FORMULATION, MODELING AND ANALYSIS OF A MISSION TO THE MOON'S SCHRODINGER CRATER. Charles R. Weisbin[1], Pamela Clark[2], Virgil Adumitroaie[1], Joseph Mrozinski[1], Kacie Shelton[1], Hook Hua[1], Jeffrey H. Smith[1], Alberto Elfes[1], William Lincoln[1], Robert Silberg[1]; [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109; [2]Goddard Space Flight Center, 8800 Greenbelt Road, Greenbelt, Maryland 20771. E-mail: Charles.R.Weisbin@jpl.nasa.gov

Introduction: NASA is exploring the possibility of conducting a series of missions on the Moon, based at a proposed landing site at Shackleton crater near the lunar south pole. In a previous paper [1], we described the analysis of a mission in which a group of astronauts and their robotic assistants would travel from Shackleton to Malapert Mountain, about 130 km away, for a total round-trip excursion of about 350 km.

In this study, we formulate and analyze a mission from Shackleton to Schrodinger Crater and back, which would last approximately 90 days and cover about 1100 km. Schrodinger is thought to expose underlying stratigraphic material from South Pole Aitken Basin, the oldest, largest basin on the Moon. Scientific exploration in this region supports Lunar Exploration Analysis Group (LEAG) [2] goal 1, objective A-6: to understand volcanic processes on the Moon. Proposed impact-basin features to study include rim and rim deposits, the central ring, wrinkle ridges, and floor fractures.

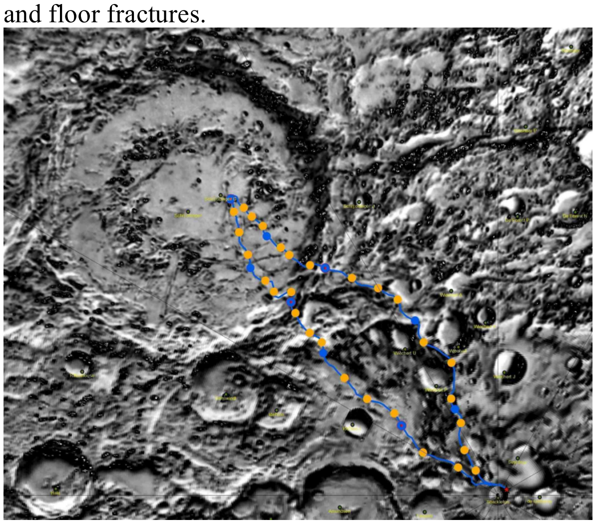

Figure 1: Hypothetical 90-day excursion from a Shackleton crater outpost (lower right) to Schrodinger crater and back.

Case Study: The crew for this hypothetical mission consists of 4 astronauts working in teams of 2. Each team rides a Lunar Exploration Rover (LER). During lunar day, the rovers need to be recharged for 24 hours after each 3-day period of use. (Note that a "day" as a quantity of time refers to a 24-hour period, not to the period of lunar daylight, which lasts 2 weeks.) During lunar night, the rovers need to be recharged for 8 hours after 16 hours of use.

The 2 recharging stations, which use solar panels to convert sunlight to electricity and then store the electricity in fuel cells, are each carried by a large vehicle called an All-Terrain Hex-Legged Extra-Terrestrial Explorer (ATHLETE), which is controlled remotely from Earth. These vehicles could also carry consumables (e.g., oxygen, food, water) and laboratories if desired.

Figure 1 shows an initial set of target localities. Blue indicates localities of primary importance, and orange indicates those of secondary importance. Science-activity targets are specified only for the primary localities. Science at secondary localities is optional but desirable to enhance mission value.

Each primary locality contains 6 sites, spaced about 1 to 2 km apart, where scientific experiments are to be conducted. Each team of 2 astronauts visits 3 of the 6 sites.

In addition, on the outbound leg of the mission, two Portable Utility Palates (PUPs) are to be placed about 1/3 and 2/3 of the distance between the landing site and Schrodinger crater. The PUPs carry batteries that could be used to replace depleted LER batteries in an emergency.

Other selected constraints include the following:

- LER average driving speed: 5 km/h
- ATHLETE average driving speed: 1 km/h
- Maximum LER driving time per day: 8 hours
- Maximum ATHLETE driving time per day: 24 hours during daylight, 12 hours during lunar night
- All science tasks must be done EVA (i.e., as extravehicular activities)
- EVA constraints:
  - 4 EVAs per day maximum (1 egress + 1 ingress from pressurized cabin onboard the LER = 1 EVA)
  - maximum 8 hours per EVA
  - maximum 24 hours of EVA per week
  - Astronauts must rest for one day following 6 days of working EVA.

We modeled the maximum 24 EVA hours per week as 4 EVA hours per day for each of the 6 working days in a week. To avoid time-consuming repeated ingress/egress from the LER pressurized cabins, travel from site to site within a locality is done “chariot” style—i.e., riding outside the cabin in space suits. This travel thus counts against the maximum EVA time for each astronaut. Travel from locality to locality is to be done riding inside the pressurized cabin, where space suits are not needed, and thus does not count as EVA time.

Two major science packages are to be deployed inside Schrodinger basin. Other science activities include panoramic visual surveys, laying geophones for active seismic sensing, collecting interesting rocks, and acquiring regolith (soil) samples via core-drilling, raking, and drive tubes. We assume that the 2 ATHLETES will drive the maximum distance each day: 24 km during lunar day and 12 km during lunar night.

Mission design is computed using a tool called “HURON” (HUman-Robot Optimization Network) [3, 4]. We begin by using HURON iteratively to estimate the amount of time available for science activities (all of which, as noted, must be EVA) at each of the 12 primary localities; this amount is then used as a constraint. Coincidentally, this turns out to be 4 hours per locality, the same amount of time as our modeled constraint for EVA hours per day. For each of the 27 secondary localities, we assume that 2 hours is spent doing science.

Analysis Research Issues: In addition to research challenges similar to those of the Malapert study (e.g., convergence of a combinatorially explosive optimization problem, meeting mission goals within constraints), the current study deals with issues of day/night operation and coordination of astronauts and their rovers with the slower ATHLETES that carry the mechanism needed to recharge the rovers.

Results: About 80% of the weighted importance of total targeted science (which, as mentioned, was comprised solely of activities at the primary localities) is achieved. The 4 hours available per primary locality are insufficient to complete all desired experiments since this time includes EVA chariot-style driving from site to site within the locality. However, when the value of the enhancing science activities of the secondary localities is added to that of the primary localities, the total weighted importance of mission science rises to nearly twice the targeted value.

Our modeled mission consumes 85 of the maximum-allowed 90 days. At this writing, we are in the process of refining the model to use more of the available mission time to increase the science value.

Sensitivity analysis reported in the full presentation includes the results of varying EVA time/week (3, 4, 5 hours/day for a 6-day week); mission duration (60, 90, 120 days); rover speed (5, 10, 15 km/h); number of localities visited (19, 38, 51); ingress/egress time (10, 20, 30 minutes).

Implications for Field Science: The EVA constraint of 24 hours per week limits the amount of science that can be accomplished. Having the science and architect communities focus jointly on science which may be conducted as intravehicular activity (IVA) within engineering and operation constraints, perhaps with robotic assistance, seems extremely important.

The ATHLETE speed of 1 km/h (much slower than the LER speed of 5 km/h) introduces a lag time, with the LERs and astronauts awaiting arrival of the ATHLETES for recharging. If the ATHLETES can be safely operated at higher speeds, the wait time could be minimized.

Conduct of science experiments during the lunar night has been assumed and modeled within this analysis. A joint discussion of the anticipated feasibility, efficiency and safety of this activity should be reviewed.

New paradigms are under consideration within the International Working Group which involve moving the infrastructure and landing the crew directly at sites of interest, rather than having the crew traverse long distances from a landing site to the desired destinations. Such mission formulations are perfectly applicable to our HURON analysis capability, and will be studied in the near term.

References: [1] Weisbin C.R., Clark P., Shelton K., Smith J. H., Mrozinski J., Lincoln W., Elfes A., Hua H., Adumitroaie V., and Silberg R., (2009) 40th LPSC, Abstract #1054. [2] NASA LEAG Clive Neal chair, http://www.lpi.usra.edu/leag/meetings.shtml. [3] Weisbin, C. R., Mrozinski J., Lincoln W., Elfes A., Shelton K., Hua H., Smith J. H., Adumitroaie V., Silberg R., (2010) "Lunar Architecture and Technology Analysis Driven by Lunar Science Scenarios," Systems Engineering Journal, Vol. 13, No. 3. [4] Elfes, A. (2008), Weisbin C. R., Hua H., Smith J. H., Mrozinski J., and Shelton K., (2008) “The HURON Task Allocation and Scheduling System: Planning Human and Robot Activities for Lunar Missions,” Proceedings of the WAC 2008 ISIAC.