TESTING OF SLUSH ICE PENETRATING PROBE IN EUROPA, ENCELADUS AND MARS ENVIRONMENTS

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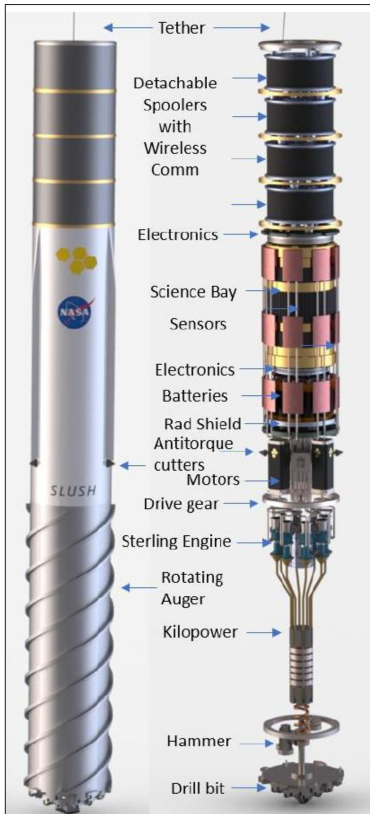
Introduction: The ocean worlds of Europa and Enceladus, and the subsurface of Mars are primary targets in the search for past and present life. Current research indicates that these three celestial bodies possess large bodies of liquid water—a key building block of life—beneath a layer of ice. The icy outer shells of Europa and Enceladus that sit above their global oceans are estimated to be a few kilometers to tens of kilometers thick [1]. On Mars, recent investigations suggest large bodies of water exist beneath more than one kilometer of ice [2]. The Search for Life Using Submersible Heated (SLUSH) probe is a hybrid, thermo-mechanical probe capable of penetrating the icy formation to reach the subsurface liquid water. To improve efficiency and drilling speed, SLUSH combines the two existing methods for traveling through ice: thermal (melting) and mechanical (cutting) [3]. "Slushing" uses drilling to break the ice and heat to partially melt the ice chips to form slush to enable the efficient transport of ice chips behind the probe.

SLUSH design: SLUSH has a heated drill bit with a rotary percussive mechanism in the front and an antitorque system on the side. It uses a Kilopower nuclear reactor for both thermal and electrical needs [4]. The fission reactor can be turned on/off and is self-moderating, simplifying thermal management. Sterling engines convert the thermal power to electrical. SLUSH baselines a tethered approach for communication with a lander on the surface. The system uses two conductive microfilaments and an optical fiber. The tethered approach provides high bandwidth and the accurate depth of the probe (using a rotary encoder). If the tether breaks, for example, from diurnal tidal stresses expected on Europa, the broken microfilaments can be used as an antenna for a so called "Tunable Tether" approach. The tether is wound inside several spool bays pucks that are left behind in the ice once the spool is depleted. The pucks act as transceivers/receivers to enable radio frequency (RF) communication through the microfilaments and decrease the probe length as they are released, making penetration more efficient.



System	Mass (kg)	Length (cm)
Tether	39	N/A
Wireless Comm	4	N/A
Spooler	41	20
Science Bay	N/A	65
Electronics	10	20
Batteries	20	50
Thermal design	11	N/A
Anti-torque	3	10
Motor	12	20
Percussion	13	30
Kilopower	N/A	130
Heated bit/auger	14	15
TOTAL	**189**	**~5 m**

Figure 1 Conceptual design of SLUSH with major components labeled. SLUSH is approximately 5 m in length and 50 cm in diameter.

Prototype probe: A stand-alone prototype probe has been developed to demonstrate the technology in a compact design. The probe will be tested in ice at temperatures found on Europa (250 K - 100 K) to at least 2x its length. It has all the critical functionality to demonstrate thermo-mechanical drilling, generation of slush, and refreezing above the probe. Once validated, the probe can be scaled to a larger design capable of carrying science payloads to study terrestrial glaciers in preparation for a future deep drilling mission.

The drilling subsystem has been used to compare the three drilling methods (thermal, mechanical, and thermo-mechanical or slushing). Testing has been conducted in relevant ambient and vacuum environments using "warm" (260 K) and "cold" (130 K) ice. Slushing is shown to be the fastest and most efficient penetration method in the tested environments.

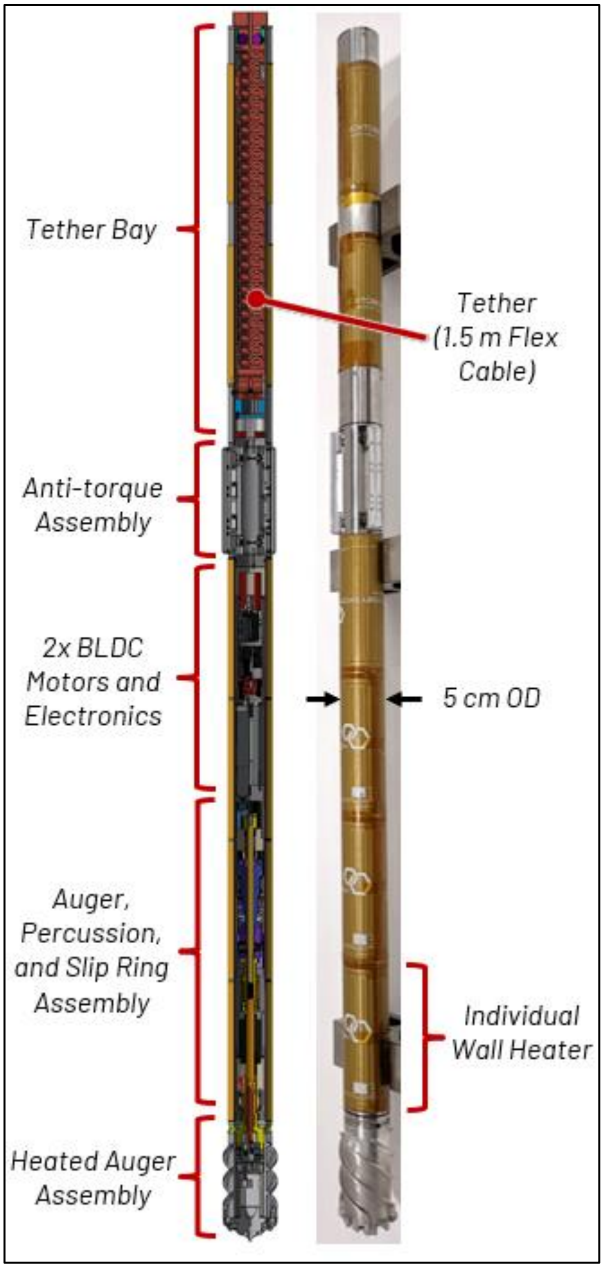


Figure 2 SLUSH prototype standalone probe with main subassemblies labeled. The probe is designed to drill under its own weight to twice its length.

The tether and spooler section is also being developed in parallel to allow the probe to drill to longer lengths. Simulations and initial testing have been conducted to demonstrate RF communication through a broken tether.

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