INITIAL ASSESSMENT OF IN-SITU RESOURCE UTILIZATION FOR HUMAN MISSIONS TO TITAN

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Introduction: As we follow NASA's blueprint [1] for extending human presence deeper into the solar system in-situ resource utilization will be become even more critical that it is for inner solar system travel. The leading candidate for human exploration in the outer planets is the moon of Saturn, Titan [2]. In this research we are working to identify and characterize the potential resources that Titan could offer to a human mission to its surface.

Approach: Since a human mission architecture to Titan has not yet been developed, we will start with a generic set of mission phases likely to common to most if not all architectures. We evaluate each of these for consumables needs to support human travel to and habitation on Titan. We then consider the accessible components of Titan's atmosphere and upper surface. The known constituents are evaluated for their potential use. The next step will bel to consider the systems and operational complexity necessary to extract, process, store and utilize those components. From this data, mission architecture options can be conceived for evaluation and maturation. The work described here takes the first few steps on this path, setting the stage for architecture development.

Human Mission Elements and Phases: The skeleton of a human mission to Titan begins with an Earth to Titan phase that must be made as short as possible to avoid the detrimental effects of long-term deep space travel, including radiation dosage and physical deconditioning from the microgravity environment. Nuclear propulsion systems being considered for reduced travel time to Mars could also be considered for Titan missions [3]. The second phase is landing on the surface of Titan which must be made as safe as possible. The third phase is living on the surface which will include a breathable atmosphere and comfortable environment of a spacecraft cabin or habitat. The fourth phase is extravehicular exploration of the Titan surface with possible use of mobility vehicles such as rovers or flying machines. The fifth phase is liftoff and return to space. The final phase is the return trajectory back to Earth.

In this heavily simplified starting point of an architecture, we can identify several consumable needs. They are similar to those studies for missions to Mars [4]. These needs may include rocket engine propellants and oxidizers for the transit spacecraft and lander, water, oxygen and nitrogen for the crew, and power generation for the lander/habitat, and possibly for mobility vehicles as well.

ISRU Options on Titan: Considering these consumables needs, we evaluate Titan's surface and atmospheric composition for potential resources. Titan is a cryogenically cold ocean world with a surface pressure of 1.45 atm, and surface air density of about 4.3x that of Earth. It is also almost 10 times further from the sun than Earth, as a result the amount of sunlight reaching Titan is about 1% of what reaches Earth. What could Titan possibly offer to offset the consumables needs for a human mission?

We'll first consider the atmosphere. Titan's thick atmosphere is 95% Nitrogen, with the balance made of gaseous methane CH_4) and other trace hydrocarbons such as ethane (C_2H_6), diacetylene (C_4H_2), methylacetylene (CH_3C_2H), acetylene (C_2H_2) and propane (C_3H_8). Can this atmosphere be utilized in some way? The first option considered is the use of Nitrogen for make–up gas in the lander and habitat cabin. Since the habitable atmosphere will be maintained at approximately 80% Nitrogen, losses from normal leakage and airlock purges could be replenished using warmed, filtered Titan air.

The second option for use of the atmosphere could be for power generation such as wind power [5]. For most of the Titan year the winds are expected to be fairly light, but the fact that the air is 4.3x as dense as Earth's means that even a light wind can carry significant momentum that can be harnesses for turning a power generator. Hendrix & Yung [6] investigated another options for generating power from the wind. In their work, they considered harnessing higher windspeeds found in the higher atmosphere using buoyant, tethered wind power generators. Hendrix & Yung also considered power generation methods using compounds found in the atmosphere including hydrogenation of acetylene [6].

Next, we consider the materials found on the surface of Titan. Here we find water ice, liquid methane and liquid ethane and hydrocarbon-based tholins.

Water ice has the same potential as ice sought after on Mars and the Moon. However, in the cold climate of Titan water ice I as hard as rock making processing more challenging. If extracted, warmed and purified it could be used by the crew while on the surface and even transported back to the transit vehicle for use during the return trip to Earth. It could also be electrolyzed to provide habitat cabin makeup gas as well used in combustion of methane for power generation [6] or as propellant oxidizer. Extracted hydrogen could also be used as a propellant for nuclear thermal propulsion systems for a return trip.

This latter option is a good segway to address potential uses of liquid methane. Liquid methane is found abundantly in the northern latitudes of Titan in rivers, lakes and seas. The methane on Titan could be used as an ascent vehicle propellant or as fuel in a power production plant. Alternatively, more hydrogen could be extracted from Methane and ethane to add to propellant generation capabilities. The result are multiple options for powering surface mobility systems, ascent vehicles and the orbital transit spacecraft. In a longer term scenario, methane rivers and lakes could be used to generate power just as we use them here on Earth [6].

Tholins are generated by exposure of atmospheric hydrocarbons and nitrogen to UV radiation and subsequently combining to form polymer-based particles [5]. These ingredients spark the potential for use in forming plastics. These plastics could then be utilized as construction material and 3D printing of components.

Summary: Titan is likely to be the next destination for human exploration after Mars, and even though it is much further away than Mars, its atmosphere and surface are rich in resources. Abundant and accessible nitrogen, water ice and methane are leading options to support human missions. Further research should be done to explore the potential for Titan as a human destination, and particularly how ISRU systems developed for the Moon and Mars could be adapted to this fascinating world in the outer solar system.

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