Small Spacecraft Sample Return Mission Concept to Support Gateway and Lunar Science

Alan M. Cassell
Entry Systems and Technology Division
Mission Design Center, Spaceflight Division
NASA Ames Research Center, Moffett Field, CA 94035
Alan.M.Cassell@nasa.gov

Jeffrey D. Smith, Matthew M. Wittal, Randy D. Gordon, Jennifer G. Morgan
Deep Space Logistics
NASA Kennedy Space Center, FL 32899

ABSTRACT

Sustaining long-term presence at the Moon will likely require innovative and cost-effective approaches for frequent and affordable payload return. NASA Ames Research Center and the Deep Space Logistics team at Kennedy Space Center (which manages the Gateway Logistics Services missions) have investigated the development of a small spacecraft-based sample return capability to complement the limited sample return capacity available with the early Orion missions. The goal is to demonstrate a cost-effective capability as part of an early Deep Space Logistics mission and provide up to 10 kg (~ 4 L volume) of scientific payload returned from the Gateway. The mission concept envisions the progressive addition of sample return capabilities, including returning temperature- and acceleration-sensitive payloads, and evolution into a commercially provided service, similar to existing International Space Station payload return logistics. An overview of payload science and technology use cases and small spacecraft mission concepts will be presented to engage scientists, payload developers and mission planners who are considering Lunar exploration activities that will require the return of high-value samples from the Gateway and/or the lunar surface.

INTRODUCTION

The Lunar Gateway is a planned orbital outpost to support Lunar surface, Cislunar, and deep space exploration activities. NASA, together with international and commercial partners, are providing various capabilities, infrastructure, and services to build the Lunar economy. As Gateway capabilities and transportation logistics evolve, utilization is expected to increase, providing ample science, technology demonstration, and commercial development opportunities. Elements of the transportation network supporting Lunar activities are primarily focused on the outbound and Lunar surface segments, which include Commercial Lunar Payload Services (CLPS), Human Landing System (HLS), Space Launch System (SLS)/Orion crew transportation system, and Gateway Logistics Services (GLS). Initially, the only Earth return segment will be provided via Orion. However, infrequent mission cadence (once every 12 months), limited payload return mass (100 kg), and operational constraints suggest that additional sample return logistics capability will be needed.[1] A potential approach to augment payload return is to host a small spacecraft return system (SSRS) on the GLS spacecraft as a ride along payload.[2] This approach could not only provide additional payload return capability to complement Orion but also give additional operational flexibility by considering conducting operations when the Gateway is not tended by crew.

Gateway Logistics

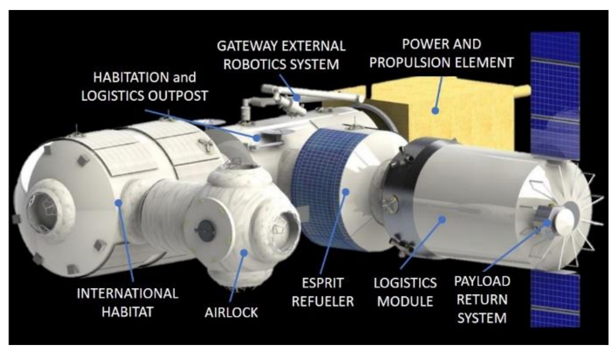

Figure 1: Planned Gateway elements showing Logistics Module with attached small spacecraft-based payload return system.

As astronauts prepare for missions to the lunar surface, they will need deliveries of critical pressurized and unpressurized cargo, science experiments and supplies (e.g., consumables), sample collection materials and other mission critical items. The GLS program, which is modelled after the Commercial Resupply Services and Commercial Crew programs supporting the International Space Station, will manage firm, fixed price contracts for delivery and logistics services in support of the Artemis missions.[3] Each GLS mission will include the capability to deliver at least 3,400 kg of pressurized cargo and 1,000 kg of unpressurized cargo for each Artemis mission. Figure 1 shows the planned Gateway elements with the Logistics Module (LM) docked to the European System Providing Refueling, Infrastructure and Telecommunications (ESPRIT) Refueler segment. The LM would arrive at Gateway prior to launch of the crewed Artemis missions and would remain docked at the Gateway for six to twelve months. The LM will also serve as a platform to remove trash after undocking from Gateway with nominal disposal in a heliocentric orbit. A number of secondary mission concepts and mission enhancement options are being considered after its primary mission is completed. Potential LM secondary missions could include hosting internal or external experiments or ride along spacecraft to conduct additional science or technology demonstrations. The possibility of extended LM secondary missions is being considered to increase science, utilization and to provide a critical capability for a potential SSRS pathfinder mission.

Small Spacecraft Return System Concept

The SSRS pathfinder flight system concept is shown in Figure 2. The system has two primary elements: the spacecraft bus and the sample return capsule. The carrier spacecraft is based on a generic Evolved Secondary Payload Adapter (ESPA) Grande class bus with interfaces and performance specifications required to accommodate a sample return capsule. The payload return capsule chosen is based on the heritage Stardust sample return capsule design.[4] The Stardust design was baselined for the feasibility assessment due to its capability to re-enter at super orbital velocities (11-12 km/s) combined with its ability to receive samples during mission operations through a hinge mechanism at the split-line between the forebody heat shield and back shell. This clamshell-like mechanism was demonstrated on both the Stardust[5] and OSIRIS-Rex[6] missions. In addition, the capsule design includes a descent system (comprised of supersonic drogue and main parachute) that slows the capsule to ~7-10 m/s at touchdown after returning to Earth.

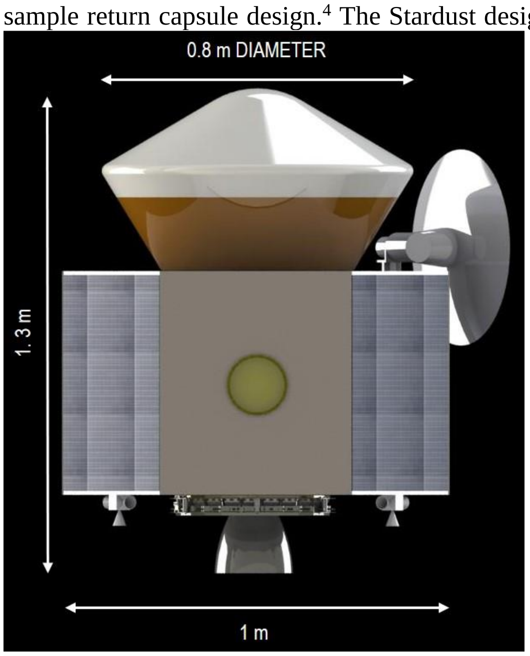

Figure 2: Small spacecraft return system pathfinder concept.

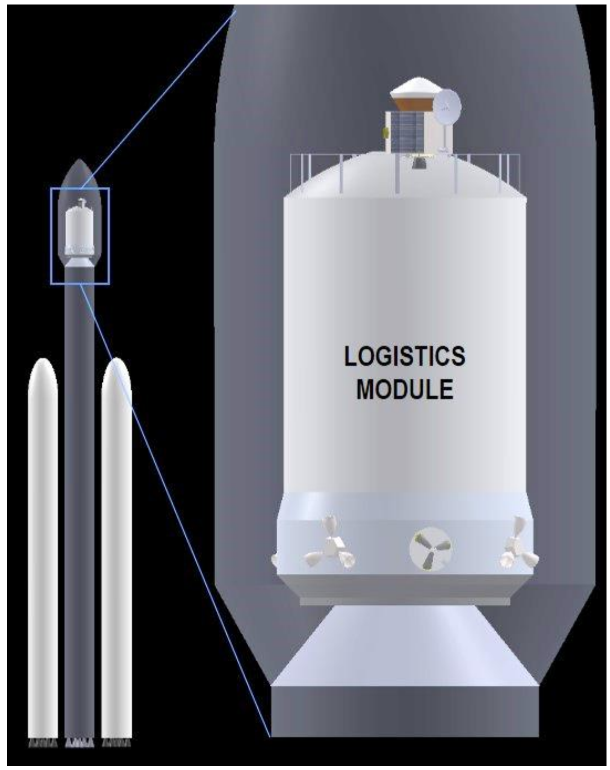

Figure 3: Small spacecraft return system pathfinder concept externally attached to Logistics Module inside the launch vehicle 5.4 m diameter fairing.

External payload accommodation onto the LM will utilize the International External Robotic Interface Interoperability Standards (IERIIS).[7] Detailed requirements are still to be determined, but options such as the Small on-orbit replaceable units (ORU) Robotics Interfaces (SORI) or Large External Robotics Interfaces (LORI) are considered here.[8] For the purposes of this feasibility assessment, we assumed the LM would have ORI based external payload volume ~1 m^3 and mass ~250 kg, similar to ESPA Grande port accommodation specifications.[9] Since the SORI and LORI mechanical and electrical interfaces are well-defined to allow for interoperability, there is some flexibility with how to implement the SSRS pathfinder mission concept as part of the pathfinder mission objectives. For example, depending upon the goals of the pathfinder mission, critical operational objectives could be implemented to demonstrate critical interfaces and robotic arm operations.

PATHFINDER MISSION CONCEPT

Mission Design

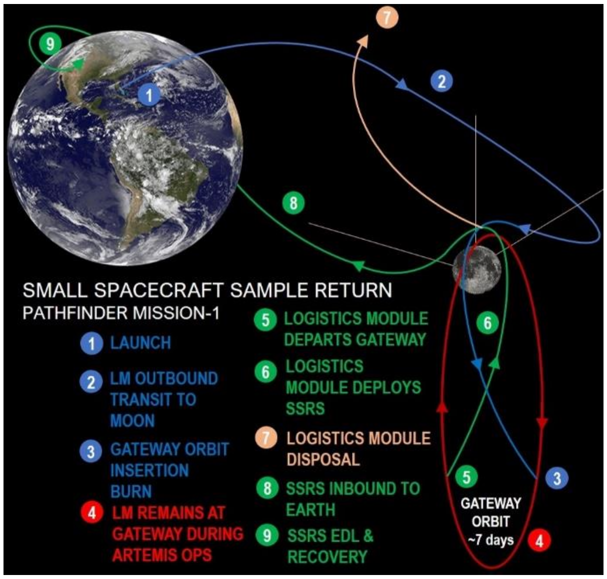

Figure 4: Pathfinder mission Concept of Operations.

The Pathfinder Mission Operational Concept is shown in Figure 4. The mission begins with the SSRS attached to the LM and launching from Kennedy Space Center. After separation from the upper stage, the LM transits to the Moon. Transit durations are to be determined, but could last as long as 120 d. Upon Lunar arrival, injection into the Near Rectilinear Halo Orbit (NRHO) is performed. After required phasing burns, the LM performs rendezvous, proximity operations and docking (RPOD) maneuvers with the Gateway. The LM will remain at Gateway until the Artemis mission its supporting is complete. While the SSRS is at Gateway, there are multiple options to conduct science, qualify sample handling and transfer operations, or just demonstrate the SSRS capability. After the LM undocks from Gateway, a departure burn out of NRHO is performed to target a Lunar gravity assist. Shortly thereafter the SSRS is deployed from the LM for return to Earth, while the LM continues on to perform other secondary missions or final disposal maneuvers After the Lunar gravity assist maneuver, a series of trajectory correction maneuvers are completed to target landing into the Utah Test and Training Range. After entering the atmosphere at ~11 km/s, the vehicle slows to drogue deployment conditions (M~1.5) to stabilize the vehicle through transonic flight, and then the main parachute is extracted close to the surface to further slow the descent to a terminal velocity < 10 m/s. Retrieval of the capsule shortly after touchdown is performed with a helicopter-based recovery team that secures the vehicle and transfers it to the awaiting recovery facility for payload processing.

Early Pathfinder Mission Demonstration Concept

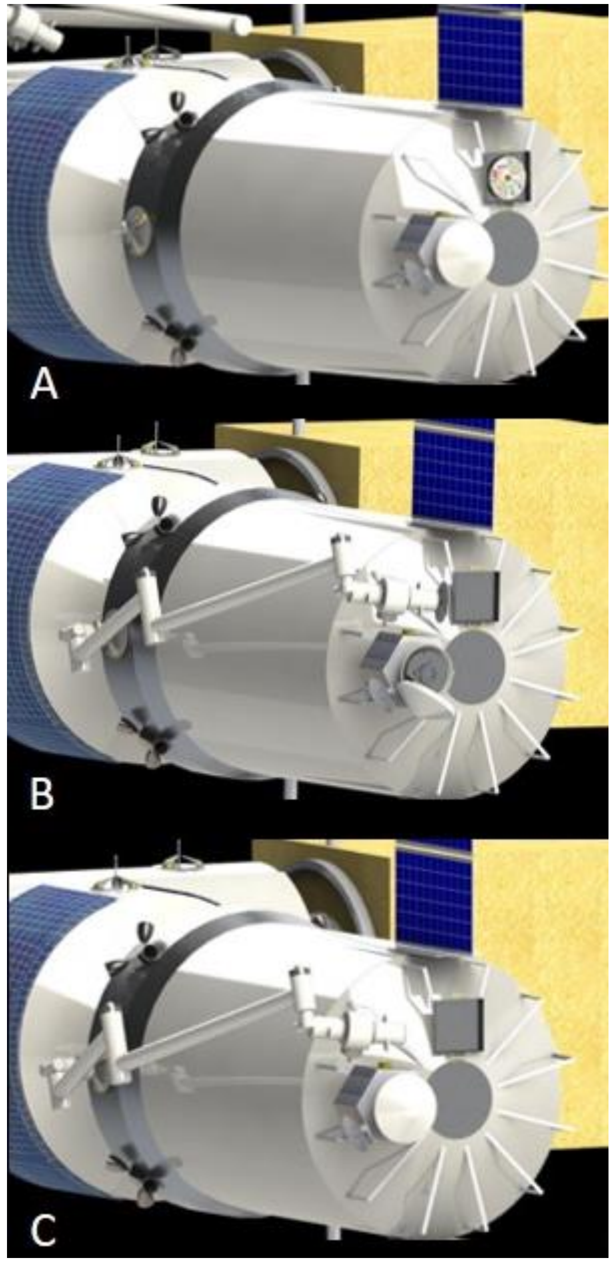

Figure 5: Transfer operations of externally exposed samples transferred into the SSRS using the robotic arm.

There are multiple scenarios to consider for conducting science during the Pathfinder Mission. An illustrative example is shown in figure 5. This concept is based upon the Materials International Space Station Experiment (MISSE) platform.[10] The MISSE series has tested over 4,000 material samples and specimens to demonstrate their durability in the punishing low earth orbit space environment. A similar platform is envisioned for the Gateway, and would be modeled after the EXPOSE, a multi-user facility mounted outside the ISS which is dedicated to astrobiology experiments.[11] Here the concept would be to expose the materials to the environment of the NRHO as shown in panel A of Figure 5. After the desired exposure time has elapsed, the materials experiment tray is robotically transferred into the awaiting SSRS after opening the sample return capsule (panel B). Once the experiment exposure tray is secured inside the SSRS, the capsule is closed and prepared for departure operations (panel C).

There are many possibilities to consider as future add-on capabilities including Gateway internal (pressurized) to unpressurized transfer into the awaiting SSRS (Figure 6). This capability will be possible once the airlock segment is added to the Gateway. The airlock would be similar to the Kibo module on ISS, which allows for deployment or transfer of payloads, satellites or other experiments to external mounting points or into a waiting payload return system.

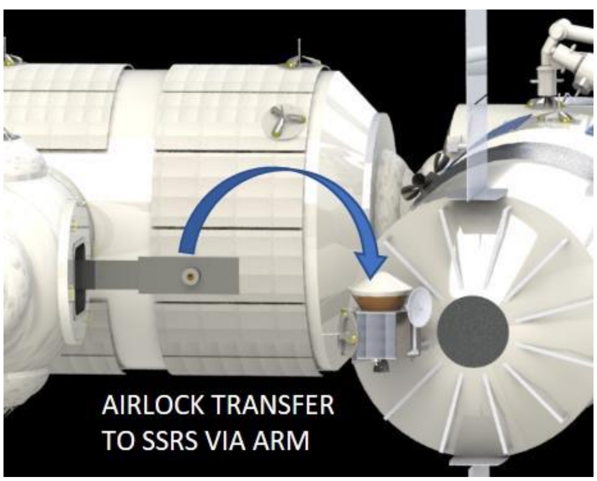

Figure 6: Pressurized internal payloads can be transferred robotically to the awaiting SSRS using the airlock segment combined with the robotic arm.

ENTRY SEGMENT ENVIRONMENTS

The Earth return leg presents some mission design challenges including entry velocities near 11 km/s. If utilizing a Stardust like entry vehicle design that is unguided, the deceleration loads can be quite high. A guided entry vehicle capability would significantly lower the deceleration loads and provide other operational flexibility. Figure 6 compares entry trajectories using a Stardust-like ballistic vehicle (50 kg) entering with an entry flight path angle (γ) of -6 deg with a guided blunt body capsule (70 deg, sphere cone, 1.5 m diameter, 100 kg entry mass) capable of also entering at -6 deg γ, but with an angle of attack of -16 deg to generate lift.

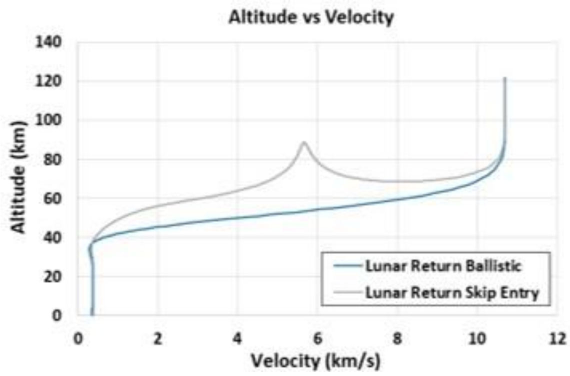

Figure 7: Ballistic versus guided atmospheric flight trajectories from lunar return velocities, using a Stardust like ballistic vehicle (50 kg) entering with an entry flight path angle (γ) of -6 deg with a guided blunt body capsule capable (70 deg, sphere cone, 1.5 m diameter, 100 kg entry mass) also entering at – 6 deg γ, but with an angle of attack of -16 deg to generate lift.

Notable in Figure 7 is the ability to use the lift of the guided vehicle to perform a skip entry, which has multiple benefits including increased downrange (Figure 8) and substantial lowering of deceleration loads (Figure 9). Deceleration sensitive payloads such as biological systems necessitate the use of a guided entry vehicle configuration that is capable of managing these loads. While guided vehicles are more complex and require sophisticated guidance algorithms and reaction control systems, they provide significant operational advantages for the return segment. A recent demonstration of small spacecraft-based return system was demonstrated in the Chang’e 5 sample return mission, which performed a skip entry.[12]

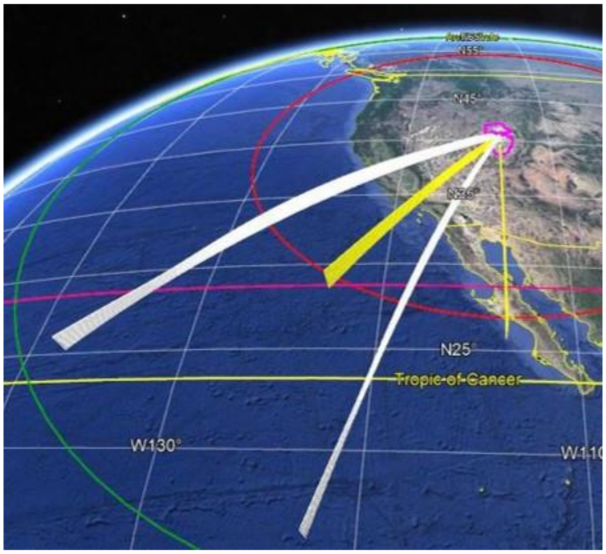

Figure 8: Downrange comparison between the ballistic (yellow) and lifting (white) blunt body entry configurations.

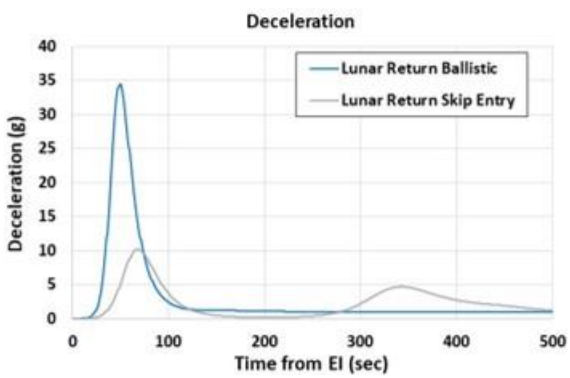

Figure 9: Deceleration load comparison between ballistic and guided blunt body entry systems.

EVOLVING RETURN SYSTEM CAPABILITY

In addition to the materials science example already described, there are many other materials science technologies that could benefit from the capability including in-space manufacturing, in-situ resource utilization, and radiation hardened electronics research. For human research applications, the return of stabilized samples from crew or other model systems to understand and help mitigate the long-term effects of deep space exploration on the human body (synergistic effects of radiation, microgravity, loads, etc.) would be extremely valuable. A related area of research in biological science is high-throughput omics analysis of returned samples from microbiological, plant or animal models. Temperature control will be necessary, and combined with a system capable of managing entry deceleration loads, would allow live samples to be returned. Finally, Lunar Surface science, including return of regolith, core samples or volatiles that require cryopreservation or are hermetically sealed are also high priority.[1]

CONCLUSIONS

As we transition from a low Earth orbit-based research station to an orbiting lunar outpost, the use of smaller flight system elements will allow for significant cost savings over traditional International Space Station based operational approaches. A small spacecraft based, on-demand payload return capability significantly enhances Gateway utilization and can evolve as Cislunar infrastructure develops. Furthermore, developing this capability with commercial partners will accelerate commerce development and lower the cost per returned kilogram of payload to return valuable science and technology payloads.

References

1. Artemis-3 Science Definition Team Report, NASA/SP-20205009602.
2. Wittal, M. M.; Smith, J. D.; Cassell, A. M. "Mission Design Considerations for Robotic Lunar and Gateway Payload Return" AAS Astrodynamics Specialist Conference, AAS 21-724, 2021.
3. https://www.nasa.gov/content/about-gateway-deep-space-logistics
4. Willcockson, W. H. "Stardust Sample Return Capsule Design Experience" Journal of Spacecraft and Rockets, vol 36 (3), 470-474, 1999.
5. Tsou, P., Brownlee D., Sandford S., Hörz F., and Zolensky M., "Wild 2 and interstellar sample collection and earth return," Journal of Geophysical Research, vol. 108, p. 8113, 2003.
6. Ajluni T., Everett D., Linn T., Mink R., Willcockson W. and Wood J., "Osiris-rex, returning the asteroid sample," pp. 1–15, 2015.
7. International External Robotic Interface Interoperability Standards (IERIIS), Baseline version, 2019.
8. https://explorers.larc.nasa.gov/HPMIDEX/pdf_files/17Ba_Gateway_PL_IF.pdf
9. https://www.csaengineering.com/content/dam/moog/literature/Space_Defense/spaceliterature/structures/moog-sais-espa-ring-datasheet.pdf
10. https://www.nasa.gov/centers/langley/news/factsheets/MISSE.html
11. Rabbow, E. et al "EXPOSE, an Astrobiological Exposure Facility on the International Space Station – from Proposal to Flight," Orig. Life. Evol. Biosph., vol 39 (6), 581-598, 2009.
12. https://www.planetary.org/space-missions/change-5