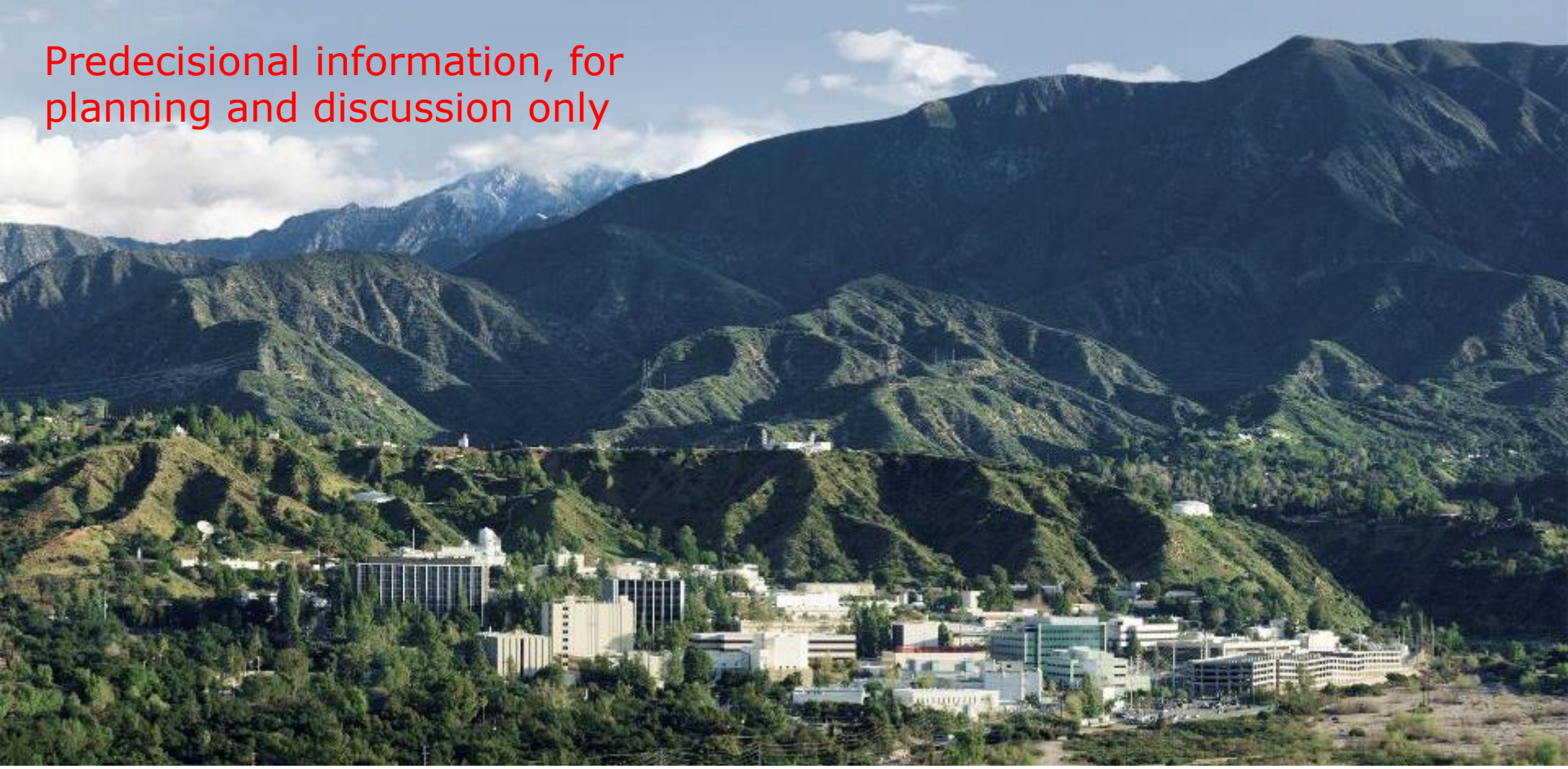

Predecisional information, for planning and discussion only

Design for AM Workshop *Design Scrimmage*

Designing a Subsurface Probe for Enceladus in an Afternoon

Michael Schein, Section 3550, Jet Propulsion Laboratory, California Institute of Technology

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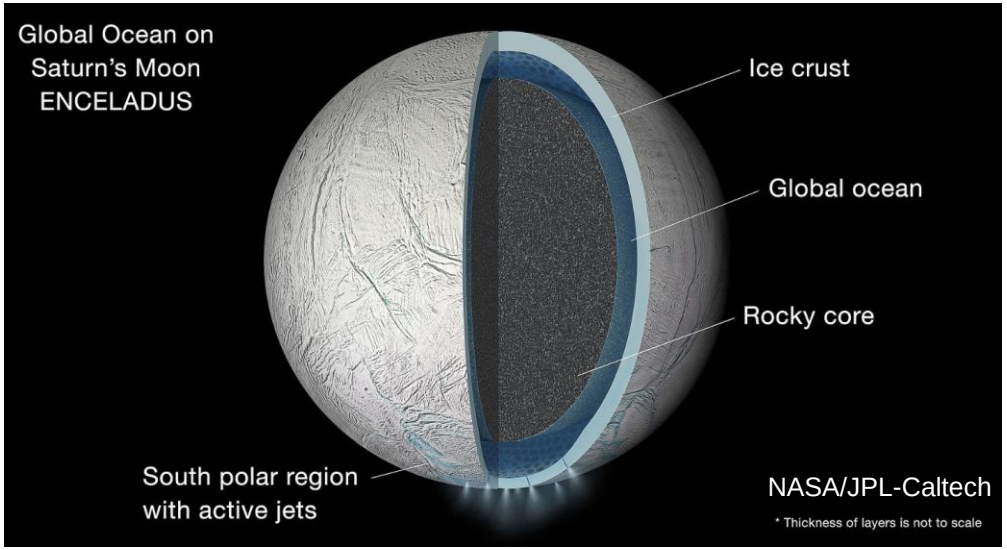
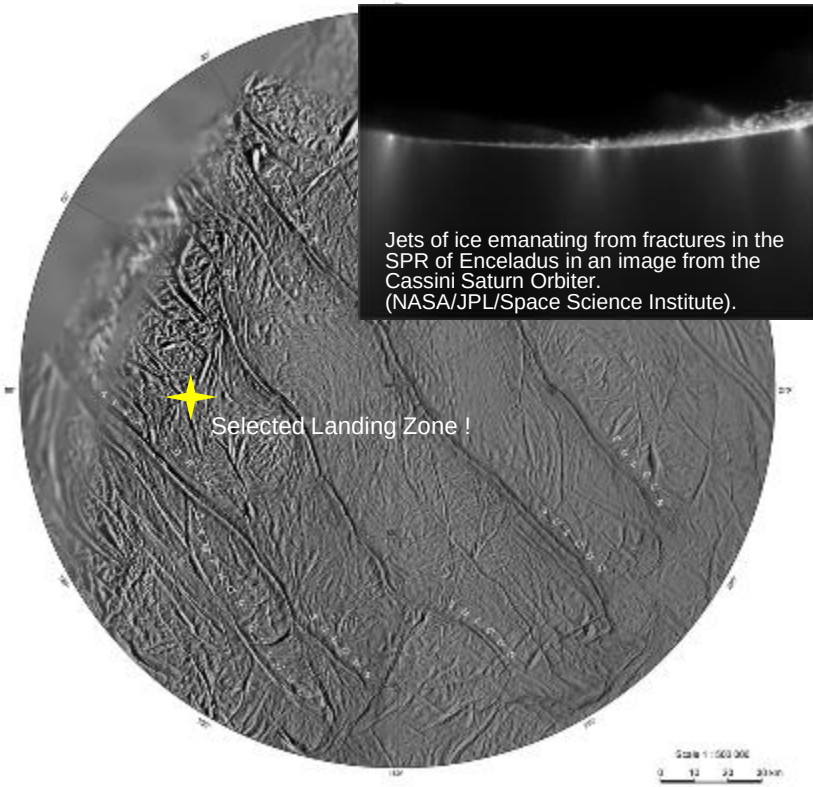
Jet Propulsion Laboratory
California Institute of Technology

Our Hypothetical Mission

Background: A radar sounding survey mission to Enceladus has shown stable subsurface “lens lakes” of water exist in the South Polar Region (SPR) at depths of three km, though location resolution is poor (5 km). These lakes are extremely interesting for their life hosting potential.

<u>Your Mission</u>: Given the provided mission elements, identify design features and approaches that help maximize data return using the advantages of Additive Manufacturing (extra points for coming up with a great mission name acronym).





Composite map of Enceladus's SPR showing cracks dubbed 'tiger stripes' where the geysers are located (NASA/JPL/Space Science Institute).

Previous JPL work in ice covered lake exploration

Predecisional information, for planning and discussion only

Micro-Submersible Lake Exploration Device

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Jet Propulsion Laboratory, California Institute of Technology

Abstract

As the number of unexplored areas of the world rapidly dwindle, highly precise and efficient instruments are needed to retrieve accurate data from remote aquatic habitats. Since the discovery of subglacial lakes in Antarctica, underwater vehicles are essential to investigating these challenging aquatic habitats and gaining insight on glacial formation, ice flow and discharge, basal water transfer, and the geometry of ice-water interface. The Micro-Subglacial Lake Exploration Device (MSLED) is a compact underwater vehicle designed specifically to explore aquatic, isolated environments. Equipped with conductivity, temperature and depth sensors (CTD), semi-autonomous capabilities, a camera, fiber optic cable, and other technologies, the MSLED is a one-of-a-kind instrument built to explore and gather data in stark terrain.

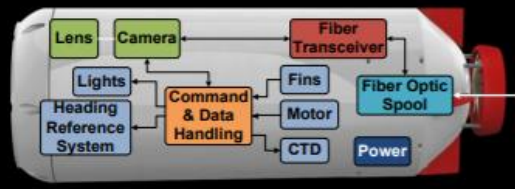
Science

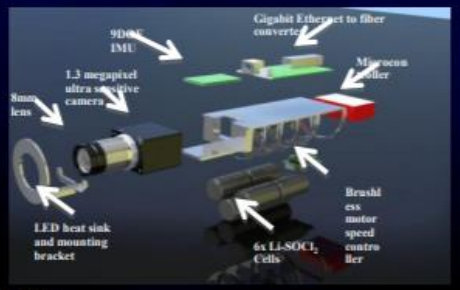
With an inventory of at least 145 Antarctic subglacial lakes, understanding the movement of ice flow is imperative to predicting the future of ice sheets and their effect on rising sea levels. The other avenue of exploration is to gain information on the subglacial biotic ecosystem that is currently not well understood. These studies illustrate that the subglacial environment is a vastly understudied, potential, ecosystem with the potential to impact our understanding of global biogeochemical cycles, astrobiology, and the biodiversity of cold, aquatic, dark environments. Also, with the prospect of subglacial lakes on Jupiter's moon Europa, a strong foundation of knowledge is necessary for successful extra-terrestrial exploration. Using various biogeochemical measurements will also test the hypotheses that glaciological, hydro-oceanographic sedimentological, and biochemical processes combine to stabilize the ice shelf and control the structure and function of microorganisms inhabiting the subglacial habitat.

System Overview

The communication sub-system on board MSLED transmits and receives data simultaneously over a single multi-mode fiber optic transmission line. The surface station requires real-time video, heading reference system data, and CTD data to navigate and explore areas of interests. MSLED receives commands to operate the fins, motor, lights and camera. In order to couple all the data together, the command and data handling system packetizes the data from all the subsystems digitally. This digital data is managed by the camera and the electrical signal is converted to optics using a fiber optic transceiver. The transceiver transmits the data, through the existing Ice Borehole Probe, to the surface ground station, to be converted back to electrical signals. The data can then be coordinated by the graphical user interface.

Technical requirements and constraints:
- •Fiber communication must integrate into 1 km of 62.5/125 multi-mode fiber cable currently being used on the Ice Borehole Probe
- •Components must fit within a 7.5 cm diameter, 25 cm long cylinder
- •Signals must transmit 3 km without noticeable degradation to video quality or sensor data fidelity
- •Components must withstand temperatures -10 to +65 °C
- •Transmit high definition video and sensor data (CTD, IMU status, etc.) to surface station
- •Receive navigation control signals from surface station
- •Transmit data at gigabit speed simultaneously





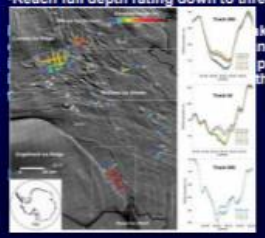
Mechanical
Structure determines function. Due to the strict size dimensions of MSLED, the structure has certain design requirements to house and protect the internal components. These constraints include rated pressure, rated temperature, and size. The structure subsystem has the following constraints:
- •Withstand pressures at 3km of depth
- •Withstand temperatures ranging from +/-10 °C
- •Overall size of the device which will be no more than 8 cm in diameter by 40 cm in length

The structure is composed of an external and an internal component. The external shell provides protection from the environment while the internal shell is where the various components are mounted. The external structure is divided into three major sections: the nosecone, the main hull and the tail cone. The nosecone contains the camera, camera lens and LED's. The main hull has two sections: the forward part of the hull is where the electronics, power and communication subsystems are housed; the aft section of the hull contains the fiber optic cable. The tail cone holds the propulsion, the control hardware and CTD sensor.

Mission Summary

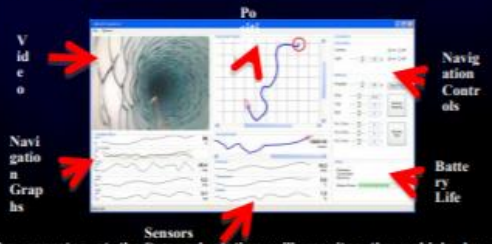
A finely crafted underwater vehicle will be needed to address the questions surrounding subglacial environments. MSLED is a small (8 cm diameter and 30 cm in length) torpedo-shaped underwater robot designed to be submerged in subglacial Antarctic lakes to navigate semi-autonomously and record data within the lake. Tethered to the Ice Borehole Probe, MSLED will have the capability to detach and roam freely due to the optical fiber cable with a range of 1 km and will eventually reattach and be brought to the surface. Of primary importance are the innovative size and capabilities of MSLED, for example:

- •Capture high-resolution video and images of the lake
- •Record up to 2.5 hours of real-time video
- •Navigate towards pressure, temperature, turbidity, and depth gradients semi-autonomously
- •Stop at significant detected geothermal hotspots and conduct further measurements
- •Reach full depth rating down to three kilometers



ke Engelhardt to collect measurable nd conductivity, as well as visual p to four hours. If space per-mits, h appropriate biosensors to detect

Ground Station



The operator at the ground station will monitor the vehicle by a graphical user interface that displays the submarine's video, status data of the different sensors, as well as horizontal and vertical position in real-time and with history, where possible. Furthermore, the operator shall be able to control the vehicle and send commands for camera, lighting, fins, and heading.

Acknowledgements

The work described here was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration and funded by the National Science Foundation and through the NASA Earth Science Cryosphere Program. The authors would like to thank the scientists and engineers at the following institutions; Woods Hole Oceanographic Institution (Dana Yoerger), Communications Architectures and Research at JPL (Malcom Wright), WHOI Deep Ocean Exploration Institute (Chris German) and the Monterey Bay Aquarium Research Institute (Hans Thomas). Also special thanks to UCSC Department of Earth and Planetary Sciences (Slawek Tulaczyk), UCSD Institute of Geophysics and Planetary Physics (Helen Fricker) for their science support and collaboration.

ESA ongoing work on Enceladus exploration

A lander mission to probe subglacial water on Saturn's moon Enceladus for life ☆

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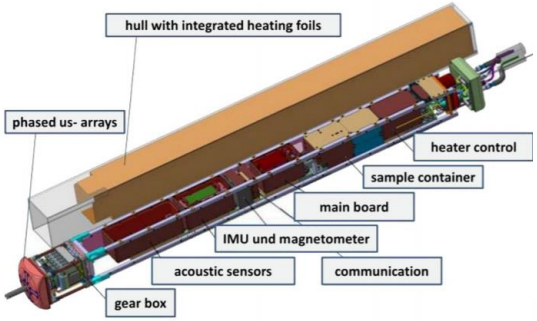


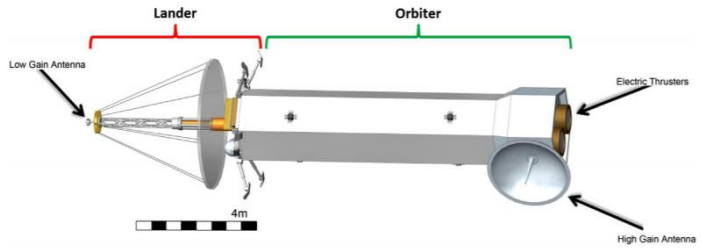
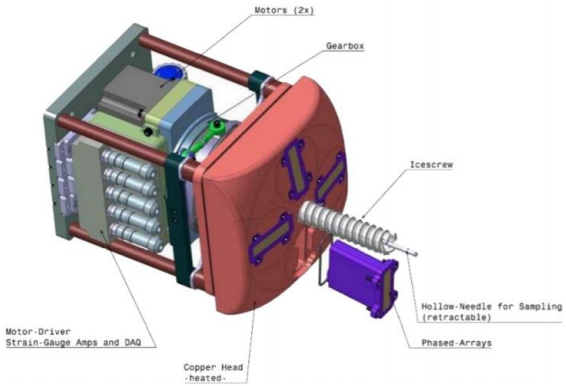


Fig. 8. Preliminary design of the Combined Spacecraft, comprised of the Orbiter and Lander, before Lander separation.

Fig. 9. Preliminary launch configuration of the Combined Spacecraft, within a provisional launch vehicle fairing with dimensions of 5.4 × 17 m² (Ariane V fairing).



The Saturnian moon Enceladus with its extensive water bodies underneath a thick ice sheet cover is a potential candidate for extraterrestrial life. Direct exploration of such extraterrestrial aquatic ecosystems requires advanced access and sampling technologies with a high level of autonomy. An innovative exploration concept has been developed as part of the research consortium Enceladus Explorer (2012-14). It is based upon the minimally invasive melting probe IceMole, which enables to travel along a curved trajectory and allows obstacle avoidance as well as target selection maneuvers. These maneuvers, however, necessitate a sophisticated on-board navigation system capable of autonomous operations including in-ice attitude determination, localization, and forefield exploration, which are integrated through a high-level sensor fusion. The Enceladus Explorer Initiative (EnEx), established by the DLR Space Administration in 2015, addresses these challenges and contributes to developing key technologies for a future exploration mission to Enceladus.

Requirements for our hypothetical probe:

Falcon Heavy Launch =
11000 kg to Enceladus
-3000 kg deorbit burn module,
-3000 kg relay orbiter mass
-1500 kg landing module mass
= **3500 kg probe mass budget**

SpaceX, Inc

Mission Performance Requirements:

- ❑ Land on Enceladus SPR (assume success, hurrah!)
- ❑ Identify target lake location using crawler and radar sounder
- ❑ Travel up to 5 km to get within drill range
- ❑ Set up surface base with stable communication to relay satellite
- ❑ Thermally drill down through up to 3000 m of ice
- ❑ Enter lake environment, travel up to 100 km
- ❑ Release array of independent explorer drones (RTG power, 50W each)

Required Data Products (both surface and subsurface):

- Environment physical properties, water and ice constituents
  - mass spec, temp & pressure sensors (small, low power, many signal lines)
- Video feed
  - multiple cameras (3 on surface, min. of 2 per drone, low power, high data rate)
- Sonic Sensors (Subsurface only)
  - small, low power, includes both sonar emit and receive
- Multispectral imaging
  - hypothetical technology level, medium size, medium power, very high data rates
- Seismic sensing (Low power, wireless, need to place 12 surface sensors during travel, add'l 12 sensors to be placed in subsurface lake environment, data relayed to surface by subsurface probe
- Radar sounder (Surface only) (large, high power)
- Magnetometer (small, low power, needs to be min of 3 m from any magnetic material
- In-situ biological activity analysis (medium size, high data rate, medium power draw)

- Communications, Surface: High Gain Antenna (very large, high power) and Laser Communications Module (medium size, medium power)

- Communications, Subsurface: Probe to Surface: Trailing fiber optic cable; stationary receiver at bottom of bore hole, probe to receiver: short range: laser, medium range: long wave radio, long range: sonic pulse