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Design and development of volatile analysis system for analog field test of lunar exploration mission

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Abstract

The recent evidence of water in the lunar crater Cabeus from the LCROSS mission (Colaprete et al., 2010) provides confirmation of a valuable resource on the lunar surface. To understand this resource and the impact it can have on future exploration, further information is needed on the distribution and availability of the water ice. The Lunar Advanced Volatile Analysis (LAVA) subsystem is a part of the Regolith & Environment Science and Oxygen & Lunar Volatile Extraction (RESOLVE) payload, designed to provide ground truth to the volatile distribution near the permanently shadowed regions on the lunar surface. The payload is designed to drill and extract a regolith core sample, heat the regolith to drive off the volatiles, and identify and quantify the volatile resources. The LAVA subsystem is specifically responsible for processing and analyzing the volatile gas sample from the lunar regolith sample. The main objective of this paper is to provide insight into the operations and hardware for volatile analysis developed and deployed at the 2012 RESOLVE Field Test on the slopes of Mauna Kea. The vision of employing Commercial Off the Shelf (COTS) and modified COTS hardware to lower the cost for mission-enabling field tests will be highlighted. This paper will discuss how the LAVA subsystem hardware supported several high level RESOLVE mission objectives to demonstrate the challenging lunar mission concept proposed.
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Keywords: In Situ Resource Utilization; Field test; Volatile analysis; Lunar regolith; Lunar resources

1. Introduction

The ability to make propellants and consumables for life support can have a significant impact on exploration capability, greatly reducing reliance on mass-limited launch loads. The extraction and processing of space resources into useful products is known as In Situ Resource Utilization (ISRU). These resources can have a substantial effect on individual missions and mission architecture concepts (Sanders and Larson, 2010; Rapp, 2012; Sanders and Duke, 2005). There is a significant cost for mass that is required to be launched out of earth's gravity well which limits the capability of exploration missions. The understanding of the resources on the lunar surface will greatly influence future exploration architectures as possible sources of fuel or life support necessities. Exploration is enhanced when you can 'live off the land', similar to a Lewis and Clark type of exploration architecture. The knowledge of the volatile distribution of resources will also further scientific understanding of the lunar history and surface characteristics. ISRU for lunar applications includes collecting volatile gases such as water or hydrogen

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to use as mission consumables or processing lunar regolith to extract the oxygen from the minerals.

Several lunar missions indicate the presence of considerable quantities of hydrogen-bearing molecules in permanently shadowed craters near the lunar poles. Remote-sensing missions such as Clementine (1994) (Nozette et al., 1996) and Lunar Prospector (1998) (Feldman et al., 2000, 1998) indicated the possibility of significant concentrations of hydrogen and possible ice deposits at the lunar poles (Schmitt et al., 2000). The Lunar Crater Observation and Sensing Satellite (LCROSS) mission in 2009 gathered data from a debris plume created by a spent Centaur rocket striking the lunar surface and measured water ice estimated to be $5.6 \pm 2.9\%$ by mass (Colaprete et al., 2010). Several other volatile species were identified by the LCROSS mission to be present in the debris plume that include but are not limited to hydrogen sulfide, ethylene, carbon dioxide, and methanol. Water ice, along with other volatiles that are co-located, would be extremely useful resources for future exploration missions. While the LCROSS mission greatly advanced our understanding of the resources in this lunar polar region, there are many unknowns that need to be explored to enhance ISRU-enabled exploration. These include the spatial resolution of the volatile resources as well as insight into the feasibility of processing the lunar regolith for these resources. In an effort to address these unknowns and provide ground truth data of the LCROSS mission, the RESOLVE project is designed to perform several key tasks to enable exploration. The payload hardware will prospect for local resources on the lunar surface, perform volatile resource identification and quantification via regolith processing, and perform an ISRU demonstration of oxygen extraction from the lunar regolith.

2. RESOLVE project and LAVA subsystem

Knowing that useful resources, such as water, carbon monoxide, and hydrogen are available on the lunar surface and other locations around the solar system is important; however, questions remain to be answered before in situ utilization of these resources is practical. Specifically, it is necessary to know (1) what volatiles are present and in what quantities, (2) how they are spatially distributed on and under the surface, and (3) what material characteristics and operating environments could influence future ISRU designs. The RESOLVE project is comprised of a suite of subsystems which include prospecting and processing tools to support a robotic mission architecture. A neutron spectrometer and near infrared spectrometer are used as prospecting instruments for near real time sampling site localization and a coring drill acquires subsurface regolith samples. Processing of the sample is done in a heated reactor within the Oxygen Volatile Extraction Node (OVEN) subsystem and the evolved volatiles are analyzed in the LAVA subsystem. In addition to the analysis of the volatiles released during the heating of the sample, an ISRU capability of extracting the oxygen from the lunar minerals will also be conducted with the hardware to demonstrate the technology and quantify the oxygen production rate while identifying any contaminants present in the process gas stream.

Here we will focus on the design and field test operation of the LAVA subsystem. The LAVA subsystem is responsible for analyzing the evolved volatiles released from heating a regolith sample. The main resource of interest is water, with hydrogen, helium, carbon monoxide and carbon dioxide also of high importance. These species were identified as potential resources that may be present based on the science data collected from the previous lunar polar missions (Colaprete et al., 2010). While water quantification was the highest priority, there were numerous other volatile species included in the species the instrumentation was required to detect. Previous analysis of analytical tools (Lueck et al., 2008) with a current evaluation of the analytical technology and mission duration requirements led to the selection of a unique micro-gas chromatograph–mass spectrometer (GC–MS) to perform the gas analysis (Brooks-Loftin et al., 2013). The volatile gas sample was delivered from the heated OVEN reactor to a heated gas sample tank, referred to as the surge tank, for quantification. An aliquot of the gas sample was transferred to the GC–MS through a gas manifold with modified commercial valves for volatile identification. In addition to the analysis, the remaining volatile gas sample was passed over a condenser plate designed to capture water for imaging. The formation of liquid water demonstrates the extraction and isolation of the water resource from the regolith sample.

3. Goals and objectives for the field test

A field demonstration on the slopes of Mauna Kea was coordinated for various ISRU technologies including the RESOLVE project (Larson, 2012). This field test provided a lunar analog for the mission that would provide the project an opportunity to validate RESOLVE's capabilities and meet the demanding timeline associated with this mission. There is a known benefit to utilizing field tests for technology development and operational mission testing (National Aeronautics and Space Administration, 2012, 2011; Sanders and Larson, 2010; Schreckenghost et al., 2010; Tunsten et al., 2004). Field tests often provide a stepping stone to more challenging environments as was the case with the 2012 ISRU Field Test conducted on the slopes of Mauna Kea. The remote location, harsh conditions, and similarities to the final mission target site provided the team the opportunity to advance both the hardware technology and the mission operations. This third generation of hardware (Sanders & Larson, 2012; Larson et al., 2011; Captain et al., 2010; Sanders et al., 2005) was designed to operate in a field test environment that included several challenging conditions, including wide ambient temperature conditions, dust storms, indirect