

## AN OVERVIEW OF THE CSA RECENT ACTIVITIES IN SPACE ROBOTICS

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### ABSTRACT

Robotics is one of Canada's four key industrial capabilities in space. Since Canadarm 1, which flew many years aboard the Space Shuttles, Canada has pursued to develop and expand its expertise in Space Robotics. These investments have opened the door to Canadian astronaut flights, commercial opportunities and have helped to forge the Canadian leadership in space robotics.

Current developments aim at ensuring that Canadian technologies and science expertise play a key role in future human spaceflight and planetary exploration missions. Canadian space robotics technologies are now expanding beyond space manipulators, including rovers, robotics tools, active vision sensors, and science instruments to explore Mars, Moon and Asteroids. Next year, Canada will celebrate twenty years of operations for the Canadarm 2; the Mobile Servicing System (MSS) is still used on a weekly basis for maintaining elements on the International Space Station (ISS) and to perform experiments and rendezvous with commercial visiting vehicles. In addition, the CSA has been allocated an extra CAD\$2.15 Billion for the next 24 years to implement the Canadarm 3 that will fly on the Lunar Orbital Platform-Gateway (referred as the Lunar Gateway) and to explore the Moon surface and its vicinity using rovers and orbiters. This investment will increase Canadian robotics and science capabilities over the next five years and beyond.

This paper presents an overview of the most recent space robotics activities conducted under the leadership of the Canadian Space Agency as well as the current plans to explore the Moon. It also addresses long-term commitment such as the Canadarm 2 on the ISS as well as active vision systems to be delivered to the ISS. Finally, it provides an overview of upcoming projects such as the Lunar Accelerated Exploration Program (LEAP) and the Canadarm 3 to be delivered as part of the lunar Gateway.



Figure 1: Capture of Dragon by Canadarm 2

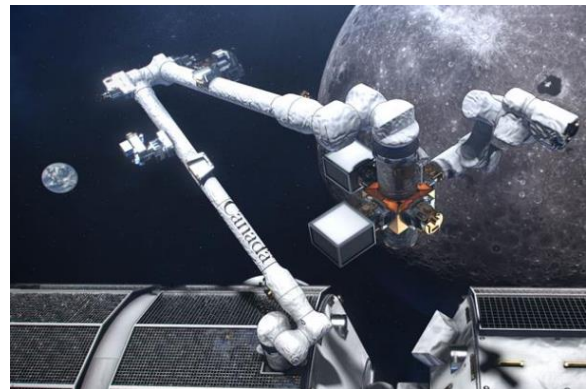


Figure 2: Canadarm 3 Concept on lunar Gateway



Figure 3: CSA Juno rover night driving simulation fall 2019

## 1 INTRODUCTION

In addition to its Canadarm 2 flagship mission under the International Space Station (ISS) contribution and the upcoming elements such as the Dexterous Deployment Vision System (DDVS) and the replacement cameras for the Mobile Servicing System (MSS), Canadian space robotics is expanding rapidly. In early 2019, the Prime Minister of Canada announced the Canadarm 3 and the Lunar Exploration Accelerated Program (LEAP) for a total investment of CAD\$2.15 Billion over 24 years. These programs will enable Canada to provide an advanced manipulator for the Lunar Gateway, develop payloads, and conduct science on and around the Moon. While the details of these contributions are being orchestrated, previous and ongoing studies and technology development are applied to form the basis of these international contributions to explore the Moon and its vicinity.

## 2 ORBITAL ROBOTICS

Orbital robotics is the field for which Canada is best known. Activities started in the 1970s with the provision of the Shuttle Remote Manipulator System (SRMS). Since then, Canada has also provided robotic elements to the International Space Station and occasionally, on orbit servicing missions and now expands towards a contribution to the Lunar Gateway.

### 2.1 International Space Station (ISS)

Canada's flagship space robotics program: the MSS on-board the ISS, has been ongoing since the launch of Canadarm 2 in 2001. With the extension of the ISS program to 2024, the lifetime of the MSS will be extended to 23 years, which goes beyond the original system designed lifetime. Year after year, the MSS is used routinely to conduct maintenance operations on the ISS and to capture incoming vehicles. Over the last eight years, the MSS has seen, on average, more than 650 hours of operation per year and as much as 1358 hours in 2019. With the increase in visiting vehicles and required maintenance, this number is increasing. In fact, after the replacement of the Latching End-Effector (LEE) and the planned replacement of the cameras, the On-Orbit Replacement Unit (ORU) concept, adopted during its development, is performing well and enabling to even go beyond what had initially been planned. As a matter of fact, replacement cameras are being tested on Earth and are planned to be installed over the next year, tackling the challenge of using more recent technologies while respecting the original interface requirements to ensure ease of replacement.

In addition to the replacement of various elements, new capabilities such as the MSS Application Computer (MAC) will be activated during the coming year to optimize the time required to conduct routine operations

and move towards increased autonomy of the Canadarm 2, with nearly 100% of the ISS robotic operations controlled remotely from the ground.

A second innovative project being developed for the ISS is the DDVS, a dual-purpose active vision system that will be capable of inspecting the ISS for damage and performing relative navigation for incoming vehicles. The configuration currently under development is derived from the successful Canadian TriDAR sensor. It uses a combination of sensors to cover a broad spectrum of specifications in terms of range, resolution and accuracy. Fig. 4 shows an artist's concept of the DDVS being manipulated by the Dextre robot.



Figure 4: DDVS sensor at the tip of Dextre

The system is designed to function with uncooperative targets (i.e. unmarked, no retro-reflectors), using only geometric information. In relative navigation mode, the long-range LIDAR sensor has a range of 2 m to 1 km and a rated accuracy (both in range and lateral) of 10 mm at 10 meter range. It also uses a far-field camera to complement the LIDAR information.

The DDVS sensor is designed for a five-year operational life and it will interface with the ISS Wi-Fi networking infrastructure. Its planned launch date is scheduled for 2022.

### 2.2 Human Space Flight Beyond LEO

With the growing pace of enabling manned exploration further beyond LEO, Canada has taken the steps over the last three to four years to define and take a strategic position. With the prime minister of Canada announcement in February 2019, Canada has confirmed its partnership with NASA to provide the robotics arm for the Lunar Gateway referred as the Canadarm 3 or DSXR. The advanced robotics arm will include three parts: a large 8.5 m long arm, a smaller dexterous arm and a set of exchangeable tools. It will be used to: maintain, repair and inspect the Gateway, capture

visiting vehicles, relocate Gateway modules, support astronauts during spacewalks and enable science both in cis-lunar orbit and on the surface of the Moon. Equipped with 4K cameras and built as a fully automated capable arm incorporating Artificial Intelligence (AI) features, the new Canadarm will provide autonomous operations. It is currently planned to be delivered along with part of the Gateway module using the NASA Space Launch Services (SLS) in 2026.



Figure 5: Artist rendering of Canadarm 3 grappling a visiting vehicle

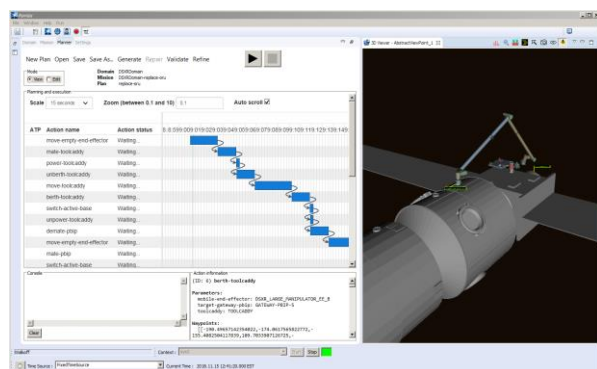


Figure 6: Snapshot of the System of Execution and Planning In Apogee (SEPIA) in development for automation of Canadarm 3

### 3 PLANETARY ROBOTICS

In addition to its traditional role in orbital robotics, Canada is expanding its space robotics capabilities to other application areas. One of the most promising area is planetary robotics where some of the know-how developed in past programs is being built upon and expanded.

#### 3.1 Mars

The Canadian Alpha Particle X-ray Spectrometer (APXS) is on the surface of Mars, operating at the end of the Curiosity rover Arm . Since its arrival to Gale

Crater in August 2012, APXS has now fulfilled eight years of operations.

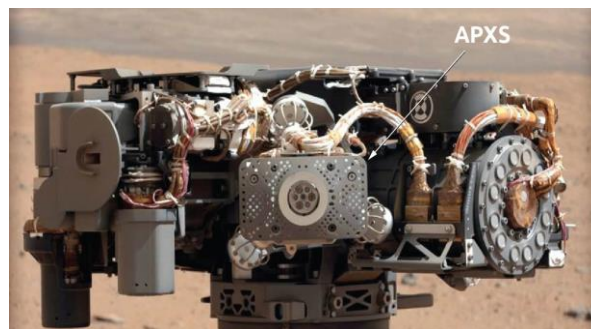


Figure 7: APXS on Mars, credit NASA[1]

In addition to science instruments such as APXS, the ExoMars Bogie Electro-Mechanical Assembly (BEMA), Actuator Drive Electronics (ADE) and the ExoMars Rover Navigation and Localization Cameras developed by MacDonald Dettwiler and Associates (MDA) have been delivered and going through testing under Canadian Contributions to the European Space Agency (ESA) [2].

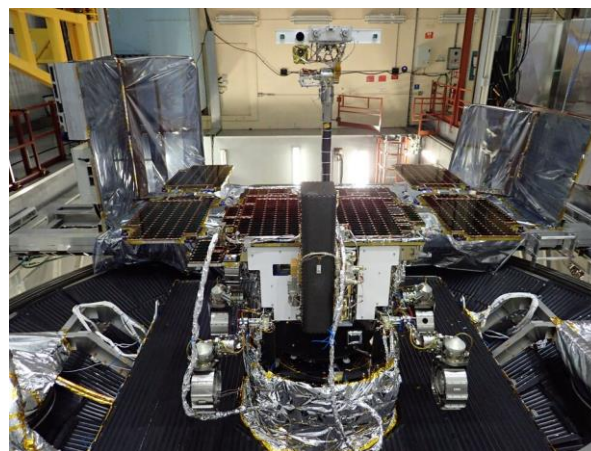


Figure 8: ExoMars rover testing, credit ESA

The next step in Mars exploration implies the return of sample tubes from the red planet. As part of this adventure, the CSA is currently contributing to the development of the Mars Sample Return (MSR) Sample Fetch Rover (SFR). This currently ongoing development is supported by MDA and benefits from their expertise acquired over the years by developing the BEMA program, rover technology development and the work performed with the CSA in 2016 to demonstrate an analogue fetch rover mission simulation. The fetch rover is a critical element of the Mars Sample Return suite of missions to bring the samples back to Earth.





Figure 9: CSA Sample Return Analogue Mission, Utah, USA 2016

### 3.2 Moon

Another key destination for planetary surface robotics is the Moon. The CSA, Canadian industry and academia have been recently involved extensively in an increasing number of studies, phases 0, technology development and analogue mission activities. To that effect, CSA has participated in ESA's Human-Enhanced Robotic Architecture and Capability for Lunar Exploration and Science (HERACLES) [3] study, to define the architecture for the next human missions to the lunar surface. In the context of an eventual return of humans to the Moon, ESA is leading the definition of precursor missions and related activities leading to surface human missions. CSA actively participated to the HERACLES study that focuses on having rovers, over 2-3 years, acquire and bring back Moon samples to a cis-lunar orbiting station for subsequent delivery and analysis on Earth. Over the last two years, two concept studies and two extended phases 0 have been completed in addition to a number of technology development activities, two analogue missions and a number of tests regarding lunar sample return. These activities resulted into the development and demonstration of multiple concepts for sample return rovers and even pressurized rovers under the International Space Exploration Coordination Group (ISECG) initiative.

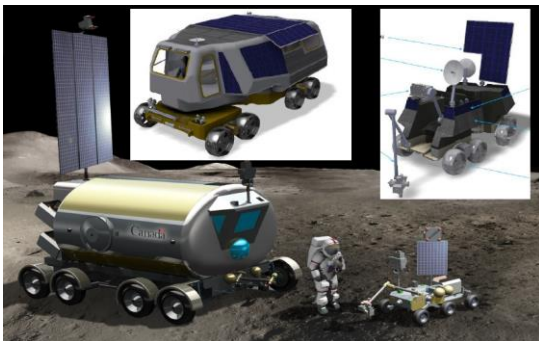


Figure 10: HERACLES & ISECG Canadian Lunar Rover concepts

Initiated in 2017, the joint ESA-CSA Lunar Exploration Analogue Deployment (LEAD) project [4] resulted in a suite of tests, demonstrations and joint simulations with the involvement of ESTEC, ESOC and CSA to fully exercise the surface capabilities and operations concept required to accomplish a mission such as HERACLES. This program resulted into multiple tests and a final simulation of an end-to-end lunar rover sample return mission involving science, engineering and operations, distributed between the three centers to perform a one-week complete analogue mission including the selection of samples, their capture and return to an ascent vehicle as per the HERACLES mission scenario. These activities were carried on using a suite of ESA and CSA tools including the CSA Software Suite Apogee [5], which were key to validate and establish lessons learned for the HERACLES mission, in particular for the feasibility assessment of the technology, science interactions in a real-time lunar context and via a largely distributed operation model. Fig. 11 shows the LEAD rover transferring a sample canister to a lander mockup [6], performed under this LEAD project.

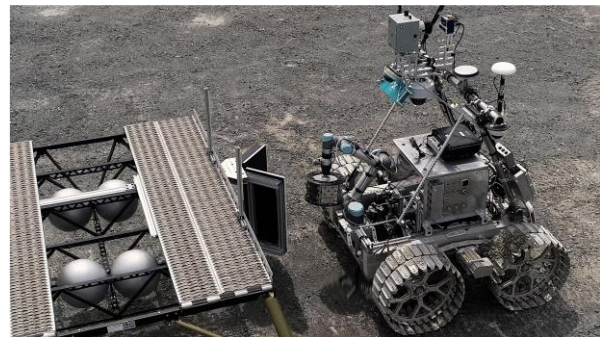


Figure 11: LEAD TRT rover delivering the samples to the lander

In parallel with the HERACLES studies and analogue testing, complete technology development and testing of a lunar night survival thermal system have been completed by Canadensys. The Mobility & Environmental Rover Integrated Technology (MERIT) project demonstrated the capability of controlling and maintaining the critical rover systems operational after simulating the lunar day and night conditions implied by an HERACLES type mission. MERIT, along with its sister project SWARM (Scalable Wheels and Advanced Rover Motion), demonstrated the durability of the rover drivetrain assembly and developed enhanced, lighter and more robust wheel prototypes. The testing performed under these programs pushed the wheels and drive unit to demonstrate over 600 km of driving on a simulated terrain covered by rocks and lunar simulant. The durability of such system will be an enabling factor to travel the very long distances on the surface of the Moon required by HERACLES and beyond.

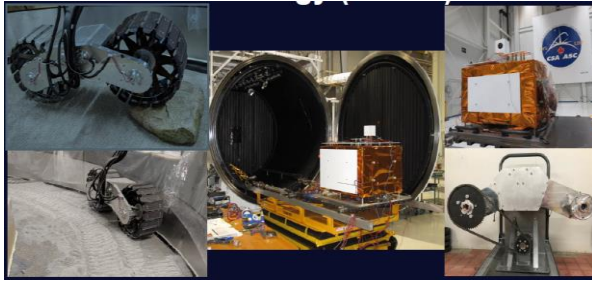


Figure 12: MERIT and SWARM wheels testing 2019-2020

In addition to the larger class of rovers required to accomplish missions such as HERACLES and human missions, Canada has accelerated the development of smaller vehicles and payloads as part of the LEAP program initiated in February 2019. As part of LEAP, Canada will fly payloads around and on the surface of the Moon. This initiative began in 2019 to deliver a suite of payload technologies including spectrometers, integrated vision systems, impact measurement systems and smaller classes of rovers: micro and nano. The definition phase of the proposed concept for potential missions to launch between now and 2024 have been developed, the technology development phase is starting and planned to be completed by the summer 2021. This will deliver an initial suite of science instruments and rover prototypes that could eventually be brought along with other ongoing and previous development to flight opportunities for LEAP by 2024-2025.

#### 4 ASTEROIDS

Canada is also currently involved in the exploration of asteroids. Canada is contributing a LASER altimeter to NASA's OSIRIS-Rex mission referred as OLA (OSIRIS-REx Laser Altimeter). Since its launch in 2016 and rendezvous in 2018, OLA has performed beyond its expectations providing amazing pictures and 3D mapping of the Bennu asteroid. The asteroid sample capture is planned for this fall and will then be brought back to Earth, providing the sample to scientists in 2023. OLA is a scanning time-of-flight LIDAR, consisting of two lasers, for short and long range, coupled to a 2-axis scanning mirror used to scan across the asteroid's surface.

OLA provides both the initial high accuracy range data of Bennu for navigation purposes, and the complete scan of the asteroid surface to generate high density maps of the Bennu surface, specifically slopes and elevations. This data is used for selection of candidate Touch-And-Go (TAG) sites; planning the final TAG maneuver; and providing context for samples collected at the TAG sample location on Bennu.

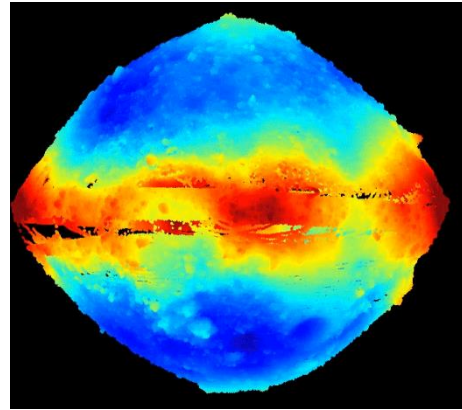


Figure 13: 3D laser picture of Bennu taken by OLA credit NASA

#### 5 CONCLUSION

With the MSS operations time increasing year after year and the recent investments announced, Canada's robotics presence in space is growing and very promising for the next two decades. With its presence in LEO, on Mars, close to an asteroid and soon on and around the Moon, Canada continues to demonstrate and expand its capabilities in space robotics in many ways to maintain its position as a world leader. This paper also presented a snapshot of recent Canadian space robotics activities conducted in the last two years, together with planned activities and development related to the next 2 decades of Canadian robotic in space.

#### 6 ACKNOWLEDGEMENT

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