipulability, pressure, and temperature requirements of the intended use case.
Developer: NASA Langley Research Center (LaRC)
Country: United States
First Use Date: TBD
Status: In Development
Material Types: Soft Materials
Assembly Agent: Robot
Operation Regime: On-Orbit, In-Space, Terrestrial
Technology Area: Robotic Assembly

8.7.47 SMA47: University of Illinois Urbana-Champaign NOM4D Materials Process Mission (UIUC NOM4D Materials Process Mission)

Description: DARPA selected University of Illinois Urbana-Champaign (UIUC) to participate in their Novel Orbital and Moon Manufacturing, Materials, and Mass-efficient Design (NOM4D) program. UIUC will demonstrate their in-space composite-forming process which will transform flattened carbon fiber into a hardened reinforced structure through a controlled chemical reaction.
Developer: Defense Advanced Research Projects Agency (DARPA), University of Illinois Urbana-Champaign (UIUC)
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Material Types: Lightweight Carbon-Fiber Reinforced Composites
Assembly Agent: Robot
Operation Regime: On-Orbit
Technology Area: Manufacturing

8.7.48 SMA48: Vulkan Experiment

Description: Vulkan was a demonstration of welding on the Soyuz 6 flight. During the experiment, cosmonauts tested several methods of welding stainless steel, aluminum, and titanium in the weightless and high vacuum of space. Plasma arc, electron beam, and gas metal arc welding was tested. This experiment produced the first demonstration of on-orbit welds.
Developer: Union of Soviet Socialist Republics (USSR)
Country: USSR
First Use Date: 1969
Status: Completed
Material Types: Metal
Assembly Agent: Human
Operation Regime: On-Orbit
Technology Area: Welding

8.8 Recycling, Reuse, and Repurposing

8.8.1 RRR01: Metal Advanced Manufacturing Bot-Assisted Assembly (MAMBA)

Description: The Metal Advanced Manufacturing Bot-Assisted Assembly (MAMBA) ground demonstration prototype was developed to process virgin or metal scrap material into ingots that could then be machined or milled to a final part. Debris from machining of metal to fabricate a part is collected and can be used for further ingot manufacturing.
Developer: Tethers Unlimited Inc, National Aeronautics and Space Administration (NASA)
Country: United States
Status: Concluded
Recyclable Items and/or material(s): Metal
Product: Metal ingots

8.8.2 RRR02: Modular Space Foundry (MSF)

Description: Cislunar Industry's Modular Space Foundry (MSF) recycles Aluminum series 2000 - 6000 as well as other non-ferrous materials into standard material products, such as rods, sheet, tubes, and wire for use in space construction. The company demonstrated control melt levitation and heating as well as rod casting through a NASA SBIR Phase I. During a SBIR Phase II, the team demonstrated MSF technologies on a parabolic flight. Prototypes for subsystems of the MSF have been tested on parabolic flights in 2024, as part of a larger project ending in 2027.
Developer: Cislunar Industries
Country: United States
First Use Date: TBD
Status: In Development
Recyclable Items and/or material(s): Aluminum 2000 - 6000 series
Non-ferrous metals
Product: Rods, sheet, tube, pipe, wire

8.8.3 RRR03: Outpost Mars Demo 1 (OMD-1)

Description: Outpost Mars Demo-1 (OMD-1) was an experiment launched on SpaceX Transporter 5 which used friction milling to demonstrate metal cutting. The experiment successfully cut one of the three coupons intended to be cut, made out of a corrosion-resistant steel. The experiment was intended to show the ability to cut and recycle materials commonly found on orbit without generating debris through the cutting process.
Developer: Nanoracks, Voyager Technologies, Maxar Technologies
Country: United States
First Use Date: 2022
Status: Completed
Recyclable Items and/or material(s): Corrosion-resistant steel
Product: Cut sheet
Cross Listing: PGM15

8.8.4 RRR04: Recyclable Packaging Materials

Description: NASA's In-Space Manufacturing program is advancing multiple technologies in recyclable packaging materials and sustainable approaches with commercial partners to enable a recycling ecosystem in space. These efforts include polyethylene-based thermally reversible materials with Cornerstone Research Group; Customizable, Recyclable ISS Packaging (CRISSP) with Tethers Unlimited, Inc.; the ERASMUS multimaterial recycling capability with Tethers Unlimited, Inc.; and automated in-process quality control of recycled filament production and polymer 3D printing with Cornerstone Research Group.
Developer: Cornerstone Research Group (CRG), Tethers Unlimited Inc, National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: TBD
Status: In Development
Recyclable Items and/or material(s): Multimaterial Polymers
Product: Multiple products, incl. filament feedstock and packaging materials

8.8.5 RRR05: ReFabricator

Description: Installed on International Space Station in early 2019, the ReFabricator was a recycler and 3D printer able to recycle various plastics into filament feedstock for further manufacturing. ReFabricator was an integrated system mainly using ULTEM 9085, a thermoplastic. Researchers planned to create packaging materials that could easily be recycled by the ReFabricator system, specifically by putting different additives into thermoplastics for desired properties. Upon initial startup, an anomaly in the recycling system occurred.
Developer: Tethers Unlimited Inc, National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2019
Status: Concluded
Recyclable Items and/or material(s): Thermoplastic polymers
Product: Filament feedstock for 3D printing

8.8.6 RRR06: Tailored Universal Feedstock for Forming Reformability Demo (TuFF Reformability Demonstration)

Description: TuFF was a small contract demonstration which expanded upon previous short fiber development work at the University of Delaware. The previous work, funded through a DARPA grant, was to develop repurposable fibers for composites with lower cost and aerospace grade performance. The follow-on demonstration, TuFF, determined the requirements to reform a composite part constructed form the fibers. The demonstration produced approaches to produce 45° & 90° bends in the original structure.
Developer: University of Delaware, Composites Automation LLC
Country: United States
First Use Date: TBD
Status: Completed
Recyclable Items and/or material(s): Thermoplastic composites with short carbon fibers
Product: Coupons

8.8.7 RRR07: Thermally Reversible Polymers for Additive Manufacturing Feedstock (Thermally Reversible Polymers for AM Feedstock)

Description: First funded as a Phase 1 SBIR in 2016, the Thermally Reversible Polymers for Additive Manufacturing (AM) Feedstock project was funded through Phase 1 and Phase 2 NASA SBIRs. The project was able to demonstrate that a component can be made with a resin and then reprocessed with properties needed for structural composites. Multiple parts were created with a reformable resin and then reshaped into other parts representing potential structural parts for planetary use.

Developer: Cornerstone Research Group (CRG)

Country: United States

Status: Completed

Recyclable Items and/or material(s): Thermally reversible polymers

Product: Panels, tubes, and other geometries made with recycled composite

8.9 Parts and Goods Manufacturing

8.9.1 PGM01: 3D Printed Space Reflector Antenna

Description: This patented concept by Orbital Composites enables on-demand construction of antennas through 3D printing. The 3D printed antennas are scalable in size and frequency range, from 4 GHz to 110 GHz. 3D printing of antennas coupled with on-orbit 3D printing allows for rapid frequency or size alterations without requiring an antenna redesign and launch. In 2023, Orbital Composites announced it received funding from USSF to develop a 3D printable quantum antenna which would allow secure, high-capacity space and terrestrial communications.
Developer: Orbital Composites
Country: United States
First Use Date: TBD
Status: In Development
End Product: Finished Part
Inputs: Earth Delivered Material
Material Types: Polymers/Composites
Operational Regime: On-Orbit
Operator: Human / Remote Human

8.9.2 PGM02: 3D Printing in Zero G TDM

Description: During this TDM, 55 parts of Acrylonitrile Butadiene Styrene (ABS) were printed between 2014 and 2016. The printer operates in a Microgravity Science Glovebox (MSG) on board the ISS.
Developer: Made In Space, National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2014
Status: Completed
End Product: Finished Part
Inputs: Earth Delivered Material
Max Dimensions: 6 cm x 12 cm x 6 cm
Material Types: ABS
Operational Regime: On-Orbit (ISS)
Operator: Human / Remote Human

8.9.3 PGM03: Additive Manufacturing Facility (AMF)

Description: The AMF is a multimaterial commercial facility for polymer printing in microgravity developed by Made in Space Inc. (now Redwire Space). The AMF was installed in the ISS EXPRESS Rack in April 2016 and offers printing for NASA or commercial products.
Developer: Made In Space, Redwire Corporation, National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2016
Status: Operational
End Product: Finished Part
Inputs: Earth Delivered Material
Max Dimensions: 14 cm x 10 cm x 10 cm
Material Types: ABS, HDPE, PEI-PC initially, more upon ISS approval
Operational Regime: On-Orbit (ISS)
Operator: Human

8.9.4 PGM04: Blue Alchemist

Description: Blue Alchemist is a technology and set of processes developed by Blue Origin to manufacture solar cells and transmission wire from lunar regolith. The process to manufacture these products includes molten regolith electrolysis and utilizes simulants that are chemically and mineralogically equivalent to lunar regolith. The overall process is mobile, scalable, and contactless, robust to regolith variations, and could be employed anywhere on the Moon. Because the process produces zero carbon emissions and requires no water, no toxic ingredients, and no other chemicals, it could have applicability for terrestrial use. As of 2024, Blue Origin has produced silicon solar cells and aluminum wire with the Blue Alchemist technology.
Developer: Blue Origin
Country: United States
First Use Date: TBD
Status: In Development
End Product: Finished Part
Inputs: ISRU
Max Dimensions: Unavailable
Material Types: Regolith simulant, electronics, polymers, metals
Operational Regime: Lunar Surface
Operator: Unavailable
Cross Listing: SI05

8.9.5 PGM05: Custom Laser Doppler Sensor

Description: The Apsidal custom laser doppler sensor is used to provide in-situ analysis and feedback control during microgravity manufacturing processes. This sensor is currently used on the UNIGLO manufacturing module on the ISS, aiding in the production of ZBLAN fibers alongside AI optimization tools.
Developer: Apsidal
Country: United States
First Use Date: 2022
Status: In Development
End Product: Finished Part
Inputs: Earth Delivered Material
Max Dimensions: Unavailable
Material Types: Glass and Glass Alloys
Operational Regime: On-Orbit (ISS)
Operator: Human / Remote Autonomous

8.9.6 PGM06: ESA Metal 3D Printer

Description: ESA's Metal 3D printer was the first metal printer installed on ISS that demonstrated the simplicity of metallic part production under microgravity environment. This printing process works by using high power lasers to melt stainless-steel wire, a material with a melting point of about 1400°C. The demonstration focused on printing four reference prints in space and comparing them to copies printed on Earth.
Developer: European Space Agency (ESA), Airbus
Country: ESA
First Use Date: 2024
Status: Operational
End Product: Test Specimen
Inputs: Earth Delivered Material
Max Dimensions: 80 x 70 x 40 cm
Material Types: Stainless-Steel Metallic Wire
Operational Regime: On-Orbit (ISS)
Operator: Human

8.9.7 PGM07: External Material Processing Platform

Description: The External Material Processing Platform is an external platform on the ISS with the capability to autonomously produce thin, metal-coated optical fibers. These fibers are expected to be useful for the medical, defense, and commercial spacecraft industries. The platform uses the vacuum and microgravity environment of space to reduce errors and defects during manufacturing.
Developer: DSTAR Communications Inc, FOMS Inc, Visioneering Space Corporation, Lunar Resources Inc, National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2019
Status: Operational
End Product: Finished Part
Inputs: Earth Delivered Material
Max Dimensions: Unavailable
Material Types: Glass and Glass Alloys
Operational Regime: On-Orbit (ISS)
Operator: Human / Remote Human

8.9.8 PGM08: Heavy-Metal Fluoride Glasses Fabrication Facility (HMFG Fabrication Facility)

Description: Flawless Photonics has developed an ISS payload designed to produce high quality glass optical fibers in microgravity. The payload successfully manufactured 5 km of optical fibers, made from Heavy-Metal Fluoride Glasses (HMFG), on the ISS in 2024. This project was funded through NASA, ESA, and the Luxembourg Space Agency (LSA).
Developer: Flawless Photonics
Country: United States
First Use Date: 2024
Status: Completed
End Product: Finished Part
Inputs: Earth Delivered Material
Material Types: Heavy-Metal Fluoride Glass, ZBLAN
Operational Regime: On-Orbit (ISS)
Operator: Human / Remote Human

8.9.9 PGM09: Industrial Crystallization Facility (ICF)

Description: The ICF is an in-space manufacturing platform developed by Redwire Space as a proof-of-concept for developing high-quality optical crystals in a microgravity environment. Using diffusion-based crystallization methods, this facility was the first to cultivate inorganic potassium dihydrogen phosphate (KDP) crystals while on board the ISS. KDP crystals are a primary component of advanced high-energy laser systems on Earth. The ICF was launched on the Grumman CRS-15 launch vehicle and is currently operating on the ISS National Lab.
Developer: Redwire Corporation
Country: United States
First Use Date: 2021
Status: Operational
End Product: Optical Crystals
Inputs: Earth Delivered Material
Max Dimensions: Unavailable
Material Types: Inorganic potassium dihydrogen phosphate (KDP)
Operational Regime: On-Orbit (ISS)
Operator: Human / Remote Human

8.9.10 PGM10: Manufacturing of Semiconductors and Thin-film Integrated Coating (MSTIC)

Description: Manufacturing of Semiconductors and Thin-film Integrated Coating (MSTIC) was an ISS demonstration platform which demonstrated production techniques for semiconductors beginning in February of 2024. The platform demonstrated production of superior semiconductor crystal microstructures on board the ISS as compared to what is feasible on Earth.
Developer: Redwire Corporation, National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2024
Status: Completed
End Product: Thin Film Semiconductor
Inputs: Earth Delivered Material
Max Dimensions: Unavailable
Material Types: Semiconductors
Operational Regime: On-Orbit (LEO)
Operator: Unavailable

8.9.11 PGM11: Multimaterial Fabrication Laboratory (FabLab)

Description: Multimaterial Fabrication Laboratory, also known as FabLab, was a Broad Agency Announcement (BAA) opportunity to develop a multimaterial printer (with a focus on metals and in-process inspection capabilities) for the ISS. The 18-month phase A efforts focused on development of ground-based prototype systems and technology demonstration. There were 3 funded companies (Interlog, Tethers Unlimited, and Techshot). Techshot, now Redwire, was the only company to continue to the next phase. FabLab is a bound metal additive manufacturing system that includes a furnace for part sintering and a laser line profilometer for in-process monitoring of the print. It was further developed for metal, plastic, and electronics fabrication. The original metal manufacturing intention of the FabLab was descoped in FY23 when the Game Changing Development (GCD) program canceled the metals manufacturing project. The electronics manufacturing project remains, but it only utilizes the printer module (1/2 of the original payload). The furnace which was used to consolidate metal components is no longer within the baseline.
Developer: Redwire Corporation, National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: TBD
Status: In Development
End Product: Finished Part
Inputs: Earth Delivered Material
Max Dimensions: 6 in x 6 in x 6 in for polymers
Material Types: Polymers and Electronics
Operational Regime: On-Orbit (ISS)
Operator: Human, Remote Human, autonomous

8.9.12 PGM12: On-Demand Manufacturing of Electronics (ODME)

Description: ODME is an ongoing project on the ISS developing printed devices such as sensors, power generators, and other electronics. Alongside technology development, various manufacturing processes are also being matured to support future demonstrations in space. An example of an integrated product is the AstroSense wearable sensor. Intended for crew health monitoring, this sensor is created using printed electronics and is preparing for a demonstration on the ISS.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: Scheduled for 2027
Status: In Development
End Product: Finished Assembly
Inputs: Earth Delivered Material
Max Dimensions: Unavailable
Material Types: Polymers and Electronics
Operational Regime: On-Orbit (ISS)
Operator: Human

8.9.13 PGM13: Optical Fiber Production in Microgravity Investigation (SpaceFiber)

Description: In collaboration with Thorlabs Inc., Made In Space conducted the Optical Fiber Production in Microgravity investigation on the ISS to set the stage for large-scale manufacture of high-quality fiber optics in orbit.
Developer: Made In Space, National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2017
Status: Concluded
End Product: Finished Part
Inputs: Earth Delivered Material
Max Dimensions: Unavailable
Material Types: Glass and Glass Alloys
Operational Regime: On-Orbit (ISS)
Operator: Human / Remote Human

8.9.14 PGM14: Orbital Fiber Optic Production Module (ORFOM)

Description: The Orbital Fiber Optic Production Module is an ISS payload designed to produce high-quality fiber optics through an automated manufacturing process. The payload, which arrived at the ISS in July of 2022, leverages the microgravity environment to avoid unwanted defects common in the terrestrial manufacturing process of fiber optics.
Developer: Mercury Systems, National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2022
Status: Operational
End Product: Finished Part
Inputs: Earth Delivered Material
Max Dimensions: Unavailable
Material Types: Glass and Glass Alloys
Operational Regime: On-Orbit (ISS)
Operator: Human

8.9.15 PGM15: Outpost Mars Demo 1 (OMD-1)

Description: Outpost Mars Demo-1 (OMD-1) was an experiment launched on SpaceX Transporter 5 which used friction milling to demonstrate metal cutting. The experiment successfully cut one of the three coupons intended to be cut, made out of a corrosion-resistant steel. The experiment was intended to show the ability to cut and recycle materials commonly found on orbit without generating debris through the cutting process.
Developer: Nanoracks, Voyager Technologies, Maxar Technologies
Country: United States
First Use Date: 2022
Status: Completed
End Product: Stock Material
Inputs: Earth Delivered Material
Max Dimensions: Unavailable
Material Types: Corrosion-resistant steel
Operational Regime: On-orbit
Operator: Automated
Cross Listing: RRR03

8.9.16 PGM16: Pharmaceutical In-Space Laboratory - Bio-Crystal Optimization Xperiments (PIL-BOX)

Description: PIL-BOX is a platform for hosting pharmaceutical experiments in space. PIL-BOX is available in three varieties depending on experiment requirements: PIL-BOX Fluidic Cassette (FC), which supports automation of fluid mixing and crystallization processes, PIL-BOX Dynamic Microscopy Cassette (DMC), which provides real time observation of crystal growth, and PIL-BOX Small Molecule Accelerated Laboratory for Structure (SMALS), which is used to create new crystal shapes of small molecule drugs.
Developer: Redwire Corporation
Country: United States
First Use Date: 2023
Status: Operational
End Product: Pharmaceutical Crystals
Inputs: Earth Delivered Material
Max Dimensions: Unavailable
Material Types: Pharmaceuticals/Drugs
Operational Regime: On-Orbit (LEO)
Operator: Unavailable

8.9.17 PGM17: Redwire Regolith Print (RegISS)

Description: RegISS is an on-orbit demonstration of 3D printing with a polymer/regolith simulant feedstock blend. It was the first demonstration of manufacturing with ISRU-derived feedstocks on ISS. This proof of concept showed the viability of printing with regolith composite material in a reduced gravity environment and is applicable to manufacturing on the lunar surface and Mars. In this effort, a previously flown version of the Additive Manufacturing Facility was modified to accommodate a new extruder and print with a feedstock consisting of regolith simulant and a thermoplastic. The payload launched to the ISS in 2021. Sample coupons were returned to Earth; however, issues encountered during production prevented further analysis.
Developer: Redwire Corporation, National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2021
Status: Operational
End Product: Finished Part
Inputs: ISRU
Max Dimensions: Unavailable
Material Types: Regolith Simulant Feedstock Blend
Operational Regime: On-Orbit (ISS)
Operator: Human
Cross Listing: SI17

8.9.18 PGM18: Sintered Inductive Metal Printer with Laser Exposure (SIMPLE)

Description: SIMPLE was a wire-fed additive manufacturing process for metals proposed for use in space. The process used inductive heating and operated in a vacuum. A low power laser provided additional heating for the sintering process.
Developer: Redwire Corporation, National Aeronautics and Space Administration (NASA)
Country: United States
Status: Concluded
End Product: Finished Part
Inputs: Earth Delivered Material
Max Dimensions: Unavailable
Material Types: Metallic
Operational Regime: Microgravity (any NASA Vehicle)
Operator: Human

8.9.19 PGM19: Space Facility for Orbital Remote Manufacturing (SpaceFORM)

Description: SpaceFORM is a suitcase platform that was sent on the Cygnus resupply flight to the ISS in order to advance on-orbit manufacturing of high-quality ZBLAN optical fibers. The ZBLAN optical fibers are produced out of heavy metal fluoride glasses and producing them in microgravity has the potential to avoid defects associated with gravity-driven processes. In August of 2019, FOMs Inc. received an award for its successful production of fibers.
Developer: FOMS Inc, ISS National Lab
Country: United States
First Use Date: 2019
Status: Completed
End Product: Finished Material
Inputs: Earth Delivered Material
Max Dimensions: up to 50 km of optical fibers per mission
Material Types: ZBLAN (High-Quality Fluoride-Glass Material)
Operational Regime: On-Orbit (ISS)
Operator: Remote Human

8.9.20 PGM20: Turbine Ceramic Manufacturing Module (TCMM)

Description: The Turbine Ceramic Manufacturing Module demonstrated production of a single-piece ceramic turbine blisk (blade + disk) on board the ISS. It was successfully launched on Northrop Grumman's CRS-14 mission, becoming the first ceramic facility on the ISS. The project focused on utilizing ceramic additive Stereolithography (SLA) to produce advanced parts, ultimately leading to decreased part mass, fatigue, and residual stress.
Developer: Redwire Corporation
Country: United States
First Use Date: 2020
Status: Completed
End Product: Finished Part
Inputs: Earth Delivered Material
Max Dimensions: Unavailable
Material Types: Metal Alloys
Operational Regime: On-Orbit (ISS)
Operator: Human

8.9.21 PGM21: Universal Glass Optics Manufacturing Module (UNIGLO)

Description: The UNIGLO project is an ISS experiment focused on demonstrating ZBLAN fiber production. It also leverages Artificial Intelligence (AI) and advanced sensor technology to improve production and in-situ analysis. One technology developed for this analysis is a custom Laser Doppler Sensor. The sensor is able to provide feedback control of the process, and alongside AI Support, the entire production of fibers can be optimized.
Developer: Apsidal
Country: United States
First Use Date: 2022
Status: Operational
End Product: Optical Components
Inputs: Earth Delivered Material
Max Dimensions: Unavailable
Material Types: optical fibers, fiber lasers, magnetic fibers, super-continuum sources, capillary optics and adiabatic tapers
Operational Regime: On-Orbit (ISS)
Operator: Human / Remote Human

8.9.22 PGM22: Vulcan

Description: Vulcan was an in-space manufacturing facility which had the ability to produce parts from metallics, polymers, or a hybrid of materials. The facility was intended to use additive and subtractive manufacturing processes. The additive elements were derived from wire-fed welding processes. This project was funded through NASA SBIRs (phase I, II, and II-E) and a contract with the ISS Research Office.
Developer: Redwire Corporation, National Aeronautics and Space Administration (NASA)
Country: United States
Status: Concluded
End Product: Finished Part
Inputs: Earth Delivered Material
Max Dimensions: Unavailable
Material Types: Metallics and Polymers
Operational Regime: On-Orbit (ISS)
Operator: Human

8.9.23 PGM23: W-Series Platform

Description: The W-Series Platforms are free-flying, in-space production facilities with reentry capabilities. The first W-Series platform, dubbed W-1, launched in June 2023 and returned to Earth in February 2024. During its stay in space, the capsule successfully grew crystals of the Ritonavir drug which is used for treatment of HIV and hepatitis C. The reentry capsule is built by Varda Space Industries, whereas the satellite bus is a Photon spacecraft built by RocketLab.
Developer: Varda Space Industries
Country: United States
First Use Date: 2023
Status: Operational
End Product: Finished Part
Inputs: Earth Delivered Material
Max Dimensions: Unavailable
Material Types: Pharmaceuticals/Drugs
Operational Regime: On-Orbit (LEO)
Operator: Unavailable

8.10 Surface Infrastructure

8.10.1 SI01: 3D Printed Habitat Challenge

Description: In an effort to crowdsource ideas, NASA developed the 3D Printed Habitat Challenge. This Challenge took place in three phases. The Phase I competition awarded prize money for an optimal design of a 3D printed habitat. The Phase 2 competition focused on the composition and strength of 3D printed material of a Martian regolith and recycled trash composition. Phase 3 included three levels for 3D printing of subscale habitats with perforations and structural requirements as well as two levels for virtual Building Information Modeling competitions for a fully outfitted virtual habitat.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
Status: Completed
Materials (Imported vs. ISRU): ISRU
Construction Agent: Robot
Auto / Fly-by-Wire / Planned: Planned

8.10.2 SI02: Additive Construction with Mobile Emplacement (ACME)

Description: In 2014, a joint venture between NASA's Space Technology Mission Directorate Game Changing Development Program and the United States Army Corps of Engineers (USACE) resulted in the Additive Construction with Mobile Emplacement (ACME) project. ACME combined the expertise, technology, and goals of NASA's MSFC and KSC, the USACE, Contour Crafting Corporation, and the Pacific International Space Center for Exploration Systems. By 2018, the project successfully completed additive construction (both 2D landing pad and 3D wall construction) demonstrations with materials made from simulated planetary regolith. Additional work related to ACME includes two Center Innovation Fund efforts awarded by the MSFC Chief Technologist, as well as the Additive Construction of Expeditionary Structures (ACES) project under the USACE.
Developer: National Aeronautics and Space Administration (NASA), United States Army Corps of Engineers
Country: United States
First Use Date: TBD
Status: In Development
Materials (Imported vs. ISRU): ISRU
Construction Agent: Human
Auto / Fly-by-Wire / Planned: Planned

8.10.3 SI03: All-Terrain Hex-Limbed Extra-Terrestrial Explorer (ATHLETE)

Description: The All-Terrain Hex-Limbed Extra-Terrestrial Explorer (ATHLETE) vehicle, developed at JPL, is a vehicle intended to support human exploration on the lunar surface. The vehicle includes a habitable volume mounted on six 6-degree-of-freedom robotic arms, each with a 1-degree-of-freedom wheel attached. The robotic arms and wheels are able to traverse stable terrain in a standard rover-like configuration. For more difficult terrain, the wheels can be locked, and the robotic arms can act as legs.
Developer: NASA Jet Propulsion Laboratory (JPL)
Country: United States
First Use Date: 2005
Status: In Development
Construction Agent: Robot
Auto / Fly-by-Wire / Planned: Unavailable
Cross Listing: RM01

8.10.4 SI04: Automated Reconfigurable Mission Adaptive Digital Assembly Systems (ARMADAS)

Description: The Automated Reconfigurable Mission Adaptive Digital Assembly Systems (ARMADAS) project developed and demonstrated autonomous assembly of building-block-based "digital materials" and structures. The ARMADAS project seeks to provide integrated system design to address the full lifecycle of a persistent asset or surface structure. Project structural assembly systems and robots are specifically designed for energy efficient re-use, upgrade, recycling, reconfiguration, simplified robotic manipulation, inspection, and maintenance. Ground demonstration was completed showing autonomous robotic assembly of a 256-unit cell reconfigurable structure. Solar panel, wire routing, and functional module installation outfitting capabilities were also demonstrated. The technology is envisioned to be applied to sustainable and extensible orbital and surface space infrastructure construction.
Developer: NASA Ames Research Center (ARC)
Country: United States
First Use Date: TBD
Status: In Development
Materials (Imported vs. ISRU): Imported and ISRU
Construction Agent: Robot
Auto / Fly-by-Wire / Planned: Auto
Cross Listing: SMA06

8.10.5 SI05: Blue Alchemist

Description: Blue Alchemist is a technology and set of processes developed by Blue Origin to manufacture solar cells and transmission wire from lunar regolith. The process to manufacture these products includes molten regolith electrolysis and utilizes simulants that are chemically and mineralogically equivalent to lunar regolith. The overall process is mobile, scalable, and contactless, robust to regolith variations, and could be employed anywhere on the Moon. Because the process produces zero carbon emissions and requires no water, no toxic ingredients, and no other chemicals, it could have applicability for terrestrial use. As of 2024, Blue Origin has produced silicon solar cells and aluminum wire with the Blue Alchemist technology.
Developer: Blue Origin
Country: United States
First Use Date: TBD
Status: In Development
Materials (Imported vs. ISRU): ISRU
Construction Agent: Robot
Auto / Fly-by-Wire / Planned: Unavailable
Cross Listing: PGM04

8.10.6 SI06: Crew Health and Performance Analog (CHAPEA)

Description: The Crew Health and Performance Analog (CHAPEA) project has two main purposes: to run an analog to understand crew health and performance outcomes associated with their operational trades, as well as to demonstrate design and construction of a regolith 3D printed habitat for Mars. The CHAPEA team partnered with ICON to 3D print a realistic Mars habitat using lavacrete, with the intention to maximize in-situ resource utilization.
Developer: NASA Johnson Space Center (JSC)
Country: United States
First Use Date: 2023
Status: Operational
Materials (Imported vs. ISRU): ISRU and possibly imported binder
Construction Agent: Robot
Auto / Fly-by-Wire / Planned: Planned

8.10.7 SI07: FLEX

Description: The Astrolab FLEX rover will be capable of carrying science payloads, logistics payloads, and crew on planetary and lunar surfaces. The rover is currently under development and expected to launch to the Moon in 2026 on the SpaceX Starship with 1500 kg of commercial customer cargo. The rover is equipped with a steerable high-gain antenna, adaptable suspension, remote science mast, crew interfaces, and a 2-meter, 6-degree-of-freedom robotic arm.
Developer: Astrolab
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Auto / Fly-by-Wire / Planned: Planned
Cross Listing: RM14

8.10.8 SI08: Gaseous Lunar Oxygen from Regolith Electrolysis Project (GaLORE)

Description: The Gaseous Lunar Oxygen from Regolith Electrolysis (GaLORE) project team won an internal award to develop the melting technology. Regolith on the Moon is made from oxidized metals like iron oxide, silicon oxide and aluminum oxide. GaLORE advanced technology to heat the regolith to more than 3,000 degrees Fahrenheit and flow electricity through the molten material, causing a chemical reaction that splits the regolith into gaseous oxygen and metals.
Developer: NASA Kennedy Space Center (KSC)
Country: United States
Status: Completed
Materials (Imported vs. ISRU): ISRU
Construction Agent: Robot
Auto / Fly-by-Wire / Planned: Auto

8.10.9 SI09: In-Situ Fabrication and Repair Project (ISFR)

Description: In the 2004-2007 timeframe, habitats and structures were part of the In-Situ Fabrication and Repair (ISFR) project at NASA's Marshall Space Flight Center (MSFC). The ISFR project developed technologies for fabrication, repair and recycling of tools, parts, and habitats and other structures using in-situ resources. The in-situ resources evaluated during this time included lunar raw materials, recycled spacecraft, human waste, trash, etc. Approximately 27 different research projects were funded by this effort, including identification and usage of raw materials (e.g., regolith, rocks, and lava tubes), autonomous construction technologies such as an inflatable dome and contour crafting. Processing technologies funded by the ISFR effort included glass melting for structural members and rebar, as well as foldable and deployable structures.
Developer: NASA Marshall Space Flight Center (MSFC)
Country: United States
First Use Date: TBD
Status: In Development
Materials (Imported vs. ISRU): ISRU
Construction Agent: Human
Auto / Fly-by-Wire / Planned: Fly by Wire

8.10.10 SI10: ISRU Pilot Excavator (IPEx)

Description: The ISRU Pilot Excavator (IPEx) is a teleoperated mobile robotic platform with a unique space regolith excavation capability. Its design incorporates net-zero reaction force, thus allowing it to load, haul, and dump space regolith under extremely low gravity conditions with high reliability.
Developer: NASA Kennedy Space Center (KSC)
Country: United States
First Use Date: TBD
Status: In Development
Materials (Imported vs. ISRU): ISRU and Construction
Construction Agent: Robot
Auto / Fly-by-Wire / Planned: Planned

8.10.11 SI11: Lightweight Surface Manipulator System (LSMS)

Description: Lightweight Surface Manipulation System (LSMS) is a crane with multiple end effectors being developed at NASA Langley. LSMS is designed to be scalable to a wide range of reach and tip mass requirements, with 12 years of design heritage and testing on 1000 kg (lunar) tip mass capable prototype unit. The LSMS allows for fine positioning of a payload in both the translational and rotational directions. Attachments include buckets, pallet forks, grappling devices, sensors, and robotic arms.
Developer: NASA Langley Research Center (LaRC)
Country: United States
First Use Date: TBD
Status: In Development
Materials (Imported vs. ISRU): Imported
Construction Agent: Robot
Auto / Fly-by-Wire / Planned: Planned
Cross Listing: RM22

8.10.12 SI12: Lunar Attachment Node for Construction and Excavation (LANCE)

Description: The Lunar Attachment Node for Construction and Excavation (LANCE) is a lightweight bulldozer blade designed to attach to the Chariot chassis. LANCE was developed at KSC and tested in lunar regolith simulant in 2008.
Developer: NASA Kennedy Space Center (KSC)
Country: United States
First Use Date: 2008
Status: Completed
Materials (Imported vs. ISRU): Imported
Construction Agent: Robot
Auto / Fly-by-Wire / Planned: Planned

8.10.13 SI13: Lunar Communication Tower Construction Demonstration

Description: The Lunar Communication Tower Construction Demonstration was a demonstration performed by GITAI in collaboration with KDDI Corporation of Japan. During this demonstration, a 5-meter-tall communications tower was constructed using stackable modules. The assembly agents include the GITAI R1 rover and three GITAI IN1 robotic arms. During the demonstration, the R1 delivered stackable modules to the worksite and the IN1 robotic arms iteratively translated the modules to the top of the tower and attached the new module, thus increasing the overall tower height.
Developer: GITAI
Country: United States
First Use Date: 2024
Status: Completed
Materials (Imported vs. ISRU): Imported
Construction Agent: Robot
Auto / Fly-by-Wire / Planned: Planned
Cross Listing: SMA24

8.10.14 SI14: Lunar Rover (R1.5)

Description: The GITAI Lunar Rover is a four-wheeled, robotic integrated rover which is intended to operate on the lunar surface. The rover is capable of general-purpose tasks such as exploration, mining, inspection, maintenance, and assembly. The rover is integrated with two robotic arms with generic gripper end effectors to allow for general purpose use. This rover has been tested in a simulated lunar environment at JAXA's Sagamihara Campus. In March 2023, a demonstration of cooperative lunar base construction using two GITAI inchworm-type robotic arms and two GITAI Lunar Robotic Rovers was successfully completed in a simulated lunar environment. By cooperation with an inchworm-type robotic arm, self-repairing (e.g., changing the rover tire) is available as well. The Lunar Rover has evolved since its inception, beginning with the R1 model and turning into the current R1.5 model. GITAI plans to send the R1.5 to the Moon by 2025.
Developer: GITAI
Country: Japan
First Use Date: Scheduled for 2025
Status: In Development
Construction Agent: Robot
Auto / Fly-by-Wire / Planned: Auto

8.10.15 SI15: Moon to Mars Planetary Autonomous Construction Technologies (MMPACT)

Description: The Moon to Mars Planetary Autonomous Construction Technologies (MMPACT) project will focus on the utilization of lunar in-situ materials for the manufacturing construction of large-scale infrastructure elements like habitats, berms, landing pads, blast shields, walkways, floors, storage facilities, and roads using one or both of two techniques.
Developer: NASA Marshall Space Flight Center (MSFC), ICON
Country: United States
First Use Date: TBD
Status: In Development
Materials (Imported vs. ISRU): ISRU
Construction Agent: Human
Auto / Fly-by-Wire / Planned: Planned

8.10.16 SI16: Redwire Mason Tool Suite (Redwire Mason)

Description: In 2023, Redwire was selected for a NASA Tipping Point to prototype Mason, a first-of-its-kind manufacturing technology which seeks to build critical infrastructure needed for lunar and Mars surfaces. Mason is a tool suite designed to be scalable and platform agnostic for use on different landers, rovers, or robotic arms. Mason will convert lunar or Martian regolith into strong, solid material similar to concrete. It includes three tools: a grader tool called BASE (Blade for Autonomously Surfacing Environments), a compaction tool called PACT (Planetary Automated Compaction Tool), and a microwave sintering tool called M3LT (Microwave Melter of Martian and Lunar Terrain).
Developer: Redwire Corporation
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Materials (Imported vs. ISRU): ISRU
Construction Agent: Unknown
Auto / Fly-by-Wire / Planned: Unknown

8.10.17 SI17: Redwire Regolith Print (RegISS)

Description: RegISS is an on-orbit demonstration of 3D printing with a polymer/regolith simulant feedstock blend. It was the first demonstration of manufacturing with ISRU-derived feedstocks on ISS. This proof of concept showed the viability of printing with regolith composite material in a reduced gravity environment and is applicable to manufacturing on the lunar surface and Mars. In this effort, a previously flown version of the Additive Manufacturing Facility was modified to accommodate a new extruder and print with a feedstock consisting of regolith simulant and a thermoplastic. The payload launched to the ISS in 2021. Sample coupons were returned to Earth; however, issues encountered during production prevented further analysis.
Developer: Redwire Corporation, National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2021
Status: Operational
Materials (Imported vs. ISRU): ISRU
Construction Agent: Robot
Auto / Fly-by-Wire / Planned: Planned
Cross Listing: PGM17

8.10.18 SI18: Relevant Environment Additive Construction Technology (REACT)
Description: Relevant Environment Additive Construction Technology (REACT) was a NASA funded Announcement of Collaborative Opportunity contract between AI SpaceFactory and KSC. Additionally, AI SpaceFactory contracted LERA, a structural engineering consulting firm. The REACT team is designing a safe haven type structure and developing the construction technologies and materials necessary for a large, regolith polymer composite based 3D printed structure for the lunar surface. By the end of the project, the REACT team intends to demonstrate the material and structural design.
Developer: AI SpaceFactory, LERA, NASA Kennedy Space Center (KSC)
Country: United States
First Use Date: TBD
Status: In Development
Materials (Imported vs. ISRU): ISRU and possibly imported binder
Construction Agent: Robot
Auto / Fly-by-Wire / Planned: Planned

8.10.19 SI19: RoboSimian
Description: The RoboSimian traverse vehicle out of NASA's Jet Propulsion Laboratory (JPL) is a robot with four wheels mounted on the end of 7-degree-of-freedom robotic arms. The robot was constructed in response to a Defense Advanced Research Projects Agency (DARPA) challenge to advance the use of robots in disaster situations. The vehicle can carry 20 kg and is capable of traversing complex environments through use of the four independent limbs, seven sets of stereo cameras, and a LiDAR mapping device.
Developer: NASA Jet Propulsion Laboratory (JPL)
Country: United States
First Use Date: 2014
Status: Completed
Construction Agent: Robot
Auto / Fly-by-Wire / Planned: Unavailable
Cross Listing: RM37

8.10.20 SI20: Site Preparation Tooling for Operations on Mobility Platforms (STOMP)
Description: NASA Kennedy Space Center is developing a roller compactor tool for modular attachment to a construction mobility platform, specifically RASSOR 2, which is a SWAMP Work's lunar rover being developed. STOMP will demonstrate digging, dumping, and compacting bulk regolith on the lunar surface and is being designed to match the current dimensions of the bucket drums of RASSOR 2 to maintain full mobility capabilities.
Developer: NASA Kennedy Space Center (KSC)
Country: United States
First Use Date: TBD
Status: In Development
Materials (Imported vs. ISRU): ISRU
Construction Agent: Robot
Auto / Fly-by-Wire / Planned: Unavailable

8.10.21 SI21: Solar On-orbit Welder for Assembly, Repair, and Manufacturing (SO-WARM)

Description: The Solar On-Orbit Welder for Assembly, Repair, and Manufacturing (SO-WARM) system, developed by Outward Technologies, relies on direct solar-thermal heating of materials to weld metals (aluminum and titanium) and join non-metal materials. SO-WARM is a lightweight and versatile design that can weld parts, control the temperature, and be used as a cutting tool.
Developer: Outward Technologies
Country: United States
First Use Date: TBD
Status: In Development
Materials (Imported vs. ISRU): Imported or ISRU
Construction Agent: Robot
Auto / Fly-by-Wire / Planned: Auto
Cross Listing: SMA37

8.10.22 SI22: Tall Lunar Tower (TLT)

Description: Tall Lunar Tower (TLT) is a Project Polaris activity from NASA's ESDMD to demonstrate assembly of a large truss-based tower. High performance truss-based towers could be assembled on planetary surfaces to support solar arrays, communications antenna, and navigation beacons. An assembly demonstration of an engineering development unit was completed in September 2023 at NASA Langley Research Center where a 4.5-meter-tall tower was assembled. A tower configuration utility was created based off the Euler buckling limitations allowing rapid scaling of the tower to support various payloads. The dimensions of the demonstration tower were scaled to support 1000 kg payloads at 50 meters height. The resulting structure, which would be assembled by 1.3-meter-reach robotic manipulators, would have a mass of 110 kg. The TLT process uses automated robotic assembly to construct towers to elevate payloads. Towers can be constructed by a variety of 6-DOF serial robotic manipulators fitted with specialized end effectors designed to hold, sense, and join struts into repeating truss bays. After each bay is constructed, a lifter system raises the completed bays and supported payload. TLT tower assembly concepts are compatible with various truss structures and using in-situ resources for truss components. In the future, TLT plans to demonstrate this scalable surface construction capability and utility outfitting, using the lessons learned from the initial demonstration.
Developer: NASA Langley Research Center (LaRC)
Country: United States
First Use Date: TBD
Status: In Development
Materials (Imported vs. ISRU): Imported or ISRU
Construction Agent: Robot
Auto / Fly-by-Wire / Planned: Auto
Cross Listing: SMA41

8.11 Inspection and Metrology

8.11.1 IM01: Active Debris Removal by Astroscale - Japan (ADRAS-J)

Description: Active Debris Removal by Astroscale - Japan (ADRAS-J) was a mission to safely approach and characterize an existing piece of large debris. The ADRAS-J spacecraft was selected by JAXA for Phase I of its Commercial Removal of Debris Demonstration (CRD2) Project and was launched in February 2024 from New Zealand on a Rocket Lab Electron. The spacecraft successfully approached and inspected an H2A rocket body which was launched in 2009. The position of the uncooperative rocket body was initially communicated to the ADRAS-J spacecraft through ground-based observations, after which onboard systems executed closer RPO activities. At its final approach, the spacecraft maneuvered within 15 meters of the client object, a historic feat in RPO. In August of 2024, Astroscale Japan announced it had been selected by JAXA for a second mission titled ADRAS-J2, in which another spacecraft would travel to the H2A rocket body, grapple it, and lower its orbit for eventual disposal.
Developer: Astroscale, Japan Aerospace Exploration Agency (JAXA)
Country: Japan
First Use Date: 2024
Status: Completed
Contact (Y/N): No, free-flying
Inspection Type/Key Units: Visual, LiDAR
Resolution: Unavailable
Data Analysis: Unavailable
Cross Listing: RCDM001

8.11.2 IM02: AeroCube-10

Description: The AeroCube-10 demonstration mission was a pair of 1.5U CubeSats (one with 28 deployable atmospheric probes and a laser beacon, another with a camera and propulsion system). AC-10B entered "orbit" around AC-10A and used its onboard camera to take resolved images of AC-10A. AC-10B took photos from 22 meters away.
Developer: The Aerospace Corporation
Country: United States
First Use Date: 2019
Status: Completed
Contact (Y/N): No, free-flying
Inspection Type/Key Units: Visual
Resolution: <10 meters
Inspection Aids/Fiducials/Cues: GPS, ADCS, Ground Station comms
Data Analysis: Off-board
Cross Listing: RCDM002

8.11.3 IM03: Automated Navigation and Guidance Experiment for Local Space (ANGELS)

Description: Automated Navigation and Guidance Experiment for Local Space (ANGELS) evaluated space situational awareness techniques in the region around its Delta IV launch vehicle upper stage. The mission began with experiments approximately 50 km away from the upper stage and progressed to within several kilometers using ground-commanded authorization to proceed at points throughout the experiment.
Developer: Air Force Research Laboratory (AFRL)
Country: United States
First Use Date: 2014
Status: Completed
Contact (Y/N): No, free-flying
Inspection Type/Key Units: Visual
Resolution: High
Inspection Aids/Fiducials/Cues: SSA Sensor payload, GPS, accelerometers
Data Analysis: Autonomous
Cross Listing: RCDM013

8.11.4 IM04: Biclops

Description: Biclops utilizes the stereo-camera pair of the Triclops system as a separate product offering depth-sensing, spatial object detection, and 3D mapping. The cameras can be programmed to operate asynchronously, offering different fields of view or orthogonal camera directions. The entire system is housed in a 1U CubeSat footprint.
Developer: TRL11
Country: United States
First Use Date: TBD
Status: In Development
Contact (Y/N): No
Inspection Type/Key Units: Visual
Resolution: High
Inspection Aids/Fiducials/Cues: Adaptive Exposure
Data Analysis: Off-board
Cross Listing: RCDM016

8.11.5 IM05: Démonstration d'Inspection et Amarrage Novatrice Embarquée (DIANE)

Description: The DIANE mission, led by Thales Alenia Space, is a demonstration of rendezvous, capture and inspection capabilities. Supported by the French space agency CNES, the mission will use a pair of spacecraft which are a part of the European Robotic Orbital Support Services (EROSS) program. EROSS intends to use two spacecraft to test rendezvous and servicing using a robot arm. After the EROSS demonstration, DIANE will spin the client satellite in order to represent loss of attitude and orbit control. From there, the mission will demonstrate the ability to capture and inspect a now uncontrolled spacecraft. The two spacecraft are slated to launch before the end of 2028.
Developer: Thales Alenia Space
Country: France, Italy, European Union
First Use Date: Scheduled for 2028
Status: In Development
Contact (Y/N): Y, robot-arm
Inspection Type/Key Units: Unavailable
Resolution: Unavailable
Inspection Aids/Fiducials/Cues: Unavailable
Data Analysis: Unavailable
Cross Listing: RCDM020

8.11.6 IM06: Elytra

Description: Elytra is an ESPA-based electric space tug system designed to launch with Firefly Aerospace's Alpha launch vehicle, Medium Launch Vehicle (MLV), and potentially other launch vehicles. The three classes of Elytra vehicles, Dawn, Dusk, and Dark, provide expanding capabilities to clients, including payload hosting, final orbit delivery, LEO to GEO transfer, and lunar orbit transfer. Elytra is expected to perform demonstrations on orbit no earlier than 2025 and a variant will serve as a transfer vehicle for Firefly's Blue Ghost Mission 2 to the lunar surface in 2026. The vehicle can deliver 2,700 kg of payload capacity to lunar orbit with the ability to provide on-orbit services for up to 5 years. It also has sufficient propellant reserve to enable a variety of advanced mission opportunities, such as lunar sample return to Earth and further exploration to nearby planets like Mars and Venus.
Developer: Firefly Aerospace
Country: United States
First Use Date: Scheduled for 2025
Status: In Development
Contact (Y/N): No, free-flying
Inspection Type/Key Units: Visual, UV
Resolution: 0.2 m resolution at 50 km
Data Analysis: Off-board
Cross Listing: RCDM024, R06

8.11.7 IM07: European Robotic Orbital Support Services - Servicing Component (EROSS-SC)

Description: The European Robotic Orbital Support Services (EROSS) project is focused on developing technologies to support orbital operations in LEO and GEO. It has evolved through several phases and is now scoped to develop an operational mission demonstrating docking, rendezvous, inspection, and other servicing capabilities. Funded through the European Commission and led by Thales Alenia Space, the EROSS-SC mission is scheduled for an In-Orbit Demonstration (IOD) in 2026, followed by an operational mission in 2027-2028.
Developer: Thales Alenia Space, European Commission (EC)
Country: European Union
First Use Date: Scheduled for 2028
Status: In Development
Contact (Y/N): Y
Inspection Type/Key Units: Unavailable
Resolution: Unavailable
Inspection Aids/Fiducials/Cues: Unavailable
Data Analysis: Unavailable
Cross Listing: RCDM029, RFT10

8.11.8 IM08: eXperimental Small Satellite 10 (XSS-10)

Description: eXperimental Small Satellite 10 (XSS-10) was a micro-satellite with objectives to demonstrate autonomous navigation, proximity operations, and inspection of another space object. The satellite was launched and completed operations, including the imaging of a Delta II upper stage, in 2003.
Developer: Air Force Research Laboratory (AFRL)
Country: United States
First Use Date: 2003
Status: Completed
Contact (Y/N): No, free-flying
Inspection Type/Key Units: Visual
Resolution: High
Inspection Aids/Fiducials/Cues: GPS, Star Tracker, SGLS system
Data Analysis: Autonomous
Cross Listing: RCDM030

8.11.9 IM09: eXperimental Small Satellite 11 (XSS-11)

Description: eXperimental Small Satellite 11 (XSS-11) was a micro-satellite demonstrating rendezvous and proximity operations with an expended rocket body. XSS-11 demonstrated technologies necessary to plan and evaluate autonomous rendezvous and proximity operations with an expended rocket body and other space objects near its orbit.
Developer: Air Force Research Laboratory (AFRL)
Country: United States
First Use Date: 2005
Status: Completed
Contact (Y/N): No, free-flying
Inspection Type/Key Units: Visual
Resolution: High
Inspection Aids/Fiducials/Cues: RPOD, On-orbit command/control
Data Analysis: Off-board
Cross Listing: RCDM031

8.11.10 IM10: Extravehicular Activity Infrared Camera (EVA IR Camera)

Description: NASA Langley's EVA IR Camera was a tool developed to detect subsurface damage to the reinforced carbon-carbon structures of the space shuttle. The camera was first demonstrated during the third EVA of STS-121.
Developer: NASA Langley Research Center (LaRC)
Country: United States
First Use Date: 2006
Status: Completed
Contact (Y/N): Yes, robot-arm
Inspection Type/Key Units: Visual
Resolution: Unavailable
Inspection Aids/Fiducials/Cues: Unavailable
Data Analysis: Off-board

8.11.11 IM11: Fovea M1 Camera (Fovea M1)

Description: Fovea is a radiation hardened camera designed for ISAM applications, spacecraft and space station monitoring, and Earth observation. The camera system is capable of capturing full-motion video in high dynamic range.
Developer: TRL11
Country: United States
First Use Date: TBD
Status: Operational
Contact (Y/N): No
Inspection Type/Key Units: Visual
Resolution: High
Inspection Aids/Fiducials/Cues: Adaptive Exposure
Data Analysis: Off-board

8.11.12 IM12: Fovea M2 Camera (Fovea M2)
Description: Fovea is a compact, radiation hardened, high dynamic range camera designed for ISAM applications, spacecraft and space station monitoring, and Earth observation. The Fovea M2 camera is smaller and lighter than the Fovea M1 camera and is offered in focal lengths between 3 mm and 25 mm.
Developer: TRL11
Country: United States
First Use Date: TBD
Status: Operational
Contact (Y/N): No
Inspection Type/Key Units: Visual
Resolution: High
Inspection Aids/Fiducials/Cues: Adaptive Exposure
Data Analysis: Off-board

8.11.13 IM13: Laser Camera System (LCS)
Description: The Laser Camera System (LCS) developed by Neptec is a camera system which provides inspection in space. The camera was initially demonstrated during STS-105 and was later used to inspect for damage which may have occurred during launch beginning with STS-114. The camera was designed to mount to the end of Canadarm and is able to generate a 3D mapping of any scanned surface.
Developer: Neptec Design Group Ltd
Country: Canada
First Use Date: 2001
Status: Completed
Contact (Y/N): No, tethered
Inspection Type/Key Units: Laser
Resolution: 100 µm at 1.2 m, 3 mm at 5 m
Data Analysis: Off-board

8.11.14 IM14: Laura-1
Description: The Laura-1 spacecraft was created by Rogue Space Systems as a platform for the inspection of in-space assets. The spacecraft is complete with a suite of sensors such as long- and short-range cameras for still imagery, lidar, and HD color video cameras. Laura uses a Scalable Computing Platform (SCP) and GPU Edge Compute Cluster to support its operations. Its satellite bus has a 3U hosting volume and is capable of high delta-v propulsion.
Developer: Rogue Space Systems Corporation
Country: United States
First Use Date: TBD
Status: In Development
Contact (Y/N): No, free-flying
Inspection Type/Key Units: Visual
Resolution: High
Inspection Aids/Fiducials/Cues: Multispectral sensor capabilities
Data Analysis: Off-board

8.11.15 IM15: Mycroft
Description: Mycroft is a Space Situational Awareness (SSA) spacecraft that builds upon technology developed for the XSS-10, XSS-11, and ANGELS missions. The spacecraft was launched on the AFRL's ESPA Augmented Geosynchronous Laboratory Environment (EAGLE) to test characterization and navigation capabilities in the surrounding region. Mycroft was also dispatched to inspect AFRL's defunct S5 satellite in GEO.
Developer: Air Force Research Laboratory (AFRL)
Country: United States
First Use Date: 2018
Status: Completed
Contact (Y/N): No, free-flying
Inspection Type/Key Units: Visual
Inspection Aids/Fiducials/Cues: SSA Camera, ADCS sensors/software
Data Analysis: Autonomous
Cross Listing: RCDM062

8.11.16 IM16: Optimus Viper Spacecraft (Optimus Viper)
Description: The Optimus Viper spacecraft are 200 kg inspection spacecraft developed by Space Machines Company. The "space first responders" are intended to offer inspection to client spacecraft within 24 hours. The Optimus Viper spacecraft utilize state of the art RPO capabilities and rely on the SolsticeOS AI-driven software to coordinate rapid-response operations. Initial demonstration missions are planned for 2026.
Developer: Space Machines Company
Country: Australia
First Use Date: Scheduled for 2026
Status: In Development
Contact (Y/N): No
Inspection Type/Key Units: Visual
Resolution: Unavailable
Inspection Aids/Fiducials/Cues: Unavailable
Data Analysis: Unavailable

8.11.17 IM17: Orbital Express

Description: Launched March 8, 2007, as part of the United States Air Force Space Test Program (STP), Orbital Express demonstrated automated rendezvous and capture of two spacecraft (ASTRO and NEXTSat), transfer of propellant, tank venting, and transfer of a modular spacecraft component. Flow sensors demonstrated 5 to 10 percent flow rate error on N2H4 transfer with no significant issues. The mission demonstrated 9 mate/demate cycles on orbit and demonstrated robotic Orbital Replacement Unit (ORU) transfer and installation.
Developer: Defense Advanced Research Projects Agency (DARPA), National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2007
Status: Completed
Contact (Y/N): Yes, robot-arm
Inspection Type/Key Units: Visual
Resolution: Unavailable
Inspection Aids/Fiducials/Cues: GPS, ADCS, Ground Station comms
Data Analysis: Unavailable
Cross Listing: PRMUI27, RFT31

8.11.18 IM18: Orion Camera Suite

Description: The Orion camera suite, which was first used in space during the Artemis I mission in 2022, is a suite of 11 cameras integrated into the Orion spacecraft to provide inspection and navigation capabilities. The camera suite includes four cameras mounted to the end of each of the four Orion solar arrays to provide inspection, one optical navigation camera to determine the spacecraft's relative position and velocity, and six additional internally and externally mounted cameras to provide in-flight video recording of events.
Developer: Redwire Corporation, Lockheed Martin, National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2022
Status: Completed
Contact (Y/N): No, tethered
Inspection Type/Key Units: Visual
Resolution: Unavailable
Data Analysis: Unavailable
Cross Listing: RCDM068

8.11.19 IM19: Otter

Description: Otter, from Starfish Space, is a low cost, rapidly deployable satellite servicing vehicle which will perform inspection, life extension, and end-of-life satellite services in LEO and GEO. Otter will leverage Starfish Space's Cephalopod software to perform autonomous rendezvous and proximity operations, CETACEAN software to provide relative navigation, Nautilus capture mechanism to provide docking without standardized, pre-installed interfaces on client satellites, and Manta articulating boom to provide tunable thrusting capabilities while docked to a client. Starfish Space has agreements to provide Otter vehicles for customers including Intelsat, USSF, and NASA.
Developer: Starfish Space
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Contact (Y/N): Y, robot-arm
Inspection Type/Key Units: Unavailable
Resolution: Unavailable
Inspection Aids/Fiducials/Cues: Unavailable
Data Analysis: Unavailable
Cross Listing: RCDM070, R23

8.11.20 IM20: Owl

Description: Building off of the Scout-Vision and Sparrow hardware and software, Owl is a gimbaled, long range, space domain awareness payload designed for tracking & cataloging, resident space object observation, and enabling evasive action for self-defense.
Developer: Scout Space Inc
Country: United States
First Use Date: TBD
Status: In Development
Contact (Y/N): No
Inspection Type/Key Units: Visual
Resolution: Unavailable
Inspection Aids/Fiducials/Cues: Unavailable
Data Analysis: Off-board

8.11.21 IM21: Quadclops
Description: Rated for GEO and designed for use in RPOD applications, the Quadclops is a four-camera system that combines two stereoscopic imagers, a center long-distance imager, and a fourth wide-angle situational awareness camera into a single integrated system. The system can be combined with a SDK for integrating gathered image data into user applications.
Developer: TRL11
Country: United States
First Use Date: TBD
Status: In Development
Contact (Y/N): No
Inspection Type/Key Units: Visual
Resolution: High
Inspection Aids/Fiducials/Cues: Adaptive Exposure
Data Analysis: Off-board
Cross Listing: RCDM078

8.11.22 IM22: RemoveDEBRIS
Description: The RemoveDEBRIS mission was a small satellite mission which was launched from the ISS in 2018 to demonstrate in-orbit debris removal technologies. The technologies tested include a space debris harpoon, which captured a target from 1.5 m, a space debris net, which captured a free-flying CubeSat, and a visual-based navigation system, which used laser and visual sensors to track a free-flying CubeSat.
Developer: Airbus, University of Surrey
Country: European Union
First Use Date: 2018
Status: Completed
Contact (Y/N): No, free-flying
Inspection Type/Key Units: Visual, LIDAR
Resolution: Unavailable
Data Analysis: Unavailable
Cross Listing: RCDM084

8.11.23 IM23: Robotic External Leak Locator (RELL)
Description: NASA's Robotic External Leak Locator (RELL) is a robotic, remote-controlled tool that helps mission operators detect the location of an external leak and rapidly confirm a successful repair. In 2020, astronauts installed a permanent housing on ISS for two RELL robots to dock to when not performing inspections.
Developer: NASA Goddard Space Flight Center (GSFC)
Country: United States
First Use Date: 2015
Status: Operational
Contact (Y/N): Yes, robot-arm
Inspection Type/Key Units: Ammonia sensor
Resolution: High
Inspection Aids/Fiducials/Cues: Mass spec, Ion vacuum pressure gauge
Data Analysis: Autonomous

8.11.24 IM24: SCOUT-Vision
Description: SCOUT-Vision was a space situational awareness payload that provides data to support identification and tracking of objects in its vicinity. The payload uses the company's software suite to enable on-demand, on-site inspections for space assets. The first SCOUT-Vision payload was launched in 2021 on Orbit Fab's Tenzing spacecraft.
Developer: Scout Space Inc
Country: United States
First Use Date: 2021
Status: Concluded
Contact (Y/N): No, free-flying
Inspection Type/Key Units: Visual
Resolution: High
Inspection Aids/Fiducials/Cues: Stereoscopic and Multispectral configurations
Data Analysis: Autonomous
Cross Listing: RCDM088

8.11.25 IM25: Seeker
Description: Seeker was a 3U spacecraft which was deployed from Orbital ATK Enhanced Cygnus ISS resupply spacecraft. The CubeSat completed a 60-minute mission consisting of proximity operations around Cygnus. UT-developed vision systems, which were isolated from all other sensors on board the spacecraft, used a commercially available camera and state-of-the-art computer vision algorithms to detect the Cygnus spacecraft.
Developer: The University of Texas at Austin (UT Austin), NASA Johnson Space Center (JSC)
Country: United States
First Use Date: 2019
Status: Operational
Contact (Y/N): No, free-flying
Inspection Type/Key Units: Visual
Resolution: High
Inspection Aids/Fiducials/Cues: Elevation/Azimuth computation
Data Analysis: Autonomous (2 Hz)

8.11.26 IM26: SHIELD
Description: SHIELD is a modular upgrade system featuring a base station and deployable scouting units designed to provide dynamic inspection, space domain awareness data collection, and defensive maneuvering capabilities when installed on commercial satellites.
Developer: Katalyst Space Technologies
Country: United States
First Use Date: TBD
Status: In Development
Contact (Y/N): No, free-flying
Inspection Type/Key Units: Visual
Resolution: Unavailable
Inspection Aids/Fiducials/Cues: Unavailable
Data Analysis: Unavailable
Cross Listing: RCDM089, URMUI17

8.11.27 IM27: SIGHT
Description: SIGHT is a modular imaging sensor package designed to retrofit existing satellites with space domain awareness capabilities by attaching to an orbiting spacecraft's launch adapter ring.
Developer: Katalyst Space Technologies
Country: United States
First Use Date: TBD
Status: In Development
Contact (Y/N): No
Inspection Type/Key Units: Visual
Resolution: Unavailable
Inspection Aids/Fiducials/Cues: Unavailable
Data Analysis: Off-board
Cross Listing: URMUI18

8.11.28 IM28: Small Spacecraft Propulsion and Inspection Capability (SSPICY)
Description: The Small Spacecraft Propulsion and Inspection Capability (SSPICY) mission is a NASA-funded, Starfish-led Phase III SBIR mission during which the Starfish Otter spacecraft will inspect multiple defunct U.S.-owned spacecraft. The Otter spacecraft will operate within low Earth orbit (LEO) and will approach the defunct spacecraft within hundreds of meters.
Developer: Starfish Space, National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Contact (Y/N): No
Cross Listing: RCDM095

8.11.29 IM29: Sonatest Veo Phased Array Ultrasonic Testing (Sonatest Veo PAUT)
Description: The Sonatest Veo Phased Array Ultrasonic Testing is a phased array ultrasonic test (PAUT) device which can assess the body of the ISS following a micrometeoroid strike. By making contact between the device and the area of damage, the device is able to find hidden structures such as isogrid webs. This detection method allows a repair team to determine what type of repair is required.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2013
Status: Operational
Contact (Y/N): Yes
Inspection Type/Key Units: Ultrasonic
Resolution: 0.1 inches
Inspection Aids/Fiducials/Cues: Multi-angle top scan
Data Analysis: Off-board

8.11.30 IM30: Spacecraft on Umbilical Line (SOUL)
Description: Spacecraft on Umbilical Line (SOUL) is a tethered robotic spacecraft that is designed to provide self-inspection and self-servicing. SOUL is a small (<10 kg) robotic, self-propelled, self-navigating, autonomous vehicle that receives power and commands from the host spacecraft. It acts as a robotic arm with essentially infinite degrees of freedom and very long reach, allowing it to access parts of the spacecraft inaccessible by a traditional robotic arm.
Developer: Busek Co. Inc
Country: United States
First Use Date: TBD
Status: In Development
Contact (Y/N): Yes, tethered
Inspection Type/Key Units: Visual, near IR
Cross Listing: RCDM097, PRMUI36

8.11.31 IM31: Spacecraft on Umbilical Line Inspector (SOUL Inspector)
Description: SOUL Inspector is a variant of Busek's SOUL (Spacecraft on Umbilical Line) which hosts 4 cameras and is stowed within a 12U CubeSat deployer. SOUL Inspector is intended to be hosted on a larger satellite and will eject into space, inspect the host satellite, and return to the CubeSat deployer upon command. Up to 5 of these sorties may be performed by each hosted SOUL Inspector.
Developer: Busek Co. Inc
Country: United States
First Use Date: TBD
Status: In Development
Contact (Y/N): Yes, tethered
Inspection Type/Key Units: Visual, near IR

8.11.32 IM32: Sparrow
Description: Sparrow is a low-SWAP, close-range optical system for RPO which includes a stereoscopic sensor suite and accompanying software package. Sparrow is available in 60-degree, 27-degree, and 13-degree field of view configurations.
Developer: Scout Space Inc
Country: United States
First Use Date: TBD
Status: In Development
Contact (Y/N): No
Inspection Type/Key Units: Visual
Resolution: Unavailable
Inspection Aids/Fiducials/Cues: Unavailable
Data Analysis: Off-board

8.11.33 IM33: Tetra-5
Description: Tetra-5 is a program within the United States Space Force (USSF) to demonstrate capabilities required for on-orbit refueling. The program, which was awarded to Orion Space Systems in 2022, involves the construction of two satellites which will perform RPO, docking, inspection, and refueling operations to demonstrate the utility of commercial refueling operations. One of the two Tetra-5 satellites will receive 50 kg of hydrazine from an Orbit Fab Kamino Fuel Depot, funded through the DIU RAPIDS program. The satellite will receive propellant through the Orbit Fab RAFTI interface. The second spacecraft will demonstrate compatibility with the APS-R propellant shuttle developed by Astroscale.
Developer: United States Space Force, Orion Space Solutions
Country: United States
First Use Date: Scheduled for 2026
Status: In Development
Contact (Y/N): Yes
Inspection Type/Key Units: Unavailable
Resolution: Unavailable
Inspection Aids/Fiducials/Cues: Unavailable
Data Analysis: Unavailable
Cross Listing: RCDM105, RFT49

8.11.34 IM34: Triclops

Description: Triclops is a three-camera system designed for in-space inspection and RPO activities. The system combines the Biclops stereo-camera's operational capabilities with an added center camera with wide-field-of-view to enhance object acquisition.
Developer: TRL11
Country: United States
First Use Date: TBD
Status: In Development
Contact (Y/N): No
Inspection Type/Key Units: Visual
Resolution: High
Inspection Aids/Fiducials/Cues: Adaptive Exposure
Data Analysis: Off-board
Cross Listing: RCDM107

8.11.35 IM35: Vision Sensor Subsystem Visible Wavelength Spaceflight Camera (VSS Visible Wavelength Spaceflight Camera)

Description: The Vision Sensor Subsystem (VSS) Visible Wavelength Spaceflight Camera is a space situational awareness and inspection camera which was intended to be used during NASA's OSAM-1 Mission, which concluded in 2025 before launch. The camera would have provided long-range imagery of the client spacecraft to ground operators for assessment of the condition of the client spacecraft's grapple features in preparations for capture.
Developer: Malin Space Science Systems Inc, National Aeronautics and Space Administration (NASA)
Country: United States
Status: Concluded
Contact (Y/N): No, free-flying
Inspection Type/Key Units: Visual
Resolution: 1 cm resolution at 100 m
Data Analysis: Off-board

8.11.36 IM36: Visual Inspection Poseable Invertebrate Robot (VIPIR)

Description: VIPIR, the Visual Inspection Poseable Invertebrate Robot, was a robotic, multi-capability inspection tool designed to deliver near and midrange inspection capabilities in space. This robot was used on RRM2.
Developer: NASA Goddard Space Flight Center (GSFC)
Country: United States
First Use Date: 2015
Status: Completed
Contact (Y/N): Yes, robot-arm
Inspection Type/Key Units: Visual
Resolution: 224 x 224 pixel, 100 deg field of view
Inspection Aids/Fiducials/Cues: 8-24 mm optical zoom lens
Data Analysis: Off-board

8.11.37 IM37: Visual Inspection Poseable Invertebrate Robot 2 (VIPIR2)

Description: VIPR2 was robotic inspection camera used to visually verify entry and positioning of the flexible Cryogen Transfer Hose (CTH) into the receiver tank. VIPR2 was used on RRM3.
Developer: NASA Goddard Space Flight Center (GSFC)
Country: United States
First Use Date: 2018
Status: Completed
Contact (Y/N): Yes
Inspection Type/Key Units: Visual
Resolution: Unavailable
Inspection Aids/Fiducials/Cues: Unavailable
Data Analysis: Off-board

8.11.38 IM38: WorldView-3

Description: WorldView-3 is an Earth imaging satellite which operates at an altitude of 617 km and provides up to 680,000 sq km of imagery per day. The satellite hosts a number of instruments to provide high resolution imagery of the Earth. The satellite provided imagery of the ISS in June of 2024.
Developer: Maxar Technologies
Country: United States
First Use Date: 2014
Status: Operational
Contact (Y/N): No, free-flying
Inspection Type/Key Units: Visual
Resolution: Unavailable
Data Analysis: Off-board

9 Appendix – ISAM Cross-Cutting Capability Area Activities

In addition to the 11 functional ISAM capability areas, three cross-cutting capability areas have been identified that support these functional capability areas. These cross-cutting capability areas are crucial components that help tie together and support future ISAM missions. The three cross-cutting capabilities identified include:

- **Software and Algorithms:** Involves a range of software, programs, and algorithms that are specifically designed to support ISAM systems.
- **Management, Logistics, and Operations:** Involves the methods, infrastructure, and consumables required to facilitate sustained crewed and uncrewed space operations.
- **Laws, Policies, and Standards:** Involves the high-level government policies to include international treaties, widely used international standards, and country-specific regulations relevant to ISAM systems.

This appendix contains an overview of each cross-cutting capability area entry. Each entry contains a description and capability-area-specific data.

The Software and Algorithms entries contain information on the Developer, First Use Date, Status (either In Development or Completed), Software Type (using the same lexicon defined in Figure 13), and relevant Capability Area(s). The Associated Hardware information indicates associated entries from the functional capability areas or the general capability area to which the software applies.

The Management, Logistics, and Operations entries contain a brief description of the document being referenced and the list of authors.

The Laws, Policies, and Standards entries contain information including Document Reference Number (if applicable), date of the Most Recent Update, the Status (Published, In Progress, and Active), and the type of entry (Law, Policy, Standard, Overview, Regulation, or Treaty).

9.1 Software and Algorithms

9.1.1 SA01: Advanced RSO Characterization (ARC)

Description: ARC is a customizable software suite utilizing machine learning to process large volumes of space-domain data to produce insights for human analysts. The software classifies objects, detects behavioral anomalies, and generates actionable alerts to support timely decision-making in increasingly congested orbital environments where traditional data processing approaches fail to keep pace with exponentially growing sensor data volumes.
Developer: Katalyst Space Technologies
Country: United States
First Use Date: Unavailable
Status: Operational
Software Type: Modeling and Simulation
Availability: Commercial

9.1.2 SA02: Astraeus RPOD Flight Software

Description: The Astraeus RPOD flight software, developed by Ten One Aerospace, is a software suite which provides spacecraft mission management, on-orbit calibration, relative navigation, attitude determination and control, and trajectory guidance. The software suite is based on open-source architectures and allows for customization in order to meet mission requirements.
Developer: Ten One Aerospace
Country: United States
First Use Date: TBD
Status: In Development
Software Type: Rendezvous and Proximity Operations
Capability Area: 2
Availability: Commercial

9.1.3 SA03: Automated Navigation and Guidance Experiment for Local Space Software (ANGELS Software)

Description: The Automated Navigation and Guidance Experiment for Local Space (ANGELS) vehicle hosted software that increases the Radio Network Subsystem (RNS) range for smaller/micro satellites and increased autonomy in navigation.
Developer: Air Force Research Laboratory (AFRL)
Country: United States
First Use Date: 2014
Status: Completed
Associated Hardware: Automated Navigation and Guidance Experiment for Local Space (RCDM013, IM03)
Software Type: Rendezvous and Proximity Operations
Capability Area: 2
Availability: Military

9.1.4 SA04: Autonomous Entity Operational Network / Baseline Environment for Autonomous Modeling (AEON/BEAM)

Description: This is a modular plug-and-play software for multiagent interactions in navigation through a unity-based navigation center. The software measures the trustworthiness of the human-machine system and can be applicable to many types of vehicles including UAVs, Rovers, and Spacecraft.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2021
Status: Completed
Associated Hardware: RPO, Capture, Docking, and Mating; Inspection and Metrology
Software Type: Multi-Agent Framework
Capability Area: 2
Availability: NASA/Commercial

9.1.5 SA05: Autonomous Robotic Manipulator Software (ARMS)

Description: The Autonomous Robotic Manipulator Software (ARMS) suite, developed at NASA Langley Research Center, supports research and development in In-space Servicing, Assembly, and Manufacturing (ISAM). ARMS addresses challenges in autonomous robotic manipulation, including integration with commercial hardware, simulation, path planning, configuration management, and task execution, using a modular approach and leveraging Robot Operating System 2 (ROS 2) and its community-developed packages.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2022
Status: In Development
Associated Hardware: Precision Assembled Space Structure (SMA29)
Software Type: Robotics
Capability Area: 1
Availability: NASA

9.1.6 SA06: Autonomy Teaming and TRAjectories for Complex Trusted Operational Reliability (ATTRACTOR)

Description: Autonomy Teaming and TRAjectories for Complex Trusted Operational Reliability (ATTRACTOR) is a cyber-physical-human system (CPHS) for trajectory-based, mixed-reality multi-agent missions, comprising the following components: trajectory planning and management, navigation in challenging environments, persistent mixed-reality modeling and simulation, human-machine teaming and interaction, visual recognition and Explainable Artificial Intelligence (XAI), testing and evaluation, anomaly detection, metrics and models of trust and trustworthiness, technology integration, and demonstrations in simulation and flight.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2018
Status: Completed
Software Type: Multi-Agent Framework
Capability Area: 2
Availability: NASA

9.1.7 SA07: CEPHALOPOD

Description: CEPHALOPOD is a Starfish Space software providing autonomous rendezvous, proximity operations and docking (RPOD) using chemical and electric propulsion. CEPHALOPOD combines advanced computing techniques with novel relative motion algorithms to autonomously guide satellite maneuvers for docking with other objects in space.
Developer: Starfish Space
Country: United States
First Use Date: 2021
Status: Operational
Associated Hardware: Otter (RCDM070, R23, IM19)
Software Type: Rendezvous and Proximity Operations
Capability Area: 2
Availability: Commercial

9.1.8 SA08: Cetacean

Description: Cetacean is Starfish Space's navigation software designed to assist the host spacecraft by using a collection of commercially available sensors to deliver inspection and relative motion data. This software was first demonstrated aboard the Otter Pup 1 and will be utilized on the Otter Pup 2 and Otter vehicles to offer precise relative motion information for conducting RPO and Docking with client satellites.
Developer: Starfish Space
Country: United States
First Use Date: 2023
Status: Operational
Associated Hardware: Otter (RCDM070, R23, IM19)
Software Type: Rendezvous and Proximity Operations
Capability Area: 11
Availability: Commercial

9.1.9 SA09: Gazebo

Description: Gazebo is an open-source 2D/3D robotics simulator. Gazebo Classic integrates the Open Dynamics Engine (ODE) physics engine, OpenGL rendering, and support code for sensor simulation and actuator control. Gazebo Classic can use multiple high-performance physics engines, such as ODE, Bullet, etc. (the default is ODE). It provides realistic rendering of environments including high-quality lighting, shadows, and textures. It can model sensors that "see" the simulated environment, such as laser range finders, cameras (including wide-angle), Kinect style sensors, etc.
Developer: Open Robotics
Country: United States
First Use Date: 2002
Status: Completed
Associated Hardware: Robotic Manipulation
Software Type: Modeling and Simulation
Capability Area: 1
Availability: Open Source

9.1.10 SA10: Gazebo Assessment Seedling Study (GASS)

Description: Gazebo Assessment Seedling Study (GASS) was a software effort to assess the fidelity of sensor and pose tracking models in the Gazebo simulation framework in support of the high-precision operations of the Precision Assembled Space Structure (PASS) project. Close-proximity operations were modeled for a robotic assembly task.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2022
Status: Completed
Associated Hardware: Precision Assembled Space Structure (SMA29)
Software Type: Modeling and Simulation
Capability Area: 1
Availability: NASA

9.1.11 SA11: Interoperable Cislunar Observation Network (ICON)

Description: ICON is a decentralized tracking system utilizing a network of independent SDA enabled spacecraft to collaboratively provide digital infrastructure minimizing coverage gaps, reducing vulnerabilities, and preventing vehicle loss.
Developer: Katalyst Space Technologies
Country: United States
First Use Date: Unavailable
Status: In Development
Software Type: Multi-Agent Framework, Logistics Management
Availability: Commercial

9.1.12 SA12: Langley Standard Real-time Simulation in C++ (LaSRS++)

Description: LaSRS++ is an object-oriented, mission-verified framework for real-time dynamic 6DOF simulation of aircraft and spacecraft, capable of running from a desktop or supporting hard, synchronous, pilot-in-the-loop and hardware-in-the-loop testing. It can be and has been utilized for ISAM system modeling as well.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 1995
Status: Completed
Associated Hardware: RPO, Capture, Docking, and Mating
Software Type: Modeling and Simulation
Capability Area: 2
Availability: NASA

9.1.13 SA13: LSMS AutoNomy capabilities Development for Surface Operations (LANDO)

Description: LSMS AutoNomy capabilities Development for Surface Operations and construction (LANDO) is a software framework designed to autonomously offload payloads from a lunar lander down to the surface using the Lightweight Surface Manipulation System (LSMS).
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: TBD
Status: In Development
Associated Hardware: Lightweight Surface Manipulator System (RM22, SI11)
Software Type: Autonomy
Capability Area: 10
Availability: NASA

9.1.14 SA14: MEV-1 RPO Imager

Description: The Mission Extension Vehicle 1 (MEV-1) Rendezvous and Proximity Operations (RPO) Imager is the imager and navigational software used on the MEV-1 to complete an unplanned servicing mission. The software increased target detection range and provided more reliable RPO activities through the use of visible, infrared, and LIDAR based sensors.
Developer: Northrop Grumman
Country: United States
First Use Date: 2021
Status: Completed
Associated Hardware: Mission Extension Vehicle (RCDM060, R19)
Software Type: Rendezvous and Proximity Operations
Capability Area: 2
Availability: Commercial

9.1.15 SA15: Multi-Joint dynamics with Contact (MuJoCo)

Description: Multi-Joint dynamics with Contact (MuJoCo) is an open-source physics engine designed to support research and development across various fields, including robotics, biomechanics, and animation. It enables fast, accurate simulations, facilitating complex tasks such as optimal control, state estimation, system identification, and automated mechanism design.
Developer: DeepMind Technologies Limited
Country: United States
First Use Date: 2021
Status: Completed
Software Type: Modeling and Simulation
Capability Area: 1
Availability: Commercial

9.1.16 SA16: OSAM Architecture Simulation System (OASiS)

Description: The OSAM Architecture Simulation System (OASiS) is a LaSRS++ simulation to assess the fidelity of sensor modeling and pose estimation using fiducial markers. It was demonstrated for modeling planetary payload offloading operations.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2022
Status: Completed
Software Type: Modeling and Simulation
Capability Area: 2
Availability: NASA

9.1.17 SA17: Precision Assembled Space Structure Software (PASS Software)

Description: The Precision Assembled Space Structure (PASS) software framework and autonomous algorithms are used to control the PASS hardware and support the assembly of modular space structures.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2021
Status: Completed
Associated Hardware: Precision Assembled Space Structure (SMA29)
Software Type: Autonomy
Capability Area: 7
Availability: NASA

9.1.18 SA18: Robot Operating System (ROS)

Description: The Robot Operating System (ROS) is an open-source middleware suite that facilitates robot software development. It provides essential services such as hardware abstraction, low-level device control, common functionality implementations, inter-process communication, and package management, enabling effective management and coordination in a heterogeneous computing environment. Despite its name, ROS is not an actual operating system but a collection of software framework capabilities.
Developer: Open Robotics
Country: United States
First Use Date: 2007
Status: Completed
Associated Hardware: Robotic Manipulation
Software Type: Robotics
Capability Area: 1
Availability: Open Source

9.1.19 SA19: RPO Kit

Description: RPO Kit is a GNC software suite enabling autonomous RPO between multiple objects. By fusing a host of disparate and decentralized space data sources to estimate spacecraft orbits, poses, and states across user interest regimes, the software is able to provide maneuver solutions for formation maintenance, RPO, and collision avoidance.
Developer: Ten One Aerospace, Stanford Space Rendezvous Laboratory
Country: United States
First Use Date: TBD
Status: In Development
Software Type: Multi-Agent Framework
Capability Area: 2
Availability: Commercial

9.1.20 SA20: Scout SpaceSight

Description: Scout SpaceSight, hosted on the Saber Astronautics Space Application Marketplace (SAM), is an interactive tool built to help the space community better understand how different optical configurations would impact in-space observations. The tool allows a user to characterize camera settings and generate a synthetic image of how a spacecraft will appear to the camera.
Developer: Scout Space Inc
Country: United States
First Use Date: 2019
Status: Completed
Software Type: Modeling and Simulation
Capability Area: 11
Availability: Commercial

9.1.21 SA21: Sierra Toolkit for Autonomous Rendezvous (STAR)

Description: The Sierra Toolkit for Autonomous Rendezvous (STAR) is a software module from Sierra Space's Axelerator program powered by the AI-enabled operating system Sierra Black OS. STAR is an RPO software module which will provide RPO solutions to satellites through operational intelligence and autonomy.
Developer: Sierra Space
Country: United States
First Use Date: Scheduled for 2025
Status: In Development
Software Type: Rendezvous and Proximity Operations
Capability Area: 2
Availability: Commercial

9.1.22 SA22: SolsticeOS

Description: SolsticeOS is the AI-driven software which will autonomously coordinate on-orbit rapid response capabilities within hours. With an expected resolution of 1 cm at 1 km, this software enables the vision of future in-space operations using the Optimus Viper inspection platform.
Developer: Space Machines Company
Country: Australia
First Use Date: Scheduled for 2026
Status: In Development
Associated Hardware: Optimus Viper Spacecraft (IM16)
Software Type: Rendezvous and Proximity Operations, Logistics Management, Autonomy
Capability Area: 11
Availability: Commercial

9.1.23 SA23: Tall Lunar Tower Arm Software (TLT Arm Software)

Description: This is a software architecture designed for supervised autonomous assembly for the Tall Lunar Tower (TLT) project at NASA Langley Research Center.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2022
Status: In development
Associated Hardware: Tall Lunar Tower (SMA41, SI22)
Software Type: Robotics
Capability Area: 1
Availability: NASA

9.1.24 SA24: Trick Simulation Environment

Description: The Trick Simulation Environment, developed by NASA Johnson Space Center, is a robust framework designed to support all stages of space vehicle development. It accelerates the creation of simulations for vehicle design, performance evaluation, flight software development, dynamic load analysis, and training. By providing a common set of simulation capabilities, Trick allows users to focus on domain-specific models, streamlining processes like job ordering, input file processing, and data recording.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2015
Status: Completed
Software Type: Modeling and Simulation
Availability: Open Source

9.1.25 SA25: TumblEye

Description: The TumblEye technology is an autonomous machine vision system which derives rotation and location information from unknown objects. Its primary application is for active debris removal missions.
Developer: Kall Morris Inc
Country: United States
First Use Date: 2023
Status: In Development
Associated Hardware: RPO, Capture, Docking, and Mating
Software Type: Rendezvous and Proximity Operations
Capability Area: 2
Availability: Commercial

9.1.26 SA26: ULTOR Passive Pose and Position Engine (ULTOR P3E)

Description: ULTOR P3E or Passive Pose and Positioning Engine is an RNS (Relative Navigation System) which was used to aid docking with the HST during STS-125. The software used multiple RNS cameras and compared the landmarks and visuals with a high-fidelity model of the HST.
Developer: National Aeronautics and Space Administration (NASA)
Country: United States
First Use Date: 2008
Status: Completed
Associated Hardware: Space Shuttle
Software Type: Rendezvous and Proximity Operations
Capability Area: 2
Availability: NASA

9.2 Management, Logistics, and Operations

9.2.1 MLO01: Analysis of Historical International Space Station Logistical Mass Delivery

Description: This paper provides an analysis of cargo delivered to the ISS between 2017 and 2020. The paper includes distribution data according to commodity type, such as health care consumables or food.
Authors: Henry Leach, Michael Ewert

9.2.2 MLO02: Insights Into Space Logistics Vehicles

Description: This article offers a comprehensive overview of the competitive landscape of space logistics vehicles, with key insights highlighted from a detailed data compilation. Notable findings include the dominance of U.S.-based companies, the prevalence of start-ups in vehicle development, and the high demand for functionalities like hosted payloads and active debris removal.
Authors: New Space Economy

9.2.3 MLO03: Logistics Lessons Learned in NASA Space Flight

Description: This report outlines the logistics operations for the Shuttle and International Space Station (ISS), covering commodity manifesting, tracking, disposal, and Earth return. It provides an overview of the processes involved in managing and transporting materials to and from the ISS.
Authors: William A. (Andy) Evans, Prof Olivier de Weck, Deanna Laufer, Sarah Shull

9.2.4 MLO04: Logistics Needs for Future Human Exploration Beyond Low Earth Orbit

Description: This paper updates Lopez et al.'s 2015 publication on "Logistics Needs for Potential Deep Space Mission Scenarios Post Asteroid Redirect Crewed Mission." It refines projection rates and provides analysis for a 60-day cislunar mission and a 1200-day Mars mission.
Authors: Kandyce Goodliff, Chel Stromgren, Michael Ewert, James Hill, Cherice Moore

9.2.5 MLO05: Logistics Needs for Potential Deep Space Mission Scenarios Post Asteroid Redirect Crewed Mission

Description: This paper explores logistics requirements for a 60-day asteroid exploration mission and a 1000-day Mars mission.
Authors: Pedro Lopez Jr, Eric Schultz, Bryan Mattfeld, Chel Stromgren, Kandyce Goodliff

9.2.6 MLO06: Logistics Rates and Assumptions for Future Human Spaceflight Missions Beyond LEO

Description: This paper compiles guidelines, rates, and assumptions for assessing logistics needs in future human exploration missions beyond Low Earth Orbit (LEO). It serves as a foundational resource for planning usage rates and overall logistics supply for crewed exploration missions.
Authors: Chase Lynch, Kandyce Goodliff, Chel Stromgren, Jon Vega, Michael Ewert

9.2.7 MLO07: Modeling and Optimization for Space Logistics: Review of State of the Art

Description: This paper offers a collection of reference documents addressing key challenges in modeling and optimizing space logistics operations. It is divided into three main sections: ISAM for satellites, in-space infrastructure for space exploration campaigns, and mega-scale satellite constellations.
Authors: Koki Ho

9.2.8 MLO08: Parametric Cost Analysis of Refueling Options in Cislunar Space

Description: This paper compares the cost of expendable refueling tankers vs reusable refueling spacecraft in cislunar space.
Authors: Daniel Tiffin, Paul Friz

9.2.9 MLO09: Regenerative ECLSS and Logistics Analysis for Sustained Lunar Surface Missions

Description: This paper discusses the ECLSS Architecture and logistics requirements for sustained missions on the lunar surface.
Authors: Chel Stromgren, Callie Burke, Jason Cho, William Cirillo, Andrew Owens, David Howard

9.2.10 MLO10: Supportability for Beyond Low Earth Orbit Missions

Description: The paper presents ISS heritage information and summarizes the challenges associated with missions beyond Low Earth Orbit (LEO). It also discusses various supportability issues pertinent to human exploration beyond LEO.
Authors: William Cirillo, Kandyce Goodliff, Gordan Aaseng, Chel Stromgren, Andrew Maxwell

9.2.11 MLO11: Systems Analysis of In-Space Manufacturing Applications for the International Space Station and the Evolvable Mars Campaign

Description: This paper examines maintenance logistics challenges in low Earth orbit and beyond, providing results from a systems analysis of potential in-space manufacturing applications for the ISS and EMC. Selected results are summarized to highlight practical implications and future possibilities.
Authors: Andrew Owens, Olivier L. de Weck

9.2.12 MLO12: The International Space Station Operating an Outpost in the New Frontier

Description: This document provides a comprehensive record for operating the International Space Station. Discusses a wide range of topics to include systems, structures, communications, robotics, in-flight maintenance, and EVAs among many other topics.
Authors: Executive Editor: Robert Dempsey

9.2.13 MLO13: The Space Superhighway: A Cost Analysis of an In-Space Logistics Resupply Network

Description: This paper compares the cost of implementing expendable vs reusable solar electric propulsion tugs for a cislunar Space Superhighway logistics infrastructure.
Authors: Paul Friz, Daniel Tiffin, Edward Rosenthal

9.2.14 MLO14: The Space Superhighway: Space Infrastructure for the 21st Century

Description: This paper was the first to introduce the concept of the Space Superhighway in which a cislunar logistics network is proposed in order to facilitate missions such as satellite servicing, Earth science, and space domain awareness.
Authors: Deborah Tomek, Dr. Dale Arney, John Mulvaney, Christina Williams, Jill McGuire, Brian Roberts, Jeramie Broadway, Karl Stolleis, Josh Davis, Greg Richardson, Christopher Stockdale

9.2.15 MLO15: The Space Superhighway: Systems Analysis of an In-Space Logistics Delivery Network

Description: This paper discusses a conceptual network for an ISAM architecture that includes commercial launch vehicles, resupply tankers, orbital depots, and in-space tugs to facilitate logistics in cislunar space.
Authors: Daniel J. Tiffin and Paul D. Friz

9.2.16 MLO16: Timeline of Autonomous Cargo Spacecraft

Description: This online article provides a chronological overview of space logistics cargo spacecraft.
Authors: New Space Economy

9.3 Laws, Policies, and Standards

9.3.1 LPS01: Act on Launching Artificial Satellites and Managing Satellites (Satellite Act, Act No. 76 of 2016)

Description: The Act on Launching Artificial Satellites and Managing Satellites (Satellite Act, Act No. 76 of 2016) is a law enacted in Japan in 2016 to provide expanded guidance for the emerging space industry. This act defines the regulations for acquiring permits to operate satellites and guidance regarding de-orbit procedures and satellite termination.
Country: Japan
First Use Date: 2016
Status: Active
Document Reference Number: Act No. 76 of 2016
Most Recent Update: 2018
Type: Law

9.3.2 LPS02: Act on the Promotion of Business Activities for the Exploration and Development of Space Resources

Description: This law aims to facilitate the implementation of international agreements related to space development by establishing specific provisions under the Space Activities Act. It promotes private sector involvement in the exploration and development of space resources through a licensing framework and clarifies the rules governing ownership of such resources, in line with the principles outlined in the Basic Space Act.
Country: Japan
First Use Date: 2021
Status: Active
Document Reference Number: Act No. 83 of 2021
Most Recent Update: 2021
Type: Law

9.3.3 LPS03: Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (The Moon Agreement)

Description: These specific articles set out certain restrictions on activities on the Moon that may have an impact on the ISAM community if this treaty is adopted by a wider set of nations. The largest implications are on lunar surface construction which is a field in its early stages of development.
Country: Armenia, Australia, Austria, Belgium, Chile, Kazakhstan, Kuwait, Lebanon, Mexico, Morocco, Netherlands, Pakistan, Peru, Philippines, Saudi Arabia, Turkey, Uruguay, Venezuela
First Use Date: 1979
Status: Active
Document Reference Number: RES 34/68
Most Recent Update: 1984
Type: Treaty

9.3.4 LPS04: CFR Title 14 Chp. III - Subpart C - Licensing

Description: The provisions outlined in this section delineate the FAA's protocols and criteria governing the authorization and oversight pursuant to 51 U.S.C. subtitle V, chapter 509, of commercial space transportation endeavors conducted within the United States or by individuals holding U.S. citizenship. This regulatory framework primarily addresses the requisite procedures for obtaining authorization for launch and the operation of launch sites within U.S. territory, as well as for reentry and the operation of reentry sites within the country. It generally does not apply to activities that occur after launch ends and before reentry begins.
Country: United States
First Use Date: 2017
Status: Active
Document Reference Number: 14 CFR Chapter III
Most Recent Update: 2023
Type: Regulation

9.3.5 LPS05: CFR Title 47 Part 25 - Multiple Sections

Description: Part 25 is the FCC's all-encompassing space systems regulation that covers the licensing process for all space systems. Sections that are relevant to ISAM include 25.102, 25.109, 25.114, 25.118, 25.122, 25.124, 25.161, 25.202, 25.207, 25.208, 25.210, 25.272, 25.273, 25.279, 25.282, and 25.283. In general, 100 series sections relate to licensing requirements and 200 series sections outline technical regulations.
Country: United States
First Use Date: 2024
Status: Active
Document Reference Number: 47 CFR Part 25
Most Recent Update: 2024
Type: Regulation

9.3.6 LPS06: CONFERS Recommendations for Best Practices, Functional Requirements, and Norms for In-space Servicing, Assembly, and Manufacturing (ISAM) Power and Data Interfaces

Description: CONFERS Recommendations for Best Practices, Functional Requirements, and Norms for In-space Servicing, Assembly, and Manufacturing (ISAM) Power and Data Interfaces is a community consensus standard developed by the Consortium for Execution of Rendezvous and Servicing Operations (CONFERS). The standard outlines best practices for power and data interfaces between servicing spacecraft and client spacecraft during in-space servicing operations.
Country: International
First Use Date: TBD
Status: In Progress
Document Reference Number: AIAA S-XXX
Most Recent Update: 2024
Type: Standard

9.3.7 LPS07: CONFERS Recommendations for Best Practices, Functional Requirements, and Norms for Prepared Free-Flyer Capture and Release

Description: This document outlines optimal practices, functional prerequisites, and standards pertaining to the execution of prepared free-flyer capture and release operations between a Servicing Vehicle and a Client Space Object. It is essential to note that the scope of this document is limited to the capture operations specifically between a Servicing Vehicle and a Client Space Object, and it does not encompass procedures related to the capture of space debris or any other activities beyond this defined scope.
Country: International
First Use Date: TBD
Status: In Progress
Document Reference Number: AIAA S-158-202x
Most Recent Update: 2023
Type: Standard

9.3.8 LPS08: Convention on International Liability for Damage Caused by Space Objects (Space Liability Convention)

Description: The Convention on International Liability for Damage Caused by Space Objects, also known as the Space Liability Convention, is a treaty adopted by the General Assembly of the United Nations in 1972. The Space Liability Convention provides that a launching State shall be absolutely liable to pay compensation for damage caused by its space objects on the surface of the Earth or to aircraft, and liable for damage due to its faults in space. The Convention also provides for procedures for the settlement of claims for damages. Currently, 98 states have ratified the treaty.
Country: International
First Use Date: 1972
Status: Published
Document Reference Number: RES 2777
Most Recent Update: 1971
Type: Treaty

9.3.9 LPS09: Convention on Registration of Objects Launched into Outer Space (Space Registration Convention)

Description: The Convention on Registration of Objects Launched into Outer Space is a treaty adopted by the General Assembly of the United Nations in 1974. The treaty requires State parties to supply the UN with information about objects launched into space, including the date and location of launch, orbital parameters, and function of the spacecraft. There are currently 72 states which participate with the treaty.
Country: International
First Use Date: 1974
Status: Active
Document Reference Number: RES 3235
Most Recent Update: 1974
Type: Treaty

9.3.10 LPS10: Deregulation Act 2015

Description: The UK's Deregulation Act 2015 amends the 1986 Outer Space Act to provide more flexible licensing for space activities, individualized insurance requirements, and potential limits on liability for UK operators. These changes aim to reduce regulatory burden on and encourage private sector investment in the UK space industry.
Country: United Kingdom
First Use Date: 2015
Status: Active
Document Reference Number: 2015 c. 20
Most Recent Update: 2015
Type: Law

9.3.11 LPS11: ESA Space Debris Mitigation Requirements

Description: Also referred to as the Space Debris Mitigation Standard, this document specifies design and operational measures for spacecraft to mitigate debris. It includes sections for re-entry/design for demise, service interfaces, and other aspects of spacecraft design and mission operations.
Country: ESA
First Use Date: 2023
Status: Published
Document Reference Number: ESSB-ST-U-007
Most Recent Update: 2023
Type: Standard

9.3.12 LPS12: ESA Zero Debris Charter

Description: ESA launched a campaign in 2022 to look at creating goals related to mitigating space debris, resulting in a Zero Debris Charter - a non-binding, resolution-style document detailing high priority targets to hit by 2050, as well as a Zero Debris Approach highlighting 8 recommendations for mitigating space debris, and most recently a Zero Debris Technical Booklet. Although the Charter itself is brief, the Zero Debris Technical Booklet provides more details related to the technologies and concepts which align with the Charter.
Country: ESA
First Use Date: 2023
Status: Published
Most Recent Update: 2023
Type: Policy

9.3.13 LPS13: Guide for Berthing/Docking/Grasping Interfaces for Serviceable Spacecraft

Description: This document provides guidance for the design of space-based grasping, berthing, and docking interface mechanisms with the intent of achieving commonality for future missions. The designs presented are based on past missions from Gemini to the Space Shuttle.
Country: United States
First Use Date: 1992
Status: Published
Document Reference Number: AIAA G-056-1992
Most Recent Update: 1992
Type: Standard

9.3.14 LPS14: Guide for Utility Connector Interfaces for Serviceable Spacecraft

Description: This guide provides technical information for the development of spacecraft utility connectors. The utility connectors provide pass through of utilities such as power, fluids, and communications and are designed for engagement by humans, robotic systems, or autonomous systems.
Country: United States
First Use Date: 1995
Status: Published
Document Reference Number: AIAA G-072-1995
Most Recent Update: 1995
Type: Standard

9.3.15 LPS15: Guide to Design for On-Orbit Spacecraft Servicing

Description: This guide for on-orbit spacecraft servicing discusses several topics such as clearances, fasteners and attachment systems, mounting and locating, consumables, and serviceability checklists. The hardware guidelines are intended for on-orbit servicing operations performed by EVA or by telerobotic manipulators.
Country: United States
First Use Date: 1991
Status: Published
Document Reference Number: AIAA G-042-1991
Most Recent Update: 1991
Type: Standard

9.3.16 LPS16: Guidelines on a License to Operate a Spacecraft Performing On-Orbit Servicing

Description: This policy provides a set of on-orbit servicing specific supplementary requirements, guidelines, and sample measures for conforming with licensing requirements and regulatory obligations.
Country: Japan
First Use Date: 2021
Status: Active
Most Recent Update: 2021
Type: Policy

9.3.17 LPS17: IEEE Standard Ontologies for Robotics and Automation
Description: This standard specifies the primary concepts, relations, and axioms of robotics and automation (R&A). The standard intends to serve as a reference for robotic theory and common vocabulary to be used within the technology area.
Country: United States
First Use Date: 2015
Status: Published
Document Reference Number: IEEE 1872-2015
Most Recent Update: 2015
Type: Standard

9.3.18 LPS18: In-Space Storable Fluid Transfer for Prepared Spacecraft
Description: The In-Space Storable Fluid Transfer for Prepared Spacecraft AIAA standard is an industry consensus standard developed by the Consortium for Execution of Rendezvous and Servicing Operations (CONFERS). This document outlines the optimal methodologies and criteria for designing, verifying, and operating "prepared" in-space storable fluid transfer systems and interfaces.
Country: International
First Use Date: 2025
Status: Published
Document Reference Number: AIAA S-157-2025
Most Recent Update: 2025
Type: Standard

9.3.19 LPS19: International Docking System Standard Interface Definition Document (IDSS IDD)
Description: A standardized docking interface facilitates collaborative initiatives among the global spacefaring community, while also providing essential support for potential crew rescue missions. The IDSS was developed collaboratively by ISS partners and was initially established in 2010.
Country: International
First Use Date: 2022
Status: Published
Document Reference Number: IDSS IDD Revision F
Most Recent Update: 2022
Type: Standard

9.3.20 LPS20: International External Robotic Interface Interoperability Standards (IERIIS)
Description: This document standardizes mounting interfaces designed to facilitate on-orbit robotic operations and collaborative missions involving various spacecraft and equipment. The standard interfaces are compatible with robotic systems, particularly in deep space environments.
Country: International
First Use Date: 2019
Status: Published
Most Recent Update: 2019
Type: Standard

9.3.21 LPS21: International Rendezvous System Interoperability Standards (IRSIS)

Description: This standard establishes fundamental design parameters to enable developers to independently create compatible rendezvous operations. This standardization will enable the interoperability of various spacecraft in cislunar and deep space environments for human exploration missions.
Country: United States
First Use Date: 2019
Status: Published
Most Recent Update: 2019
Type: Standard

9.3.22 LPS22: Introduction to U.S. Export Controls for the Commercial Space Industry

Description: This guidebook serves as an introductory resource for commercial space organizations looking to enter the international market. It offers fundamental information to assist in the initial stages of preparing for the export control process.
Country: United States
First Use Date: 2017
Status: Published
Most Recent Update: 2017
Type: Overview

9.3.23 LPS23: Law of July 20th 2017 on the Exploration and Use of Space Resources

Description: This Luxembourg law outlines the legal manner in which the exploration and utilization of space resources may proceed.
Country: Luxembourg
First Use Date: 2017
Status: Active
Most Recent Update: 2017
Type: Law

9.3.24 LPS24: Licensing of Private Remote Sensing Space Systems

Description: This rule by the Department of Commerce (Commerce), through the National Oceanic and Atmospheric Administration (NOAA), revises the licensing of private remote sensing space systems under the Land Remote Sensing Policy Act of 1992. NOAA's existing regulations implementing the Act were last updated in 2006. These revisions to the regulations were written in order to reflect significant changes in the space-based remote sensing industry since that time and to modernize its regulatory approach.
Country: United States
First Use Date: 2020
Status: Active
Document Reference Number: 15 CFR 960
Most Recent Update: 2020
Type: Regulation

9.3.25 LPS25: LunaNet Interoperability Specification Version 4 - Section 3.2 Position, Navigation, and Timing Services

Description: This document specifies the essential standard services and interfaces accessible to lunar users. It ensures that users can design their systems with the confidence that these services and interfaces will be provided by available vendors.
Country: International
First Use Date: 2022
Status: Published
Document Reference Number: NASA TP 20210021073/Rev.4
Most Recent Update: 2022
Type: Standard

9.3.26 LPS26: Manipulating industrial robots Mechanical interfaces Part 1: Plates

Description: This document outlines the primary dimensions, designation, and marking specifications for a circular plate serving as a mechanical interface. It does not define other requirements, nor does it contain any correlation of load-carrying changes.
Country: International
First Use Date: 2004
Status: Published
Document Reference Number: ISO 9409-1:2004
Most Recent Update: 2004
Type: Standard

9.3.27 LPS27: Memorandum on Space Policy Directive-5—Cybersecurity Principles for Space Systems

Description: This policy document introduces the United States Government's cybersecurity principles dedicated to space systems, including techniques to mitigate cyber-risks to spacecraft and associated terrestrial infrastructure.
Country: United States
First Use Date: 2020
Status: Active
Most Recent Update: 2020
Type: Policy

9.3.28 LPS28: NTIA Manual of Regulations and Procedures for Federal Radio Frequency Management

Description: The NTIA Manual of Regulations and Procedures for Federal Radio Frequency Management, or NTIA Redbook, is a regulatory document which outlines the use of radio frequency by the US government. ISAM relevant sections of this regulation include 5.6 Space Services, 7.7 Use of Frequencies by Manned Spacecraft, 8.2.15 Referral of applications related to the Space Service, 8.2.32 Control of Emissions from space, 10.8.2 Required data for space systems, and Annex B Data and procedures for assessing interactions among stations in the space and terrestrial services.
Country: United States
First Use Date: 2023
Status: Active
Most Recent Update: 2023
Type: Regulation

9.3.29 LPS29: Outer Space and High-Altitude Activities Act 2017

Description: The Outer Space and High-Altitude Activities Act of 2017 establishes New Zealand's legal framework for space activities. The law includes information regarding permits, licenses, and policy enforcement.
Country: New Zealand
First Use Date: 2017
Status: Active
Document Reference Number: Public Act 2017 No 209
Most Recent Update: 2017
Type: Law

9.3.30 LPS30: Regulation establishing the Union Space Programme and the European Union Agency for the Space Programme and repealing Regulations (EU) No 912/2010, (EU) No 1285/2013 and (EU) No 377/2014 and Decision No 541/2014/EU

Description: This regulation establishes the Union Space Programme and the European Union Agency for the Space Programme. Outlines the main objectives for the EU space program, the governance over the program, funding, and participation in the Space Surveillance and Tracking Partnership. This has implications in ISAM as it will influence how the EU participates in the Artemis Program and ISAM system development in general.
Country: European Union
First Use Date: 2018
Status: Active
Document Reference Number: Document 52018PC0447
Most Recent Update: 2021
Type: Regulation

9.3.31 LPS31: Regulation for Enforcement of the Act concerning the Launch and Control of Satellites

Description: This regulation encompasses nearly all aspects of space regulations in Japan. Relevant articles include Article 5 (Application for Permission for Launch of Satellites, etc.), Article 7 (Rocket Safety Standards), Article 8 (Facility Safety Standards by Type), Article 13 (Application for Type Approval of Design of Rocket for Launching Satellites, etc.), Article 14 (Application for Change of Design, etc.), Article 16 (Application for Certification of Conformity of Launch Facility, etc.), Article 19 (Special Provisions for Application Procedures by the Japan Aerospace Exploration Agency), Article 20 (Application for Permission for Management of Artificial Satellites, etc.), Article 22 (Standards for Structure of Satellites), and Article 23 (Measures Concerning the Management of Artificial Satellites).
Country: Japan
First Use Date: 2017
Status: Active
Document Reference Number: Cabinet Office Order No. 50 of November 15, 2017
Most Recent Update: 2019
Type: Regulation

9.3.32 LPS32: Rendezvous and Proximity Operations (RPO) and On Orbit Servicing (OOS) – Spacecraft Fiducial Markers

Description: Rendezvous and Proximity Operations (RPO) and On Orbit Servicing (OOS) – Spacecraft Fiducial Markers is a community consensus standard developed by the Consortium for Execution of Rendezvous and Servicing Operations (CONFERS). The standard outlines requirements for fiducial markers used in activities such as RPO, capture, and servicing of spacecraft.
Country: International
First Use Date: TBD
Status: In Progress
Document Reference Number: AIAA S-155-202X
Most Recent Update: 2024
Type: Standard

9.3.33 LPS33: Schematic Overview of National Regulatory Framework For Space Activities

Description: This document, published by the United Nations Committee on the Peaceful Uses of Outer Space, provides an overview of outer space affairs regulatory frameworks by nation. The overview began development in 2009 and was finally published in 2013. Since then, four new overviews have been published, in addition to one addendum for the original 2012 release.
Country: International
First Use Date: 2024
Status: Published
Document Reference Number: A/AC.105/C.2/2024/CRP.10
Most Recent Update: 2024
Type: Overview

9.3.34 LPS34: Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space (Space Debris Mitigation Guidelines - UNCOPUOS)

Description: The Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space is a collection of voluntary consensus guidelines endorsed by the General Assembly of the United Nations. The guidelines include measures which may be taken to avoid the generation of additional space debris during future missions.
Country: International
First Use Date: 2007
Status: Published
Most Recent Update: 2010
Type: Standard

9.3.35 LPS35: Space Industry Act 2018

Description: This legislation is aimed at promoting and regulating the United Kingdom's growing space industry. The act specifically establishes regulatory elements pertaining to: "space activities," "sub-orbital activities," and "associated activities" carried out within the United Kingdom. In addition, it grants the UK Civil Aviation Authority (CAA) new responsibilities and powers to regulate commercial spaceflight activities, positioning the CAA as a central regulatory body for the UK's space industry.
Country: United Kingdom
First Use Date: 2018
Status: Published
Document Reference Number: 2018 c. 5
Most Recent Update: 2018
Type: Law

9.3.36 LPS36: Space systems - Part 5: Determination of reactivity of system/component materials with aerospace propellants Safety and compatibility of materials

Description: This standard outlines test equipment and techniques for identifying interactions between materials and aerospace fluids. It applies to determining reactions between propellants and materials used in propellant storage, transfer, and flight systems.
Country: International
First Use Date: 2023
Status: Published
Document Reference Number: ISO 14624-5:2023
Most Recent Update: 2023
Type: Standard

9.3.37 LPS37: Space Systems - Rendezvous And Proximity Operations (RPO) And On Orbit Servicing (OOS) - Programmatic Principles And Practices

Description: This standard outlines safe practices for rendezvous and proximity operations (RPO) and on-orbit servicing (OOS) in order to encourage proliferation. This is intended to be the predominate standard for RPO and OOS space systems.
Country: International
First Use Date: 2022
Status: Published
Document Reference Number: ISO 24330:2022
Most Recent Update: 2022
Type: Standard

9.3.38 LPS38: Space Systems - Structural Components and Assemblies

Description: This document establishes standards for the spacecraft structures, ranging from design and material selection to inspection techniques. This standard applies to a wide range of structures, including subsystem structures, spacecraft structures, and launch vehicle structures.
Country: International
First Use Date: 2011
Status: Published
Document Reference Number: ISO 10786:2011
Most Recent Update: 2011
Type: Standard

9.3.39 LPS39: Space Systems - Structures, Structural Components, and Structural Assemblies

Description: This document sets a standard for the design, analysis, material selection, fabrication, testing, and inspection of structural components in space systems, including payloads, spacecraft, upper stages, and launch vehicles.
Country: United States
First Use Date: 2005
Status: Published
Document Reference Number: AIAA S-110-2005
Most Recent Update: 2005
Type: Standard

9.3.40 LPS40: Standard Vocabulary for Space Automation and Robotics

Description: This standard defines over 200 terms which are used in the field of automation and robotic systems with the intent to provide common definitions to be used within the field.
Country: United States
First Use Date: 1995
Status: Published
Document Reference Number: AIAA S-066-1995
Most Recent Update: 1995
Type: Standard

9.3.41 LPS41: The Artemis Accords

Description: Established in 2020, the Artemis Accords seeks to enshrine a set of common principles for the civil use and exploration of outer space. Section 10 outlines the limitations concerning space resources which has implications on the lunar surface construction aspect of ISAM. Additionally, Section 11 outlines how to handle deconfliction of activities, setting up of safety zones, as well as notification and coordination of activities.
Country: Argentina, Australia, Bahrain, Brazil, Canada, Colombia, Czech Republic, Ecuador, France, Germany, Iceland, India, Israel, Italy, Japan, Luxembourg, Mexico, Netherlands, New Zealand, Nigeria, Poland, South Korea, Romania, Rwanda, Senegal, Singapore, Spain, Saudi Arabia, Ukraine, United Arab Emirates, United Kingdom, United States, Isle of Man
First Use Date: 2020
Status: Active
Most Recent Update: 2020
Type: Policy

9.3.42 LPS42: The Outer Space Act 1986

Description: This act provides the United Kingdom's policy and regulation for launching or procuring the launch of a space object, operating a space object, and any activity in outer space by any person connected with the country.
Country: United Kingdom
First Use Date: 1986
Status: Active
Document Reference Number: 1986 c. 38
Most Recent Update: 1986
Type: Law

9.3.43 LPS43: Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (The Outer Space Treaty)

Description: Serving as the foundational legal framework governing international space activities, the Outer Space Treaty establishes the peaceful methods by which space as a domain may be utilized and explored. Article VI states that State Parties to the Treaty shall bear international responsibility for national activities in space, whether such activities are carried on by governmental agencies or non-governmental entities. This encompasses all ISAM activities and is relevant to highlight to all participants of the ISAM community. Article XI requires states participating in the treaty to inform the Secretary-General of the UN as well as the public and international community of the nature, conduct, and results of all space activities.
Country: Afghanistan, Algeria, Antigua and Barbuda, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahamas, Bahrain, Bangladesh, Barbados, Belarus, Belgium, Benin, Bosnia and Herzegovina, Brazil, Bulgaria, Burkina Faso, Canada, Chile, China, Croatia, Cuba, Cyprus, Czech Republic, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Estonia, Fiji, Finland, France, Germany, Greece, Guinea-Bissau, Hungary, Iceland, India, Indonesia, Iraq, Ireland, Israel, Italy, Jamaica, Japan, Kazakhstan, Kenya, North Korea, South Korea, Kuwait, Laos, Lebanon, Libya, Lithuania, Luxembourg, Madagascar, Mali, Malta, Mauritius, Mexico, Mongolia, Morocco, Myanmar, Nepal, Netherlands, New Zealand, Nicaragua, Niger, Nigeria, Norway, Oman, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Poland, Portugal, Qatar, Romania, Russia, Saint Vincent and the Grenadines, San Marino, Saudi Arabia, Seychelles, Sierra Leone, Singapore, Slovakia, Slovenia, South Africa, Spain, Sri Lanka, Sweden, Switzerland, Syria, Thailand, Togo, Tonga, Tunisia, Turkey, Uganda, Ukraine, United Arab Emirates, United Kingdom, United States, Uruguay, Venezuela, Vietnam, Yemen, Zambia
First Use Date: 1966
Status: Active
Document Reference Number: RES 2222 (XXI)
Most Recent Update: 1967
Type: Treaty

9.3.44 LPS44: US Commercial Remote Sensing Policy

Description: This policy applies to various facets of U.S. commercial remote sensing space capabilities. It provides direction on the licensing and operational protocols governing U.S. commercial remote sensing space systems. Additionally, it delineates guidelines for the utilization of these capabilities by the United States Government and outlines procedures for foreign entities seeking access to them. Moreover, the policy addresses government-to-government interactions concerning intelligence, defense, and foreign policy matters, specifically focusing on U.S. commercial remote sensing space capabilities.
Country: United States
First Use Date: 2003
Status: Active
Most Recent Update: 2003
Type: Policy

9.3.45 LPS45: US National Space Policy December 2020

Description: This document details the making of space policy through the legislative process and the implementation of that policy in the United States' civilian and military space programs through regulatory agencies.
Country: United States
First Use Date: 2020
Status: Active
Most Recent Update: 2020
Type: Policy

10 Appendix – ISAM Developers

This appendix contains more information on the developers identified in the document. Information for each developer includes a Description, Country where the team is headquartered, Type (industry, government, or academia), Year Founded, the URL for the developer's website, and the State of Play entries that the developer has contributed to.

10.1 AI SpaceFactory

Description: AI SpaceFactory is a construction technology company specializing in the design and construction of habitats on planetary bodies. It develops advanced construction technologies for space exploration using autonomous robotics and sustainable materials.
Country: United States
Type: Industry
Year Founded: 2017
URL: https://www.aispacefactory.com/
State of Play Entries: SI18

10.2 Air Force Research Laboratory (AFRL)

Description: The Air Force Research Laboratory (ARFL) is a government research laboratory performing research and development for the U.S. Air Force and the U.S. Space Force. Its main purpose is to develop and deliver warfighting technologies to the U.S air, space, and cyberspace forces by conducting cutting-edge research in various areas of science and technology, including aerospace systems, robotics, directed energy, communication systems, artificial intelligence, and materials science.
Country: United States
Type: Government
Year Founded: 1997
URL: https://www.afrl.af.mil/
State of Play Entries: RCDM013, RCDM030, RCDM031, RCDM062, IM03, IM08, IM09, IM15, SA03

10.3 Airbus

Description: Airbus is a European aerospace company with a long history of technology development for the aviation and space industries. Airbus currently supports space exploration through collaborations with NASA, ESA, and other organizations. Technology developed by Airbus is currently used on the International Space Station, as well as many spacecraft and in-space telescopes.
Country: Netherlands, France
Type: Industry
Year Founded: 1970
URL: https://www.airbus.com/en
State of Play Entries: RM12, RCDM007, RCDM084, PRMUI03, PGM06, IM22

10.4 Altius Space Machines Inc

Description: Altius Space Machines is a space technology company specializing in satellite servicing, satellite end-of-life services, and orbital debris mitigation technologies. Its scope of operations encompasses rendezvous and capture devices, spacecraft mechanisms, in-space propellant transfer, and other satellite servicing technologies. Altius Space Machines is a subsidiary company of Voyager Space Holdings.
Country: United States
Type: Industry
Year Founded: 2010
URL: https://voyagertechnologies.com/company/
State of Play Entries: RCDM023, RCDM055, URMUI02

10.5 Ananth Technologies

Description: Tasked with supporting the development of the Indian aerospace economy, Ananth technologies was founded in 1992. Working alongside clients such as the Indian Space Research Organisation (ISRO), Ananth Technologies provides services throughout the product lifecycle, including design, development, manufacturing, test, and more.
Country: India
Type: Industry
Year Founded: 1992
URL: https://ananthtech.com/
State of Play Entries: RCDM096

10.6 Apech Labs

Description: Apech Labs, headquartered at the University of Buffalo Incubator @ Baird, is a technology company specializing in advanced mechatronics solutions across the aerospace, defense, space, and energy industries.
Country: United States
Type: Industry
Year Founded: 2020
URL: https://www.apechlabs.com
State of Play Entries: RCDM051

10.7 Apsidal

Description: Apsidal is a computing and manufacturing technology company focused on photonics and quantum information solutions. Its developments include AI-enhanced photonics manufacturing processes and optical technologies for quantum applications.
Country: United States
Type: Industry
Year Founded: 2019
URL: http://apsidal.net/
State of Play Entries: PGM05, PGM21

10.8 Astrolab

Description: Astrolab is a space technology company with headquarters in Hawthorne, California. The company is focused on development and production of their FLEX rovers, which will transport logistics and crew across other planetary or lunar surfaces.
Country: United States
Type: Industry
Year Founded: 2019
URL: https://www.astrolab.space/
State of Play Entries: RM14, SI07

10.9 Astroscale

Description: Astroscale is a space technology company specializing in on-orbit servicing and mitigation of space debris. It develops and deploys technologies and spacecraft to perform life extension, end-of-life disposal, and active debris removal.
Country: Japan
Type: Industry
Year Founded: 2013
URL: https://astroscale.com/
State of Play Entries: RCDM001, RCDM010, RCDM011, RCDM017, RCDM025, RCDM026, RCDM049, RCDM052, R03, R07, R08, R15, RFT02, RFT22, IM01

10.10 Atomos Space

Description: Atomos Space, based out of Broomfield, Colorado, is a small US space logistics, transportation, and RPOC focused company, providing orbital transfer services for satellites and spacecraft. In 2025, Atomos was acquired by Katalyst Space Technologies.
Country: United States
Type: Industry
Year Founded: 2018
URL: https://www.atomosspace.com
State of Play Entries: RCDM059, RCDM079, R17, R24, RFT24, RFT36

10.11 Aurelia Institute

Description: The Aurelia Institute is a research & development institute focused on in-space architecture, space policy, and outreach. Their space architecture research revolves around Tessellated Electromagnetic Space Structures for the Exploration of Reconfigurable, Adaptive Environments (TESSERAE) modular habitation tiles, meant to be used as self-assembling building blocks for future habitation systems.
Country: United States
Type: Industry
Year Founded: 2021
URL: https://aureliainstitute.org
State of Play Entries: SMA42

10.12 AVS

Description: Added Value Solutions (AVS) is a research and technology organization founded in 2006. It develops solutions for several sectors including space, energy, and physics.
Country: Spain
Type: Industry
Year Founded: 2006
URL: https://www.a-v-s.es/areas/space
State of Play Entries: RCDM017, RCDM056, R03

10.13 Blue Origin

Description: Blue Origin is an American aerospace manufacturer and spaceflight services company. It focuses on developing technologies for reusable rocket systems and has made strides in commercial space travel with its New Shepard and New Glenn rockets.
Country: United States
Type: Industry
Year Founded: 2000
URL: https://www.blueorigin.com/
State of Play Entries: R02, PGM04, SI05

10.14 Busek Co. Inc

Description: Busek Co. Inc. is a space propulsion technology company specializing in the design and development of electric propulsion systems. Busek designs and develops Hall thrusters, electrospray thrusters, and ion thrusters for applications including satellite station keeping, orbit transfers, and interplanetary missions.
Country: United States
Type: Industry
Year Founded: 1985
URL: https://www.busek.com/
State of Play Entries: RCDM097, PRMUI36, IM30, IM31

10.15 Caltech

Description: The California Institute of Technology (Caltech) is a research university in southern California that was founded in 1891. Caltech is focused on science and engineering research, having notable contributions to the aerospace industry through managing organizations like the NASA Jet Propulsion Laboratory.
Country: United States
Type: Academia
Year Founded: 1891
URL: https://www.caltech.edu/
State of Play Entries: SMA07

10.16 Canadian Space Agency (CSA)

Description: The Canadian Space Agency (CSA) is the national space agency of Canada. Its main purpose is to advance the knowledge of space through science and ensure social and economic benefits for Canadians. It has developed several robotic manipulation systems to support human exploration.
Country: Canada
Type: Government
Year Founded: 1989
URL: https://www.asc-csa.gc.ca/eng/
State of Play Entries: RM04, RM05, RM06, RM10, RCDM039, RCDM050, RCDM058, RCDM069, PRMUI13, PRMUI23, PRMUI28, PRMUI29, PRMUI30

10.17 Champaign-Urbana Aerospace

Description: Champaign-Urbana Aerospace is an Illinois-based aerospace company providing a range of space software and hardware products. It leverages its long-term partnership with the University of Illinois Urbana-Champaign to conduct research and development activities in the aerospace industry.
Country: United States
Type: Industry
Year Founded: 1998
URL: https://cuaerospace.com/
State of Play Entries: RCDM037, PRMUI12

10.18 Chase Defense Partners

Description: Chase Defense Partners is an aerospace company based out of Hampton, Virginia. Operating since 2000, the company has experience in business development and sales as well as engineering and manufacturing.
Country: United States
Type: Industry
Year Founded: 2000
URL: https://www.chasedefense.com/
State of Play Entries: RFT18

10.19 China Academy of Space Technology (CAST)

Description: The China Academy of Space Technology (CAST), headquartered in Haidian District, Beijing, and employing over 10,000 people, is a spacecraft development organization within the China Aerospace Science and Technology Corporation (CASC).
Country: China
Type: Government
Year Founded: 1968
URL: https://www.cast.cn/english
State of Play Entries: RM08, RM13, RCDM090, RCDM091, RCDM092, R27

10.20 CisLunar Industries

Description: CisLunar Industries, headquartered in Loveland, Colorado, is a space technology company focused on developing sustainable solutions for in-space manufacturing and resource utilization.
Country: United States
Type: Industry
Year Founded: 2017
URL: https://www.cislunarindustries.com/
State of Play Entries: RRR02

10.21 ClearSpace

Description: ClearSpace, headquartered in Renens, Vaud, Switzerland, is a Swiss-based company focused on space debris removal and in-orbit servicing technologies.
Country: Switzerland
Type: Industry
Year Founded: 2018
URL: https://clearspace.today/
State of Play Entries: RCDM018, R05

10.22 Composites Automation LLC

Description: Composites Automation LLC is a composite manufacturing technology company specializing in novel composite manufacturing materials, design, and processes. Its scope of developments includes unique composite processing, analytical, and finite element design capabilities.
Country: United States
Type: Industry
Year Founded: 2001
URL: https://www.compositesautomationllc.com/
State of Play Entries: RRR06

10.23 Cornerstone Research Group (CRG)

Description: Cornerstone Research Group (CRG) is an aerospace and defense firm providing research and development of advanced materials and technology solutions for various industries including aerospace, defense, energy, and transportation.
Country: United States
Type: Industry
Year Founded: 1997
URL: https://www.crgrp.com/
State of Play Entries: RRR04, RRR07

10.24 Dawn Aerospace

Description: Dawn Aerospace is a space industry company that focuses on implementing opportunities in the space habitat for terrestrial life through improvising space transportation. It focuses on a scalable and sustainable processes to deliver Earth-to-Orbit Logistics to an In-Space environment.
Country: Netherlands/New Zealand
Type: Industry
Year Founded: 2017
URL: https://www.dawnaerospace.com/
State of Play Entries: RCDM022, PRMUI06, RFT07

10.25 DeepMind Technologies Limited

Description: DeepMind Technologies Limited is a British-American artificial intelligence research laboratory which serves as a subsidiary of Google. Founded in the UK in 2010, it was acquired by Google in 2014. The company is based in London, with research centers in Canada, France, Germany, and the United States.
Country: United States, United Kingdom
Type: Industry
Year Founded: 2010
URL: https://deepmind.google/
State of Play Entries: SA15

10.26 Defense Advanced Research Projects Agency (DARPA)

Description: The Defense Advanced Research Projects Agency (DARPA) is a research and development agency of the U.S. Department of Defense tasked with the development of new technologies for use by the military. Its main purpose is to make investments in breakthrough technologies for national security, including autonomous vehicles, stealth technology, directed energy, artificial intelligence, robotics, and other domains.
Country: United States
Type: Government
Year Founded: 1958
URL: https://www.darpa.mil/
State of Play Entries: RM15, RM31, RM35, RCDM066, RCDM083, PRMUI27, RFT31, SMA07, SMA47, IM17

10.27 Defense Innovation Unit (DIU)

Description: Defense Innovation Unit (DIU) is an organization within the U.S. Department of Defense focused on accelerating the adoption of commercial technologies to address national security challenges.
Country: United States
Type: Government
Year Founded: 2015
URL: https://www.diu.mil/
State of Play Entries: R02

10.28 D-Orbit

Description: D-Orbit is an aerospace company specializing in orbital transportation and space logistics. Its scope of operations includes orbital transportation and end-of-mission disposal. Its developments include mission control software, space cloud computing, and an orbital transfer vehicle.
Country: Italy
Type: Industry
Year Founded: 2011
URL: https://www.dorbit.space/
State of Play Entries: RCDM086, R14, R25

10.29 DSTAR Communications Inc

Description: DSTAR Communications Inc is an optical materials technology company. Its developments include biomedical photonics technologies for life sciences, integrated laser subsystems, and an external material processing platform on the International Space Station with autonomous, high throughput manufacturing capability.
Country: United States
Type: Industry
Year Founded: 2018
URL: https://dstarcom.com/
State of Play Entries: PGM07

10.30 Enduralock

Description: With its origins in its founders' medical technology research, Enduralock is a small space infrastructure company based out of Lenexa, Kansas, specializing in providing advanced fastening solutions, with focus primarily on the automotive and aerospace industries.
Country: United States
Type: Industry
Year Founded: 2006
URL: https://enduralock.com/
State of Play Entries: RCDM027, PRMUI07, RFT09, SMA11, SMA34

10.31 Eta Space

Description: Eta Space is an aerospace company specializing in technology for cryogenic fluid management and chemical propulsion systems. The company is currently developing technologies related to refrigeration and storage, liquid hydrogen testing, in-space propellant depots, cryocooler development, zero loss propellant storage and transfer, and ISRU and cryogenic liquefaction.
Country: United States
Type: Industry
Year Founded: 2019
URL: https://etaspace.com/
State of Play Entries: RFT23

10.32 European Commission (EC)

Description: The European Commission (EC) is the primary executive branch of the European Union (EU). It is responsible for space policy decisions regarding the EU, as well as funding several flagship European space missions. It shares common goals with the European Space Agency (ESA), although their membership differs slightly.
Country: European Union
Type: Government
Year Founded: 1958
URL: https://commission.europa.eu/index_en
https://commission.europa.eu/topics/space_en
State of Play Entries: RCDM029, RCDM099, PRMUI37, RFT10, IM07

10.33 European Space Agency (ESA)

Description: The European Space Agency (ESA) is an intergovernmental space organization with a mission to shape the development of Europe's space capability and ensure that investment in space continues to deliver benefits to the citizens of Europe and the world. The agency's work is focused on implementing European space policy, enacting activities and programs in the space field, and coordinating the European space program, national programs, and industry activities.
Country: Multinational
Type: Government
Year Founded: 1975
URL: https://www.esa.int/
State of Play Entries: RM12, RCDM008, RCDM017, RCDM047, RCDM056, RCDM077, RCDM086, R03, R25, PRMUI21, RFT11, RFT34, SMA12, PGM06, LPS11, LPS12

10.34 Exotrail

Description: Exotrail is an end-to-end space mobility operator with a mission to deliver mobility solutions for an efficient and sustainable space.
Country: France
Type: Industry
Year Founded: 2017
URL: https://www.exotrail.com/
State of Play Entries: R28

10.35 Firefly Aerospace

Description: Firefly Aerospace is an aerospace company specializing in the launch, landing, and in-space operation of space systems. Its current developments include the production of small-lift launch vehicles, the design and deployment of lunar landers, and the operation of surface mobility vehicles.
Country: United States
Type: Industry
Year Founded: 2017
URL: https://fireflyspace.com/
State of Play Entries: RCDM024, RCDM109, R06, IM06

10.36 Flawless Photonics

Description: Flawless Photonics is a telecommunications company centered around the manufacturing of ZBLAN, a fluoride glass used in creating advanced optical fibers. Flawless Photonics specializes in manufacturing and purification processes to enable large-scale ZBLAN production.
Country: United States
Type: Industry
Year Founded: 2017
URL: https://www.flawless-photonics.com/
State of Play Entries: PGM08

10.37 Flight Works Inc

Description: Flight Works Inc. is a California-based aerospace company with experience in space mobility, electronics, pumps, and valves. Current developments include modular green propulsion technologies, small satellite pump-fed propulsion systems, and space-grade motion controllers.
Country: United States
Type: Industry
Year Founded: 2002
URL: https://www.flightworksinc.com/
State of Play Entries: RFT16, RFT17, RFT35

10.38 FOMS Inc

Description: FOMS Inc, or Fiber Optic Manufacturing in Space Inc, is a space technology company focused on the in-space manufacturing of optical fibers. FOMS is currently developing equipment for the fabrication of specialty optical fibers on the International Space Station.
Country: United States
Type: Industry
Year Founded: 2019
URL: https://fomsinc.com/
State of Play Entries: PGM07, PGM19

10.39 General Motors

Description: General Motors is a multinational automotive manufacturing company specializing in automobiles and trucks, automotive components, and engines. Its space-related developments include robotic manipulation systems.
Country: United States
Type: Industry
Year Founded: 1908
URL: https://www.gm.com/
State of Play Entries: RM36

10.40 German Space Agency (DLR)

Description: The German Space Agency at the German Aerospace Center (DLR), (formerly DLR Space Administration) is the national space agency of Germany. Its main purpose is the planning and implementation of the German national space program and the management of Germany's contributions to the European Space Agency (ESA) and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT).
Country: Germany
Type: Government
Year Founded: 1969
URL: https://www.dlr.de/en
State of Play Entries: RM07, RCDM014, RCDM046, PRMUI20

10.41 GITAI

Description: GITAI is a robotics company specializing in the design and development of robotic systems for space construction and maintenance applications. Its systems support teleoperability and autonomous robotic manipulation and its developments include lunar rovers and robotic manipulators for satellite, terrestrial, and space station applications.
Country: United States
Type: Industry
Year Founded: 2016
URL: https://gitai.tech/
State of Play Entries: RM16, RM17, RM39, RM40, RM41, PRMUI11, PRMUI22, SMA16, SMA19, SMA24, SI13, SI14

10.42 GMV

Description: GMV is a technology company founded in 1984 that provides services to a variety of different sectors. Acting as both a consultant and a developer, GMV produces solutions for the defense and space sectors as well as healthcare and cybersecurity.
Country: Spain
Type: Industry
Year Founded: 1984
URL: https://www.gmv.com/en
State of Play Entries: RCDM008, RCDM017, RCDM056, R03

10.43 Harbin Institute of Technology (HIT)

Description: The Harbin Institute of Technology is a public science and engineering university in Harbin, Heilongjiang, China. It is now affiliated with the Ministry of Industry and Information Technology. The university has two satellite campuses in Shenzhen, Guangdong (as Harbin Institute of Technology, Shenzhen) and in Weihai, Shandong (as Harbin Institute of Technology, Weihai). Harbin Institute of Technology offers 73 undergraduate degree programs, 143 master programs, and 81 doctorate programs, mainly focused on science and engineering.
Country: China
Type: Academia
Year Founded: 1920
State of Play Entries: RM08, RM13, RM48

10.44 iBOSS

Description: iBOSS was formed in 2017 to produce commercially available products and services related to iBOSS technologies developed under a partnership between several German institutions. The company is focused on development and applications of the iSSl modular coupling kit.
Country: Germany
Type: Industry
Year Founded: 2017
URL: https://www.iboss.space/
State of Play Entries: RCDM046, PRMUI20

10.45 ICON

Description: ICON is an architecture and construction technology company specializing in 3D printing and advanced materials. Its developments include the design of 3D printed space habitats to support the future exploration of the Moon and lunar surface construction technologies.
Country: United States
Type: Industry
Year Founded: 2017
URL: https://www.iconbuild.com/
State of Play Entries: SI15

10.46 Impulse Space

Description: Impulse Space is a start-up company founded by SpaceX veterans that focuses on in-space transportation for payload delivery and hosting.
Country: United States
Type: Industry
Year Founded: 2021
URL: https://www.impulsespace.com/
State of Play Entries: R16

10.47 Indian Space Research Organisation (ISRO)

Description: The Indian Space Research Organisation (ISRO) formed in 1969, replacing the Indian national Committee for Space Research (INCOSPAR). Missions developed and executed by ISRO have made India the fourth nation to successfully land on the Moon, as well as the fourth nation to accomplish successful space docking
Country: India
Type: Government
Year Founded: 1969
URL: https://www.isro.gov.in/
State of Play Entries: RCDM096, R04

10.48 Infinite Orbits

Description: Infinite Orbits, based out of Toulouse, Occitanie, France, specializes in on-orbit servicing via advanced satellite technology and space debris management.
Country: France
Type: Industry
Year Founded: 2020
URL: https://www.infiniteorbits.io/
State of Play Entries: RCDM067

10.49 ISS National Lab

Description: The ISS National Lab was formed when the U.S. portion of the International Space Station was appointed as a national laboratory in 2005. Since its inception, the ISS National Lab has leveraged its microgravity environment to conduct research in science, manufacturing, and technology development.
Country: United States
Type: Government
Year Founded: 2005
URL: https://issnationallab.org/
State of Play Entries: PGM19

10.50 Japan Aerospace Exploration Agency (JAXA)

Description: The Japan Aerospace Exploration Agency (JAXA) or National Research and Development Agency Aerospace Research and Development Organization is the Japanese national air and space agency. It is designated as a core performance agency to support the Japanese government's overall aerospace development and utilization. Its scope of operations includes integrated operations from basic research and development to utilization.
Country: Japan
Type: Government
Year Founded: 2003
URL: https://global.jaxa.jp/
State of Play Entries: RM19, RM20, RCDM001, IM01

10.51 Kall Morris Inc

Description: Kall Morris is an aerospace company focused on developing technologies for on-orbit satellite operations, particularly Rendezvous and Proximity Operations (RPO) and docking. The company has been awarded funding through SpaceWERX Orbital Prime and the USAF. The company is based in Marquette, Michigan.
Country: United States
Type: Industry
Year Founded: 2019
URL: https://www.kallmorris.com/
State of Play Entries: RCDM009, RCDM082, SA25

10.52 Katalyst Space Technologies

Description: Katalyst Space Technologies is an aerospace company headquartered in Flagstaff, Arizona. The company focuses on using in-space servicing technologies to repair and upgrade satellites after they have launched.
Country: United States
Type: Industry
Year Founded: 2019
URL: https://www.katalystspace.com/
State of Play Entries: RCDM089, URMUI17, URMUI18, IM26, IM27, SA01, SA11

10.53 Launcher Space

Description: Launcher Space was an aerospace company which specialized in the development of rockets and transfer vehicles to deliver small satellites to orbit. Its scope of developments included liquid propulsion technology and onsite 3D manufacturing for high-efficiency engines. Launcher Space was acquired by Vast in 2023.
Country: United States
Type: Industry
Year Founded: 2017
URL: https://www.launcherspace.com/
State of Play Entries: R22

10.54 LERA

Description: LERA Consulting Structural Engineers is a structural engineering firm specializing in structural design. The company's areas of expertise include structural designs, feasibility studies, peer reviews, value engineering, computational design, blast analysis and design, forensic consulting, and special inspections.
Country: United States
Type: Industry
Year Founded: 1923
URL: https://www.lera.com/
State of Play Entries: SI18

10.55 Lockheed Martin

Description: The Lockheed Martin Corporation is an aerospace, arms, defense, information security, and technology corporation specializing in Aeronautics, Missiles and Fire Control (MFC), Rotary and Mission Systems (RMS), and Space. Its developments include the Orion spacecraft command module, in space manufacturing technologies, and hydrogen fluid management systems.
Country: United States
Type: Industry
Year Founded: 1995
URL: https://www.lockheedmartin.com/
State of Play Entries: RCDM012, RCDM053, RCDM068, PRMUI04, RFT05, SMA21, IM18

10.56 Lunar Resources Inc

Description: Lunar Resources Inc is a space technology company focusing on in-space manufacturing and resource extraction. Its prospective developments include in-situ construction of lunar infrastructure such as a radio observatory, photovoltaic power grid, and regolith additive manufacturing.
Country: United States
Type: Industry
Year Founded: 2019
URL: https://www.lunarresources.space/
State of Play Entries: PGM07

10.57 Made In Space

Description: Made In Space was an aerospace company specialized in commercial additive manufacturing in microgravity. The company was acquired by Redwire Corporation in 2020.
Country: United States
Type: Industry
Year Founded: 2010
URL: http://madeinspace.us/
State of Play Entries: PGM02, PGM03, PGM13

10.58 Malin Space Science Systems Inc

Description: Malin Space Science Systems is a California-based aerospace company specializing in space camera and instrument systems. The company has contributed to a variety of exploration missions such as Mars Global Surveyor, Mars Orbiter, and Lunar Reconnaissance Orbiter among others.
Country: United States
Type: Industry
Year Founded: 1990
URL: https://www.msss.com/
State of Play Entries: IM35

10.59 Martin Marietta Corporation

Description: The Martin Marietta Corporation was an aerospace company specialized in missile technology. Its developments included the Titan program, the Viking program, and the space shuttle external tank. In 1995, it merged with Lockheed Corporation to form the Lockheed Martin Corporation.
Country: United States
Type: Industry
Year Founded: 1961
State of Play Entries: RFT45

10.60 Maxar Technologies

Description: Maxar Technologies is a space technology company specializing in manufacturing communication, Earth observation, radar, and on-orbit satellite servicing. Its developments include the Power and Propulsion Element for the Lunar Gateway, 3D geospatial analytics, satellite imagery, analytics, and data modeling.
Country: United States
Type: Industry
Year Founded: 2017
URL: https://www.maxar.com/
State of Play Entries: RM15, RM18, RM24, RM25, RM32, RM33, RM44, RCDM065, URMUI13, RFT30, SMA38, RRR03, PGM15, IM38

10.61 Maxon Group

Description: Maxon Group is an electronic manufacturer of high precision motor systems. Its developments include electric AC motors, DC motors, encoders, gears, motor controllers, and sensors for applications within the aerospace, automotive, communication, industrial automation, measuring and testing, medical, and security technology industries.
Country: Switzerland
Type: Industry
Year Founded: 1961
URL: https://www.maxongroup.com/
State of Play Entries: RCDM047, PRMUI21

10.62 McDonnell Douglas Astronautics Company

Description: McDonnell Douglas Astronautics Company refers to the space segment of the McDonnell Douglas Corporation. This Missouri-based aerospace manufacturer merged with Boeing in 1997.
Country: United States
Type: Industry
Year Founded: 1967
State of Play Entries: RFT01

10.63 MDA Space

Description: MDA Space is a space technology company specializing in robotics, satellite technology, and satellite operations. Its developments include the Mobile Servicing System for the International Space Station, which includes Canadarm2, and the Canadarm3 for the Lunar Gateway.
Country: Canada
Type: Industry
Year Founded: 1968
URL: https://mda.space/
State of Play Entries: RM04, RM05, RM06, RM10, RM15, RM18, RM23, RM24, RM25, RM31, RM32, RM33, RCDM039, RCDM050, RCDM054, RCDM058, RCDM069, PRMUI13, PRMUI23, PRMUI28, PRMUI29, PRMUI30, PRMUI39

10.64 Mercury Systems

Description: Mercury Systems is a technology company focused on aerospace and defense applications. Its developments include electronic warfare development systems, communications and networking technologies, sensors and scanners, military rugged display systems, rugged servers and subsystems, computer boards, and microelectronic components.
Country: United States
Type: Industry
Year Founded: 1981
URL: https://www.mrcy.com/company
State of Play Entries: PGM14

10.65 Millennium Space Systems

Description: Millennium Space Systems is a U.S.-based aerospace company specializing in the design and manufacturing of satellite systems. In 2021, it was acquired by Boeing, integrating its capabilities into Boeing's space and satellite division.
Country: United States
Type: Industry
Year Founded: 2001
URL: https://www.millennium-space.com/
State of Play Entries: RCDM083, RCDM109

10.66 Momentus Inc

Description: Momentus Space is a spaceflight company specializing in on-orbit servicing of space infrastructure and propulsion systems. Its developments include in-space transportation and orbit transfer technologies, and water plasma-based propulsion systems in the form of Microwave Electrothermal Thruster (MET) propulsion technology.
Country: United States
Type: Industry
Year Founded: 2017
URL: https://investors.momentus.space/
State of Play Entries: R29

10.67 MOOG

Description: Moog is an electromechanical technology company specializing in precision motion control systems. Its developments include actuators, motion controllers, rotary joints, and motors for robotic systems.
Country: United States
Type: Industry
Year Founded: 1953
URL: https://www.moog.com/
State of Play Entries: RM15, RCDM063, R21, PRMUI26, RFT27

10.68 Motiv Space Systems

Description: Motiv Space Systems is a robotics company specializing in robotic arm systems for use in space or on planetary surfaces. Its developments include the xLink Robotic arm for the OSAM-2 demonstration mission and the robotic arm for the NASA JPL 2020 Mars Perseverance Rover.
Country: United States
Type: Industry
Year Founded: 2014
URL: https://motivss.com/
State of Play Entries: RM09, RM50, PRMUI24

10.69 Nanoracks

Description: Nanoracks, acquired by Voyager Space in 2021, is a private aerospace company specializing in providing commercial spaceflight services and hardware for space missions
Country: United States
Type: Industry
Year Founded: 2009
URL: https://voyagertechnologies.com/company/
State of Play Entries: RRR03, PGM15

10.70 NASA Ames Research Center (ARC)

Description: NASA's Ames Research Center (ARC) conducts research and development activities in aeronautics, space exploration, space technology, and science. ARC was the second NACA laboratory founded to conduct research on early aircraft, and now provides expertise in space domains such as small satellite technologies, supercomputing, intelligent robotics, planetary science, and other research areas.
Country: United States
Type: Government
Year Founded: 1939
URL: https://www.nasa.gov/ames
State of Play Entries: RM29, RM42, SMA06, SI04

10.71 NASA Goddard Space Flight Center (GSFC)

Description: NASA's Goddard Space Flight Center (GSFC) is a research, development, and operations center focused on increasing the scientific understanding of the Earth, Solar System, and universe. GSFC operates many NASA science missions, including the Hubble Space Telescope and James Webb Space Telescope, operates satellite tracking networks, and supports many NASA and international spacecraft and missions.
Country: United States
Type: Government
Year Founded: 1959
URL: https://www.nasa.gov/goddard
State of Play Entries: RCDM006, RCDM081, RFT41, IM23, IM36, IM37

10.72 NASA Jet Propulsion Laboratory (JPL)

Description: NASA's Jet Propulsion Laboratory (JPL) is a federally funded research and development center (FFRDC) managed by Caltech. JPL's core capability is to integrate science, engineering, and technology to provide end-to-end implementation of robotic space missions. JPL is responsible for developing NASA's Mars rovers and other robotic science missions, operating the Deep Space network, and research and development of other space technology.
Country: United States
Type: Government
Year Founded: 1936
URL: https://www.jpl.nasa.gov/
State of Play Entries: RM01, RM26, RM37, URMUI02, URMUI14, SI03, SI19

10.73 NASA Johnson Space Center (JSC)

Description: NASA's Johnson Space Center (JSC) is the lead center for human space exploration, training the agency's astronaut corps, running International Space Station (ISS) mission operations, and advancing other human exploration capabilities. JSC has led NASA's human exploration missions including Apollo, Space Shuttle, and ISS, and Artemis development, and performs research and development of several human spaceflight technologies.
Country: United States
Type: Government
Year Founded: 1961
URL: https://www.nasa.gov/centers/johnson/home/index.html
State of Play Entries: RFT32, SI06, IM25

10.74 NASA Kennedy Space Center (KSC)

Description: NASA's Kennedy Space Center (KSC) serves as NASA's launch facility, and it also performs research in several areas related to humans living and working on planetary bodies. The center supports commercial launches and provides facilities for a number of commercial launch companies to run their launch operations.
Country: United States
Type: Government
Year Founded: 1962
URL: https://www.nasa.gov/centers/kennedy/home/index.html
State of Play Entries: SI08, SI10, SI12, SI18, SI20

10.75 NASA Langley Research Center (LaRC)

Description: NASA's Langley Research Center (LaRC) is the nation's first civilian aeronautics research and development laboratory, and today supports aeronautics, science, and space missions. The research at LaRC provides improvements to aviation, expands understanding of Earth's atmosphere, develops technology for space exploration, and analyzes new system concepts.
Country: United States
Type: Government
Year Founded: 1917
URL: https://www.nasa.gov/langley
State of Play Entries: RM02, RM22, RM47, SMA05, SMA22, SMA27, SMA30, SMA39, SMA40, SMA41, SMA46, SI11, SI22, IM10

10.76 NASA Marshall Space Flight Center (MSFC)

Description: NASA's Marshall Space Flight Center (MSFC), located in Huntsville, Alabama, is a leader in design, development, and test and evaluation with an emphasis on technology and system development for human exploration. NASA MSFC also has a rich history of science for robotic missions and is home to NASA's Planetary Missions Program Office.
Country: United States
Type: Government
Year Founded: 1960
URL: https://www.nasa.gov/centers/marshall/home/index.html
State of Play Entries: RFT12, RFT13, SMA02, SMA03, SMA10, SMA28, SMA43, SI09, SI15

10.77 National Aeronautics and Space Administration (NASA)

Description: The National Aeronautics and Space Administration (NASA) is America's civil space program with an emphasis on human exploration, space science (Earth science, planetary science, heliophysics, biological and physical science, and astrophysics), and advancement in space technology. NASA performs these activities at 20 centers and facilities across the U.S. and the International Space Station.
Country: United States
Type: Government
Year Founded: 1958
URL: https://www.nasa.gov/
State of Play Entries: RM24, RM27, RM30, RM35, RM36, RCDM019, RCDM021, RCDM032, RCDM033, RCDM038, RCDM041, RCDM042, RCDM043, RCDM044, RCDM045, RCDM063, RCDM065, RCDM066, RCDM068, RCDM095, RCDM100, RCDM103, RCDM110, R09, R10, R11, R12, R13, PRMUI01, PRMUI08, PRMUI15, PRMUI16, PRMUI17, PRMUI18, PRMUI19, PRMUI25, PRMUI26, PRMUI27, PRMUI33, PRMUI35, URMUI01, URMUI03, URMUI04, URMUI05, URMUI06, URMUI07, URMUI08, URMUI09, URMUI12, URMUI13, URMUI15, URMUI16, URMUI19, RFT03, RFT06, RFT17, RFT18, RFT19, RFT20, RFT25, RFT26, RFT27, RFT28, RFT30, RFT31, RFT39, RFT40, RFT42, RFT43, RFT46, RFT47, RFT52, RFT53, RFT54, SMA01, SMA04, SMA08, SMA09, SMA13, SMA17, SMA18, SMA20, SMA23, SMA29, SMA35, SMA44, RRR01, RRR04, RRR05, PGM02, PGM03, PGM07, PGM10, PGM11, PGM12, PGM13, PGM14, PGM17, PGM18, PGM22, SI01, SI02, SI17, IM17, IM18, IM28, IM29, IM35, SA04, SA05, SA06, SA10, SA12, SA13, SA16, SA17, SA23, SA24, SA26

10.78 National Space Development Agency of Japan (NASDA)

Description: The National Space Development Agency of Japan (NASDA) was a Japanese national space agency responsible for developing, launching, and tracking satellites. It also developed and operated the N-I, N-II, and H-I launch vehicles. In 2003, NASDA merged with the Institute of Space and Astronautical Science (ISAS) and the National Aerospace Laboratory of Japan (NAL) to become the Japan Aerospace Exploration Agency (JAXA).
Country: Japan
Type: Government
Year Founded: 1969
State of Play Entries: RM11, RCDM028

10.79 National University of Defense Technology (NUDT)

Description: The National University of Defense Technology (NUDT) was founded as China's People's Liberation Army (PLA) Military Academy of Engineering, or Harbin Military Academy of Engineering. Its disciplines cover eight categories, including science, engineering, military science, management, philosophy, economics, law, and literature.
Country: China
Type: Government
Year Founded: 1953
URL: https://english.nudt.edu.cn/
State of Play Entries: RCDM004, R01, RFT51

10.80 Naval Research Laboratory (NRL)

Description: The Naval Research Laboratory (NRL) is a research and engineering lab which advances technology for the US Navy and US Marine Corps. The NRL conducts a broad program of scientific research and advanced technology development. NRL's scientists and engineers conduct basic and applied research across a wide spectrum of scientific disciplines for both immediate and long-range national defense needs. NRL's research is primarily sponsored by government agencies including the Office of Naval Research, Naval Systems Commands and Warfare Centers, Air Force, Army, DARPA, Department of Energy, and NASA.
Country: United States
Type: Government
Year Founded: 1923
URL: https://www.nrl.navy.mil/
State of Play Entries: RM15

10.81 Neptec Design Group Ltd

Description: Neptec Design Group was a Canadian aerospace company specializing in machine vision systems. It was acquired by MDA space in 2018.
Country: Canada
Type: Industry
Year Founded: 1990
State of Play Entries: RCDM108, RCDM110, IM13

10.82 North American Rockwell

Description: North American Rockwell was a corporation formed by the acquisition and merger of the Rockwell Standard with North American Aviation. Its main developments included the Apollo command and service module and the Apollo-Soyuz Test Project Docking Module.
Country: United States
Type: Industry
Year Founded: 1967
State of Play Entries: RCDM005

10.83 Northrop Grumman

Description: Northrop Grumman is a global aerospace, defense and security company that serves as a major contractor of the U.S. government. As part of its Space Systems sector, Northrop Grumman designed and built the Mission Extension Vehicle to provide life extension services to GEO satellites.
Country: United States
Type: Industry
Year Founded: 1994
URL: https://www.northropgrumman.com/
State of Play Entries: RCDM060, RCDM061, RCDM073, R18, R19, R20, URMUI10, URMUI11, RFT08, RFT33, SA14

10.84 NovaWurks

Description: NovaWurks is an aerospace company specializing in small satellite technologies. Its developments include integrated small satellites for the DARPA Phoenix project.
Country: United States
Type: Industry
Year Founded: 2011
URL: https://www.novawurks.com/
State of Play Entries: RCDM094, PRMUI34, RFT44, SMA36

10.85 Obruta Space Solutions

Description: Obruta Space Solutions is an aerospace company specializing in rendezvous, proximity operations, and docking systems and orbital logistics. Its developments include debris removal technologies and on-orbit servicing technologies.
Country: Canada
Type: Industry
Year Founded: 2016
URL: https://www.obruta.com/
State of Play Entries: RCDM085

10.86 Oceaneering International Inc

Description: Oceaneering International Inc is a marine engineering company that provides engineered services and hardware to marine and space operations. It has developed multiple technologies and systems for commercial and government undersea operations. Some of those technologies and capabilities translated to space, including space suits, interfaces, and robotics.
Country: United States
Type: Industry
Year Founded: 1964
URL: https://www.oceaneering.com/
State of Play Entries: RCDM057, RCDM087, PRMUI10, PRMUI32

10.87 OHB

Description: OHB is a German aerospace company specializing in spacecraft hardware and satellite systems. They are the largest supplier of components for the Ariane 5 program.
Country: Germany
Type: Industry
Year Founded: 1981
URL: https://www.ohb.de/en/
State of Play Entries: RCDM018, R05

10.88 Open Robotics

Description: Open Source Robotics Foundation (OSRF), operating as Open Robotics, is a nonprofit headquartered in California, focused on developing and promoting open-source software for robotics research, education, and product development.
Country: United States
Type: Industry
Year Founded: 2012
URL: https://www.openrobotics.org/
State of Play Entries: SA09, SA18

10.89 Orbit Fab

Description: Orbit Fab is an aerospace company specializing in in-space fuel transfer and storage. Its developments include in-orbit fuel depot satellites, fluid transfer interfaces, and mission analysis software.
Country: United States
Type: Industry
Year Founded: 2018
URL: https://www.orbitfab.com/
State of Play Entries: RCDM036, RCDM074, RCDM080, RCDM104, RFT14, RFT15, RFT21, RFT37, RFT38, RFT48

10.90 Orbital Composites

Description: Orbital Composites is an additive manufacturing company specializing in robotic 3D printing and composites manufacturing. Its developments include orbital manufacturing and assembly, thermal protection systems, GEO and cislunar optical Imaging, and communication satellites.
Country: United States
Type: Industry
Year Founded: 2014
URL: https://www.orbitalcomposites.com/
State of Play Entries: PGM01

10.91 Orbital Matter

Description: Orbital Matter is a Polish aerospace company specializing in space construction. Their aim is to develop in-space additive manufacturing systems for large structures.
Country: Poland
Type: Industry
Year Founded: 2022
URL: https://www.orbital-matter.com/
State of Play Entries: SMA12

10.92 Orion Space Solutions

Description: Founded in 2005 as ASTRA and rebranded in 2022, Orion Space Solutions specializes in providing advanced technology solutions and services for space missions and satellite operations.
Country: United States
Type: Industry
Year Founded: 2005
URL: https://orion.arcfield.com/
State of Play Entries: RCDM105, RCDM106, RFT49, RFT50, IM33

10.93 Outward Technologies

Description: Outward Technologies is an aerospace engineering company which focuses on the utilization of solar energy for extraction of materials from lunar regolith. The intended applications of this technology development include construction of habitable structures on other planetary surfaces, lunar resource extraction, and in-situ resource utilization.
Country: United States
Type: Industry
Year Founded: 2017
URL: https://outward.tech/
State of Play Entries: SMA37, SI21

10.94 People's Liberation Army (PLA)

Description: The People's Liberation Army (PLA) is the military for the People's Republic of China. The PLA has a space program that supports China's military operations, providing reconnaissance, navigation, communication, and other functions.
Country: China
Type: Government
Year Founded: 1927
State of Play Entries: RCDM004, R01

10.95 Premier Industries

Description: Premier Industries is a Minnesota-based company centered around the development and manufacturing of regulator and valve systems.
Country: United States
Type: Industry
Year Founded: 1995
URL: https://premierind.us/
State of Play Entries: RFT52

10.96 QinetiQ Space

Description: QinetiQ Space is an aerospace company specializing in design, integration, test, and training for space infrastructure and other mission systems. It operates in a number of areas, including secure communications and position, navigation, and timing. QinetiQ Space was acquired by Redwire Corporation in 2022.
Country: Multinational
Type: Industry
Year Founded: 2001
URL: https://www.qinetiq.com/en/markets/space
State of Play Entries: RCDM047, PRMUI21

10.97 Quadrus Corporation

Description: Formed in 1995, Quadrus Corporation specializes in engineering software solutions and advanced manufacturing. They are the inventors of the Distributed Test, Analysis and Simulation System (DTASS), a suite of hardware and software tools created for use in product development.
Country: United States
Type: Industry
Year Founded: 1995
URL: https://www.quadruscorp.com/
State of Play Entries: RFT43

10.98 Redwire Corporation

Description: Redwire is an aerospace company specializing in in-space manufacturing and infrastructure technologies. Its developments include solar arrays and deployable structures, microgravity manufacturing technologies, RF systems and satellite payloads, digital engineering, modeling, and simulation tools.
Country: United States
Type: Industry
Year Founded: 2020
URL: https://redwirespace.com/
State of Play Entries: RM45, RCDM068, SMA14, SMA28, SMA45, PGM03, PGM09, PGM10, PGM11, PGM16, PGM17, PGM18, PGM20, PGM22, SI16, SI17, IM18

10.99 RKK Energiya

Description: Energia Corporation, formerly RKK "Energiya", NPO Energia,
TsKBEM, and OKB-1 is a Russian space company specializing in the production of spaceflight components. The company was founded in 1946 and was responsible for the construction of the Sputnik 1 artificial satellite. Its current developments include the Russian Soyuz MS spacecraft, the Russian Orbital Segment of the ISS, the Sea Launch project, and the Universal Spacecraft Configuration for use on satellites.
Country: Russia
Type: Industry
Year Founded: 1946
URL: http://www.energia.ru/ru/corporation/corporation.html
State of Play Entries: RCDM003, PRMUI02

10.100 Rogue Space Systems Corporation

Description: Rogue Space Systems Corporation is an aerospace company specializing in satellite design and on-orbit servicing. Its operations include designing satellite vehicles and subsystems to provide on-orbit services to satellite operators.
Country: United States
Type: Industry
Year Founded: 2020
URL: https://rogue.space/
State of Play Entries: IM14

10.101 Roscosmos

Description: Roscosmos is a Russian state-run corporation responsible for operating the Russian state space program. Roscosmos was founded in 1992 after the dissolution of the USSR. The state-run company is responsible for conducting research, maintaining the Russian space flight program, and partnering with other countries in the operation of the ISS.
Country: Russia
Type: Government
Year Founded: 1992
URL: http://www.roscosmos.ru/
State of Play Entries: R13, RFT34

10.102 RUAG

Description: RUAG is an aerospace company specializing in military and commercial aerospace technologies. Its developments include information and communication systems, small-caliber ammunition, as well as aircraft and rotorcraft servicing.
Country: Switzerland
Type: Industry
Year Founded: 1999
URL: https://www.ruag.com/en
State of Play Entries: RCDM047, PRMUI21

10.103 Russia

Description: Russia is a Eurasian country which was founded in the early 1990s after the dissolution of the USSR. The country is the largest in the world by area and hosts approximately 144 million people. The country is a cooperative partner in the operation of the ISS and maintains its own space program.
Country: Russia
Type: Government
Year Founded: 1991
URL: http://government.ru/en/
State of Play Entries: RM46

10.104 Scout Space Inc

Description: SCOUT Space is an aerospace company specializing in autonomy and inspection technologies for the space industry. Its developments include in-space observation, digital twin environments, space traffic management, and proximity operations.
Country: United States
Type: Industry
Year Founded: 2019
URL: https://www.scout.space/
State of Play Entries: RCDM088, IM20, IM24, IM32, SA20

10.105 SENER

Description: SENER is an international engineering firm specializing in the aerospace, civil, and energy sectors. Its developments include electromechanical systems, antennas and RF equipment, guidance, navigation and control systems, and space-grade power electronics.
Country: Spain
Type: Industry
Year Founded: 1967
URL: https://www.group.sener/
State of Play Entries: RCDM047, RCDM099, PRMUI21, PRMUI37

10.106 Sierra Lobo

Description: Sierra Lobo is an Ohio-based engineering company offering a variety of services for government and commercial customers, such as hardware development and testing, systems engineering support, integration, and project management.
Country: United States
Type: Industry
Year Founded: 1993
URL: https://sierralobo.com/
State of Play Entries: RM43

10.107 Sierra Nevada Corporation

Description: Sierra Nevada Corporation is an aerospace company specializing in aerospace, security and defense technologies. The company offers technical solutions for spacecraft, aircraft, and cybersecurity to government and industry customers. Its developments include aircraft modification, intelligence, surveillance technologies, electromagnetic spectrum operational capabilities, and joint all-domain command and control (JADC2).
Country: United States
Type: Industry
Year Founded: 1963
URL: https://www.sncorp.com/
State of Play Entries: RCDM047, PRMUI21

10.108 Sierra Space

Description: Sierra Space is an aerospace corporation with headquarters in Louisville, Colorado. The company was spun off from Sierra Nevada Corporation in 2021. The company is responsible for development of Dream Chaser and is currently developing technologies for Orbital Reef.
Country: United States
Type: Industry
Year Founded: 2021
URL: https://www.sierraspace.com/
State of Play Entries: RCDM066, RCDM098, RCDM102, PRMUI38, SA21

10.109 Space Applications Services

Description: Space Applications Services is an aerospace company specializing in aerospace technology solutions in the fields of spacecraft, launch and reentry, and robotics. Its developments include a joint venture for a lunar payload delivery service, and a robotic arm, the Walking Manipulator.
Country: Belgium
Type: Industry
Year Founded: 1987
URL: https://www.spaceapplications.com/
State of Play Entries: RM49, RCDM040, PRMUI14

10.110 Space Machines Company

Description: Space Machines Company is an Australian aerospace company focusing on proximity operations and space intelligence. Their products combine mass-produced satellite systems with AI-driven software solutions to create technologies capable of in-space inspection and data gathering.
Country: Australia
Type: Industry
Year Founded: 2019
URL: https://www.spacemachines.com/
State of Play Entries: IM16, SA22

10.111 Stanford Space Rendezvous Laboratory

Description: The Space Rendezvous Laboratory is part of the department of Aeronautics and Astronautics at Stanford University. It focuses on the development of Distributed Space Systems (DSS) through interdisciplinary research in Astrodynamics, control systems, and hardware-in-the-loop testing.
Country: United States
Type: Academia
Year Founded: 2013
URL: https://slab.stanford.edu/
State of Play Entries: RCDM100, SA19

10.112 Spaceflight

Description: Spaceflight was an aerospace company that provided rideshare launch opportunities, in-space transportation, and other mission services. Its developments included an array of on-orbit Sherpa vehicles that provided transportation and avionics to hosted payloads. Spaceflight was acquired by Firefly Aerospace in 2023.
Country: United States
Type: Industry
Year Founded: 2011
URL: https://fireflyspace.com
State of Play Entries: R26

10.113 SpaceWorks Enterprises Inc

Description: SpaceWorks is an aerospace company that provides engineering services to government and industry customers in the areas of design, prototyping, and flight demonstrations.
Country: United States
Type: Industry
Year Founded: 2000
URL: https://www.spaceworks.aero/
State of Play Entries: RCDM034, PRMUI09

10.114 SpaceX

Description: SpaceX is an aerospace company that develops and operates launch vehicles and communications satellites. SpaceX pioneered reusability and quick turnover launch availability with their Falcon 9 and Falcon Heavy launch systems, and they are currently operating the Starlink communications constellation. Its current developments include the Starship super heavy-lift space vehicle, which will also include on-orbit cryogenic propellant transfer.
Country: United States
Type: Industry
Year Founded: 2002
URL: https://www.spacex.com/
State of Play Entries: RCDM101, RFT29

10.115 Spar Aerospace

Description: Spar Aerospace was an aerospace company which provided technology solutions to the Canadian Space Agency in support of the American Shuttle Program. Spar was responsible for providing the Canadarm for the Space Shuttle and the Canadarm2 for the ISS. Spar Aerospace is now part of MDA Space.
Country: Canada
Type: Industry
Year Founded: 1967
State of Play Entries: RM03

10.116 Starfish Space

Description: Starfish Space is an aerospace company specializing in satellite servicing. The company develops satellite servicing technologies such as rendezvous and capture software and robotics, and it plans to offer satellite mission extension, debris removal, and autonomous transportation.
Country: United States
Type: Industry
Year Founded: 2019
URL: https://www.starfishspace.com/
State of Play Entries: RCDM064, RCDM070, RCDM071, RCDM072, RCDM095, R23, IM19, IM28, SA07, SA08

10.117 Swedish Space Corporation

Description: Swedish Space Corporation is a state-owned entity that provides a range of space-related services, including satellite operations and launch support.
Country: Sweden
Type: Government
Year Founded: 1972
URL: https://sscspace.com/
State of Play Entries: RCDM076

10.118 Ten One Aerospace

Description: Ten One Aerospace specializes in spacecraft flight software and guidance, navigation, and control systems. Founded in 2020, Ten One Aerospace has developed software and hardware for use in Rendezvous and Proximity Operations (RPO).
Country: United States
Type: Industry
Year Founded: 2020
URL: https://www.tenonespace.com
State of Play Entries: SA02, SA19

10.119 Tethers Unlimited Inc

Description: Tethers Unlimited Inc is an aerospace company specializing in space debris mitigation, in-space transportation, and other areas of space logistics. The company was acquired by Amergint Technologies, ultimately becoming the ARKA group, and its developments include robotic assembly and fabrication technologies, small satellite subsystems, and satellite communications technologies.
Country: United States
Type: Industry
Year Founded: 1994
URL: https://arka.org/our-legacy/
State of Play Entries: RM21, RCDM015, PRMUI05, SMA25, RRR01, RRR04, RRR05

10.120 Thales Alenia Space

Description: Thales Alenia Space is a joint venture between Thales Group and Leonardo dedicated to building space systems. With a history developing systems for both European customers and abroad, Thales Alenia Space contributes to technologies for space exploration, Earth observation, defense, and more.
Country: France
Type: Industry
Year Founded: 2007
URL: https://www.thalesaleniaspace.com/en/
State of Play Entries: RCDM020, RCDM029, RFT10, RFT11, IM05, IM07

10.121 The Aerospace Corporation

Description: The Aerospace Corporation is a Federally Funded Research and Development Center (FFRDC) in El Segundo, California. It provides aerospace consulting and technical guidance to the national security and civil space sectors.
Country: United States
Type: Industry
Year Founded: 1960
URL: https://aerospace.org/
State of Play Entries: RCDM002, IM02

10.122 The Boeing Company

Description: The Boeing Company is a global aerospace company specializing in the development, manufacture, and servicing of commercial airplanes, defense, and space systems. It has developed numerous spacecraft, including much of the International Space Station structural assembly.
Country: United States
Type: Industry
Year Founded: 1916
URL: https://www.boeing.com/
State of Play Entries: RCDM075, PRMUI31, SMA26, SMA31, SMA33

10.123 The University of Texas at Austin (UT Austin)

Description: The University of Texas at Austin is a public research university in Austin, Texas. The Austin campus is the flagship campus of the University of Texas university system, and it employs 3,000 teaching faculty and is home to over 52,000 students.
Country: United States
Type: Academia
Year Founded: 1883
URL: https://www.utexas.edu/
State of Play Entries: IM25

10.124 ThinkOrbital

Description: ThinkOrbital is a company specializing in space infrastructure solutions, focusing on the development and deployment of modular space habitats and structures.
Country: United States
Type: Industry
Year Founded: 2020
URL: https://thinkorbital.com
State of Play Entries: SMA15

10.125 TRL11

Description: TRL11 is a California-based aerospace company founded in 2022. Focusing on video solutions for space applications, TRL11 has developed camera and recording systems for use cases such as Earth observation, spacecraft proximity operations, and more.
Country: United States
Type: Industry
Year Founded: 2022
URL: https://www.trl11.com/
State of Play Entries: RCDM016, RCDM078, RCDM107, IM04, IM11, IM12, IM21, IM34

10.126 True Anomaly

Description: True Anomaly is a private space technology company focusing on global security and space sustainability via advanced satellite tracking and space domain awareness solutions.
Country: United States
Type: Industry
Year Founded: 2021
URL: https://www.trueanomaly.space/
State of Play Entries: RCDM048

10.127 TsKBEM

Description: TsKBEM, which translates to the Central Design Bureau of Experimental Machine Building, was a previous name of RKK Energiya. This company is a Russian manufacturer of spacecraft and space components. It developed the SSVP docking system, a system to enable the rendezvous and capture, docking, and crew transfer used on most Soviet and Russian crewed space vehicles
Country: USSR
Type: Industry
Year Founded: 1946
State of Play Entries: RCDM093

10.128 U.S. Naval Academy

Description: The United States Naval Academy is a service academy in Annapolis, Maryland. It is an undergraduate institution where attendees, referred to as midshipmen, are trained and educated for service in the United States Navy.
Country: United States
Type: Academia
Year Founded: 1845
URL: https://www.usna.edu/homepage.php
State of Play Entries: RM38

10.129 Union of Soviet Socialist Republics (USSR)

Description: The Union of Soviet Socialist Republics was a country founded in 1922 and dissolved in 1991. The country played a critical role in the "Space Race" of the 20th century, launching the first artificial Earth satellite in 1957 and the first human in space 1961, and acting as the main rival of the United States in the race to put a human on the Moon.
Country: USSR
Type: Government
Year Founded: 1922
State of Play Entries: SMA32, SMA48

10.130 United Launch Alliance (ULA)

Description: United Launch Alliance (ULA) is an aerospace, defense, and launch service provider formed by a joint venture between Lockheed Martin and The Boeing Company. ULA manufactures and operates launch vehicles such as their Atlas V and Delta IV Heavy rockets, and it is currently developing the Vulcan Centaur heavy-lift launch vehicle.
Country: United States
Type: Industry
Year Founded: 2006
URL: https://www.ulalaunch.com/
State of Play Entries: RFT04

10.131 United States Army Corps of Engineers

Description: The U.S. Army Corps of Engineers is a group within the United States Army which offers engineering services through a civilian and military workforce. The Corps' 37,000 employees offer engineering solutions in areas such as infrastructure maintenance and military facility installation both domestically and abroad.
Country: United States
Type: Government
Year Founded: 1802
URL: https://www.usace.army.mil/
State of Play Entries: SI02

10.132 United States Department of Energy (DOE)

Description: The U.S. Department of Energy is a department of the executive branch of the United States which is responsible for managing the U.S. nuclear infrastructure, administering U.S. energy policy, and funding research and development of energy technologies. The department operates 17 research and development facilities across the United States.
Country: United States
Type: Government
Year Founded: 1977
URL: https://www.energy.gov/
State of Play Entries: URMUI01

10.133 United States Space Force

Description: The United States Space Force, established as an independent service branch within the U.S. Department of the Air Force, is a military branch responsible for organizing, training, and equipping space forces to protect U.S. and allied interests in space.
Country: United States
Type: Government
Year Founded: 2019
URL: https://www.spaceforce.mil/
State of Play Entries: RCDM035, RCDM073, RCDM105, RCDM106, RCDM109, RFT08, RFT33, RFT49, RFT50, IM33

10.134 University of Arizona

Description: The University of Arizona is a public research university in Tucson, Arizona. The university employs 3,300 faculty and is home to more than 51,000 students.
Country: United States
Type: Academia
Year Founded: 1885
URL: https://www.arizona.edu/
State of Play Entries: RM27

10.135 University of Delaware

Description: The University of Delaware is a state-assisted, privately governed, teir-1 research university in Newark, Delaware. The university employs over 1300 faculty, is home to more than 23,000 students, and operates 80 university research centers.
Country: United States
Type: Academia
Year Founded: 1743
URL: https://www.udel.edu/
State of Play Entries: RRR06

10.136 University of Illinois Urbana-Champaign (UIUC)

Description: The University of Illinois Urbana-Champaign is an R1 research university in Champaign, Illinois. The university has over 50,000 students, with over 2,000 academic staff.
Country: United States
Type: Academia
Year Founded: 1867
URL: https://illinois.edu/
State of Play Entries: SMA47

10.137 University of Maryland Space Systems Laboratory (UMD SSL)

Description: The University of Maryland Space Systems Laboratory (UMD SSL) is a research facility located at the University of Maryland College Park campus. The SSL is centered around the lab's Neutral Buoyancy Research Facility, a 50-foot diameter, 25-foot deep, 367,000-gallon water tank used to conduct research in a simulated in-space environment.
Country: United States
Type: Academia
Year Founded: 1976
URL: https://ssl.umd.edu/
State of Play Entries: RM34

10.138 University of Surrey

Description: The University of Surrey Space Centre, founded in 2003, conducts research and development in various areas of space technology, with a focus on satellite systems and space missions. The center is part of the University of Surrey, which has a longstanding involvement in aerospace engineering and related fields.
Country: England
Type: Academia
Year Founded: 1966
URL: https://www.surrey.ac.uk/surrey-space-centre
State of Play Entries: RCDM084, IM22

10.139 VARDA SPACE INDUSTRIES

Description: Varda Space Industries is a private aerospace company focused on in-space manufacturing and satellite deployment. The company has pursued the development of technologies for manufacturing products in low Earth orbit, aiming to leverage microgravity environments.
Country: United States
Type: Industry
Year Founded: 2020
URL: https://www.varda.com/
State of Play Entries: PGM23

10.140 VISIONEERING SPACE CORPORATION

Description: Visioneering Space Corporation is a space engineering company focused on designing and building spaceflight and scientific research systems. Its developments in mechanical, electro-mechanical, and opto-mechanical engineering include the Mars Atmosphere and Volatile EvolutioN satellite (MAVEN), the Neutron star Interior Composition ExploreR (NICER), the Sample Analysis at Mars instrument on the Curiosity Rover, and the Lunar Atmosphere and Dust Environment Explorer (LADEE).
Country: United States
Type: Industry
Year Founded: 2000
URL: https://www.visioneeringspace.com/
State of Play Entries: PGM07

10.141 VOYAGER TECHNOLOGIES

Description: Voyager Technologies, headquartered in Denver, Colorado, is a space exploration and technology company focused on developing and operating space infrastructure and systems. In 2025, the company changed its name from "Voyager Space" to align with increased focus on national security applications.
Country: United States
Type: Industry
Year Founded: 2019
URL: https://voyagertechnologies.com/
State of Play Entries: RRR03, PGM15

10.142 WESTINGHOUSE ELECTRIC COMPANY

Description: Westinghouse Electric Company is an energy technology company formed in 1999 as a spinoff from the Westinghouse Electric Corporation. Westinghouse Electric Company focuses on the supply of nuclear energy technology and services.
Country: United States
Type: Industry
Year Founded: 1886
URL: https://www.westinghousenuclear.com/
State of Play Entries: SMA35

11 Appendix – ISAM Facilities

This appendix contains more information on the facilities identified in the document. Information for each facility includes a Description, Type (identifying what type of entity operates the facility), Location of the facility, URL for more information on the facility, and the Related Capability Area(s) that the facility supports.

11.1 Adaptive Robotics and Technology (ART) Lab

Description: The Adaptive Robotics and Technology (ART) Lab located at Texas A&M in College Station, Texas focuses on theories and technologies for human robot interfaces and adaptive robots. Faculty and students conduct research focused on developing algorithms for consensus-based decision making, task allocation, and collective task performance in robotic swarms and develop unconventional robot and mechanism designs.
Type: Academia
Location: Texas A&M University, College Station, TX
URL: https://art.engr.tamu.edu/
Related Capability Area(s): RM, SMA

11.2 Adaptive Robotics Laboratory

Description: The Adaptive Robotics Laboratory is located at the Powerhouse Energy Campus of Colorado State University in Fort Collins, Colorado. The main mission of the lab is to explore fundamental science and applications for adaptive robots. The lab designs and builds adaptive robots that can reconfigure their structure, shape, and functionality for various tasks in diverse environments.
Type: Academia
Location: Colorado State University, Fort Collins, CO
URL: https://www.engr.colostate.edu/laboratories/adaptive-robotics-laboratory/
Related Capability Area(s): RM, SMA

11.3 Additive Manufacturing Facility (AMF)

Description: The ISS Additive Manufacturing Facility (AMF) is an innovative 3D printing facility aboard the International Space Station (ISS), jointly developed by NASA and Made In Space, Inc. This facility empowers astronauts to fabricate tools, parts, and customized items directly on the ISS, reducing the need for resupply missions from Earth and enabling in-situ resource utilization.
Type: NASA
Location: ISS
URL: https://ntrs.nasa.gov/api/citations/20160011465/downloads/20160011465.pdf
Related Capability Area(s): PGM

11.4 Astrobee Microgravity Test Facility

Description: The Astrobee facility is operated out of NASA Ames Research Center in Silicon Valley, California. One of its main functions is to conduct research that supports scientists who are performing space-based research.
Type: NASA
Location: ISS
URL: https://www.nasa.gov/astrobee
Related Capability Area(s): RM, IM

11.5 Autonomy Lab for Intelligent Flight Systems (A-LIFT)

Description: The NASA LaRC Autonomy Lab for Intelligent Flight Systems aims to prepare its workforce for upcoming autonomy and robotics challenges in space exploration and aeronautics, supporting complex missions like asteroid retrieval, planetary exploration, pollution measurements, and UAS integration. The lab includes an outdoor flying space of 60 by 60 feet and 50 feet tall, along with an indoor flight space measuring 1680 square feet.
Type: NASA
Location: LaRC
URL: https://researchdirectorate.larc.nasa.gov/a-lift/
Related Capability Area(s): IM

11.6 Center for Robotics Research

Description: The Center for Robotics Research, which is located at the University of Cincinnati in Cincinnati, Ohio, focuses on design and analysis of stationary and robotics systems. The main research objectives of the Center include robotics applications, robot vision and navigation, computer architecture, and robot kinematics and dynamics. Future endeavors for the Center will be to focus on developing robotic prototype systems/machines that can be licensed to Industry.
Type: Academia
Location: University of Cincinnati, Cincinnati OH
URL: https://ceas.uc.edu/research/centers-labs/center-for-robotics-research.html
Related Capability Area(s): RM, SMA

11.7 Coded Structures Laboratory

Description: The Coded Structures Lab is applying programmable material, mechanical-meta material, and autonomy principles to develop In-Space Assembly Robotic Construction Systems. The lab is equipped with rapid prototyping equipment, mechanical testing equipment, and facilities to test robotic assembly.
Type: NASA
Location: ARC
URL: https://www.nasa.gov/ames/ocs/seminars/kenneth-cheung
Related Capability Area(s): SMA

11.8 Collaborative and Autonomous Vehicle Ecosystem (CAVE)

Description: The Collaborative and Autonomous Vehicle Ecosystem (CAVE) lab is located in the Guidance and Control Systems Labs at the Aerospace Corporation. It provides an environment for research, development, integration, and testing of autonomous subsystems and systems with robotic arms, rovers, and drones. The lab's goal is to explore how increased autonomy and collaborative robotics can enable successful autonomous space systems.
Type: Aerospace Corporation
Location: Los Angeles, CA
URL: https://aerospace.org/sites/default/files/GCS/
Related Capability Area(s): RCDM, SC, PRUMI, RM

11.9 Collaborative Robotics and Intelligent Systems Institute (CoRIS)

Description: The Collaborative Robotics and Intelligent Systems (CoRIS) Institute promotes a holistic approach to exploring robotics and intelligent systems. Students and faculty engage in cutting-edge robotics research, development, and applications to improve human lives. As robotic technology advances, the CoRIS Institute will continue to harness the power of robotics to learn how they will serve humanity best.
Type: Academia
Location: Oregon State University
URL: https://engineering.oregonstate.edu/CoRIS
Related Capability Area(s): IM

11.10 Cryogenics and Fluids Lab

Description: The Cryogenics and Fluids Lab located at Goddard Space Flight Center (GSFC) has been used in collaboration with KSC to develop fluid transfer components and subsystems. The lab was used as a manufacturing and assembly area to fabricate the OSAM-1 propellant transfer system (PTS) and to advance other R&D efforts related to on-orbit fluid transfer.
Type: NASA
Location: GSFC
URL: https://cryo.gsfc.nasa.gov/
Related Capability Area(s): RFT

11.11 Dynamic and Autonomous Robotic Systems (DARoS) Lab

Description: The Dynamic and Autonomous Robotic Systems (DARoS) Laboratory is developing robotic systems for common goods. The lab's primary research area is in dynamic locomotion of legged systems. The ultimate goal for faculty and students is to create robots to be practical tools for humans by enhancing them to be faster, smarter, and more robust.
Type: Academia
Location: University of Massachusetts-Amherst, Amherst, MA
URL: https://www.umass.edu/robotics/daros
Related Capability Area(s): RM

11.12 Edwards Air Force Base

Description: Edwards Air Force Base is a United States Air Force installation located in California that is focused on conducting tests and demonstrations of aircraft and spacecraft for the military. The Air Force Research Laboratory (AFRL)'s Propulsion Directorate, which is hosted at Edwards Air Force Base, maintains the AFRL Rocket Lab, which contributes to research on in-space propulsion, green propellants, modular propulsion units, and the cislunar logistics chain.
Type: AFRL
Location: Edwards Air Force Base, CA
URL: https://www.edwards.af.mil/
Related Capability Area(s): RPOC, RFT, ULRM, PRUMI

11.13 Engineering, Development, and Operations (EDO) Test Facilities

Description: The KSC Engineering, Development, and Operations (EDO) Test Facility has been used in collaboration with GSFC and JSC to develop fluid transfer components and systems. It was used as a test area to advance the design of the OSAM-1 Propellant Transfer System (PTS). It has also been used to support Gateway propellant transfer technology development and testing along with other R&T efforts related to on-orbit fluid transfer. With the 50'x50' floor footprint, it is ideal for large test setups that require an indoor climate-controlled facility. In addition, a large quantity of fluids test equipment is readily available to support a broad array of testing.
Type: NASA
Location: KSC
URL: https://public.ksc.nasa.gov/partnerships/capabilities-and-testing/testing-and-labs/
Related Capability Area(s): RFT, IM

11.14 Express Logistics Carriers

Description: The Express Logistics Carriers (ELC) were designed to provide additional storage and support for external payloads aboard the ISS. Developed by NASA and the Brazilian Space Agency, all four ELC payloads can provide electrical power, mechanical mounting surfaces, and data and command handling services for various science experiments.
Type: NASA
Location: ISS
URL: https://en.wikipedia.org/wiki/ExPRESS_Logistics_Carrier
Related Capability Area(s): PRUMI

11.15 Flight Robotics Laboratory

Description: The Flight Robotics Laboratory (FRL) at Marshall Space Flight Center is a testing facility that has a large precision air-bearing floor, offering an 8-degree-of-freedom manipulator and a dynamic lighting simulator for sun motion and brightness simulation. This enables testing of various objects, including full systems, spacecraft, sensors, and cameras, with recent testing of Proximity Operations Sensors for the Dragon capsule in support of SpaceX.
Type: NASA
Location: MSFC
URL: https://www.nasa.gov/wp-content/uploads/2023/07/avionics-design.pdf?emrc=402b5d
Related Capability Area(s): RM, SC, IM

11.16 Flight Simulation Facilities (FSF)

Description: The Flight Simulation Facilities located at Langley Research Center hosts various simulation setups such as the Cockpit Motion Facility, the Research Flight Deck, and the Development and Test Simulator (DTS). The simulators offer high-fidelity, real-time, human-in-the-loop flight capabilities for conducting various aerospace and space-based research.
Type: NASA
Location: LaRC
URL: https://csaob.larc.nasa.gov/facilities/?doing_wp_cron=1689264976.5941989421844482421875
Related Capability Area(s): IM

11.17 Formation Control Testbed (FCT)

Description: The Formation Control Testbed (FCT) (a.k.a. Robodome) is a technology development testbed for various mission and research concepts. Specific development and testing include robotic manipulation, satellite characterization, vision-based and relative sensor development, and autonomous rendezvous and docking. These capabilities allow high fidelity, system-level ground testing of spacecraft architectures and autonomous operations.
Type: NASA
Location: JPL
URL: https://scienceandtechnology.jpl.nasa.gov/formation-control-testbed-fct
Related Capability Area(s): RCDM

11.18 General Robotics, Automation, Sensing and Perception (GRASP) Laboratory

Description: The GRASP Lab, located at the University of Pennsylvania, is a multidisciplinary robotics lab with two separate locations on campus. Both GRASP lab locations provide space that fosters collaboration between students, research staff, and faculty focused on robotic and intelligent systems. Both labs support experiments, computing power for modeling and testing, and prototyping machinery.
Type: Academia
Location: University of Pennsylvania, Philadelphia, PA
URL: https://www.grasp.upenn.edu/
Related Capability Area(s): IM

11.19 High Performance Robotics (HiPeR) Lab

Description: The High Performance Robotics lab supports research involving fundamental robotic capabilities in order to enhance the systems' capabilities by using advanced algorithms, mechanical design, and control strategies. Specific research areas also include vehicle design, safety, localization, and motion planning.
Type: Academia
Location: University of California-Berkeley, Berkeley, CA
URL: https://hiperlab.berkeley.edu/
Related Capability Area(s): IM

11.20 Human-Center Robotics Lab; Robot Learning Lab; Robotics and State Estimation Lab

Description: There are several robotic labs located at the University of Washington. Researchers focus on various research topics which include mechanism design, sensors, computer vision, robot learning, Bayesian state estimation, control theory, numerical optimization, biomechanics, manipulation, and human-robot interaction.
Type: Academia
Location: University of Washington-Seattle, Seattle, WA
URL: https://robotics.cs.washington.edu/
Related Capability Area(s): IM, RM

11.21 Integrated Structural Assembly of Advanced Composites (ISAAC)

Description: ISAAC is located at NASA's Langley Research Center in Hampton, Virginia. ISAAC is an automated robotic platform that supports research on the design, analysis, manufacturing and evaluation of advanced composite materials and structures. ISAAC is a state-of-the-art composite fabrication facility that was designed and built by Electro-impact. ISAAC can be scaled directly to Industry practice.
Type: NASA
Location: LaRC
URL: https://researchdirectorate.larc.nasa.gov/isaac/
Related Capability Area(s): RM, SC

11.22 Kirtland Air Force Base

Description: Kirtland Air Force Base specializes in research, development, and testing among its other missions and is home to AFRL's Space Vehicles Directorate which develops and transitions new space technologies to national security space use. The Space Warfighting Operations Research and Development (SWORD) Laboratory is a 26,000 square foot facility that hosts research and development programs that support space warfighting capabilities, including space domain awareness, spacecraft resilience, and autonomy.
Type: AFRL
Location: Kirtland Air Force Base, NM
URL: https://www.afrl.af.mil/News/Article-Display/Article/2629320/afrl-opens-space-warfighting-operations-research-and-development-sword-laborato/
Related Capability Area(s): RCDM, PRUMI, IM, ULRM, R

11.23 Laboratory for Computational Sensing and Robotics (LCSR)

Description: The Laboratory for Computational Sensing and Robotics (LCSR) is located in Baltimore, Maryland at Johns Hopkins University. LCSR's mission is to create knowledge and foster innovation to further the field of robotics science and engineering. LCSR is a hub for students and researchers to focus on robotics engineering, development, and research.
Type: Academia
Location: Johns Hopkins University, Baltimore, MD
URL: https://lcsr.jhu.edu/
Related Capability Area(s): IM

11.24 Lunar Lab and Regolith Testbeds

Description: The Lunar Lab and Regolith Testbeds are located at NASA's Ames Research Center in Mountain View, California. The facility houses a lunar lab with multiple testbeds and a variety of lunar simulants. It has recently been equipped with a new dust mitigation and safety system so the testbeds can be customized for specific research.
Type: NASA
Location: ARC
URL: https://sservi.nasa.gov/testbed/
Related Capability Area(s): SC

11.25 Maryland Robotics Center

Description: The Maryland Robotics Center is located at the University of Maryland, College Park. This interdisciplinary research facility's mission is to advance robotic systems and various applications of robotics through educational programs and research. The center has 26 labs for robotics research which include all aspects of robotics, including robotic platforms, autonomy for robotics systems, and the design of component technologies.
Type: Academia
Location: University of Maryland, College Park, MD
URL: https://robotics.umd.edu/facilities
Related Capability Area(s): RM

11.26 Materials and Processes Laboratory

Description: The Material and Processing Laboratory is located at NASA's Marshall Space Flight Center in Huntsville, Alabama. The laboratory has experience in metals, composites, additive manufacturing, non-destructive evaluation, and fracture and failure analysis. The laboratory also provides capabilities including materials testing, damage tolerance assessments, and environmental effects.
Type: NASA
Location: MSFC
URL: https://www.nasa.gov/sites/default/files/atoms/files/5-565173b_mpl.pdf
Related Capability Area(s): PGM

11.27 Measurement System Laboratory (MSL)

Description: The MSL is a 175,000-square-foot, five-story laboratory containing 40 state-of-the-art research labs and workspace to enable the development, testing, and implementation of new sensor and instrument technologies. Serving as the primary research and development facility for multiple NASA focus areas, the goal of the MSL is to enable the agency in achieving its missions in space exploration, science, and aeronautics with a flexible, modular design that utilizes shared facilities and capability with an emphasis on collaboration.
Type: NASA
Location: LaRC
URL: https://www.youtube.com/watch?v=-Yn5k7_fQys
Related Capability Area(s): IM

11.28 Multi-level Agile Cross-disciplinary Revolutionary Operations (MACRO) Lab

Description: The MACRO lab supports full-scale autonomous assembly of large space structures. It is a multi-level facility (recessed floors and elevated ceilings) that will enable operational testing of environmental scenarios (orbital, surface, and sub-surface). The lab integrates Langley Research Center's expertise and capabilities in autonomy, structures, predictive modeling, simulation, and systems analysis. Attached to the lab is a room with dark walls and ceiling to support testing of sub-scale autonomous robotic operations and metrology systems.
Type: NASA
Location: LaRC
Related Capability Area(s): RM

11.29 Naval Center for Space Technology (NCST)

Description: The Naval Center for Space Technology (NCST) at the U.S. Naval Research Laboratory (NRL) assists with the development of all areas of Navy space program interest from basic research to spacecraft development. The Robotic Servicing of Geosynchronous Satellites (RSGS) robotic servicing payload is being developed and tested at NCST.
Type: NRL
Location: Washington, DC
URL: https://www.nrl.navy.mil/Our-Work/Areas-of-Research/Naval-Center-for-Space-Technology/
Related Capability Area(s): PRUMI, RM, RCDM

11.30 Planetary Analog Test Site

Description: Planetary Analog Test Site, known as the Rock Yard, at NASA's Johnson Space Center in Houston, provides a large multi-acre test area which simulates general features of the lunar and Martian surface terrain environment consisting of various slopes, grades, simulated craters and strewn rock field conditions.
Type: NASA
Location: JSC
URL:
https://www.nasa.gov/centers/johnson/engineering/integrated_environments/space_analog_testing/index.html
Related Capability Area(s): RM, SC, IM

11.31 Raven

Description: Raven is a NASA flight experiment conducted on the International Space Station (ISS) to facilitate the development and validation of Autonomous Rendezvous and Capture (AR&C) technologies. Its mission aims to demonstrate advanced sensors, vision processing algorithms, and high-speed space-rated avionics, forming an autonomous navigation system.
Type: NASA
Location: ISS
URL: https://nexis.gsfc.nasa.gov/raven.html
Related Capability Area(s): RPOC

11.32 ReFabricator

Description: ReFabricator is an advanced recycling system aboard the International Space Station (ISS), developed by NASA in collaboration with Tethers Unlimited Inc. It facilitates the recycling of plastic waste and 3D printing of new items, promoting sustainability and reducing the reliance on resupply missions from Earth.
Type: NASA
Location: ISS
URL: https://science.nasa.gov/science-news/news-articles/the-in-space-refabricator
Related Capability Area(s): PGM

11.33 Robotic Operations Center

Description: The Robotic Operations Center, or ROC, is the newest facility for satellite servicing development. Within its black, curtain-lined walls, the team is testing technologies and operations for multiple exploration and science missions, including the OSAM-1 mission. The ROC has been continuing and expanding the work of the Servicing Technology Center since the summer of 2015 and houses multiple robots including a hexapod robot which simulates the movement of a satellite in space.
Type: NASA
Location: GSFC
URL: https://nexis.gsfc.nasa.gov/facility.html
Related Capability Area(s): RM

11.34 Robotics and Autonomous Systems Center (RASC)

Description: RASC research spans the major areas of robotics, including health, service, socially assistive, distributed, networked, marine, aerial, humanoid, haptics, space, robot vision and robot learning, and impacts a broad spectrum of applications, including assistance, training and rehabilitation, education, environmental monitoring, emergency response, homeland security, and entertainment.
Type: Academia
Location: University of Southern California, Los Angeles, CA
URL: https://rasc.usc.edu/
Related Capability Area(s): IM

11.35 Robotics and Mechanisms Lab (RoMeLa)

Description: RoMeLa is a state-of-the-art robotics research facility for graduate and undergraduate research and education with an emphasis on studying robotics.
Type: Academia
Location: University of California, Los Angeles, CA
URL: https://www.romela.org/
Related Capability Area(s): RM

11.36 Robotics and Mechtronics Lab

Description: Students can study areas such as robotic intelligence, vision, system dynamics and control, human-robotic interactions, machine learning, industrial automation.
Type: Academia
Location: Virginia Polytechnic Institute and State University, Blacksburg, VA
URL: https://autonomyandrobotics.centers.vt.edu/groups/rml.html
Related Capability Area(s): IM, RM

11.37 Robotics Lab

Description: The Planetary Robotics Laboratory (PRL) is a facility dedicated to rapid prototyping of robotic systems and algorithms for space and terrestrial applications. It focuses on designing, testing, and coordinating mobile and manipulative robots, including limb-controlled robots for in-space construction and multiple heterogeneous rovers for surface operations, with simulated natural terrain capabilities.
Type: NASA
Location: JPL
URL: https://www-robotics.jpl.nasa.gov/
Related Capability Area(s): RM

11.38 Roverscape

Description: The NASA Ames Roverscape is an 11,500 square meter, outdoor, robotics research, development, and test facility. The Roverscape is designed to support testing of mobile robot locomotion, navigation, and operations. The Roverscape is also suitable for conducting simulations of planetary surface missions.
Type: NASA
Location: ARC
URL: https://www.nasa.gov/feature/roverscape
Related Capability Area(s): SC

11.39 Satellite Servicing Technology Center

Description: The Servicing Technology Center (STC), established in 2011, serves as a pivotal hub for technology and operations development. With a primary focus on NASA's Robotic Refueling Mission (RRM), the STC facilitates the integration, testing, and refinement of satellite-servicing tools and techniques for on-orbit operations on the International Space Station, contributing significantly to the advancement of space robotics.
Type: NASA
Location: GSFC
URL: https://nexis.gsfc.nasa.gov/facility.html
Related Capability Area(s): PRUMI

11.40 Simulated Lunar Operations Laboratory

Description: The SLOPE lab is a unique indoor laboratory designed to mimic lunar and planetary surface operations. The lab contains several large soil bins for rover testing, including an adjustable tilt-bed as well as equipment for evaluating performance of tires, excavation tools and other vehicle components.
Type: NASA
Location: GRC
URL: https://www.nasa.gov/nasaglenntours/2023/the-simulated-lunar-operations-lab-slope-tour/
Related Capability Area(s): SC

11.41 Simulation, Emulation, Navigation, Sensors and STAR (SENSS) Laboratory

Description: The Simulation, Emulation, Navigation, Sensors and STAR (SENSS) Laboratory is a facility at NASA Johnson Space Center which supports the development and testing of guidance, navigation, and control algorithms for rendezvous and proximity operations and entry, descent, and landing activities. The facility features the 6-degree-of-freedom tendon-actuated robot (STAR), which can support a 50 kg payload.
Type: NASA
Location: JSC
URL: https://ntrs.nasa.gov/citations/20230000141
Related Capability Area(s): RPOC

11.42 Six-Degree-of-Freedom Dynamic Test System

Description: Located at Johnson Space Center in Houston, Texas, the Six-Degree-of-Freedom Dynamic Test System is a real-time, 6-DOF, short range motion base simulator. It was designed to simulate the relative dynamics of two bodies in space docking or berthing. Mikrolar's P8050 Hexapod is being used to upgrade the payload capabilities from the previous hexapod.
Type: NASA
Location: JSC
URL: https://www.mikrolar.com/nasa-jsc
https://ntrs.nasa.gov/api/citations/20120016822/downloads/20120016822.pdf
Related Capability Area(s): RCDM

11.43 Small Satellite Dynamics Testbed

Description: The Small Satellite Dynamics Testbed (SSDT) at the Jet Propulsion Laboratory offers infrastructure that supports small satellite guidance and control testing in a relevant dynamics environment while constrained by the gravity of Earth.
Type: NASA
Location: JPL
URL: https://scienceandtechnology.jpl.nasa.gov/small-satellite-dynamics-testbed-ssdt
Related Capability Area(s): RCDM

11.44 Space Rendezvous Laboratory (SLAB)

Description: (SLAB) is a research and development laboratory that performs fundamental and applied research at the intersection of Astrodynamics, GN&C, Environment Characterization and Decision Making to enable future Distributed Space Systems (DSS).
Type: Academia
Location: Stanford
URL: https://slab.stanford.edu/
Related Capability Area(s): IM

11.45 Space Robotics Laboratory (SRL)

Description: The Space Robotics Laboratory at the U.S. Naval Research Laboratory (NRL) provides testbeds to develop robotic systems and demonstrate their operations. The lab enables hardware-in-the-loop testing and is supporting the test and development of the Robotic Servicing of Geosynchronous Satellites (RSGS) robotic servicing payload.
Type: NRL
Location: Washington, DC
URL: https://www.nrl.navy.mil/Our-Work/Areas-of-Research/Naval-Center-for-Space-Technology/
Related Capability Area(s): PRUMI, RM, RCDM

11.46 Space Systems Laboratory

Description: The Space Systems Laboratory is located at the University of Maryland, College Park, Maryland. The lab is centered around the Neutral Buoyancy Research Facility, a 50-foot diameter, 25-foot-deep water tank used to simulate the microgravity environment of space. The Space Systems Laboratory focuses on research in space robotics, space simulation, human factors, and artificial intelligence applications.
Type: Academia
Location: University of Maryland, College Park, MD
URL: https://ssl.umd.edu/about
Related Capability Area(s): IM

11.47 Space Systems Laboratory (SSL)

Description: The Space Systems Laboratory, founded in 1995, is located at the Massachusetts Institute of Technology in Cambridge, Massachusetts. The lab focuses on cutting-edge research projects that will contribute to current and future exploration and development of space. The lab has multiple facilities to support the design, fabrication, and test of flight hardware.
Type: Academia
Location: Massachusetts Institute of Technology, Cambridge, MA
URL: https://ssl.scripts.mit.edu/www/
Related Capability Area(s): RPOC, SMA

11.48 Spacecraft Structures and Dynamics Lab

Description: The research complex, established in 1962, supports spacecraft and launch vehicle dynamics research, featuring a 55-foot Vacuum Chamber and a previously used 60-foot Vacuum Sphere. The facility includes a large backstop for structural dynamics testing of launch vehicles and spacecraft components, along with a 107-foot tower used for model tests of the US Air Force Thor family of launch vehicles, now primarily dedicated to deployable space structures research.
Type: NASA
Location: LaRC
URL: https://researchdirectorate.larc.nasa.gov/facilities-capabilities/
Related Capability Area(s): RM, IM, SC

11.49 Structures and Materials Lab

Description: The James H Starnes, Jr. Structures and Materials Lab is located at the NASA Langley Research Center in Hampton, Virginia. The lab conducts materials and structural analysis for aircraft design and development of new structural concepts for aeronautical and space vehicles. The facility focuses on experiments in metallurgy, composite materials, environmental effects, and manufacturing technology to create materials that can withstand various conditions. Additionally, the lab houses a 1.2 million lbf test frame from the 1940s, used for researching robotics and in-space assembly.
Type: NASA
Location: LaRC
URL: https://ntrs.nasa.gov/citations/20220014087
Related Capability Area(s): SC, RM, SMA

11.50 Swamp Works Laboratory

Description: This Swamp Works Laboratory is a research and technology incubator based out of Kennedy Space Center's Science and Technology Division, located on Merritt Island, Florida. The lab hosts a range of projects in areas such as applied physics, cryogenics, electrostatics and surface physics, robotics integration, advanced manufacturing, and 3-D printing.
Type: NASA
Location: KSC
URL: https://www.nasa.gov/sites/default/files/atoms/files/sp-2017-01-008-ksc_ub_swamp_works_flyer_508.pdf
Related Capability Area(s): RM, PGM, SC, IM

11.51 The Institute for Robotics and Intelligent Machines

Description: The Institute for Robotics and Intelligent Machines is located at the Georgia Institute of Technology in Atlanta, Georgia. The Institute supports and facilitates several research facilities that advance the boundaries of robotics research. Fundamental research includes expertise in mechanics, control, perception, artificial intelligence and cognition, interaction, and systems.
Type: Academia
Location: Georgia Institute of Technology, Atlanta, GA
URL: https://research.gatech.edu/robotics
Related Capability Area(s): RM

11.52 The Japanese Experiment Module (JEM) Exposed Facility

Description: The Japanese Experiment Module's (JEM) Exposed Facility (EF) is an external platform on the International Space Station (ISS), developed by the Japan Aerospace Exploration Agency (JAXA). It enables the installation of scientific experiments and instruments exposed directly to the space environment, fostering a wide range of research activities in microgravity conditions.
Type: JAXA
Location: ISS
URL: https://humans-in-space.jaxa.jp/en/biz-lab/experiment/facility/ef/
Related Capability Area(s): RM

11.53 The Robotics Institute

Description: The Robotics Institute was established in 1979 and is located at Carnegie Mellon University in Pittsburg, Pennsylvania. The facility has 100,000 square feet for faculty, students, and researchers to conduct basic and applied research in robotics technologies. Robotics research work is primarily focused on core technologies like locomotion, control, machine learning, and computer vision.
Type: Academia
Location: Carnegie Mellon University, Pittsburg, PA
URL: https://www.ri.cmu.edu/about/
Related Capability Area(s): RM

11.54 The University of Michigan Robotics Institute

Description: The University of Michigan Robotics Institute is located at the University of Michigan in Ann Arbor, Michigan. The Ford Motor Company partnered with the University of Michigan to build the Ford Robotics building. The facility was designed to serve as collaborative environment with labs, classrooms, an indoor flight lab for flying autonomous vehicles, and an outdoor obstacle course for walking robots.
Type: Academia
Location: University of Michigan, Ann Arbor, MI
URL: https://robotics.umich.edu/
Related Capability Area(s): RM

11.55 West Virginia Robotic Technology Center (WVRTC)

Description: The West Virginia Robotic Technology Center, which is located in Fairmont, West Virginia, conducts research that supports robotic space operations and technology. The prime focus is to support NASA's Goddard Space Flight Center's research efforts, which include efforts to capture orbiting satellites for refueling and repair. The WVRTC houses multiple robotic platforms for technology development to test machine vision algorithms, haptics sensors, and teleoperation procedures.
Type: Academia
Location: West Virginia University, WV
URL: https://wvrtc.wvu.edu/
Related Capability Area(s): RM, RPOC

11.56 Wright-Patterson Air Force Base

Description: Wright-Patterson Air Force Base, located in Dayton, Ohio, is one of the largest Air Force bases in the United States and houses the headquarters for the Air Force Research Laboratory (AFRL). The AFRL facilities support robotic control systems, additive manufacturing for space systems, and advanced materials for in-space manufacturing and assembly.
Type: AFRL
Location: Wright-Patterson Air Force Base, OH
URL: https://www.afrl.af.mil/
Related Capability Area(s): SMA, PGM

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