Designing a Submarine for the Exploration of Titan's Methane Seas.

A. López[1], B. Rivera-Muñiz[2], and J. Colón[2] [1]The Arecibo Observatory (STAR Academy) (micoral@outlook.com), [2]The Arecibo Observatory (UAGM)

Introduction: This project was completed as part of the requirements for graduation at STAR Academy at The Arecibo Observatory as a high school level investigation with the purpose of exposing students to real scientific research. The main goal for this project was to explore the possibility and design a prospect submarine for the exploration of Titan's methane seas. Developing and completing a mission with a submarine to explore Saturn's biggest moon, Titan, would be an enormous accomplishment for humankind. The hypothesis for this project was that the development of a submarine for the exploration of Titan is possible and can be developed by integrating recent research developments and innovating ideas that have been already explored. The National Aeronautics Space Administration (NASA) is in the process of building a submarine for Titan [1]. There are differences between the NASA's submarine and the one being designed in this project. Characteristics such as the efficiency of the submarine, how can the submarine obtains data of the celestial body, and if the submarine is sustainable in the conditions on Titan are analyzed and explained.

The information the submarine is capable of collecting could help in further studying Titan, such as in identifying the presence of living organisms. Knowing more of how Titan works as a system, can help us better understand Earth. There is an average amount of information of Titan, obtained from the spacecraft Cassini and the Huygens probe [2]. The data of the probe contributed with the selection of the specific destination that could be explored, technologies that should be applied, the design of the submarine, and other details.

Titan: Due to Titan's dense atmosphere, the moon remained a mystery for a long period of time. The atmosphere's orange organonitrogen kept the surface of Titan a secret. With the Cassini spacecraft and the Huygens probe it was possible to uncover what was under that orange haze. The Cassini-Huygens mission was successfully able to land the Huygens probes on Titan's surface. At the beginning, the probe could only see an orange haze, but then when it was closer to the ground it caught astonishing photos of Titan. In the photos, rock formations that looked like mountains could be seen, and one of the details that caught most attention was the dendritic rain patterns. This dendritic rain patterns made scientist assume there were traces of rivers in Titan. The Huygens data helped create lakes and seas maps, and a global geological map [3]. The geological map in Figure 1 was used to decide where it would be the optimal target for our submarine design.

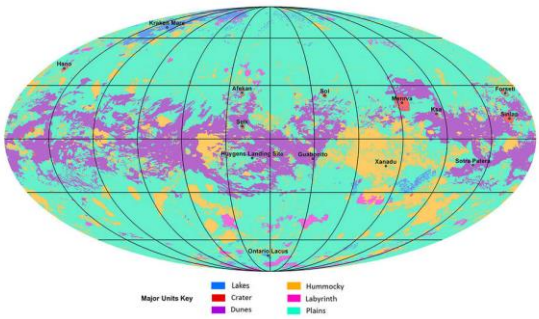

Figure 1: Geological Map of Titan (Credits: NASA/JPL-Caltech/ASU)

The Kraken Mare is the largest body of liquid in Titan. The Kraken Mare is considered a sea since it is bigger than the Caspian Sea on Earth. It lounges over approximately 1000 km towards mid-latitudes. An estimate of the depth appears to be 160 meters, but it may not be the actual depth. The sea covers an area of 154,441 mi.^{2} approximately. Kraken Mare appears to have an island called Mayda Insula. The sea can be connected hydrologically to the second largest sea, Ligei Mare. Our proposed submarine would advance near this island to it with detail. The Sea is divided into three parts, Kraken-1, Kraken-2 and The Throat of the Kraken. The throat of the Kraken Mare is believed to have currents [4]. Depending on how tides and wind currents move in Kraken, it is plausible that thermal stratification occur. On Titan tidal forces are strong because of Saturn's large gravity, but the tidal forces change to slower periods; this is due to the 15.945 Earth day orbital period. Tidal amplitudes have been detected of few of tens of centimeters on the Kraken Mare with the velocity of currents of a few centimeters per second. The exact composition of the sea is unknown, but it is known the sea is mostly composed of methane and has ethane, nitriles and higher hydrocarbons [5]. This composition could increase the density, viscosity and dielectric constant. The density of methane is 0.656 kg/m^3 and ethane is 1.36 kg/m^3. The density of both methane and ethane is approximately 2/3 that of water, meaning the viscosity will be similar to water. Our proposed submarine could be exploring the Kraken-1 and possibly the Kraken-2 region, while The Throat of the Kraken is an area that submarine most likely should not be exploring, due to the expected larger currents and possible whirlpools.

Design: One of the most important elements analyzed in this project were the material of the submarine, since most of the other branches of the design rely on

this. The overall idea of the submarine's composition is that it will have three layers. The first layer will be composed of a materials that will resist -179˚C. This material will be located at the outer part of the submarine. The second layer will serve as an insulator. The third layer located in the inside of the submarine will be a material that will let the heat escape slowly conserving a specific amount of heat. Each of the materials selected complies with a specific purpose. The outer part layer will help the submarine be able to resist Titans extreme conditions, the second layer will have the function of regulating the temperature inside the submarine, and the third layer will be the material that will allow the heat to escape slowly to avoid increasing the chances of methane boiling in the surroundings of the submarine, creating difficulties for the submarine.

Technologies: The various types of technology, such as sensors and other instruments will help identify and acquire important data such as physical properties and chemistry of the Kraken Mare, more information about the tides, seasons, geological information of Titan and further more. The technologies inside the instrument will allow the exploration of important questions such as if there can be a carbon-based life form or can the exploration of the Kraken Mare hold clues to how life originated on our planet.

Engine: A radioisotope thermoelectric generator will be powering the submarine. A radioisotope thermoelectric generator, also known as an RTG or RITEG, uses an array of thermocouples to convert the heat released by the decay of a suitable radioactive material into electricity by the Seebeck Effect [6]. This generator contains no moving parts and uses nuclear power. The RTGs have been used in satellites and space probes. An RTG was used in the Cassini probe. RTGs are usually the most desired power sources for unmaintained situations that need a few hundred watts of power for extended durations time, for which fuel cells, batteries or generators do not provide economically viable options, and where solar cell are not efficient. Solar cells are not efficient in this design due the low amounts solar energy that reaches the intended location. These characteristics of the RTG makes it perfect for the submarine engine. The expenses of RTGs tend to limit their use to niche applications in extreme situations. Much like the extreme situations that happen in Titan like the atmosphere whether and etc. Due to the RTGs lifespan, the proposed submarine will be able to operate for approximately 87 years. RTGs pose a risk of radioactive contamination which will not be a problem since there will not be any humans around the engine once it is launched and arrived at Titan, however, these are important considerations in terms of the effects it could have on the unexplored regions of Titan, and the data that will be collected.

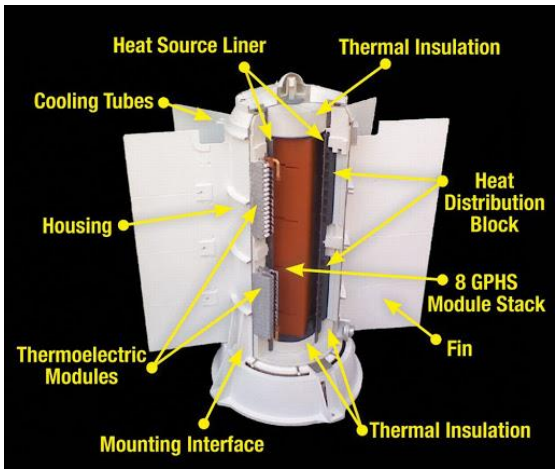

Figure 2: Radioisotope Thermoelectric Generator (Credits: NASA)

Conclusion: The development of a submarine for the exploration of Titan's methane seas is possible. Approaching this project by using known research results helped design the submarine part by part, making it possible to hypothetically visit Titan and complete a mission acquiring important data along the way. This submarine design could be the building blocks of more complex studies and designs.

Acknowledgments: Funding for the STAR Academy program is provided by NASA's Near Earth Observation Program grant 80NSSC19K0523 for the Arecibo Observatory Planetary Radar Program, awarded to the University of Central Florida. The program is administered by the Ana G. Méndez University.

References: [1] Hartwig, J., Colozza, A., Lorenz, R., Oleson, S., Landis, G., Schmitz, P., et.al, (2016). *"Exploring the depths of Kraken Mare – Power, thermal analysis, and ballast control for the Saturn Titan submarine"*. Cryogenics, 74, 31–46. [2] Lavoie Sue, (2019). *JPL Photo journal*. https://photojournal.jpl.nasa.gov/spacecraft/Huygens%2BProbe. [3] Lavoie Sue, (2019). *JPL Photo journal*. https://photojournal.jpl.nasa.gov/catalog/PIA20713. [4] Lorenz, R.D., (2014). *"The Throat of Kraken: Tidal Dissipation and Mixing Timescales in Titan's Largest Sea"*. 45th LPSC: 1476. [5] Lorenz, R.D., (2017). *"Drifting buoy and autonomous submersible designs for the scientific exploration of Titan's seas"*. OCEANS 2017 - Aberdeen, 1-8. [6] R.G. Lange, W.P. Carroll, (2008). *"Review of recent advances of radioisotope power systems"*, Energy Conversion and Management, Volume 49, issue 3, p. 393-401.