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Dragonfly: In Situ Exploration of Titan's Prebiotic Organic Chemistry and Habitability

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Abstract

Titan's abundant complex carbon-rich chemistry, interior ocean, and past presence of liquid water on the surface make it an ideal destination to study prebiotic chemical processes and to document the habitability of an extraterrestrial environment [*e.g.*, 1-6]. Moreover, Titan's dense atmosphere and low gravity provide the means to access different geologic settings over 10s – 100s of kilometers apart, via exploration by an aerial vehicle. *Dragonfly* is a rotorcraft lander mission proposed to New Frontiers to use Titan's unique natural laboratory to understand how far chemistry can progress in environments that provide key ingredients for life.

1. Introduction

Exploration of Titan is a high science priority due to the level of organic synthesis that it supports. Moreover, the opportunities for organics to interact with liquid water at the surface and via exchange with the interior ocean further possible progression of chemical processes, providing an unparalleled opportunity to investigate prebiotic chemistry, as well as to search for signatures of potential water-based or even hydrocarbon-based life. Beyond this rich chemistry, Titan's Earth-like geology, with a methane cycle instead of a water cycle, allows study of familiar processes under different conditions. The diversity of Titan's surface materials and environments drives the scientific need to be able to sample a variety of locations, thus mobility is key for *in situ* measurements.

2. Exploring Titan by Air

It has long been recognized that Titan's rich organic environment provides a unique opportunity to explore prebiotic chemistry (for example, the Campaign Strategy Working Group (CSWG) on Prebiotic Chemistry in the Outer Solar System [5, 6]), and development of Titan mobile aerial exploration was identified as a desirable next step after *Cassini-Huygens*. Several airborne strategies have been considered for Titan, including exploration by helicopter [6], helium or hydrogen airship [7, 8], Montgolfière hot-air balloon [9-12], and airplane [7, 13], but access to surface materials for analysis presents a challenge. While multiple *in situ* landers could also address Titan's surface chemical diversity, multiple copies of instrumentation and sample acquisition equipment would be necessary to achieve the same breadth of science as a mobile vehicle.

A more efficient approach is to convey a single instrument suite to multiple locations using a lander with aerial mobility. Heavier-than-air mobility at Titan is highly efficient [6, 14]. At the surface, Titan's atmosphere is 4 times denser than Earth's, reducing the wing/rotor area required to generate a given amount of lift, making all forms of aviation easier (lighter- and heavier-than-air). The low gravity (1.35 m/s^2) reduces the required magnitude of lift – a strong factor in favor of a heavier-than-air vehicle.

Recent developments in autonomous aircraft make such an exploration strategy a realistic prospect. Modern control electronics make a multi-rotor vehicle [15] mechanically simpler than a helicopter (*cf.* proliferation of terrestrial quadcopter drones). Multi-rotor vehicles offer improved flight control authority and surface sampling capability, redundancy, and failure tolerance; moreover, the system is straightforward to test on Earth and to package in an entry vehicle.

Although for a given vehicle mass and rotor diameter, the shaft power required to hover on Titan is 38 times less than on Earth [6, 15], this is still too high for continuous flight if powered by an MMRTG. However, flight ranges of a few 10s of km are possible using power from a battery, which can be recharged via an MMRTG in less than one Titan day, between flights, science activities, and direct-to-Earth communication. Adopting rotors as a substitute for the retrorockets used to effect soft touchdown on Mars landers means the ability to take off and land elsewhere follows with little incremental cost but with tremendous science enhancement. Furthermore, a relocatable lander is robust to power source underperformance or to science energy demands – the system merely takes longer to recharge between flights. *In situ* operations strategies similar to those proven by Mars rovers [16,17] can proceed at a more relaxed pace with 16-day Titan-sols.

Dragonfly is a rotorcraft-enabled lander designed to take advantage of Titan's environment to be able to sample materials in different geologic settings. Dune sands likely represent a 'grab bag' site of materials sourced from all over Titan [10], much as the rocks at the *Mars Pathfinder* landing site collected samples from a wide area [18]. Environments that offer the most likely prospects for chemical evolution similar to that on Earth occur on Titan's land. Areas of particular interest are impact-melt sheets [19] and potential cryovolcanic flows where transient liquid water may have interacted with the abundant photochemical products that litter the surface [2].

3. Titan *In Situ* Science

The compositions of the solid materials on Titan's surface are still essentially unknown. Measuring the compositions of materials in different environments will reveal how far prebiotic chemistry has progressed. Surface material can be sampled with a drill and ingested using a pneumatic transfer system [20] into a mass spectrometer [21] to identify the chemical components available and processes at work to produce biologically relevant compounds. Bulk elemental surface composition of each site can be determined by a neutron-activated gamma-ray spectrometer [22]. Meteorology measurements [23-25] can characterize Titan's atmosphere and diurnal and spatial variations therein. Geologic features can be characterized via remote-sensing observations, which also provide context for samples. Seismic sensing can probe subsurface structure and activity.

In addition to surface investigations, *Dragonfly* can perform measurements during flight, including atmospheric profiles and aerial observations of surface geology, which also provide sampling context and scouting for landing sites.

Dragonfly is a truly revolutionary concept, providing the capability to explore diverse locations to characterize the habitability of Titan's environment, investigate how far prebiotic chemistry has progressed, and search for chemical signatures indicative of water- and/or hydrocarbon-based life.

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