LUNAR SURFACE GRAVIMETRY VIS-À-VIS ARTEMIS. Kieran A. Carroll, Canadensys Aerospace Corporation, 10 Parr Boulevard, Caledon, Ontario, Canada L7E 4G9, kieran.carroll@canadensys.com.

Introduction: Gravimetry surveying is a standard geophysical exploration technique on Earth, used to detect the presence of subsurface density variations by measuring variations in the magnitude of the gravity force vector, between various locations at the surface; it also detects the effect of changes in the Earth's shape due to tidal forcing due to the Sun and the Moon, which provides information about the Earth's deep interior structure. Its application is notable due to the fact that nothing blocks gravity; unlike some other geophysical measurement techniques, in which shielding by near-surface material causes signals from greater depths to fade, gravimetry surveys are capable of detecting subsurface density variations at great depths as well as near the surface.

Gravimetry surveying is also one of the techniques that has previously been used on the Moon's surface. The Traverse Gravimeter Experiment (TGE) was carried to the Moon by the crew of Apollo 17, and used to make measurements at 9 stations along a 10 km traverse across the Taurus Littrow Valley (TLV) [1]. Interpretation of these measurements contributed to the discovery of the subsurface rock structure underlying the TLV, a 1 km thick sheet of basalt, contributing significantly to the understanding of the geological history of that region of the Moon.

Gravity measurements have also been made from satellites orbiting the Moon, the most recent and best measurements having been made by the GRAIL mission [2]. GRAIL's results excel particularly in their global coverage, producing by far the best global lunar gravity field model to date. Because the spatial resolution of any gravity survey is roughly equal to the distance from source, and GRAIL's lowest orbit altitude above the Moon was above 10 km, the best GRAIL-derived lunar global gravity model (GRGM1200A) has a "pixel size" of 9 km. While a ground gravity survey will of course have much more limited geographical coverage, it will also have much finer spatial resolution; by surveying on the ground, subsurface geological features on the order of 100m or less in size can typically be resolved.

VEGA Gravimeter Instrument: A new lunar-surface-compatible gravimeter instrument (VEGA = Vector Gravimeter/Accelerometer) has been under development, with funding support from the Canadian Space Agency, over the past 7 years; it is at an advanced stage of development, and is within a year of having a flight-ready instrument available.

VEGA (described in some detail in [3]) is an absolute gravimeter, with zero bias, making it particularly compatible with surveys carried out using relatively slow lunar rovers. It has demonstrated repeatability close to 1 ppm in the lab on Earth, with anticipated repeatability of 0.3 mGal on the Moon's surface. This instrument is small (<10x10x20 cm) and low in mass (2.1 kg), compatible with being mounted on any and all lunar landers, and all but the smallest lunar rovers. Canadensys is currently developing a microrover capable of being equipped with a VEGA gravimeter and of surviving the lunar night, for carrying out multi-day multi-km-scale gravimetry surveys on the Moon.

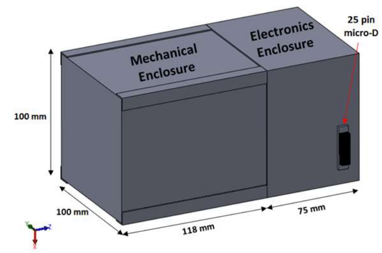

Figure 1: VEGA gravimeter layout

Recent lunar exploration gravimetry investigations studied: The development of the VEGA instrument enables gravimetry surveying on the Moon to begin again, after a 48-year-and-counting hiatus. There are many possible targets for such science investigations; several have been defined and studied [4][5] in parallel with VEGA development.

Probe the Structure of the Moon's Deep Interior. An investigation (GLIMPSE = Gravimetry of the Lunar Interior through the Moon's PulSE) has been studied [6] and proposed to NASA's LSITP program, for using the technique of Tidal Tomography [7][8] to determine changes in the Moon's shape due to body tides caused by the Earth's and Sun's gravity gradient fields, by measuring changes in gravity as the distance from the Moon's centre to points on the surface change with time. This is sensitive to the distribution of density and structural stiffness throughout the body of the Moon. VEGA's accuracy is sufficient that measurements made at one or more static locations (on lunar landers) on the Moon's surface, over a period of time of a week or more, are expected to be able to constrain significantly models of the Moon's deep interior structure; a testable hypothesis is that the Lunar nearside/farside dichotomy extends to heterogeneity of the Lunar mantle.

Search for Lunar Ice Deposits. Gravimetry measurements could potentially detect the gravity signature of bulk deposits of water ice in lunar permanently shadowed regions (PSRs), through the lower density of ice versus regolith, or through the density increase in porous regolith if its pores are infiltrated with ice. A gravimetry traverse across an exposed patch of frost in a PSR could constrain the depth of the deposit of that volatile material. Also, traverses across other portions of PSRs could potentially detect deposits of ice that do not present surface expressions of frost.

Search for and Map Lava Tubes. The possibility of lava tubes beneath the Moon's surface has been a subject of speculation for many years, which has increased since the discovery of the first pit crater on the Moon [9], raising the possibility of some such pits being skylights into lava tubes. We have studied the gravimetric signature at the surface due to the mass deficit of a hollow lava tube [10][11]; the gravity low that would be produced by reasonably-small lava tubes would be easily detectable using VEGA. Thus the size of such a lave tube could be estimated, and its course mapped by carrying out a gravimetry survey on the surface above it, in the vicinity of such a skylight.

Investigate Lunar Swirls. Swirl features on the Moon's surface (e.g., Reiner Gamma, Mare Ingenii) are typically accompanied by strong local magnetic anomalies. A possible cause for these mysterious features could be the intrusion of iron-rich material near the surface, which could cause local gravity highs on the surface above them. Rover missions have been proposed to explore lunar swirl areas, equipped with fields-and-particles instruments; a gravimeter could usefully complement those, to test that conjecture.

Gravimetry vis-à-vis Artemis: Gravimetry was chosen as one of the priority science investigations in NASA's previous human lunar exploration program. It would also be a natural fit with the Artemis program's planned missions and their goals.

- GLIMPSE investigations can be advanced by placing gravimeters on any Artemis lander element. The data from GLIMPSE gravimeters at different locations on the Moon can be combined in a single model, even if taken at different times, and geographical diversity of measurement locations will provide increased spatial resolution for the recovered model of the Moon's internal density and stiffness. Because of this, equipping multiple landers at multiple locations with gravimeters will greatly increase the science return of this investigation.
- VEGA instruments can be carried on Artemis lunar rover elements (either human-driven or robotic), and used to carry out ground gravity surveys anywhere those rovers travel, just as was done using the Traverse Gravimeter instrument on Apollo 17.
- With Artemis focusing on lunar polar exploration, with a goal of finding and extracting significant amounts of polar volatiles, gravimetry surveying can contribute in two ways. The first is to make measurements that can help geologists determine the geological structures underlying PSRs and their surroundings, in order to provide geostructural and geomorphological context for measurements taken using other instruments (e.g., neutron spectrometers). This will aid in developing models of the deposition and transport history of volatiles in any particular PSR, which will help make predictions as to grade versus depth of ice deposits. These models will drive the design of ISRU architectures. The second is to seek to measure directly the gravity signature of large, deep ice-beds in PSRs (if any such exist)
- The goals of Artemis include setting up the first permanent human base on the Moon. Challenges include the effects of radiation, thermal extremes and micrometeorite bombardment on people and structures on the Moon's surface. Lava tubes could provide a location for a human base that is safe from these environmental hazards. Gravimetry surveying around lunar pit craters, using a gravimeter mounted aboard a robotic rover, can provide a quick, inexpensive means for determining whether there is a lava tube associated with a given pit, and estimating its depth, diameter and course. This technique could be a first step in scouting locations for a possible long-term human base on the Moon.

References:

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