Thermal Design Concerns for the Phase 2 Triton Hopper. J.W. Hartwig[1], D. Sagmiller[2], A. Colozza[3], G. Landis[1], and S.R. Oleson[1] [1]NASA Glenn Research Center, Cleveland OH, [2]Montana State University, Bozeman, MT, [3]Vantage Partners, Brookpark, OH. Jason.W.Hartwig@nasa.gov

Introduction: Vehicle concepts are currently being designed and developed to explore the surface and thin atmosphere of Neptune's moon Triton [1] for a potential two year mission to investigate astrobiological and geological aspects of the moon. Visited once by the Voyager-2 fly-by, Triton, the only large moon in the Solar System in a retrograde orbit, is a captivating and presently geologically active destination within the Solar System believed to have been de-stabilized from the Kuiper belt and captured by Neptune. The motivation for the new exploration mission to visit Triton is threefold:

(1) Astrobiological – captured Kuiper Belt Objects (KBOs) are rich in tholins, which are organic compounds such as amines and nitriles, which may be precursors to life
(2) Geological – to improve understanding of history and evolution of outer Solar System bodies. Triton is dynamic with its cantaloupe terrain, active geysers, and rarified atmosphere.
(3) Pathfinder – for exploring surfaces of other icy bodies such as Pluto, Mars, Jupiter moons (Europa, Ganymede, Callisto), and Saturn moons (Enceladus, Tethys)

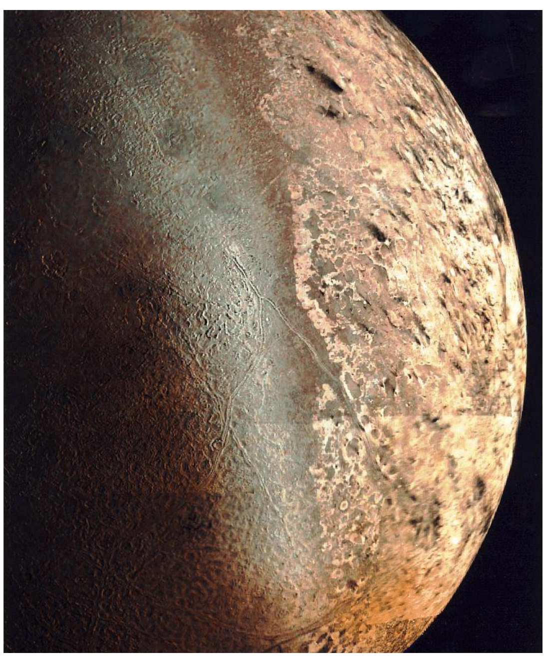

Figure 1: Photomosiac of Triton from Voyager-2. Credit: NASA JPL

Phase 1 Design Overview: The Phase 1 concept for the Triton hopper is depicted in Figure 2, along with a breakdown of subsystems. A hopper was chosen over a rover to enable the ability to sample the atmosphere and plumes of geyers, in addition to surface sampling over a number of locations on the surface. Further, the original mission desire was that the vehicle could cover the entire distance from pole to equator (~ 2100 km) in two years. The hopper is a fully instrumented, unique, cryogenic-rated autonomous design capable of sampling atmospheric, surface, and subsurface ice on Triton.

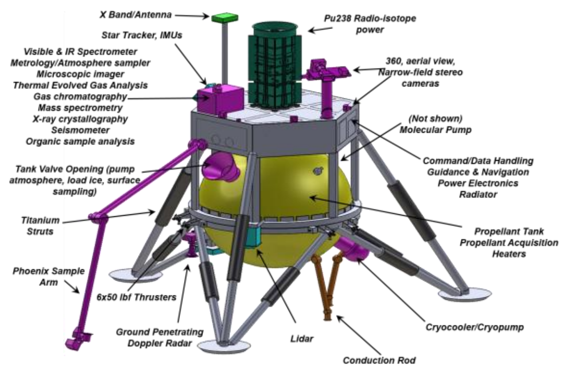

Figure 2: Triton Hopper Subsystems

The hopper has multiple science packages as shown, including visible and infrared spectrometer, seismometer, Doppler wind measurment, x-ray crystallography, and multiple cameras. Titanium struts are used for support. The tank valve opening and sample arm serve double duty – to sample the atmosphere and surface, respectively, and to collect solid and gaseous nitrogen for use as a propellant. A turbo-molecular pump and a cryocooler heat exchanger are used in tandem to cryopump the atmosphere into the tank, while the sample arm scoops solid nitrogen. The hopper is powered by a radio-isotope generator, with waste heat used to maintain comminucation, data handling, and navigation systems at Earth room temperature, but also to liquefy, gasify, and pressurize the solid nitrogen inside the propellant tank. Multiple thrusters are then used to propel the vehicle into the atmosphere by expelling the stored nitrogen. Further details about the design, mission, trade studies, and concept of operation are available in [2].

Phase 2 Design Concerns: The goal for the Phase 2 Triton hopper is to update the design and to develop performance enhancements to cover the entire ~2000 km distance from pole to equator in two years; the Phase 1 point design was only capable of covering 300 km. This requires the system to gather propellant quicker, to hop more often, and/or to increase the propellant gas temperature. There are three thermal design concerns that are currently being resolved under the Phase 2 redesign to achieve these performance enhancements.

(1) Unknown Thermo/Mechanical Properties

The state and properites of the solid nitrogen on the surface of Triton is not fully understood. There is uncertainty in, or lack thereof, mechanical and thermodynamic properties, a lack of in-situ data for Triton due to only having a single fly-by, and there have been sparse experiments performed on Earth documenting the solid nitrogen properties. Furthermore, due to the temperature variation expected on Triton's surface between pole and equator, the ice is expected to behave differently at the pole (33K) versus equator (38K) because solid nitrogen passes through the α/β transition temperature [3]. Lastly, accurate, reliable thermodynamic property models are also needed to understand interactions between the environment (atmosphere and surface) and the propellant acquisition system and how to gasify, and eventually use the propellant for thrust. To mitigate these risks, the team is conducting a thorough review of available thermodynamic property data as well as generating solid nitrogen at the desired tempertures and measuring its properites to help fill gaps.

(2) Low Propellant Acquisition Rates

The hopper relies on harvesting nitrogen gas and solid nitrogen ice into a propellant tank, where it is eventually liquefied, gasified, pressurized, and used to create the thrust needed to hop a distance of ~ 5 km. The overall goal is to speed up propellant acquisition rates so that the hopper can traverse significantly farther distances than the Phase 1 concept. For gas harvesting, in Phase 1, feasibility of a cryopumping (cooling gas inside the tank onto a cold head where the gas freezes) method was presented; in Phase 2, the team is optimizing the size, mass, and performance of the cryocooler, cold head, tank interfacing system, and "hot-side" cold sink systems. Phase 1 did not take into account environmental heating, therefore a detailed parasitic heat leak model is being developed for the environment and vehicle. A transient, coupled mass/energy model is being developed that accounts for parasitic heat leak, freezing, and ice accumulation to determine the maximum allowable solid nitrogen production rate in the tank as a function of cryocooler lift, as well as the ice accumulation thickness as a function of time. The mass and power of the cryopumping system will be traded with the mass of ice accumulation yield, and thus allowable distance per hop. The thermal sink system inside the tank used to distribute cooling from the cold head to tank wall will also be optimized. Additionally, the feasibility of using direct sublimation from the surface will be assessed for being a viable enhancing propellant acquisition strategy. For ice harvesting, thermodynamic modeling will be developed in conjunction with new ice acquisition data to down-select the optimal solid propellant acquisition method at both polar and equatorial regions.

(3) Non-optimized Propellant Tank and Thruster

The Phase 1 hopper used a thick-walled propellant tank, a heating system to pressurize nitrogen, and a cold gas thruster to hop from one location to the next. It is not clear if a higher performing (and thus farther hopping) system is achieved from either a warm gas or a liquid nitrogen-based propulsion system is achievable. For each of the three propulsion concepts, the propellant tank must be optimized in order to determine the required time between hops to process the propellant, and to refine the thruster performance curve as a function of time to determine the total distance per hop. Thermodynamic properties and ice accumulation models will be used to develop a model for the propellant inside the tank, and to quantify heat input requirements to liquefy and gasify the propellant; this, in turn, specifies the time between hops. Then tank blowdown models will be developed to more precisely quantify the hopping distance; models will be used to bound the inlet conditions of the thruster as a function of time during hop to refine the performance curve and thus hopping distance. Iteratively, the mass of the tank (insulation thickness, tank material, size, and maximum allowable working pressure) must be traded for the performance of the thruster to find a minimum tank mass that maximizes performance. Tank support struts and thermal linkings to the surroundings will also be optimized.

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References: [1] Cruikshank, D. et al. (1995) "Neptune and Trinton" University of Arizona Press. [2] Oleson et al., (2018) "Triton Hopper: Exploring Neptune's Captured Kuiper Belt Object," *NASA-TM-2018-219423*. [3] Giauque, W.F. and Clayton, J.O. (1933) "The Heat Capacity and Entropy of Nitrogen. Heat of Vaporization. Vapor Pressures of Solid and Liquid. The Reaction 1/2 N2 1/2 O2= NO from Spectroscopic Data," *Journal of the American Chemical Society*, 55, 4875–4889.