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Notional Concept of Operations and System Capability Definition for Enabling Scientific Ocean Access Missions on Icy Worlds

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Abstract

NASA Planetary Science Division's Decadal Surveys have placed a high priority on the science exploration of our solar system's ocean worlds such as Europa and Enceladus. In order to pursue the development of an overarching science-driven mission framework for a series of potential ocean worlds access missions, new robotic system capabilities will need to be established. One such capability under consideration is a cryobot capable of rapid penetration and scientific sampling of thick ice shells down to the ice-ocean interface where it would deliver an autonomous undersea explorer payload. Past [1, 2, 3] and more recent efforts [4] aimed at identifying key concepts of operations and technologies trades for accelerating the landing and deployment of a cryobot capability have highlighted the need for developing a comprehensive set of end-to-end mission architectures. We outline here some of the critical phases common to these architectures.

1. Introduction

Scientific interest in Ocean Worlds is focused towards three major themes: 1) Geodynamics: what is the structure and dynamic state of the icy crust and ocean interface?; 2) Habitability: does the Ocean World's past or present state provide the necessary environments to support life?; and 3) Life Detection: did life emerge on one of these Ocean Worlds, and does it persist today?.

Recognizing that many key questions related to these themes are best answered through in situ analysis of the ice shell interior and ocean, the planetary science community is exploring various technical solutions that may become sufficiently mature to support future missions in the next 15 to 20 years. One such solution under consideration is a highly autonomous cryobot vehicle capable of rapid penetration and scientific sampling of thick ice shells down to the ice-ocean interface where it would deliver a long range undersea explorer as illustrated on figure 1

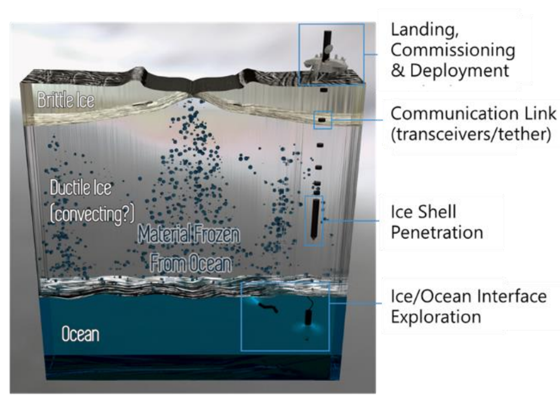

Figure 1: Europa example showing different mission phases that place environmental constraints on mission architecture, robotic vehicle design, and concept of operations.

2. Mission Architectures and Concept of Operations

To better understand commonalities of mission architectures and concepts of operations for Ocean Worlds subsurface and ocean access missions, we have initially selected three bodies: Europa, Enceladus and Ceres. Our common approach is for a totally self-contained probe, able to meet planetary protection requirements, and carrying a full suite of sensors, on-board computing/control, and in situ science instrument suite. The data link for science and engineering telemetry back to the surface is achieved through the use of discrete self-powered dual RF/acoustic transceiver "pucks" that communicate with the lander power and electronics payload that is buried at a shallow depth. For Europa, this concept removes the high radiation exposure risk associated with leaving this payload on the surface lander. Communications back to Earth are conducted through either a Direct-to-Earth lander antenna, or through the use of an orbital relay. The probe ability to efficiently penetrate thick ice shells is provided through a combination of thermal and mechanical methods: 1) passive melting using a multi-kW thermal inventory; 2) active melting using water jetting and 3) heated mechanical cutting and drilling. To provide the necessary heat and electrical power in support of these ice penetration capabilities we have focused on the use of radioisotope thermoelectric generators.

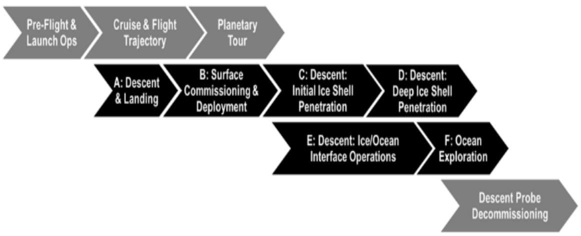

Figure 2: Notional end-to-end Concept of Operations for a Cryobot and its ocean-exploring science payload

A representative end-to-end concept of operations is shown in Figure 2. Operations can roughly be divided into three major groups: 1) Ground, launch and flight; 2) the science mission proper and 3) end-of-mission decommissioning.

The central part of the Cryobot mission concept of operations consists of: A) Descent and landing onto a safe and scientifically interesting region of the surface; B) Commissioning and deployment of the Cryobot to the icy surface.; C) Initial cryogenic ice entry phase that requires handling sublimation at the vacuum-ice interface with potentially dry, brittle, particulate filled material; D)Descent phase through cryogenic ice that slowly warms with depth to near freezing point; E) Detection of the ocean-ice interface followed by safe probe anchoring ahead of that interface; F) Ocean exploration: deployment of an ocean explorer payload and operations within the water near the interface

3. System Capability Definition

High level constraints on the system capability definition have been drafted by considering all mission phases and critical operations. Some critical drivers that we have studied include: 1) Compliance of radioisotope thermal & electrical power systems throughout all mission phases; 2) Meeting Planetary Protection requirements; 3) Ability to operate across a wide range of extreme environments, from 100 K in vacuum to 100's of bars pressure; 4) Active thermal control for collection and distribution of the large heat inventory to the cryobot head and body; 5) Start-up penetration phase on cryogenic ice surface, potentially in high radiation environment; 6) Detecting/avoiding in-ice hazards; 7) Reliable anchoring at ice/ocean interface and deployment of ocean explorer; 8) Effective communication architecture; and 9) Decommissioning at end of mission

4. Summary and Conclusions

We have advanced definition of a subsurface and ocean access robotic science exploration capability by considering end-to-end Ocean Worlds mission architectures and concepts of operations. We have assessed a number of critical challenges, including some that have been little studied to date. We will discuss an initial definition of a path forward to successfully develop viable solutions in the near term.

Acknowledgements

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