National Aeronautics and Space Administration

Accessing Mars Climate Record through Deep-Subsurface Pulsed Plasma Discharge Drilling

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Program: FY21 R&TD **Strategic Focus Area: Localization and Mobility**

Objectives. Plasma drilling is a deep drilling technology which leverages electrical discharges to fracture rocks and sediments. Plasma drilling is investigated as a performance enhancer for existing thermal-probe technology for use in planetary sub-glacial exploration missions. The hypothesis is that the cracking of ice induced by the plasma discharges results in a local reduction of thermal conductivity capable of decreasing the conductive thermal losses that make up the majority of a thermal probe's power budget in cryogenic ice conditions.

Background. Subsurface samples are imperative for determining the composition of planetary objects such as Mars and Europa. Analysis of these samples provide insight regarding both the structure of these bodies, their climate history, as well as searching for life. Drilling into these extreme environments, however, presents a challenge due to the low pressure and low temperature environments as well as the power limitations of the available equipment. The two predominant methods involve either mechanically breaking or thermally melting down the material. Melt probes require a substantial amount of power, so boosting their efficiency is necessary before they can be used on other planets. Current melt probe designs experience a low-level efficiency due to the dissipation of thermal energy to the surrounding ice. A thermal probe capable of pulsed plasma discharges can create shockwaves that crack the surrounding ice reducing its equivalent thermal conductivity. After cracks have been formed, a traditional hot-tip melt probe can be used to melt the ice surface with a decreased loss of thermal energy.

Approach and Results. To experimentally perform a direct comparison between a melt probe and plasma enhanced thermal probe, a cold testbed was envisioned Fig 1-D. The design, construction and testing of a simple melt probe made out of commercial off the shelf components was conducted, Fig1-B&C. Descend speed and consumed power where characterized in detailed to later be used as a baseline to compare performance with plasma discharge module.

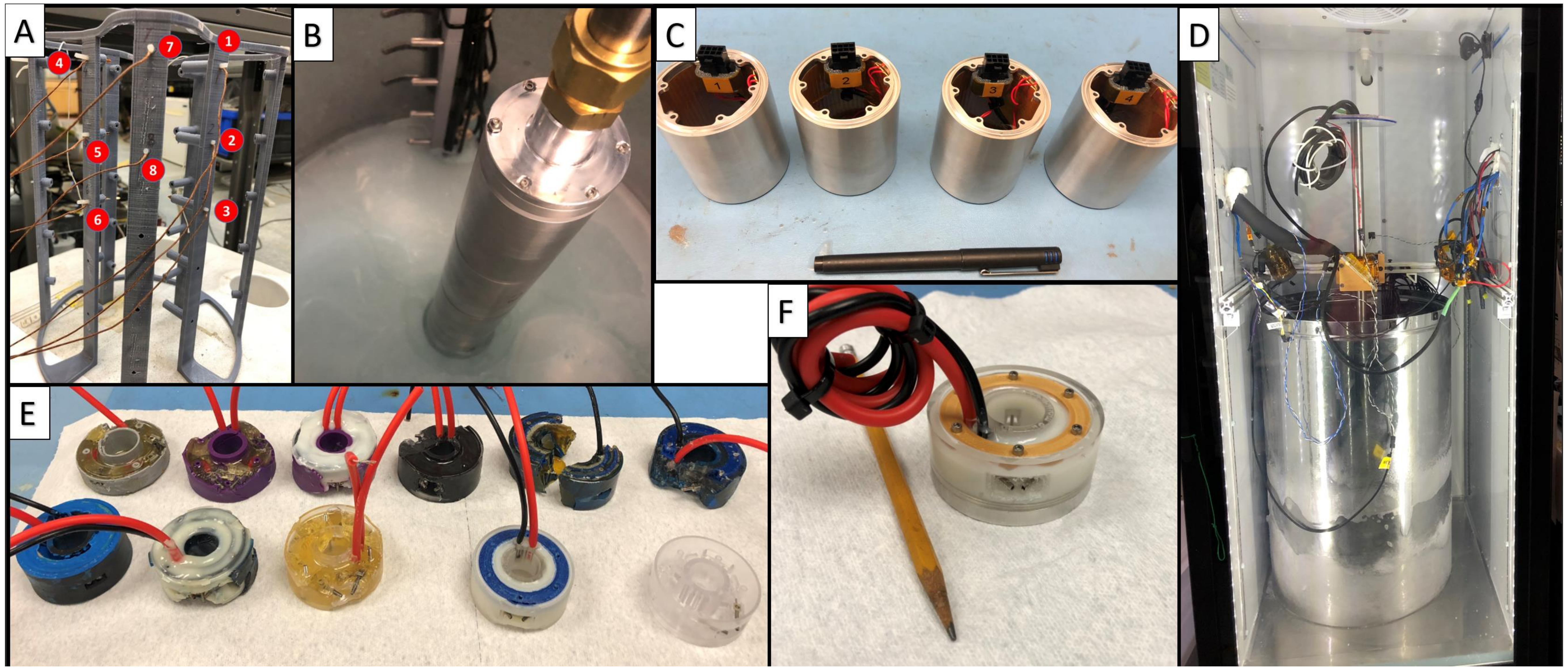
The integral component of this task, the high-voltage module capable of delivering pulsed-plasma discharges, was designed and tested. 12 revisions of this component were iterated on during FY21, Fig1-E. The large number of revisions were due to the peculiar challenges in realizing a compact, mechanically robust, self-heating, plasma discharge module. Early versions did not survive plasma discharges as they would break apart. Intermediary versions were able to sustain tens of plasma discharges but ultimately end up breaking apart. Two conflicting properties made the design of the plasma module so challenging:
-The need for it to be electrically insulative, which limited materials to epoxy/resins and plastics.
-The need to be thermally conductive. Since the module sits on top of the melt head of the probe, it needs to generate some heat to avoid getting frozen in. The electrical heaters on the module need to be sufficiently isolated from the high voltage portion to avoid shorts. The fact that the man material of the module is epoxy/resins makes transferring the heat to the external surface tricky.

For FY22 a metallized plasma discharge module will be tested.

Significance/Benefits to JPL and NASA. From FY20, the preliminary findings of the thermal model when coupled with the thermal conductivity experimental data shows that a 25% reduction in thermal conductivity from the plasma discharges generates 10-20% savings on consumed power for constant probe geometry and descend velocity. These power savings could enable a thermal probe mission to Mars that employs solar power as opposed to a significantly more expensive RTG mission. Furthermore, these efficiencies could be applied to any thermal probe on any planetary system, including Ocean Worlds. Even a radioisotope-powered thermal probe on Europa on Enceladus could benefit from the reduction on thermal conductivity and increase its descend velocity without incurring penalties on power.

The engineering challenges discovered during FY21 will make any gains on efficiency trade with respect to considerable complexity. The design, assembly and operation of a compact, heated, plasma discharge module is challenging under laboratory conditions which indicates that designing a flight version would be a non-trivial task.

Publications. Guglielmo Daddi, Fernando Mier-Hicks. Thermal Probe Enhanced with Pulsed Plasma Discharges for Efficient Ice Penetration. Journal of Thermophysics and Heat Transfer 0 0:0, 1-8



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