RESOLVE MISSION ARCHITECTURE FOR LUNAR RESOURCE PROSPECTING AND UTILIZATION.


Introduction: Design Reference Mission (DRM) evaluations were performed for the The Regolith & Environment Science, and Oxygen & Lunar Volatile Extraction (RESOLVE) project to determine future flight mission feasibility and understand potential mission environment impacts on hardware requirements, science/resource assessment objectives, and mission planning. DRM version 2.2 (DRM 2.2) is presented for a notional flight of the RESOLVE payload for lunar resource groundtruth and utilization (Figure 1) [1]. The rover/payload deploys on a 10 day surface mission to the Cabeus crater near the lunar south pole in May of 2016. A drill, four primary science instruments, and a high temperature chemical reactor will acquire and characterize water and other volatiles in the near subsurface, and perform demonstrations of In-Situ Resource Utilization (ISRU). DRM 2.2 is a reference point, and will be periodically revised to accommodate and incorporate changes to project approach or implementation, and to explore mission alternatives such as landing site or opportunity.

RESOLVE Project and Payload: The Regolith & Environment Science, and Oxygen & Lunar Volatile Extraction (RESOLVE) project is developing the capability to explore and utilize the Moon’s polar region volatiles in the 2015-2016 timeframe [2, 3]. The project is currently developing a third generation Ground Development Unit for field testing at Mauna Kea, Hawaii in the summer of 2012.

The estimated RESOLVE flight payload is 72 kg with margin. Major elements include the:
- **Drill** capable of acquiring core samples to 1 m depth, or augered cuttings to 0.5 m depth.
- **ISRU Reactor** capable of heating samples to 150 C for volatile extraction, or 900 C for oxygen extraction and water production via hydrogen reduction processing.
- **Gas Chromatograph** and **Mass Spectrometer** used to assay volatiles driven off by the reactor.
- **Neutron Spectrometer** used to detect subsurface hydrogen during 3,000 m total rover traverses.
- **Near Infrared Spectrometer** used to detect surface volatiles during rover traverses, as well as analyze auger cuttings.

### FIGURE 1: RESOLVE DRM 2.2 SUMMARY

<table>
<thead>
<tr>
<th>Destination:</th>
<th>Moon South Pole</th>
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</thead>
<tbody>
<tr>
<td>Landing Site:</td>
<td>Cabeus A1</td>
</tr>
<tr>
<td>Latitude</td>
<td>85.75 S</td>
</tr>
<tr>
<td>Longitude</td>
<td>45 W</td>
</tr>
<tr>
<td>Surface Duration:</td>
<td>10 days (8 w/ sun)</td>
</tr>
<tr>
<td>Surface Dates:</td>
<td>5/19-5/29/2016 (10 day)</td>
</tr>
<tr>
<td>2016 Secondary</td>
<td>6/18-6/25/2016 (7.5day)</td>
</tr>
<tr>
<td>2015 Primary</td>
<td>5/6 - 5/13/2015 (7 day)</td>
</tr>
<tr>
<td>2015 Secondary</td>
<td>5/31-6/10/2015(10.5day)</td>
</tr>
<tr>
<td>Primary Spacecraft:</td>
<td>Rover</td>
</tr>
<tr>
<td>Power Strategy:</td>
<td>Solar PV + Battery</td>
</tr>
<tr>
<td>Solar Array</td>
<td>250 We</td>
</tr>
<tr>
<td>Secondary Battery</td>
<td>3500 W-hr</td>
</tr>
<tr>
<td>Comm. Strategy:</td>
<td>Direct-To-Earth</td>
</tr>
<tr>
<td>Survey Track:</td>
<td>McMurdo+Troll</td>
</tr>
<tr>
<td>Payload:</td>
<td>3,000 m cumulative</td>
</tr>
<tr>
<td>Drill</td>
<td>5 x 1 m core</td>
</tr>
<tr>
<td>ISRU Reactor</td>
<td>25 Samples @ 150 C</td>
</tr>
<tr>
<td>GasChrom./MassSpec.</td>
<td>4 ISRU Demos @ 900 C</td>
</tr>
<tr>
<td>Neutron Spectrometer</td>
<td>25 Samples</td>
</tr>
<tr>
<td>Near-IR Spectrometer</td>
<td>3,000 m, 10 auger cuttings</td>
</tr>
<tr>
<td>Mission Energy:</td>
<td>51,500 W-hr available</td>
</tr>
<tr>
<td>Mission Ave. Power:</td>
<td>181 W predicted</td>
</tr>
<tr>
<td>Payload Mass:</td>
<td>72 kg</td>
</tr>
<tr>
<td>Rover+P/L Mass:</td>
<td>243 kg</td>
</tr>
<tr>
<td>Landed Mass:</td>
<td>1,285 kg</td>
</tr>
<tr>
<td>Wet Mass @ TLI:</td>
<td>3,476 kg</td>
</tr>
<tr>
<td>Launch Vehicle:</td>
<td>Atlas V 411</td>
</tr>
</tbody>
</table>

Comparative Architectures: A number of alternative implementation architectures were first considered, characterized by the primary “active” surface spacecraft, and the number and nature of sites visited. Major options included a:
- **Lander** to one stationary site.
- “Hopper” Lander to multiple stationary sites.
- **Rovers** powered by Batteries, Solar Arrays, Solar Array and Battery, or Radioisotopes.
- **Active Lander & Rover** with split payload.
The architectures were qualitatively assessed for Location, Science Return, Cost and Risk. The Solar+Battery Rover (“Sun & Shade” scenario) was selected for further study due to its ability to survive a several day mission, range 1000’s of meters beyond the landing site, sort into shadowed areas, be developed for reasonable cost, and possessing the lowest aggregate program and science risk. A highly cost constrained scenario might consider sacrificing the rover and surface mobility for a reusable “Hopper” type lander. “Splitting” the payload across a small lander and rover would have promise for a lunar X-Prize scenario.

**Spacecraft:** The DRM 2.2 surface mission is implemented by a 243 kg gross rover/payload capable of surveying 3,000 m about the landing site. Power is provided by a 250 We solar array and 3,500 W-hr rechargeable battery. The 10 day mission is predicted to consume 181 We on average. The DRM 2.2 surface mission is scheduled to address informational presentations, problem/issue resolution, or Collaborative Design sessions.

**Landing Sites:** Various south and north pole landing sites were assessed and screened for:
- Volatiles indicated in the near subsurface.
- Sunlight availability to power solar arrays.
- Communications availability direct-to-earth.
- Terrain of traversable slope and roughness.

The selected reference site for DRM 2.2 is Cabeus A1 (85.75 deg S, 45 deg W) near the lunar south pole. The location allows direct groundtruth and calibration of LCROSS results [4], and affords a 10 day surface mission with continuous line-of-sight communication to Earth, and at least 8 days of cumulative sunlight.

**Operational Concept and Analysis:** The DRM 2.2 Operations Concept is summarized in Figure 2, with cumulative science noted in Figure 1. An initial 2.5 days of sunlit operation allows deployment and checkout, and two cycles of roving, surveying, drilling and processing. The next two days assume a low-power quiescent period to accommodate a transient shadow. The remaining 5.5 days allow three additional cycles.

**Team and Methodology:** The RESOLVE Mission Architecture Team consists of the authors and colleagues at NASA JSC, KSC, ARC and GSFC. Members represent the range of necessary disciplines and perspectives including science, engineering, design, analysis, operations, subsystems and stakeholder/management. The team meets weekly in a distributed manner using telecon and WebEx. Sessions are scheduled to address informational presentations, problem/issue resolution, or Collaborative Design sessions.

**References:**

**FIGURE 2: “SUN & SHADOW” OPERATIONS CONCEPT**

- **SUN (2.5 days):**
  - Checkout
  - 1st Navigation 0.4 km
    - 3.09 hrs, 0.4 km total
    - Drill 1st Hole 4.33 hrs
    - Time 15 min Augera (1-2)
    - One 1 km Core (1)
  - Process Segments (1-10)
    - 8 segments: 28.95 hrs
    - 1 st H2 Reduction

- **SHADOW (2 days):**
  - Quiescent (Moderate Power) Ovs
    - 48 hrs
  - Consider using this “Wet” lander/rover/payload stack has a mass of 3.476 kg after trans-lunar injection. An Atlas V 411 or similar launch vehicle is required.

- **SUN (5.5 days):**
  - Battery Recharge
  - 3rd Navigation 1.0 km
    - 5, 47 hrs, 1.0 km total
    - Drill 3rd Hole 4.33 hrs
    - Two 5 km Augera (9 hrs)
    - One 15 km Core (9)
  - Process Segments (1-10)
    - 8 segments: 20.32 hrs
    - 2 nd H2 Reduction

- **4th Navigation 0.2 km
  - 5, 47 hrs, 0.2 km total
    - Drill 4th Hole 4.33 hrs
    - Two 5 km Augera (7 hrs)
    - One 15 km Core (6)
  - Process Segments (16-20)
    - 8 segments: 30.32 hrs
    - 3 rd H2 Reduction

- **5th Navigation 1.0 km
  - 5, 47 hrs, 1.0 km total
    - Drill 5th Hole 4.33 hrs
    - Two 5 km Augera (9 hrs)
    - One 15 km Core (8)
  - Process Segments (21-25)
    - 5 segments: 16.90 hrs
    - 4 th H2 Reduction