Introduction: The Endurance mission concept study was requested by the panel on Mercury and the Moon as part of the 2023–2032 Planetary Science and Astrobiology Decadal Survey. Endurance is an evolution of the Intrepid planetary mission concept study (PMCS) [1], which was designed to traverse >1,800 km on the lunar nearside to address priority science questions focused on lunar magmatism. Intrepid used solely remote sensing and non-contact instruments, and did not have the capability to collect, cache, or return samples. The Mercury and Moon panel was impressed by the Intrepid concept and sought to understand if an Intrepid-like architecture could be applied to addressing the longstanding goal of South Pole Aitken basin (SPA) sample return. A further request of the study was to compare architectures using robotic sample return (Endurance-R) with sample return via transfer to Artemis astronauts (Endurance-A).

SPA’s importance has been long recognized, and SPA Sample Return (SPA-SR) has consistently ranked as one of the top priorities for planetary exploration in the past two Decadal Surveys [2, 3], and the top priority for lunar exploration [4, 5]. While motivated by many of the same science questions, Endurance is very different from previous SPA-SR concepts. The ability to essentially combine twelve SPA-SR missions into one, in addition to the enhanced ability to choose samples through mobility (as opposed to sampling from a stationary lander), mark Endurance as a radical departure from previous approaches. In addition, the nearly order-of-magnitude increase in potential sample mass enabled by the presence of Artemis astronauts further enhances the value of this mission. All of this led the Committee on the Planetary Science and Astrobiology Decadal Survey (PSADS) to recommend Endurance-A be implemented as the “highest priority of the Lunar Discovery and Exploration Program” [6]. As further noted in the PSADS report, “Return of Endurance-A samples by Artemis astronauts is the ideal synergy between NASA’s human and scientific exploration of the Moon, producing flagship-level science at a fraction of the cost to PSD through coordination with Artemis.”

Endurance would land in the center of SPA and traverse out of the basin via two other large, ancient basins—Poincaré and Schrödinger—before rendezvousing with Artemis astronauts near the lunar south pole. Endurance’s science objectives require exploring these diverse, distinct regions, which are often separated by 100s of kilometers. Each large basin contributes to a different part of the Moon’s impact chronology, and volcanic deposits and other unique terrains along the traverse (e.g., high-thorium areas) provide insight to the Moon’s thermochemical evolution.

Developments in progress: The Endurance mission architecture is relatively straightforward, consisting of a single rover element delivered to a landing site in the central SPA by a CLPS lander. The baseline Endurance rover design resulting from the Decadal PMCS is shown on the left side of Figure 2. As the Endurance team has continued to develop the concept since the original report, additional changes have been made to the design, both to streamline and further simplify the implementation and to increase its potential utility for follow-on missions. The current baseline design is shown on the right side of Figure 2. The most noticeable difference has been to modify the mobility system by changing from a dual side rocker to a single front rocker suspension. This change saves mass and cost and improves traverse efficiency; traverse planning performed for the mission study to date indicates that the marginal improvement in terrain capability afforded by the dual rocker design should not be needed. Additional modifications currently under study include incorporation of features to allow modular instrument accommodation at various points on the rover and the inclusion of features to allow servicing and replacement.

Figure 1. The Endurance traverse (pink) draped on a topography map of the lunar farside (blue is low, red is high). SPA is the prominent, large, basin dominating the southern lunar farside.
of key wear components to maximize opportunities for follow-on missions.

In addition, a number of efforts to refine the Endurance mission concept and mature the required technologies are under way. These include:

Science definition. NASA is contemplating initiation of a Science Definition Team (SDT) to refine the science objectives and requirements, as well as the science observations and the associated instrument suite necessary to meet them.

Power. A system-level trade is underway between an RTG-based and a solar-based power system architecture. The latter has significant implications on the concept of operations and speed-made-good; the RTG-based architecture allows for extended night-time driving, thereby reducing the mission duration by more than 2 years compared to a solar-based architecture.

Autonomy. To meet the challenge of covering the distance in the envisioned mission time, the Endurance rover requires extended autonomous operations, enabling the rover to drive at the required relatively high speeds both during the lunar day and night. A significant technology development activity is being undertaken to mature perception, pose estimation, mapping, hazard avoidance and motion planning algorithms in context of lunar night-time driving. Both camera- and LIDAR-based sensing options are being examined within this context. Similarly, at the system-level, technology development activities are planned to mature the rover’s ability to autonomously plan and execute activities while managing onboard resources and assessing system health. A targeted field test campaign serves as a venue to integrate and demonstrate the mobility, autonomy, and operability aspects of the Endurance concept.

Global localization. Both optical and radiometric approaches to global localization need to be evaluated to determine their efficacy in the lunar environment both during the lunar day and night. Radiometric approaches rely on satellites in view of the rover providing radiometric measurements, including ranging, Doppler and, if available, Positioning, Navigation and Timing (PNT), whereas optical approaches rely on terrain relative navigation.

Longevity & dust mitigation. Using long-life actuators and developing effective techniques to seal them and other mechanisms from the abrasive lunar dust would be paramount to ensuring the long life required for the Endurance traverse.

Astronaut ConOps. The return of the samples via the Artemis crew is an inherent part of the Endurance mission concept. As such, the associated concept of operations (ConOps) for Artemis base-station approach, sample transfer to, and sample handling by the Artemis Crew have to be defined.

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