



On-Orbit Servicing and Beyond: A Canadian Perspective

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Why On-Orbit Servicing?

- It's 3am, on a high way going in Abitibi, north of Canada, a tractor-trailer breaks down on the side of the road...
- The Ground Solution:
 - ◆ Send in a Servicing Vehicle!
- The Space Solution:
 - ◆ Write off the Truck as a total loss
 - ◆ Abandon the cargo & collect insurance
 - ◆ Leave the Driver for the wolves

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Why On-Orbit Servicing?

- Why is Abandonment the Norm?
 - ◆ Cannot reach the satellite
 - ◆ launch vehicle shortages
 - ◆ Replacement cost same or lower than repair
 - ◆ Unable to fix current satellites on-orbit
- Space servicing architecture needed to reduce cost

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On-Orbit Servicing & Assembly

- Important thrust in CSA Tech. Req. Doc.
- Scenarios defined for horizon up to 30 years
 - ◆ Potential missions or activities
- Focus on technologies required
 - ◆ Robotics and intelligent systems
 - ◆ Miniaturisation
 - ◆ Communication

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Scenarios for the Future

0-5 yrs: MSS Ground Control

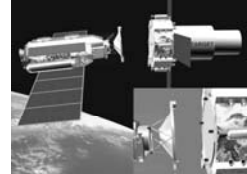
- Ground control of MSS using pre-scripted operation sequences
 - ◆ Wake-up procedure
 - ◆ Automatic trajectory
 - ◆ Capture of payloads
- For safety, autonomy limited to reactive actions
- RT supervision from ground
 - ◆ Decisions taken on the ground
- Ground segment equipped for:
 - ◆ Calibration of the MSS sensors
 - ◆ Fault-detection based on telemetry data



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5-10 yrs: Cooperative Spacecrafts

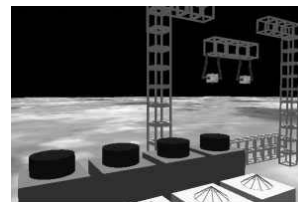
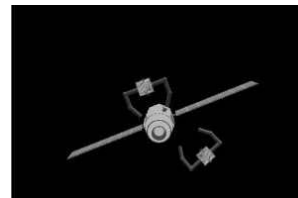
- Chaser with special tools capture satellites
 - ◆ designed to be serviced or not
- Ground teleoperation but more autonomy
 - ◆ e.g. navigation and inspection
- Free-flyer relocates satellite on a new orbit
 - ◆ Refuelling or by adding new bus
- Servicing part of design for new satellites
- Service spacecraft put microsattellites in orbit
 - ◆ Reduce launch mass



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10-20 yrs: Servicing & Assembly

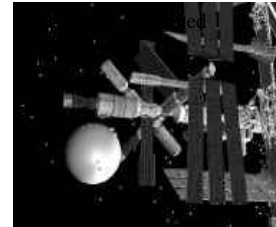
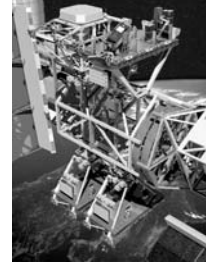
- Robotic spacecrafts collaborate autonomously to perform complex tasks
 - ◆ Capture of uncontrolled spinning satellites
 - ◆ Build simple space structure
 - ◆ Clean space debris
- On-orbit refuelling and upgrading is common
- Many spacecrafts servicable
 - ◆ Specialized EE exist to capture others
- Satellites designed with upgradable modules
 - ◆ e.g communication satellites T/R module
- Dexterity and level of intelligence is now enough to permit maintenance and repair
- Network of robotic spacecraft collaborate
 - ◆ Inter-spacecraft communication: optical



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10-20 yrs: Preparing for Human

- Cost of unmanned space systems is coming down considerably
- Launch is main driver for high costs
- Space based resources is underway:
 - ◆ Fuel generation
 - ◆ Space manufacturing of simple structures
- Technologies to support permanent human presence in space:
 - ◆ Radiation protection
 - ◆ Medical diagnosis



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20-30 yrs: Spaceship Assembly

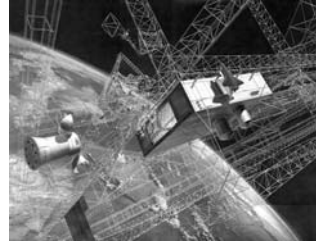
- Colony of heterogeneous robot is used to build the first manned spaceship for exploration
- Wireless communication allows exchanges of robot sensor data and sharing of computation resources among the robots
- Collaboration of robots to perform advanced tasks:
 - ◆ Grasping
 - ◆ Assembling
 - ◆ Moving of structures
- Some robots are dedicated to quality assurance to insure the proper ship assembly
- Pico-satellites reporting to the robots are used for inspection and detection of potential problems
- First LEO hotel is being constructed using space-based resources



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30 yrs+: Large Structures

- Building big solar power structures more common
- Intelligent robotic spacecraft colonies
 - ◆ No operator in the loop required
 - ◆ Autonomous planning and execution
- Knowledge sharing within colony
- Robotic S/C recombine to form new topologies
- Robotic S/C life increased with the self-diagnostic/repair capability

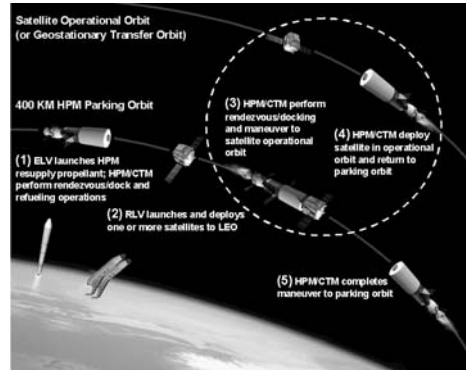


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Back to the Present

Orbital Express Program

- Increasing interest of US Air Force in space servicing
 - ◆ Change orbit of defence satellites on-demand
 - ◆ Refuelling capability needed



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Orbital Express Program

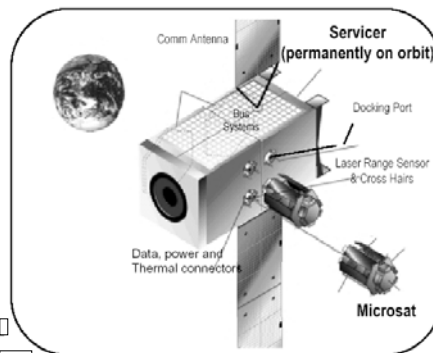
- \$100 million contract for Phase II of Orbital Express program to Boeing Phantom Works
- MDR part of the team to develop autonomous techniques for:
 - ◆ On-orbit re-supply
 - ◆ Upgrading
 - ◆ Refuelling
 - ◆ Satellites reconfiguration



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MicroSatellite Capability / Architecture

- Orbital Express ASTRO vehicle can provide bus functions to MicroSatellites
 - ◆ Maneuverability / orbit raising
 - ◆ Power
 - ◆ Communications
 - ◆ Attitude control
- More satellite mass devoted to payload



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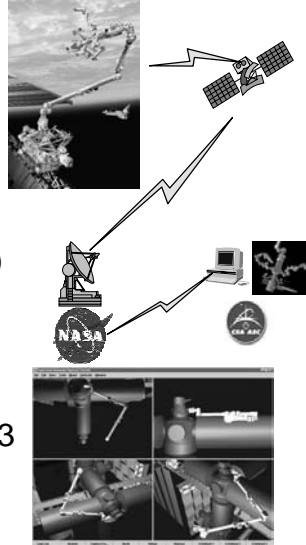
Canadian Developments

- Focused on enabling technologies
- Ground control technologies
- New arm/docking mechanisms
- Vision for rendez-vous & docking
- Simulation & experimental validation

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Robotics Ground Operations

- Simplify space robot operation
 - ◆ Not enough crew time available
 - ◆ Issue with MSS is safety
- Existing ground control technologies
 - ◆ Canada: IIRO/ROSA (MDR-CSA)
 - ◆ Germany: Rotex/Marco (DLR)
 - ◆ ESA: Dream (Trasys in Belgium)
- MSS Ground Control
 - ◆ Operation concept for March 2003
 - ◆ Independent safety monitoring
 - ◆ Space demonstration: SSRMS



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Autonomous Robotics & Ground Operation

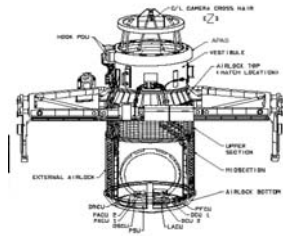
- R&D platform to test advance concepts for autonomous robotics and ground operation
- Applications: increase autonomy
 - ◆ MSS ground control
 - ◆ On-orbit robotics
 - ◆ Planetary rovers.
- Implementation on CART
 - ◆ SPDM likes operation
 - ◆ On-orbit servicing



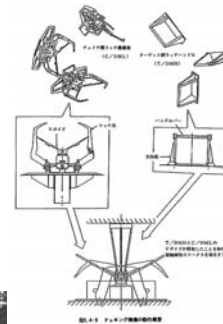
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Existing Docking Mechanisms

- Orbiter Docking System (NASA) and Adrogynous Peripheral Assembling System (Russia)



- Capture mechanism of ETS-VII (NASDA)



- LEE & PDGF (CSA/MDR)



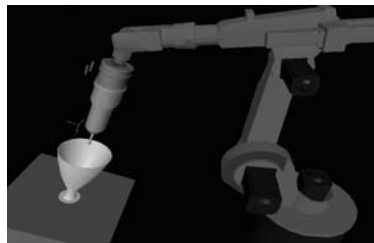
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New Docking Mechanisms

- MD Robotics end-effector



- DLR Capture Mechanism



- Michigan Aerospace Corporation docking mechanism



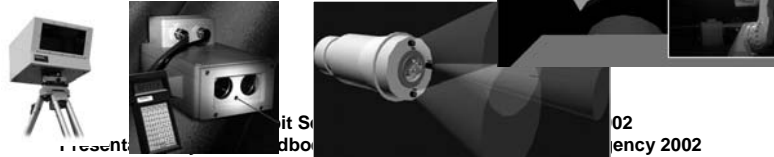
- Starsys three-fingered grappling and docking mechanism



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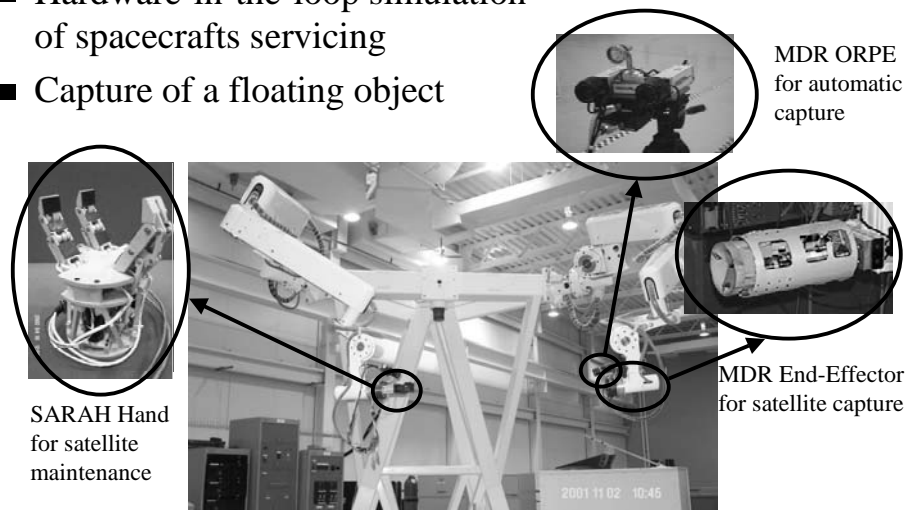
Vision Systems for Space

- Key Canadian technology for space robotics
- New generation (target free)
 - ◆ Laser Camera System (Neptec)
 - ◆ robust versus lighting condition
 - ◆ tested on Space Shuttle 2001
 - ◆ Object Recognition and Pose Estimation (MD-Robotics)
 - ◆ based on natural features
 - ◆ LIDAR System (Optech)



Experimental validation

- Hardware-in-the-loop simulation of spacecrafts servicing
- Capture of a floating object



SARAH Hand for satellite maintenance

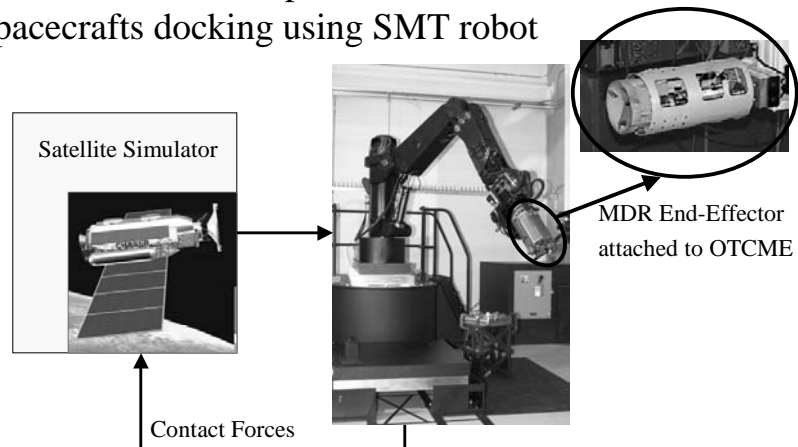
MDR ORPE for automatic capture

MDR End-Effector for satellite capture

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Hardware-in-the-Loop Verification

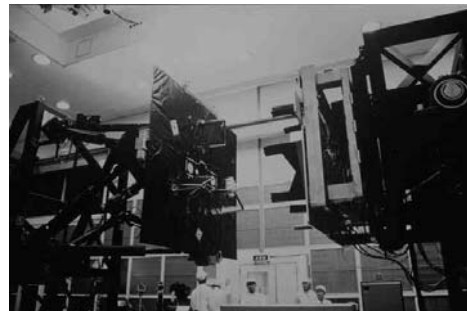
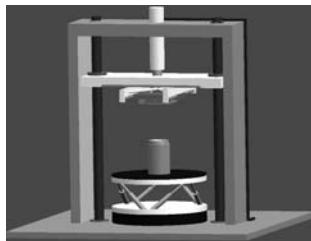
- Hardware-in-the-loop simulation of spacecrafts docking using SMT robot



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Other Testbeds

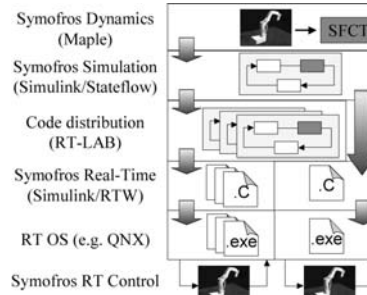
- 6 dof parallel platform for higher bandwidth, positions accuracy, and payload capacity
- Japanese facility for full scale satellite rendezvous testing



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Modeling & Simulation

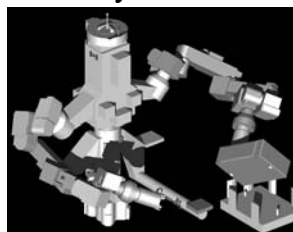
- Simulation required for
 - ◆ Operation and predictive control
 - ◆ Training and on board training
- Simulators developed:
 - ◆ MSS Operation and Training Simulator
 - ◆ SYMOFROS: CSA environment for modeling, simulation, control and real-time implementation



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Contact Dynamics Simulation

- MDR Contact Dynamic Toolkit: simulation
 - ◆ Non-real time
 - ◆ Real-time
 - ◆ Parameter identification still issue
- Advanced research in contact dynamics
 - ◆ Contact Detection
 - ◆ Contact Response
 - ◆ Numerical Integration
- Experimental verification



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Conclusion

- On-orbit servicing & assembly
 - ◆ Promising potential
 - ◆ Next commercial business
- Required concerted efforts
 - ◆ Technologies
 - ◆ Satellite developer
 - ◆ Satellite operator
- Canada investing in enabling technologies

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QUESTIONS?