Titan Turtle:
NIAC Phase II Design for a Submersible Vehicle for Titan Exploration

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Conceptual designs for a submersible vehicle for exploration of the hydrocarbon seas of Saturn's moon Titan were done by the NASA Glenn COMPASS systems engineering team, as part of the NASA's Innovative Advanced Concepts (NIAC) program. The efforts investigated what approaches and technologies would allow exploration below the surface of the low temperature (–180 °C) hydrocarbon seas of Titan. The Phase-II design refined the design concepts, looking at a smaller design supported by an orbital relay, the "Titan Turtle". The phase-II project resulted in a smaller vehicle using an orbiter supported relay/navigation link to eliminate the requirement for a large phased-array antenna. Eliminating the DTE communications requirement also reduced the associated high power required by the communications system.

I. Introduction

Saturn's moon Titan is the only moon in the solar system to have a dense atmosphere, and the only body other than the Earth to have bodies of liquid on the surface (figure 1). The Titanian oceans, however, are not composed of water, like Earth's oceans, but are in the form of a series of hydrocarbon (methane and ethane) lakes, covering a surface area of over 500,000 km^2.

Titan is scientifically fascinating in many ways [1,2]. As a representative of the icy moons of the outer solar system, knowledge of Titan will fill in our understanding of these bodies. 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 [2] including moons of Jupiter, other moons of Saturn, Neptune, and even Pluto. As a body rich in hydrocarbons, Titan is also a high priority target for astrobiology [3-5]. The Cassini/Huygens mission showed that it is a world with a surface covered in organic compounds protected with a thick nitrogen atmosphere. 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.

To date, only a single probe (the ESA/NASA Huygens mission) has landed on the surface, and while the lakes themselves has been mapped by radar, what is beneath the surface of the hydrocarbon lakes is unknown.

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Conceptual designs for a submersible vehicle for exploration of the hydrocarbon seas of Saturn's moon Titan were done by the NASA Glenn COMPASS systems engineering team [7], as part of the NASA's Innovative Advanced Concepts (NIAC) program [8]. The efforts investigated what approaches and technologies would allow exploration below the surface of the low temperature (–180 °C) hydrocarbon seas of Titan. The hydrocarbon seas of Titan differ in some significant ways from terrestrial oceans. Table 1 summarizes some of these differences.

In the Phase I design, a large vehicle (6 meters, 1400 kg) was designed for a 90-day mission, employing a large phased array to accomplish direct to Earth (DTE) communications [8-10].

The Phase-II design refined the design concepts, looking at a smaller design supported by an orbital relay [11]. Due to its distinctive ovoid shape (figure 2), the design was nicknamed the "Titan Turtle". A separate study looked at a design in which a surface vehicle deployed 3-kg expendable probes ("dropsondes") at selected locations to investigate the subsurface [12]. Each concept provided different advantages and challenges.

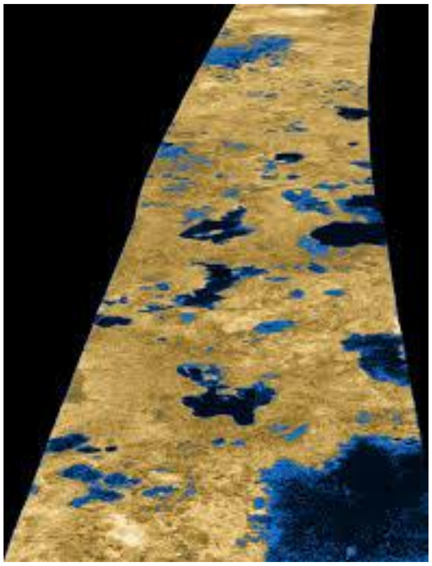

Figure 1: Titan's hydrocarbon lakes shown in false color, as viewed by the Cassini radar.

II. Vehicle Design:

The phase-II project designed a smaller vehicle using an orbiter supported relay/navigation link to eliminate the requirement for a large phased-array antenna. Eliminating the DTE communications requirement also reduced the associated high power required by the communications system. Since Ligea Mare, the baseline mission target for the revised vehicle design, is slightly shallower than the Kraken Mare destination assumed for the phaseI1 design, the design specification for the vehicle was a 200 meter maximum depth, with the capability to hover at depth while taking science measurements.

The Phase-II design vehicle is powered by a single Enhanced Multi-Mission Radioisotope Thermoelectric Generator (e-MMRTG) [13], which provides 100 W of electrical power at beginning of life (90 W_e at end of life). This provides electric power to run the science instrumentation, as well as four propulsors, allowing a speed of 0.3 m/s when submerged; 0.2 m/s when on the surface. The vehicle was designed for a 180 day primary mission in the Titan lake Ligea Mare.

Using orbiter support, instead of the direct to Earth communications, the Phase II design of the vehicle concept has a mass of 483 kg, including a 90 kg science package. The mass estimates include a 30% mass growth allowance on all systems and components. This makes a vehicle comparable to the landed mass of the Mars Curiosity rover, a 900 kg rover carrying 90 kg of science instruments.

The Entry Descent and Landing system is 163.5 kg (including 30% growth), resulting in a total entry mass of 708.5 kg.

Figure 3 shows the dimensions. The length of the vehicle is 2 meters, and fits inside a 2.7 meter diameter aeroshell for entry into the atmosphere, as can be seen in Figure 4.

Electronics for the control, data processing, and science packages are kept inside the submarine pressure vessel and warmed by waste heat from the isotope power system.

The submerged science included mapping using side-looking sonar, imaging and spectroscopy of the sea at some depths as well as some sampling of the sea's bottom and shallow shoreline.

Table 1: Properties of Titan seas compared to terrestrial oceans

Parameter	Earth	Titan
Liquid:	Water	Liquid ethane & methane (High N_2 gas solublity)
Density:	~1000 kg/m^3	~650 kg/m^3 (ethane) 450 kg/m^3 (methane)
Temp	~0 to 30 °C	-178 °C
Viscosity	1000 μPa-s	200-4000 μPa-s
Gravity	1 g	0.14 g
Depth	kilometers	200 m Ligea Mare 1000 m? Kraken Mare
Pressure	~1 Bar / 10 m depth	~ 1 Bar / 115m

While surfaced, the vehicle would not only sense weather conditions (including the interaction between the liquid and atmosphere) but also image the shoreline, as much as 2 kilometers inland. This imaging requirement pushed the landing date to Titan's next spring period (mid 2040s) to allow for surfaced lighted conditions. Submerged and surfaced investigation are key to understanding both the hydrological cycle of Titan as well as gather hints to how life may have begun on Earth using liquid/sediment/chemical interactions. An estimated 25 Mb of science data would be generated per day by the various science packages, transmitted to the orbiter with a UHF transmitter at ~100 kbps. Since the hydrocarbon oceans are transparent to radio frequency radiation at the wavelengths of interest, the vehicle is capable of communicating with the orbiter both in the submerged and surfaced configuration.

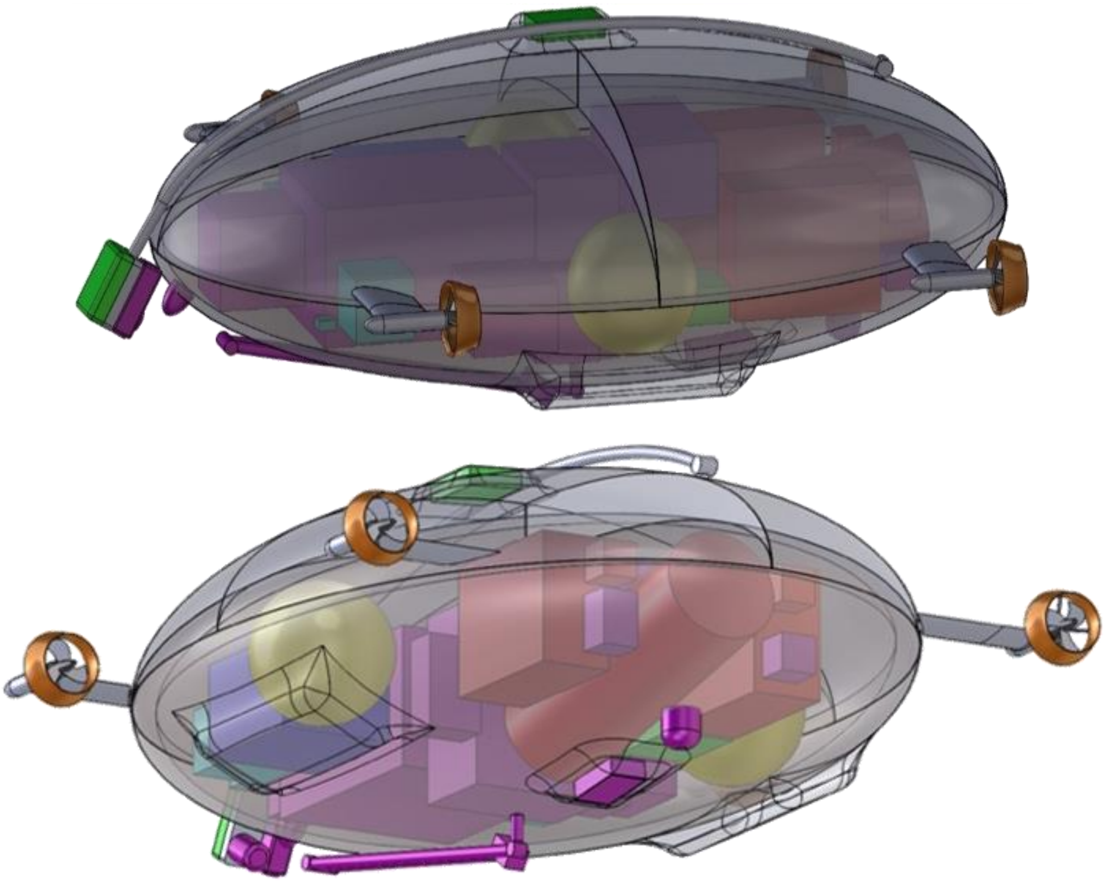

Figure 2: Transparent views of Titan Turtle conceptual design from side and front perspectives, shown with camera mast and robotic arms folded down.

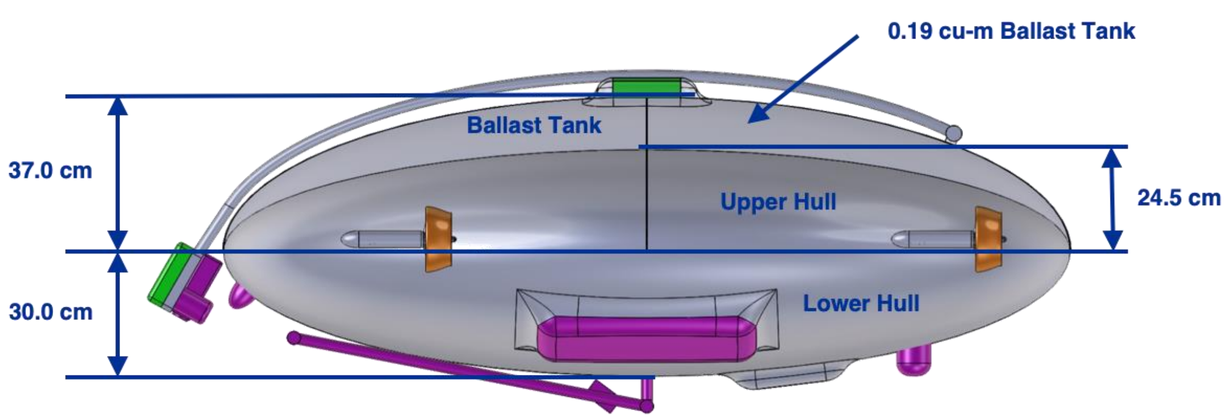

Figure 3: Dimensioned views of Titan Turtle vehicle. The robotic arm, shown on the bottom, can rotate 360 deg and extend 1.55 m downward from the base of the vehicle..

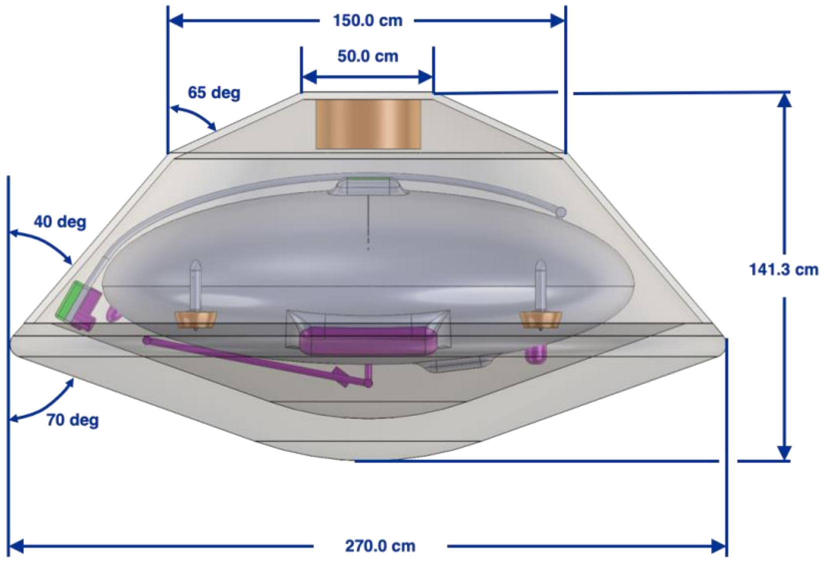

Figure 4: Dimensioned view of Titan Turtle vehicle as packaged inside the aeroshell for entry.

While surfaced, the vehicle would not only sense weather conditions (including the interaction between the liquid and atmosphere) but also image the shoreline, as much as 2 kilometers inland. The camera is on a curved deployable arm (shown in stowed position at the top of the vehicle in Figure 3) which can be deployed to a height of 1.25 m above the vehicle deck in surfaced operation. This imaging requirement pushed the landing date to Titan's next spring period (mid 2040s) to allow for surfaced lighted conditions. Submerged and surfaced investigation are key to understanding both the hydrological cycle of Titan as well as gather hints to how life may have begun on Earth using liquid/sediment/chemical interactions. An estimated 25 Mb of science data would be generated per day by the various science packages, transmitted to the orbiter with a UHF transmitter at ~100 kbps. Since the hydrocarbon oceans are transparent to radio frequency radiation at the wavelengths of interest, the vehicle is capable of communicating with the orbiter both in the submerged and surfaced configuration.

Compared to the Phase-I design, the Phase-II "Titan Turtle" vehicle is smaller: with a total mass of 500 kg for the vehicle, including growth. Including the entry descent and landing system, total mass is 708 kg. This compares favorably to the 1400 kg for the Phase-I design. The smaller design allows it to fit in a state of the art 2.7 m aeroshell, rather than requiring a new entry vehicle to be designed. The vehicle also runs with less power, using a single eMMRTG (100 W electrical power), compared to two advanced Stirling Radioisotope generators, 800 W for the Phase-I design. This reduces the expense. However, it has a slightly lower maximum speed (0.3 m/s, compared to 1 m/s), and thus requires a longer mission duration to accomplish a comparable traverse.

III. Conclusion

Titan is the only body in the solar system, other than the Earth, with open bodies of liquid on the surface. As of now, what is beneath the surface of these bodies is completely unknown. A submarine vehicle was designed to explore these bodies. Using a orbital relay satellite for transmission of data back from Titan, a 500-kg vehicle (including a 90-kg science package) was designed which could achieve a 180-day primary mission in the Titan lake Ligea Mare, fitting inside a 2.7-meter diameter aeroshell for entry into the Titan atmosphere.

A submerged, autonomous far-ranging vehicle to explore Titan's seas would be revolutionary. The vehicle designed investigates a full spectrum of oceanographic phenomena and will enhance our understanding of the history and evolution of hydrocarbons in the solar system. Operation of a submarine on Titan would be a pathfinder for later design of submersibles in the seas hidden beneath the ice crust of other outer planet moons, such as Europa, Ganymede, and Enceladus.

Acknowledgments

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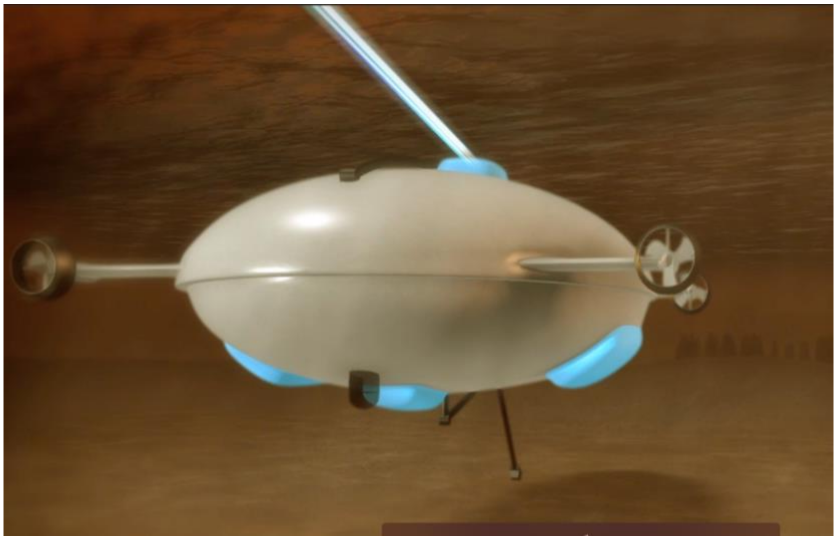

Figure 5: Visualization of the Titan Turtle doing submerged science.

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