ADVANCED SPACE ROBOTICS AND SOLAR ELECTRIC PROPULSION: ENABLING TECHNOLOGIES FOR FUTURE PLANETARY EXPLORATION. M. Kaplan and A. Tadros, SSL MDA Holdings, Inc., San Francisco, CA, michael.kaplan@sslmda.com and alfred.tadros@sslmda.com.

Introduction: Obtaining answers to question posed by planetary scientists over the next several decades will require the ability to travel further while exploring and gathering data in more remote locations of our solar system. Scientific investigations will require much more complex instrumentation, often operating in extreme environments. To meet these challenges, timely investments need to be made in developing and demonstrating several key technologies. Among these technologies are **solar electric propulsion** and **space robotics**. This abstract will explore the potential needs for and likely benefits derived from investments in these two critical technologies.

Advanced Solar Electric Propulsion (SEP): SEP technology can provide significantly higher ΔV when compared with most other propulsion technologies. Use of SEP can reduce mission life cycle costs by minimizing transit times to planetary destinations by using of constant thrust trajectories Additionally once in orbit around a destination body, most missions can benefit from the ability to change orbits, as well as to travel to additional destinations. Current examples of electric propulsion thruster technology are illustrated in Figure 1 below.

Comparison of Electric Propulsion Thrusters from 4.5–12 kW

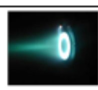
Thruster	 Aerojet XR5	 Fakel SPT-140	 Busek 12k
Power (kW)	4.5	4.5	12.5
ISP (sec)	2000	1750	2500
Throughput (MN-s)	8.7	8.2	50.0
Thrust (N)	0.26	0.29	0.64

Figure 1. Comparison of Current Electric Thruster Technology

To more fully take advantage of the potential of SEP, advances needed include increases in power levels to provide even greater ΔV as well as developing systems capable of operating in both cryogenic and extremely high radiation environment that can be present in the outer regions of the solar system. Larger amounts of power, from either larger solar arrays or space nuclear power, coupled with advances in SEP power levels could provide significant increases in ΔV. It's important to point out that the benefits of advanced SEP are not constrained only to outer planet exploration. For example, large ΔV SEP could also enable a new class of multi-asteroid mission, capable of exploring dozens of objects.

Advanced Space Robotics: Future planetary science missions will require much more sophisticated robotics that could enable much more complex investigations. We know that as missions get more complex, failures can occur. Advanced robotic systems that are capable of autonomously making repairs in space could be a huge forward, making the difference between mission success and failure. The same advanced space robotics technology could also be capable of completing assembly/deployments in space, potentially lowering launch costs. Figure 2 below illustrates a concept that we have developed to finalize spacecraft assembly on orbit under DARPA sponsorship.

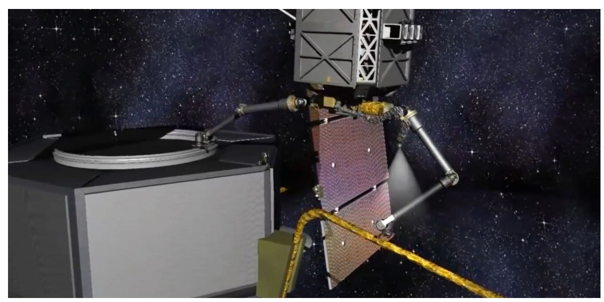


Figure 2. Notional rendering of robotic assembly in space

An added benefit could be that various elements of a spacecraft could be re-arranged during different phases of a mission, potentially reducing or even eliminating mission operations constraints to enhance scientific return. Having this technology in hand should result in the development of new spacecraft architectures to more fully leverage advanced space robotics. Investments are needed in the development of ever more sophisticated space robotics that possess increased levels of autonomy as well as the ability to work collaboratively with multiple systems. Additionally, these advanced space robotics systems will need to operate in extremely challenging environments that are present. These range from the surface of Venus (extremely high temperatures and pressures in a highly corrosive atmosphere) to the surface of Europa (cryogenic temperatures in a high radiation environment.)

Advanced SEP and Space Robotics Roadmaps: To pursue robust exploration of the solar system, roadmaps are needed for both SEP and space robotics. These roadmaps should be developed and then aligned with a future planetary mission roadmap. This could provide NASA with the ability to make timely technology development and demonstration investments to enable scientifically powerful and exciting future missions.

World Leadership in SEP and Space Robotics: SSL MDA Holdings Inc. is the world's most experienced SEP spacecraft and space robotics provider. We understand all the key technological issues regarding these technologies as well as how to incorporate these systems into successful, affordable space missions.

Unparalleled Experience in SEP Spacecraft. Our Space Systems Loral (SSL) division is the world leader in operational SEP systems; 25 of our 82 satellites operating in geostationary orbit feature Hall-effect thruster based solar electric propulsion that, combined, have greater than 60,000 hours of on-orbit Hall-effect thruster and Power Processing Unit (PPU) operation and greater than 100 years of satellite operational life. In addition, 14 more satellites with Hall-effect thruster based solar electric propulsion are currently in production. SSL sees continuing SEP advancement as a key to continual commercial success. Finally, SSL has a long and productive history working with NASA Glenn on communications and electric propulsion technologies, including conducting EP testing at GRC facilities.

Leadership in Space Robotics. Our MDA division has built most U.S. space robotic systems, including the Space Shuttle and International Space Station robotics and all the manipulators that have successfully operated in the dusty Martian environment. We understand how to seamlessly design the interfaces and operate a robotic payload which reduces integration risk. To address potential future collaborative robotic - human mission aspects of the design, we know how to leverage our 35+ years of experience working with NASA JSC to design crew- safe space robotics for the ISS and Shuttle for future planetary science missions. Recent examples of our leadership in advanced space robotics technologies include recent awards for NASA GSFC's Restore-L mission (both robotics and spacecraft bus), DARPA's Phoenix robotics technology program, DARPA's Dragonfly space robotics demonstration NASA STMD's NASA's Tipping Point initiative to advance the goals for robotic and human exploration of the solar system through the development of critical space technologies. Restore-L is a GSFC led mission to service NASA's Landsat 7 spacecraft in orbit.

As a world leader in both critical technologies, we look forward to participating in this extremely important Workshop so that we might contribute our experience and expertise in helping to make this Workshop a success.