ICEY

NCAS Final Project: Mars Rover Mission

written by

RAVELA SMYTH

Abstract

ICEY - unlock the secrets of Mars through its icy poles

The role of liquid water in the evolution of Mars is puzzling, yet its state and history holds significance in understanding the Mars climate, potential habitability, and geologic history, leaving it to be a subject of high scientific interest and inquiry. The sublimation of water at the temperature-pressure conditions at the surface of mid-latitude Mars leaves the polar regions to be the only areas where possible water in the form of ice is stable [1], thus holding the key to much of our understanding of this Red Planet, and where our mission will primarily take place. The Utopia Planitia deposit is a ~3300 km diameter basin in the northern hemisphere of Mars near its North Pole, shielded from the atmosphere by a 1-10 m "overburden" of debris and sublimation till layer, keeping ice underneath unevaporated. Here also lie earth-like landforms of scalloped depressions and polygons that clue us on Martian climate history and the enigma of water processes on Mars [2]. In complement to its icy properties, Mars' polar regions are some of the most active places on the planet, with 360° directional winds that largely determine the surface distribution of water ice and other particles [3].

Through drilling at Utopia Planitia, the primary goal of Mission ICEY is to use never reached before deep soil and water samples in this history-rich area to collect data on its chemical composition, helping us investigate the process of formation of Utopia Planitia's glacial and fluvial geomorphological features, the location and quantity of water ice, and past/current changes in these ice forms. Additionally, active Martian winds and their impacts to the planet's surface processes will propel a fleet of flying rover devices that will help us expand our range of exploration, and scout future mission locations of interest, forming the secondary goal of the ICEY mission. Along with the ongoing research of our scientific objectives, the success of the engineered technology of ICEY can be crucial for on site resource generation, bringing us closer to human missions on Mars.

Scientific Objectives

(1) Acquisition of Sample Layers from Utopia Planitia's Polygonal Terrain

Martian geology has long held a question of the sustenance of conditions necessary for liquid water at the surface to form the various widespread aqueous weather, and valley networks and lakes. Much of Mars' enigmatic geologic history relating to liquid water lies in the Noachian and Hesperian periods prior to ~3 billion years ago, and records afterwards are sparse though compelling, lying in melted ice and gullying of slopes [4]. The geologic past and present processes of water is poorly understood because of large uncertainties such as how much water was originally accreted and subsequently lost throughout Martian history [5].

It has been theorized that accumulation and removal of layered deposits have repeatedly occurred throughout Martian history, with periods of high obliquity resulting in removal of ice from high latitudes to deposition at lower latitudes [4]. Orbital and rotational motions throughout the planet's history have modulated ice and dust into the layers of deposits near the poles, and thus these layers will provide us the most complete record archive of recent geological events on Mars [7]. Therefore, Utopia Planitia's plethora of Earth analog features such as polygonal grounds and scalloped terrains (that imply its ice-filled cryosphere) are a powerful tool that may link several areas of Martian history research including: (1) interpretation of climate history (2) glacial and periglacial strata geology (3) hydrology throughout Mars.

Mission ICEY will drill through the polygons to collect data and sample its various layers in order to investigate the datings, origin, composition, and ice content of the Martian permafrost, hopefully leading us towards the answer of the role of liquid water in recent Martian geological evolution. Once the layers are drilled through by ICEY, spectrometer data will be collected and samples will be retrieved to be dated and analyzed.

(2) Acquisition of Water From Utopia Planitia Subsurfaces

A human mission holds major barriers such as lack of resources on the planet that would be difficult to transport from Earth to Mars. Water being the primary resource needed for human consumption and a base for jet propulsion fuel [6], ICEY is taking the first step at extracting water from Mars. Extraction through various means hold their own obstacles: atmospheric water vapor requires a complex and powerful mechanical system far outside of what is practical for deployment to Mars with the amounts needed; modern bodies of subsurface water has been deemed non existent at least to 200-300 m below the surface through the radar data of SHARAD and MARSIS; minute amounts of present-day brine water near the surface (e.g., RSL) would contain as little water as atmospheric vapor and are thus also unusable [8]. This leaves extraction of water from ice as the most realistic option.

Confirmed by SHADAR, Utopia Planitia is the biggest plain and impact basin on Mars, with its Western area containing stable thick ice-rich subsurfaces with possible pure ice shielded by a 1-10 m thick soil of debris to prevent diffusive interactions with Martian atmosphere [9]. The upper surface of this “overburden” sublimation till layer of soil, and well as any possible “firn” layers of granulated snow and ice crystals over our desired ice are to be drilled through with Objective #1, leaving us with the obstacle of preventing sublimation of newly exposed water ice subsurface as well as contamination of debris.

This extraction is done by first drilling the soil using ICEY’s drilling system described in the first scientific objective. After a path into our ice, ICEY will employ a source of beamed energy that injects microwaves into the soil and rocks around the ice, and the released debris-free water vapor is captured in the cold trap at the surface, then transferred to a water collection canister where it condenses into our water product to be made useful.

(3) Wind Powered Flying Technology: Expand Range and Locate Areas of Interest

Rovers have only explored a tiny portion of Mars’s 55,742,106 mi² surface area [6], leaving much of the planet to be unknown and far away from our high hopes of living on Mars. The idea of flying helicopter technology on Mars is in the works for Mars 2020 rover mission, but many difficulties have arisen both in cost and effectiveness due to the thin Martian atmosphere that forces rotorcrafts to be extremely powerful yet lightweight, and only be able to fly for minutes a day. This secondary phase of the ICEY mission aims to fulfill these two deficiencies using a fleet of lightweight autonomous rovers powered by the active Martian pole winds in Utopia Platinia that captures data in between the detail of a land rover and the overview of an orbital satellite. Taking advantage of our landing location Utopia Planitia, surface features near this icy regolith are very active, suggesting that it is among the most dynamic places on the planet. Much of that activity is driven by seasonal winds that strongly influence the whole Red Planet [3], and thus activity data captured by flying devices can be crucial to understanding Mars. Besides data, these flying devices aim to make flying more efficient and less costly by eliminating the weighty complex driving and self-propulsion systems, instead using these influential polar winds to drive the rovers and generate power. The lower cost will enable a fleet of these rovers to tumble around the planet without too much repercussion if a single rover is damaged by an unexpected hazzard. If the technology can fly safely and successfully, this will be useful for designing future Mars missions. Most importantly, the Icey-Fly fleet will fulfill a mission objective of producing a variety of mission-aiding maps that define range, slope, and solar exposure, as a valuable tool to help survey Martian terrain to be further explored with the current generation of rovers, as well as scout areas of interest for future endeavors.

Rover Specifications & Design

* Clearer images of the CAD designs can be viewed here.

(1) Chassis

Body

- Type 304 Austenitic stainless steel will be used for all of the rover body and suspension, given its durability for the -196°C and under temperatures of the Martian poles [11].

- **Warm Electronics Box (WEB)** *(Figure 1)* is the main component of the chassis body, providing protection and temperature control for the drilling system, soil analysis systems, water acquisition system, water holding tank, and computer hardware.

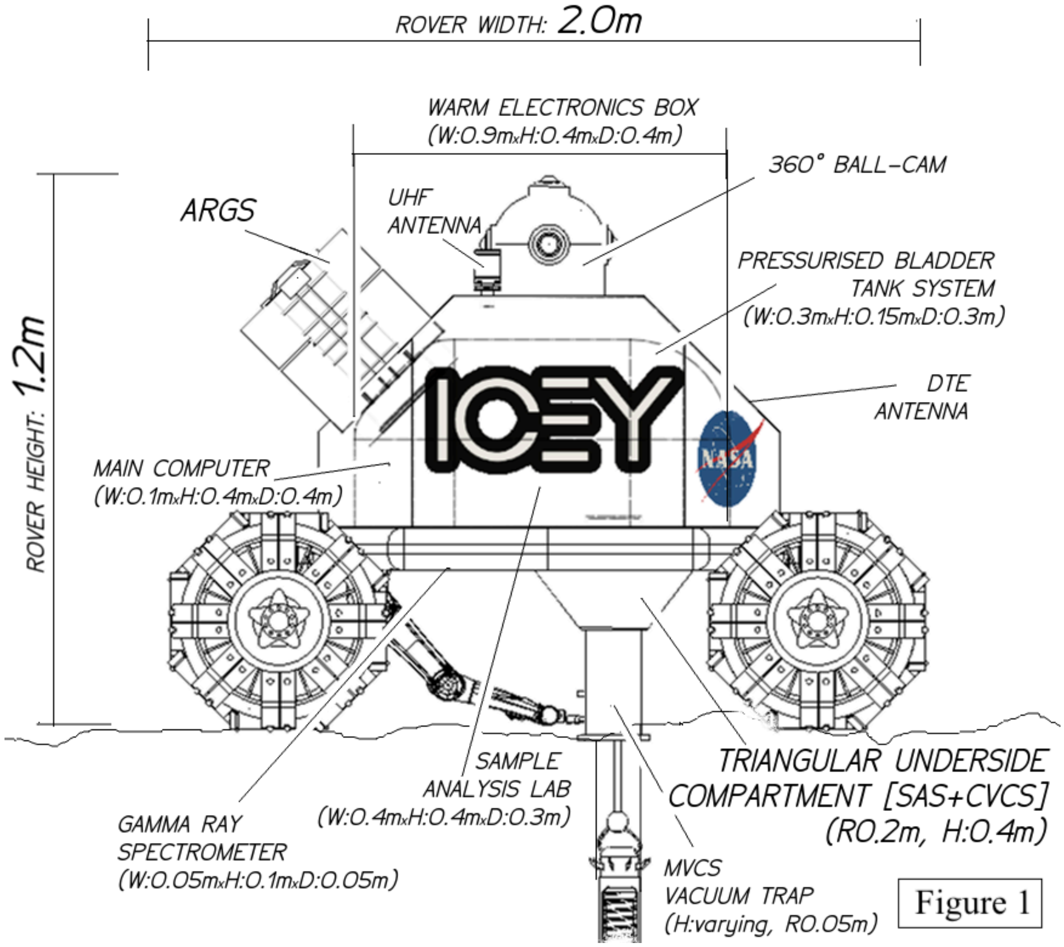


Figure 1

- The **Mesh Shell** *(Figure 2)* is lead radiation shielding for the WEB, and a camera and antenna mount with data & power transferred through wires embedded in the mesh material.

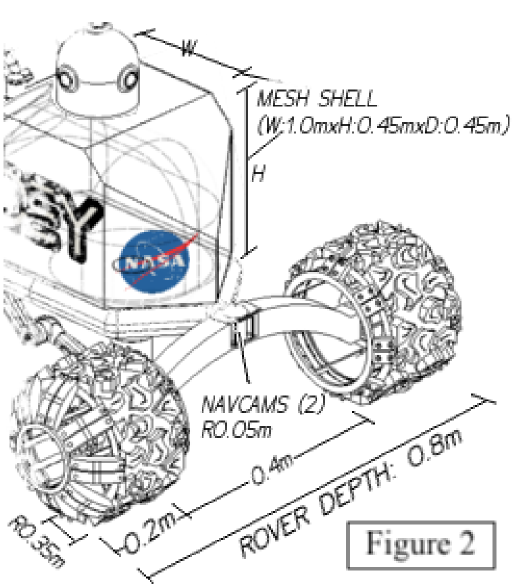


Figure 2

Suspension System *(Figure 2)*

- Four wheel suspension alternative to the Rocker-Bogie system: (1) Rocker-Bogie design with its 6-wheels has a high part count and complexity, making it costly as rovers grow larger and go longer distances. ICEY's 4WD system has a low part count and complexity. (2) Rocker-Bogie design has issues with back wheels kicking up which decreases traction and control, and mounting issues that causes high forces on the frame [12]. ICEY's 4WD system has more capability than the Rocker-Bogie in slope climbing, has a low center of gravity, and has limiters on hinges

- Large textured rubber wheels provide traction for the rocky Utopia Planitia ground. Metal spikes extrude from the wheels during the pole's sometimes frosty conditions as an anchor, as well as during its stand-still digging phases.

(2) Power Source *(Figure 3)*

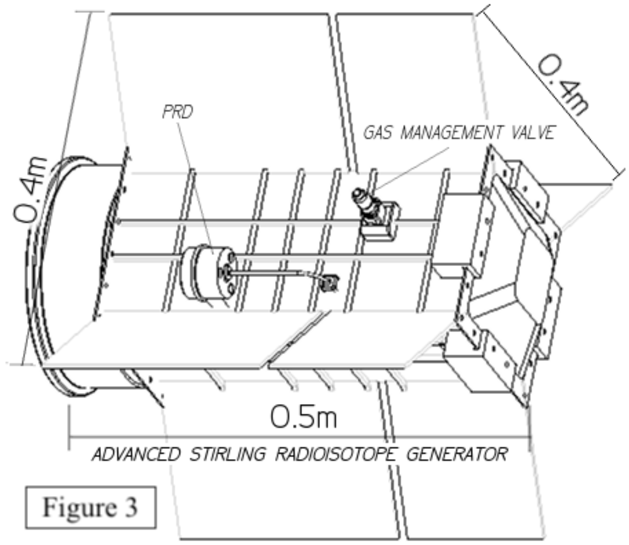


Figure 3

ICEY employs the nuclear **Advanced Stirling Radioisotope Generator** (**ASRG**) extruding from the rear of the chassis to electrically power the whole rover for communication, data processing, drilling, warming the WEB, and mobility. This was selected over other methods such as solar panels, which would be ineffective at the poles where the sun is low and frost forms, covering the solar panels. Being independent of external conditions, ASRG generates 140 Watt electrical power and 350 Watt heat with an at least 14 year life period [13].

(3) Instrument Package

(a) Flying Rovers (Icey-Fly) *(Figure 4)*

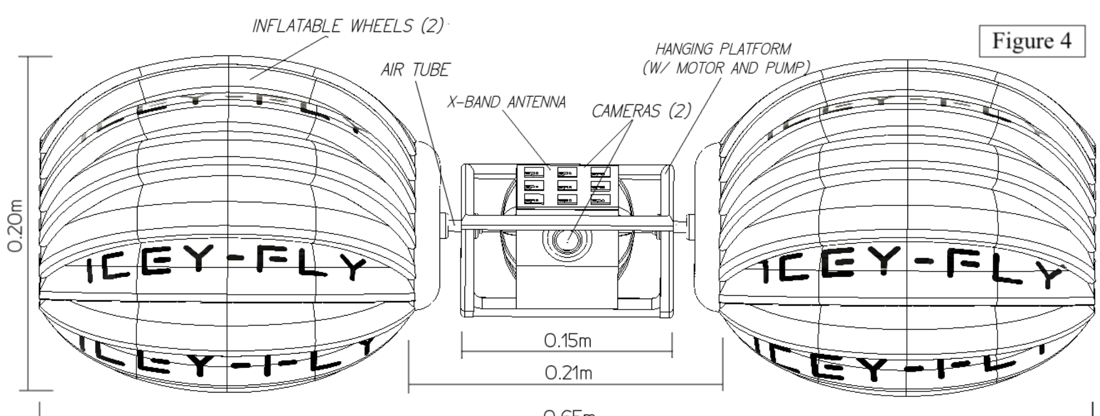


Figure 4

Icey-Fly is a whole fleet of inexpensive lightweight wind-powered rovers that can roam freely on Mars. They would be released one at a time during intervals of change of wind direction to prevent two Icey-Flys from following similar paths. This is a system of dual rotatable Vectran fiber parachute wheels, with inflate/deflate mechanisms for changing direction and stopping, that are inexpensive, simple, and lightweight. For self-sufficiency, the rotation of the shaft produces a current and a voltage that will charge a battery for the camera, communications antenna, and air pump that are located on a hanging platform between the wheels' air tubes. Stereo images will be taken from the cameras at decided intervals, data compressed, and then sent to the nearest rover or orbiter through its X-band chip-like antenna.

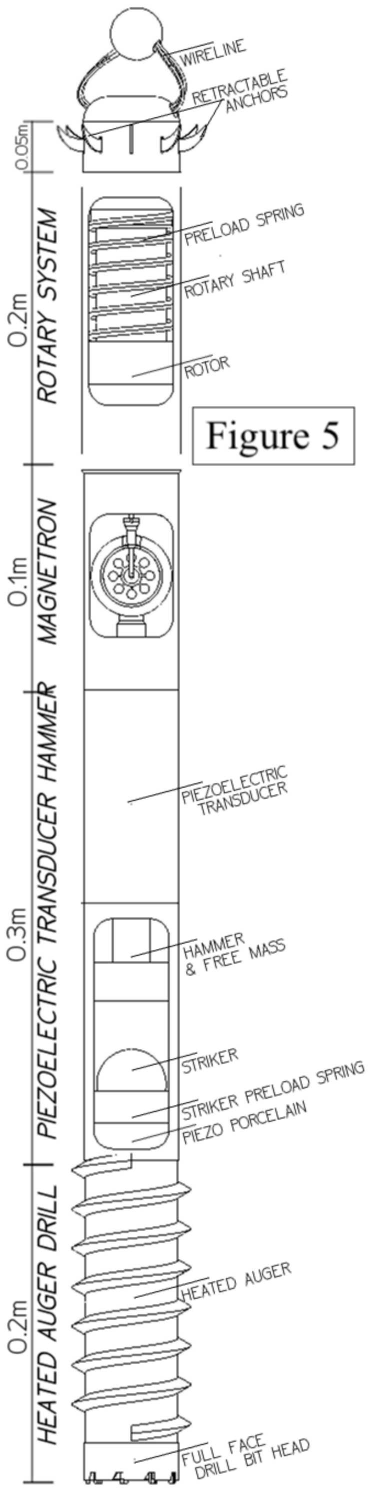


Figure 5

(b) Soil Drilling

- **Heated Auger Rod System (HARS)** *(Figure 5)* is the wireline drilling system used to drill and capture icy soil samples on auger flutes from the icy regolith of the Martian poles, to be analysed in the lab. The rod system consists of a retracting anchor, rotator, hammer, magnetron, and an auger fitted with a cartridge heater inside, all lowered as a single rod by a pulley line dispensed from the **Triangular Underside Compartment** *(Figure 1)* as it dives deep into the surface [14] [15].
- As the HARS auger drills, a regular trip to the **Soil Acquisition System (SAS)** *(Figure 6)* inside the Triangular Underside Comparment will be necessary to either dispense or scoop up the soil for sampling. In the SAS, a convection heated sample holder encloses around the HARS auger to soften the soil enough to be collected by (1) high speed centrifugal ejector (2) a rasp scoop rotating up and down the flutes. When complete, the sample holder will either be disposed out of the Triangular Underside Compartment, or transferred to the Sample Analysis Lab.
- **The Sample Analysis Lab (SAL)** *(Figure 1)* is ICEY's ChemIn-like X-ray diffraction spectrometer, an internal instrument that determines soil composition, identifying and measuring the presence of various minerals in the samples. Knowing these

minerals and their depth are essential to determining the environmental conditions or water processes that existed when they were formed, holding answers to Mars' past.

(c) Water Acquisition

Condensed water is collected into a cold trap canister with two heating methods (1) vapor released from SAS's convection (2) HARS's direct microwaving of the regolith:

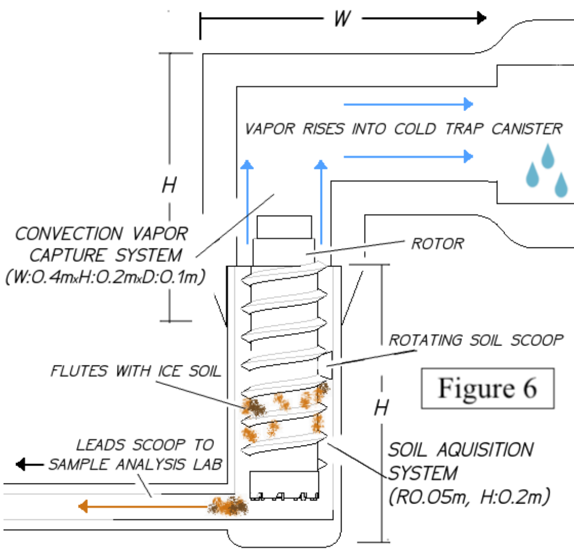
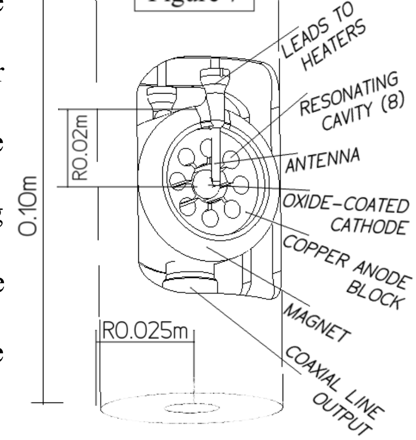


Figure 6

- **Convection Vapor Capture System** *(Figure 6)* kicks in during the Soil Acquisition System processes. When the convection heated auger is retracted into SAS for soil collection (1) the initial higher temperature of the heated auger will release water vapor, and then (2) the temperature and pressure of the SAS convection heated enclosed sample holder leads the vapor into a small cold trap canister nearer triple point conditions, and the vapor condenses into liquid to be pumped into the Pressurised Bladder Tank in the WEB.

- **Microwave Vapor Capture System** *(Figure 7)* is a down-hole wireline energy beam activated with the magnetron of the Heated Rod Auger System while the auger is drilling deep into the regolith. The microwave method consists of (1) a rotating (to prevent hot spots) magnetron, beaming low frequency microwaves into the soil around the ice [15] (2) allowing the hot water vapor to rise into a suction tube *(Figure 1)* enclosing the surface hole above, where it is led to the Convection Vapor Capture System.

Figure 7



- **Pressurised Bladder Tank** *(Figure 1)* is a pressurized water system located near the back of the chassis, consisting of (1) a welded T300 series steel tank and (2) a tank-sized balloon bladder to accept water (3) a check valve for pressure/temperature maintenance and to prevent backwards flowing. The bladder fills with water when the external pressure that is greater than the internal pressure of the bladder, compressing air to adjust to the pressure changes by eliminating or accepting the water volume changes as it expands or contracts due to heating and cooling.

(4) Robotic Mechanical Arm *(Figure 8)*

ICEY's robotic arm is a highly flexible 6 DoF, 6-axis articulated system with (1) a rotating swivel base, (2) two rotary arm joints, (3) and a 3 DoF wrist mechanism. Mainly to service the rover with retrieval tasks and equipment servicing, it is located next to the Triangular Underside Compartment. In coordination with the drilling system, the wrist mechanism of the robotic arm with its 3 DoF enables the gripper to have high dexterity and assist with the assembly/disassembly of the HARS drill, and the complex sample acquisition process and soil transferring soil to the Sample Analysis Lab.

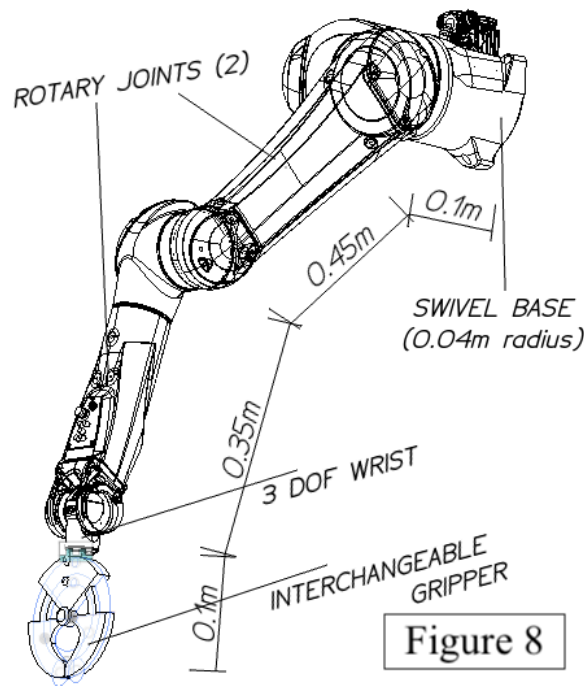


Figure 8

(5) Computer Hardware *(Figure 1)*

Due to the variety of processes orchestrated within ICEY, it will follow a modular approach in software and hardware to distribute complexity. Each of ICEY's electronic subsystems will execute a single aspect of the overall functionality, so that any malfunctions have minimal ramifications on the overall rover: (1) Drive - navigation based on autonomous data or Earth instructions (2) Power - power distribution and safety (3) Drilling - engineering processes for soil/water retrieval (4) Sample Analysis - lab data collection (5) Water Tank Pressuriser - pressure-temperature monitoring (6) Communication - two way data relaying. The subsystems for drive, communication, and power are mounted near ICEY's head inside an electrical box with the radiation hardened main computer and 10 GB memory, while the arm and sample-related subsystems have their own enclosures.

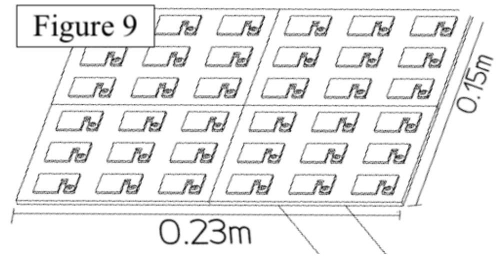
(6) Communication and Navigation Hardware

Antennas

For relaying navigation instructions (Earth→) and observation data, maps, or pictures (→Earth):

- The **Direct-to-Earth Antenna (DTE)** *(Figure 9)* establishes reliable and direct communication from Earth to ICEY using an X-band single feed circularly polarized antenna subarray, optimized with Particle Swarm Optimization.

Figure 9



- The **UHF Antenna (High-Gain)** *(Figure 10)* is an X-band antenna for two way data relaying (~11.2 GHz↑, ~12.0 GHz↓) between the rover and Icey-Fly's fleet. If the DTE antenna is down, communication with the Earth can be relayed from the UHF by the orbiters' more powerful transmitters. It is located on top of ICEY's mesh shell for maximum exposure. The data relayed will be instructions (from Earth) or observational data, maps, or pictures (from ICEY.)

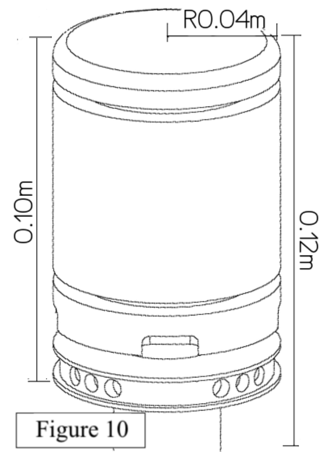


Figure 10

Cameras

- Two **Navigation Cameras** *(Figure 1)* are located in the front and rear of the chassis to offer pre-hazard avoidance and for autonomous navigation calculations.
- A **360° BallCam** *(Figure 11),* mounted on the Mesh Shell, provides color, panoramic, stereo, and high resolution images of the Mars atmosphere and environment used for observation and navigation.

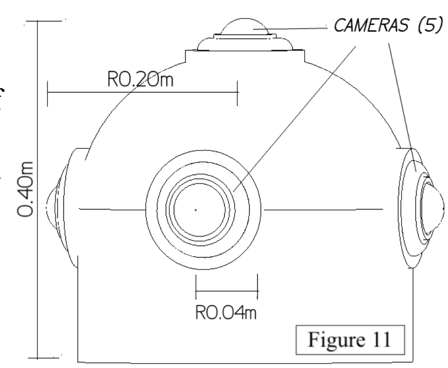


Figure 11

Gamma Ray Spectrometer (GRS) *(Figure 1)*

Located next to the Triangular Underside Compartment, the GRS probes for hydrogen (ice/soil) rich areas to navigate ICEY's digging. The instrument has two components: (1) the pulsed gamma ray emitter, and (2) the detector and electronics module that together use the intensity of gamma rays emitted by the hydrogen, to determine the depth and amount [16].

References

[1] Kowalewski, D.E., 2009. Vapor diffusion through sublimation till: Implications for preservation of ancient glacier ice in the McMurdo Dry Valleys, Antarctica. Department of Earth Sciences, Boston University, Boston.

[2] Baker, V. R. et al. Fluvial geomorphology on Earth-like planetary surfaces: a review. Geomorphology 245, 149–182 (2015).

[3] Brandt, John C. and Michael B. McElroy. The Atmosphere of Venus and Mars. New York: Gordon and Breach Science Publishers, 1968.

[4] McGill, G. E., The giant polygons of Utopia, northern Martian plains, Geophys. Res. Lett., 13, 705 – 708, 1986.

[5] Wordsworth, R. et al., 2015. Comparison of "warm and wet" and "cold and icy scenarios for early Mars in a 3-D climate model. Journal of Geophysical Research 120, pp. 1201-1219.

[6] Zacny, K. et al., 2016a. The World is Not Enough (WINE): Harvesting local resources for eternal exploration of space. s.l., AIAA SPACE Forum.

[7] Boynton, W. V., et al. (2002), Distribution of hydrogen in the near surface of Mars: Evidence for subsurface ice deposits, Science, 297, 81-85.

[8] Gendrin, A., et al. (2005), Sulfates in Martian layered terrains: The OMEGA/Mars Express view. Science, 307, I587-159I.

[9] Schroghoffer, N. & Forget, F., 2012. History and anatomy of subsurface ice on Mars. Icarus 220, pp. 1112-1120.

[10] Tanaka, K. L., and D. H. Scott (1987), Geologic map of the polar regions ofMars, U.S. Geol. Surv. Misc. Invest. Ser., I-1802C.

[11] Hurlich, A., 1963, Low temperature metals. Chem. Eng. 70 (November), 104.

[12] Thainwiboon M., Sangveraphunsiri V. and Chancharoen R., “Rocker-Bogie Suspension Performance”, Proceedings of The Eleventh International Pacific Conference in Automotive Engineering (IPC-11), November 6-9, 2001..

[13] Hoye T. J., Tantino D. C. and Chan J. (2011) NETS, Advanced Stirling Radioisotope Generator Flight Design Overview, 1-5.

[14] Vila L. J. and Malla R. B., “Dynamic Impact Force on a Special Drilling Mechanism for Planetary Exploration,” Journal ofAerospace Engineering,vol.,no.,

[15] Bar-Cohen Y., Badescu M., Sherrit S. et al., “Deep drilling and sampling via the wireline auto-gopher driven by piezoelectric percussive actuator and EM rotary motor,” in In Proceedingsof the SPIE Sensors and Smart Structures Technologies for Civil,Mechanical, and Aerospace Systems,vol.,p.A,SanDiego, CA, USA, March

[16] Goldsten J. O., Rhodes E. A. 2007. The MESSENGER Gamma-Ray and neutron spectrometer. Space Science Reviews 131:339–391.