Evolution of On-Orbit Robotics Operations and Technology for Commercial Servicing

Clean Space Industrial Days – 24 October 2018
Maxar Technologies

- Vertically integrated new space company with products across the value chain for every moment before and after launch.

- Global leader in satellite communications, earth observation, space robotics, on-orbit servicing, data analytics, ground networks, propulsion systems, cybersecurity and the protection / monitoring of space assets.

- Provider of innovative cost-effective space solutions that generate customer value by integrating leading-edge capabilities.

- ~ $3 billion revenue / 6,500 employees / international customer base
MDA – Canada’s Space Company

**Space Radar Solutions**
- Satellite-based radar missions and systems
- Radar analytics, services and imagery
- Mission and infrastructure operations

**Earth Observation Systems**
- Multi-mission Earth observation ground systems
- Mission planning through reception, processing and analytics
- Enterprise geospatial systems

**Robotics, Sensors and Automation**
- Robotic manipulators, interfaces and tools
- Rovers, sensors and mechanisms
- Space exploration, on-orbit servicing and space debris removal
- Medical, nuclear and industrial automation

**Satellite Antennas, Electronics and Payloads**
- Engineering, manufacturing and testing of satellite antennas, electronics and payloads
- Space-based communications, radar, exploration and science
- High-volume production for large satellite constellations

**Defence Systems**
- System integration and complex system delivery and operations
- C4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance)
- Engineering, production, in-service support partner
40+ Years Heritage in On-Orbit Servicing

- 90 Space Shuttle missions with robotic operations
- 18+ years of ISS robotic assembly, operations and maintenance

Space Shuttle and International Space Station experience provides foundation for the design and execution of future remotely operated Servicing Solutions

Canadarm2 robotic free flyer capture and berthing of SpaceX Dragon
# On-Orbit Servicing Market Trends

<table>
<thead>
<tr>
<th></th>
<th>Today + Tomorrow</th>
<th>Tomorrow</th>
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<tbody>
<tr>
<td><strong>Users</strong></td>
<td>Institutional Programs (e.g. Mobile Satellite Servicing)</td>
<td>Commercial Customers (TBD)</td>
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<tr>
<td><strong>Safety</strong></td>
<td>Robotics meet extremely stringent requirements for human spaceflight</td>
<td>Robotics “do not harm” either chaser or client spacecraft</td>
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<td><strong>Flexibility</strong></td>
<td>Multiple missions / multiple applications / multiple robotic tools</td>
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<td><strong>Affordability</strong></td>
<td>Custom robotics solutions funded by national space agencies</td>
<td>Standard robotics solutions that close the business case</td>
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<td><strong>Mass / Volume / Power</strong></td>
<td>Fewer constraints</td>
<td>More constraints</td>
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<tr>
<td><strong>Clients</strong></td>
<td>Cooperative (TRL 9)</td>
<td>Uncooperative (TRL 4)</td>
</tr>
<tr>
<td><strong>Interfaces</strong></td>
<td>Prepared (robotically compatible) (e.g. grapple fixtures, vision targets, etc.) (robot-payload ICD)</td>
<td>Unprepared (no interfaces, no targets, no alignments, reflective surfaces, etc.)</td>
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<tr>
<td><strong>Operations</strong></td>
<td>Tele-Operations</td>
<td>Autonomy (cost, safety, latency, off-nominal conditions, etc.)</td>
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<tr>
<td><strong>Use Cases</strong></td>
<td>Inspection, Anomaly Resolution, ORU Extraction / Insertion (Payload Upgrades) and Capture &amp; Berthing</td>
<td>On-Orbit Assembly and Refueling</td>
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Operations Flow for On-Orbit Servicing

Start → Detection of Client Satellite → Rendezvous with Client → Characterization of Client → Synchronization to Client

Robotic Capture of Client → Robotic Berthing of Client → Robotic Inspection of Client → Robotic Servicing of Client → Robotic Refueling of Client

Robotic Release of Client → Phasing to Next Client Satellite → Finish

Rendezvous and Proximity Operations
Robotics System Operations
1. Launch

2. Orbit Maneuvering
   Routine spacecraft operations

3. Far Field Rendezvous
   US Air Force XSS-11 mission used MDA provided rendezvous sensor and navigation data

4. Proximity Operations
   DARPA Orbital Express and visiting vehicle capture operations on ISS using tele-operated and autonomous systems

5. Robotic Capture & Berthing (Autonomous)
   NGSC Testbed Demonstration e.Deorbit Capture Simulations
3. Far Field Rendezvous

4. Proximity Operations

Enabling Technologies
- Lidar sensors
- Avionics software
- Space qualified cameras with customizable lenses
- Real-time data compression
- On-board image processing
- RPO sensor suite
- Pose estimation algorithms
- Safety critical implementation
5. Robotic Capture & Berthing (Autonomous)

- End Effector and Capture Tools
- Robotic Arm System
- Vision System for Autonomous Capture and Berthing
5a. Vision System

- Natural feature detection and tracking
- 6 DOF relative pose estimation
- Real-time feedback (20Hz or higher) to the robotic arm

Enabling Technologies

- Cameras with space heritage
- Smart sensors
- Image processing units (integrated, low power)
- Targets and berthing cue systems
- Safety critical algorithms
5b. Robotic Arm System

- Dexterous manipulator with low friction joints with force feedback
- Full or variable autonomy
- High bandwidth response with precise tracking

**Enabling Technologies**

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<tr>
<td>Robotic manipulator</td>
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<tr>
<td>Electromechanical joints with embedded sensors and actuators</td>
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<tr>
<td>Actuator control electronics</td>
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<tr>
<td>Human Machine Interface (HMI)</td>
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<tr>
<td>Ground Support Equipment (GSE)</td>
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5. End Effectors

- Designed for robotic operations
- Designed for worksite viewing
- 30+ years of flight experience
- Prepared and Unprepared Interfaces
- Load Capability from 5000+ Nm for ISS operations to ounces for servicing.
- Force-Moment Accommodation
- Tele-operated or autonomous
- GEO, LEO, or exploration
- Minimal mass, and power
- Integrated Sensors

Products

- End effector for Satellite capture
- Fully motorized and controlled
- Power and data interfaces
- Fuel Transfer interfaces
- Mass and power optimized

Routine robotic operations on ISS, Space Shuttle and Orbital Express

6. Servicing

6a Client Inspection / Worksite Preparation

Routine robotic operations on ISS, Space Shuttle and Orbital Express

6b Thermal Blanket Removal

Demonstrated at Hubble Space Telescope lab at Goddard Space Flight Centre

6c Lockwire Removal

Demonstrated in robotic test bed
6. Servicing

6d ORU Extraction / Insertion
Demonstrated on ISS Orbital Express and Hubble Demonstration

6e Refueling
Demonstrated on NGSC Laboratory Prototype

Enabling Technologies

- End effector with tool changer, torque driver, power / data interfaces & fluid interconnects
- Tool caddy
- Special purpose tools (e.g. refueling)
- Multi-purpose tools for mass optimization
- Avionics software (arm and joint control)
- Control systems for unprepared interfaces
- Real-time vision system to enable autonomy
- Force / moment control sensors
On-Orbit Servicing Heritage

- MDA is the global space robotics leader with 40+ years heritage. It not only provides technology and solutions but also operates and maintains robotic systems in space (e.g. MDA operates the SPDM on the MSS every day).

- In addition to designing, building, operating and maintaining the robotics systems on the International Space Station, MDA has worked with ESA and all of the European LSIs on the e.Deorbit program for the past six years.

- MDA’s extensive technical and operational heritage developed on institutional programs is a solid foundation for unlocking the potential of the commercial on-orbit servicing market.
The on-orbit servicing market is expanding from institutional programs to commercial customers.

Many of the critical technology building blocks for the nascent commercial on-orbit servicing market exist.

MDA would be pleased to discuss your requirements for space robotics solutions to address opportunities in the on-orbit servicing (and debris removal) market.

Thank you for listening.
Questions?