SAMPLE RETURN FROM TITAN. G. A. Landis[1] , S. R. Oleson[1], R. D. Lorenz[2], and the NASA Glenn COMPASS design team[1] [1]NASA John Glenn Research Center, 21000 Brookpark Road, Cleveland OH 44135. geoffrey.landis@nasa.gov, [2]Johns Hopkins Applied Physics Laboratory, 11100 Johns Hopkins Road. Laurel, Maryland 20723.

Introduction: Titan is one of the most complex and fascinating worlds in the solar system. Titan is unique in the outer solar system in that it is the only moon with a thick atmosphere, and the only body in the solar system outside the Earth with liquid seas on its surface. The Titanian oceans, however, are seas of liquid hydrocarbons, and the surface rocks are primarily water ice.

As a world with an atmosphere and liquid oceans, and the only body other than the Earth with a hydrological cycle (albeit with rains of methane taking the place of water in the phase-change cycle), Titan is a high value study for atmospheric and climate science, both in its own right, and also as an opportunity to learn about Earth by comparison to another, similar body. In addition, beneath a crust of ice, Titan is an ocean world, representative of the many ice-covered liquid oceans found in the solar system.

The surface and atmosphere are rich in the complex organic compounds known as tholins, which are ubiquitous in the outer solar system and Kuiper belt, yet not well understood. These are likely to be the molecules of the early solar system which served as the building blocks from life arose..

Bringing a sample of the surface materials of Titan to the Earth for analysis by ground-based laboratories would be a mission of exceptional scientific value for the planetary science community and for the insights in astrobiology, the origin of the solar system, and the origin of life [1,2]. Such a mission, however, would be an order of magnitude more difficult than any sample return mission previously attempted. We have analyzed a mission concept for Titan sample return in which we use propellants processed from surface and atmospheric resources on Titan to decrease the mission mass and make such a sample return possible using existing launch vehicles [3].

Mission Concept: The overall mission concept is to use resources available on Titan to produce the fuel for the Earth return, thus allowing a vehicle with empty tanks to be delivered to the Titan surface, at a considerable mass savings. An overview of the design is given in reference [3], with details of subsystems to appear in subsequent papers.

The design was for a sample mass of 3 kg. A science constraint of the mission was that the Titan surface sample was required to be maintained at Titan temperatures through the flight, Earth entry, and landing in order to ensure that the samples remained pristine. The sample temperature was not to exceed 100K during any portion of the flight.

Vehicle Design. Liquid methane/liquid oxygen was chosen as the propellant combination for both the launch from the surface of Titan as well as the injection from Saturn orbit into the trans-Earth trajectory. This is a propellant combination with a high specific impulse and significant engineering heritage.

Two return concepts were considered, a single-spacecraft direct return, in which a single spacecraft including the sample return capsule is launched directly from the surface of Titan; and a two-spacecraft approach, in which the sample launched from Titan would rendezvous with a return spacecraft waiting in Titan or in Saturn orbit to take it on the trajectory trip to Earth. The orbital rendezvous approach was seen to have significantly more complexity with no advantage in mass over the direct launch, however, and the direct launch approach was taken.

The design resulted in a three-stage launch vehicle, with two stages to launch from the surface through the thick atmosphere into Titan orbit, and a restartable third stage to leave Titan orbit, conduct multiple fly-by passes through the Saturn system, and then make a final burn at a near-Saturn pass to put the vehicle onto the Earth return trajectory. The ΔV for the launch from the surface to Titan orbit was about 4 km/s, including about 1 km/s of drag losses in the thick atmosphere, and the ΔV from Titan orbit to Earth return totaled just over 2 km/s. All three stages used the same methane/oxygen propellant.

Figure 1 shows the return vehicle. The entry capsule for Earth return, based on the OSIRIS-Rex sample return capsule [4], is visible at the top. Two 3.6 m^2 deployable solar arrays based on the ROSA technology [5] power the spacecraft, producing about 25 W at Titan. During the seven-year return cruise to Earth, the interior of the aeroshell is opened to deep space, allowing the sample to remain radiatively cooled. Length of the vehicle shown is 174 cm, with an entry vehicle diameter of about 81 cm. Total spacecraft mass is 240 kg, including 3 kg of returned sample, along with 1 kg of liquid oxygen, used as a phase-change material to maintain the sample to an average temperature of 94 K during the atmospheric entry and up to 9 hours after landing.

Figure 2 show the launch vehicle in launch configuration. Maximum diameter is 140 cm, including insulation on the fairing (jettisoned before launch); the total vehicle is 1174 cm.

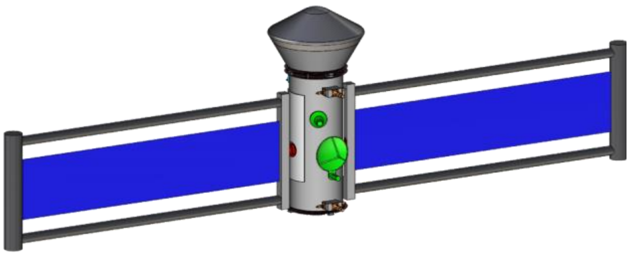

Figure 1: *Earth return spacecraft for Titan sample return mission*

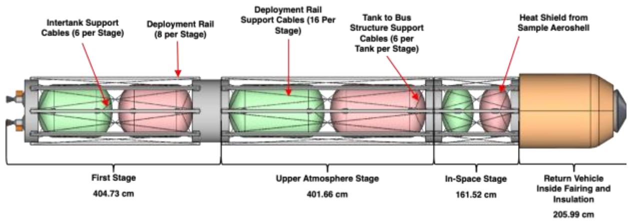

Figure 2: *Titan launch vehicle (deployed configuration)*

The size of the fuel tanks required for the vehicle to launch from the surface is high; in order to fit this vehicle in a reasonable entry vehicle to land it on the surface of Titan, the vehicle was designed to use inflatable tanks, allowing it to be compressed to less than half the deployed length for descent and landing. This allows the vehicle, along with the propellant processing plant, to fit into an entry vehicle based on the X-37C [6], a design which has been proven in Earth orbit.

Propellant Acquisition. Methane is available on the surface and in the atmosphere of Titan. Two methods were considered for harvesting the methane: pumping liquid methane from the existing methane lakes of Titan, or condensing methane vapor from the atmosphere. Condensation of methane from the atmosphere was the approach selected, in that it allowed the mission the freedom to select a landing site, rather than limiting the site to a tightly constrained location at the shore of a lake. The amount of methane in the atmosphere at the surface is at or near the saturation point of 5.7%, allowing the methane to be liquified by compression.

Oxygen for the combustion is produced from Titan water, available in the form of water-ice. Ice is harvested from the surface, crushed, melted, and the melt water distilled to remove impurities. The melt is then electrolyzed to produce hydrogen (which is vented) and oxygen, which is compressed and liquified.

Figure 3 shows the overall mission concept of operations, with a launch from Earth in 2038 and the return of the sample in 2056.

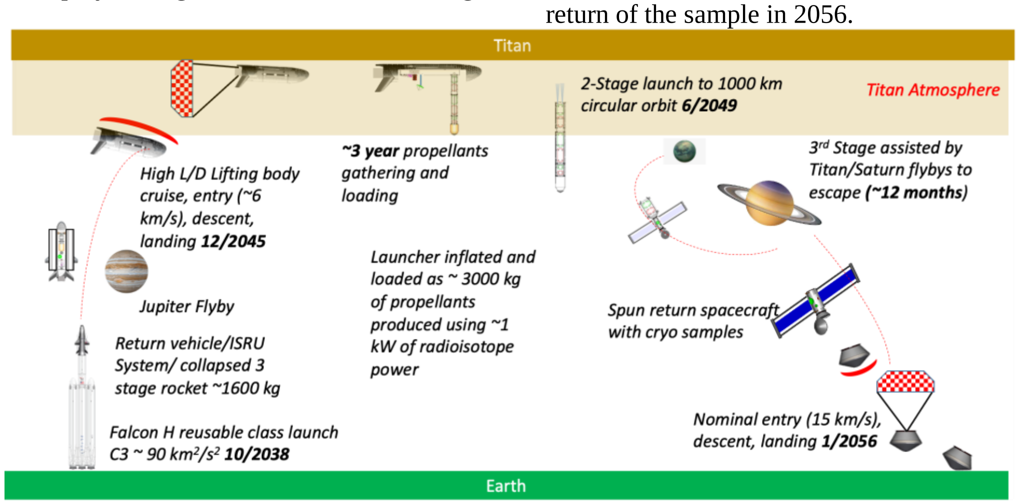

Figure 3: *Mission Concept of Operations.*

Conclusions: A design was done for a mission to return a sample from the surface of Titan, using in-situ propellant production to reduce the mission mass. Total system mass to be launched to the Saturn system is 3 tons (including an estimated growth factor of 39%, per ANSI/AIAA mass estimation guidelines) [7], a mass which puts the mission within the range off existing heavy launch vehicles such as Falcon-H. Further details can be found in reference [3].

Acknowledgments: This work was supported by the NASA Innovative Advanced Concepts program.

References: [1] Landis, G. A. and Oleson, S. R. (2021) "Planetary Science & Astrobiology Decadal Survey 2023-2032; *Bul. AAS, 53,* No. 4, e-id. 309. [2] Lorenz, R. D., Lunine, J., and Zimmerman, W. (2005) *Adv. Space Res., 36,* 2, 281-285. [3] Landis, G.A., Oleson, S.R., and R. Lorenz, R. D. (2022), AIAA 2022-1570, *AIAA Science and Tech. Forum*, Jan 3-9. [4] Ajluni, T., *et al.*, (2015) *IEEE Aerospace Conf.*, Mar 7-14. doi: 10.1109/AERO.2015.7118988. [5] McNatt, J. (2018) *Conf. Advanced Power Sys. for Deep Space Exploration*, Oct. 27-29. [6] Grantz, A. C. (2011) paper AIAA 2011-7315, *AIAA Space Conf, & Exposition*, Sept. 27-29. [7] *AIAA standard S-120A-2015* (2019). https://doi.org/10.2514/4.103858