PROMETHEUS: Progress Toward an Integrated Cryobot for Ocean World Access

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Abstract

Ocean Worlds in our Solar System are attractive candidates in the search for extra-terrestrial life. The best chances for detecting biosignatures and biology on these bodies lie in situ investigations of sub-ice oceans in contact with rocky interiors. The actual conditions that will confront an ice-penetrating vehicle ("cryobot") performing such investigations are largely unknown. However, any Ocean World cryobot must be able to, at a minimum, successfully negotiate five different operating regimes to have a chance of reaching a subsurface ocean: starting at the surface in vacuum at cryogenic temperatures; brittle/cold ice transit; ductile/warm ice transit; negotiating or penetrating salt or sediment layers, and other obstacles; and detecting and transiting ice-water transitions such as voids and the final ocean entry. PROMETHEUS (nuclear-Powered RObotic MEchanism Technology for Hot-water Exploration of Under-ice Space) represents a full cryobot concept and set of key technology demonstrations that advance the capability to perform such investigations. The PROMETHEUS concept is targeted for deployment on Europa, and consists of a fully-instrumented science vehicle able to actively control descent through the ice shell and into the subsurface ocean. The concept employs closed-cycle hot water drilling (CCHWD) technology as the primary means of penetrating ice, and making forward and turning progress. A “passive” (purely conductive) heat transfer system enables penetration starting on the surface where liquid water cannot exist until hole closure is achieved and the system proceeds inside a melt water “bubble”. PROMETHEUS is compatible with a small fission reactor (the NASA Kilopower design) and employs a vertical motion control system using a trailing tether frozen into the ice to guard against falling through voids and enabling controlled entry into the sub-ice ocean. The design is capable of achieving a 20 km descent through a Europan ice profile in under a year and under 500 kg vehicle mass, including reactor mass.
Progress Toward an Integrated Cryobot for Ocean World Access

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1. Cryobots for Ocean Worlds

The PROMETHEUS project, funded by the NASA SESAME program, aims to develop a cryobot concept for the penetration of the European ice crust into the global ocean. This concept will enable the in situ investigation of this unique environment of interest in the search for extraterrestrial life. PROMETHEUS seeks to identify, develop, and experimentally validate remaining critical components technologies to support a cryobot concept and accelerate the construction of ice in less than 350 days, carrying a payload of 39 kg.

2. Background

Since early work on “hotpenny” (purely conductive) melt probes for terrestrial glaciology [11][12][13] several groups have investigated the idea of an ice penetrator for Ocean Worlds [4][5]. A purely conductive melt probe will be stopped by areas of sediment or salt accumulation, so several types of mechanical augments have been proposed [6][7]. PROMETHEUS focuses on that several types of mechanical augments have been stopped by areas of sediment or salt accumulation, so

3. System Concept

Fig. 1 shows the PROMETHEUS vehicle concept. It is an ice-penetration robotic vehicle powered by the NASA Kilopower reactor [8] for melting the ice and delivering power to heat-pipe systems equivalent to the cryobot performance in ice. Additional, more detailed validation data, including full coverage temperature readings and control of heat distribution in the probe, and real-time readings of melt-hole diameter, will be gathered using the Highly Instrumented Probe (HIPPy) [9] in the Europa Tower in late spring 2022.

4. CCHWD in Cryogenic Ice

To validate the concept of CCHWD starting in cryogenic conditions, we have constructed the SubScale CCHWD demonstrator (Fig. 3). This cryobot incorporates all of the primary components required for CCHWD in a package that can operate at ambient temperature in the Europa Tower (Fig. 2). The SubScale CCHWD ice-penetration tests will include ice with impurities (salts) representative of Europa and will take place in the Europa Tower in February 2022.

5. Thermal Model Validation

Initial tests in the Europa Tower showed that closure of the melt hole is rapid for small probes [11]. Testing with larger-diameter probes would entail extraneous thermal challenges. The design relies on electrical heaters delivering power to heat-pipe systems equivalent to the cryobot performance. The design relies on electrical heaters delivering power to heat-pipe systems equivalent to the cryobot performance. Initial proof-of-concept tests in January 2022 will operate at 1250 W with an 1157 K max core temperature. These tests will evaluate heat pipe routing options for incorporation into the PROMETHEUS system in a low-environment and presence of the melt interfaces between heat pipes and liquid water to avoid both stagnation of the heat pipes and boiling of the water.

6. Nuclear Reactor Surrogate

We are designing and testing a surrogate thermal source (Fig. 5) with identical geometry, thermal signature and electrical output as Kilopower for use in terrestrial test beds. The Kilopower reactor is rapidly moving from concept to hardware and testing. This project was funded under the NASA SESAME program, NASA grant NNX11AF41G, NASA grant NNX14AK21G, NASA grant NNX15AK01G, and NASA grant NNX15AK21G.

7. Vertical Motion Control

During the months-long transit across the vortex it will be likely that a cryobot will encounter obstacles or voids. In order to be able to back up and deviate around obstacles, and to traverse voids or safely conduct final breakthrough at the under-ice ocean, the PROMETHEUS concept includes an in-vehicle wireless through-ice communications system to help control vertical motion. We are developing a test bed (see Fig. 6) to simulate expected events and evaluate the ability of this system along with methods to control vehicle motion when the nose is unsupported, and to detect possible non-horizontal vertical motions.

8. Conclusions

Technology enabling penetration of the European ice crust is rapidly moving from concept to hardware and testing. The SubScale CCHWD demonstrator (Fig. 3) with identical geometry, thermal signature and electrical output as Kilopower [10] for use in terrestrial test beds. The design relies on electrical heaters delivering power to heat-pipe systems equivalent to the cryobot performance. The design relies on electrical heaters delivering power to heat-pipe systems equivalent to the cryobot performance. Initial proof-of-concept tests in January 2022 will operate at 1250 W with an 1157 K max core temperature.

Bibliography


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