DIVE! DIVE! DIVE! TO EUROPA'S OCEAN, A TUNNELBOT CONCEPT STUDY. K.L. Craft[1], D. R. Meyer-Dombard[2], A. J. Dombard[2], S. R. Oleson[3], J. M. Newman[3], and the NASA Glenn Compass Team, [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD, (Kate.Craft@jhuapl.edu), [2]University of Illinois at Chicago, Chicago, IL, [3]NASA Glenn Research Center, Cleveland, OH.

Introduction: Europa, a Moon-sized icy satellite of Jupiter, contains a long-lived ocean in contact with a silicate interior and has more water within its ocean than on the whole surface of the Earth. This, along with the potential that geologic processes within its overlying ice shell allow surface materials to mix with the ocean and recharge chemical gradients, makes Europa a prime location for life. For any craft to explore the ocean, it must first overcome the challenge of traversing the ice shell. Here, we present a nuclear powered robotic mission concept [1] to tunnel into Europa (a tunnelbot) until reaching the ocean, sample for signatures of life, and assess habitability. The tunnelbot carries a payload that can measure environmental factors, search for biosignatures, and collect seismic data. How initial deployment on the surface would occur was not addressed and remains a challenge for future work.

Mission Constraints/Considerations: Based on both terrestrial experience and past Europa concepts [e.g., 2, 3], it was determined that melting through the ice would be the quickest and most efficient use of power to penetrate multiple kilometers of ice. Constraints of traversing through an ice thickness of 20 km and a penetration time of 3 years were set for the concept trades. Two potential thermal sources were considered: a nuclear reactor and plutonium bricks, and both were determined to provide sufficient heat. Additionally, with appropriate power conversion equipment, both sources can provide the 100's of watts of electrical energy to power the vehicles. The minimum 'footprint' of each of these systems defines the minimum tunnelbot diameter that could 'bore' through the ice sheet. Many trades were performed on tunnelbot diameter and length, and results found thermal flux at the tunnelbot tip needed to be about 20 W_{th}/cm^2 to achieve the desired 20 km in 3 yr.

Science Objectives and Payload: The objectives outlined in the study closely follow the Europa Lander SDT report [2] with objective 2 applicable in a subsurface context: Goal 1: Search for evidence of life on Europa; Goal 2: Assess the habitability of Europa via in situ techniques uniquely available to a [tunnelbot]; Goal 3: Characterize surface and subsurface properties at the scale of the [tunnelbot] to support future exploration [2].

Within these goals fall four main objectives: Objective 1: Analyze and characterize a wide range of organic biosignatures; Objective 2: Detect amino acids and determine enantiomeric proportions; Objective 3: Visualize the ice/ocean interface [or potential ice/lake interface if reached first]; Objective 4: Assess the habitability of Europa's ice shell and subsurface ocean

The recommended scientific instrumentation is similar to those in the Europa Lander SDT, although not all are included and some have different implementation (e.g., the seismometers are dropped behind the tunnelbot as it descends through the ice). Instruments could include a vibrational spectrometer, an organic Compound Analysis package, cameras, and seismometers; opportunity exists for instrument development.

Operations: An initial concept of operations proposes sampling the ice at the base of the lithosphere, where deeper convective ice in the shell might mix with more shallow ice, and sampling higher in the lithosphere for context. In addition, a sample will be acquired within the warmer, potentially convective deep ice, and several samples will be acquired near and at the ice-water interface, including direct exploration of the base of the ice shell to look for microbial biofilms. Red dots in Figure 1 show the sampling locations, which are tied to the notional thermal profile shown as a solid red line. The design also allows exploration of a subsurface lake within the ice shell, although such a scenario would preclude reaching the underlying ocean.

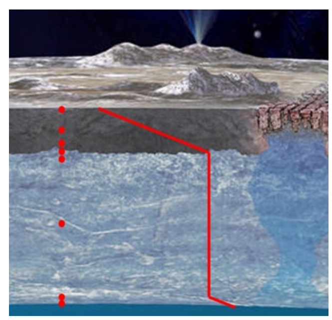

Figure 1. The red line - notional thermal profile through the shell, and the red dots - nominal sampling locations, which are tied to the thermal profile. (Modified from image courtesy NASA/JPL-Caltech.)

Data transfer and communications from the tunnelbot to the surface are provided by three repeaters that are deployed at depths of 5, 10, and 15 km, and are connected to the tunnelbot by fiber optic cable (with an RF backup link capable of transmitting through 5 km of ice).

References: [1] Oleson, S. et al. (2019) Compass Final Report: Europa Tunnelbot, *NTRS*, *in review*. [2] Stone et al. (2014), *Annals of Glaciology*, *55(65),* 2-13. [3] Winebrenner, D. (2016). Applied Physics Laboratory Ice Diver, Available at: http://kiss.caltech.edu/workshops/oceanworlds/presentations/Winebrenner.pdf. [4] Europa Lander Study 2016 Report, https://solarsystem.nasa.gov/docs/Europa_Lander_SDT_Report_2016.pdf