Constant Range Skip-Entry Technique for Lunar Returns

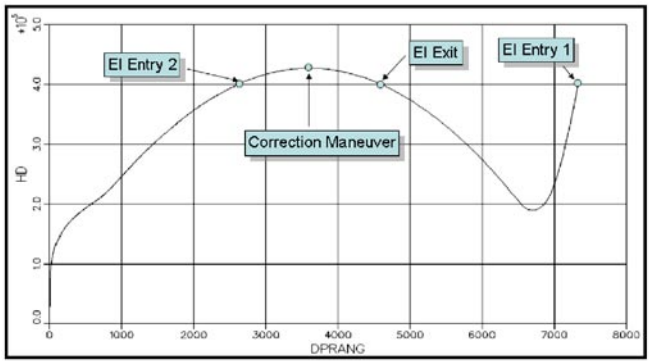
Michael A. Tigges, Johnson Space Center

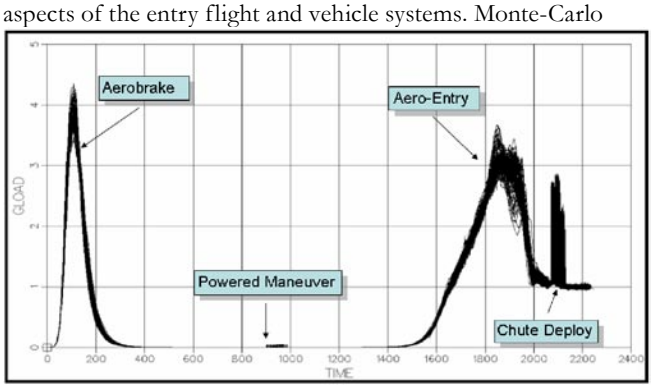
Using the Apollo strategy for returning crew at anytime from the Moon would require water landings over a wide range of latitudes. Alternatively, some current entry strategies, applied to the same problem using an aerocapture maneuver, achieve a desired orbit for circularization, phasing, deorbiting and entering a desired landing site. These strategies require either complicated recovery operations and re-use liabilities—as for water landings or significant impacts to the entry vehicle design, consumables, and propellant requirements—as for the aerocapture approach.

A standardized propulsive-assisted skip-entry (SPASE) strategy is currently under development to mitigate the aforementioned issues, enabling a lunar crew to return in an Apollo-class vehicle at anytime to a designated continental United States (CONUS) landing site. The SPASE strategy employs a skip-burn-enter technique in which an appropriately targeted exo-atmospheric-powered explicit guidance maneuver adjusts the skip maneuver exit conditions to achieve the required accuracy for a sub-circular entry flight to the desired landing site. The initial Earth entry conditions are changed by adjusting the lunar Trans Earth Injection maneuver throughout the month to maintain a constant range with the selected landing site. Achieving a fixed range for all entry scenarios holds the flight profile (accelerations and heating loads) nearly constant across the lunar return window. Selection of a proper range depends on geometric, vehicle, and abort considerations and constraints. A standardized entry permits validation of a single flight profile to accommodate all lunar return entry scenarios.

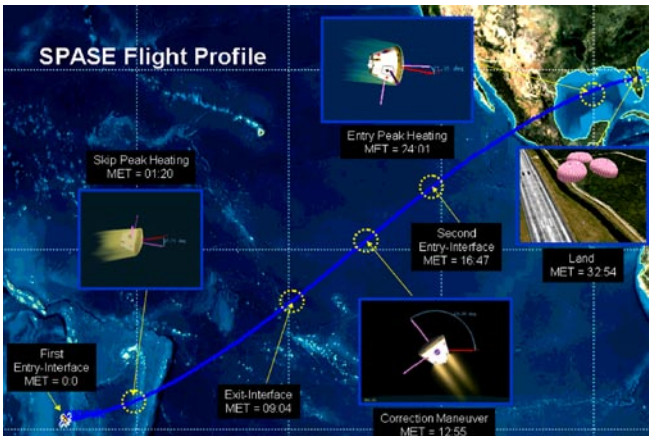
A typical flight profile is depicted for a 13,594 km range ascending approach entry to Kennedy Space Center (KSC). Entry interface occurs at 121.9 km above the Earth's surface at zero Mission Elapsed Time (MET) (MET= 0:0 mins:secs). The capsule plunges into the atmosphere at lunar return speeds, rapidly decelerates, and skips out of the atmosphere to a desired altitude. During this skip phase of the mission the vehicle updates the navigation state and performs a small maneuver to correct dispersions (MET 12:55). The vehicle enters a second time into the atmosphere at MET 16:47 for final deceleration and landing at KSC.

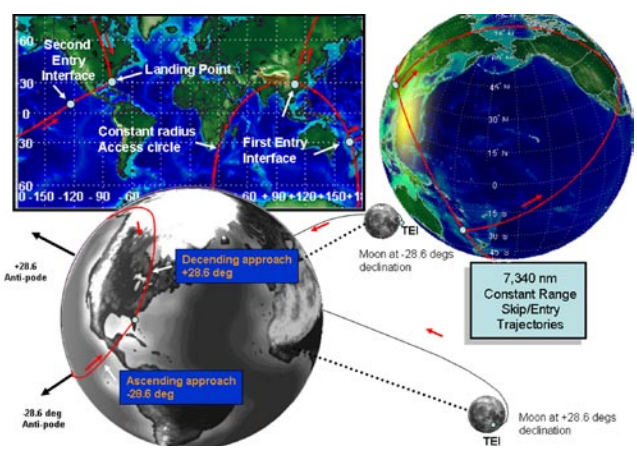
To validate the feasibility of an SPASE technique for crew return from the Moon, high-fidelity simulations model all aspects of the entry flight and vehicle systems. Monte-Carlo





simulations are used to disperse the environment (atmosphere and winds), vehicle systems (navigation, vehicle thrust, control system), and vehicle state (position and velocity) to ensure that the vehicle achieves the desired landing site with the proper reserves of consumables (fuel, oxygen, power). These simulations are also used to size the vehicle thermal protection system that protects the vehicle from the intense heat of entry; to ensure excessive accelerations and dynamic pressure limits are not exceeded; and to size the vehicle engines and control system. Several state-of-the-art guidance algorithms are used to fly the vehicle during the phases of aerocapture, powered flight, entry, and approach and landing flight. Lessons learned include the size of the worst-case landing site access envelope to aid search



and recovery forces. Current Monte-Carlo accuracy results are within 2 km at the drogue chute deployment altitude of 6.1 km. Accuracy at the ground depends on wind conditions and parachute drift after deployment.

Shown in the figure below are typical flight conditions for a KSC landing resulting from Monte-Carlo testing of a 13,594-km range SPASE flight profile. These results are used to assess the nominal and dispersed flight profiles and to ensure the crew is properly protected and not subjected to adverse conditions of flight. As shown, the vehicle can enter from either a descending or an ascending approach to a desired CONUS landing site. The targeting and maneuver execution to set up the entry flight are accomplished back at the Moon.