A CREWED HELICOPTER FOR TITAN

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Summary: A first crewed helicopter concept for the future human exploration of Saturn's moon, Titan, is presented.

Titan: Titan, Saturn's largest moon and the second largest moon in the Solar System, has a surface gravity of 1.352 m.s^{-2} or 0.138 G (< 0.166 G on the Moon), and an atmosphere denser than Earth's, with a surface pressure of 146.7 kPa or 1.45 atm. The surface temperature is 93.7 K (-179.5°C or -291.1°F). The atmosphere at the surface is made of 97% nitrogen (N_2), 2.7% methane (CH_4), and 0.2% hydrogen (H_2) by volume, with trace amounts of other gases, some toxic, others not [1]. The surface is dominated by land, made mostly of a porous H_2O ice crust partially covered with hydrocarbon precipitates and dunes, and large lakes of liquid hydrocarbons - methane (CH_4) and ethane (C_2H_6) - and dissolved nitrogen (N).

Titan Exploration: Titan is an important destination for science and exploration, in particular for planetary science and astrobiology, as it represents a frigid cauldron of prebiotic chemistry that may inform us about the origin(s) of life on Earth and the possibility of life beyond Earth. Titan was explored in-situ via the entry, descent, and landing of the NASA/ESA *Cassini* mission's *Huygens* probe, and will be explored in-situ again with NASA's *Dragonfly* rotorcraft drone mission scheduled for launch in 2028 and arrival in 2034. As Saturn is 9.58 times farther than the Earth from the Sun, Hohmann transfer times from Earth to Titan are typically 6 to 7 years. With nuclear thermal propulsion, transfer times may be reduced to 4 to 5 years. Titan is thus within plausible reach for human exploration. In anticipation of the future possibility of extended human presence on Titan, we present a concept for a crewed helicopter for Titan.

Flying On Titan: Titan's low surface gravity and denser-than-Earth atmosphere make it well-suited for flight. A VTOL (Vertical TakeOff & Landing) aircraft is required, to allow flight operations without airstrips. Among VTOL options, a helicopter with floats is optimal, as it allows astronauts to safely take off and land on all surface types on Titan: hard ground, soft ground, and liquid bodies.

The upward force of lift, L, produced by an airfoil, or rotor system, of area S, moving through an atmosphere of density ρ at an average velocity V

Figure 1. Titan Crewed Helicopter. *Flying on Titan, with Saturn seen through a rare break in Titan's haze layers. (Background painting by P. Lee)*

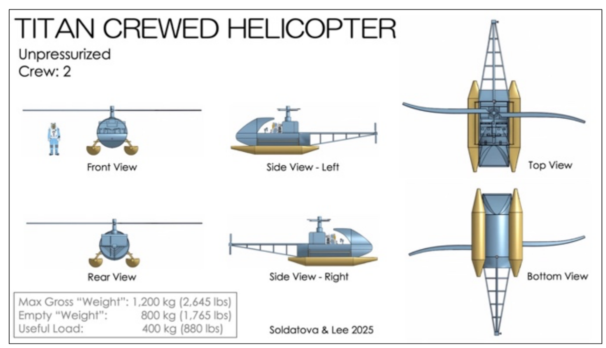

Figure 2. Titan Crewed Helicopter: Plan Views *(CAD by M. Soldatova)*

is given by the *lift equation*:

$$L = ½\, C_L \times \rho \times S \times V^2 ,$$

where C_L is the lift coefficient, a dimensionless factor related to airfoil shape and angle of attack. Titan's lower gravity and denser atmosphere than Earth's mean that lift efficiency will be increased on Titan by factors of 7.246 and 4.3265, respectively. With C_L taken as a constant, an airfoil or rotor system on Titan of surface area reduced by 20% and spinning 5 times slower than a rotor system on Earth would, to first order, generate the same amount of lift. Thus, whereas a helicopter with full sized rotors spinning at 300 RPM would be required to generate a given amount of lift on Earth, a similar helicopter with rotors reduced by 20% in area and spinning at only 60 RPM would suffice to produce the same amount of lift on Titan.

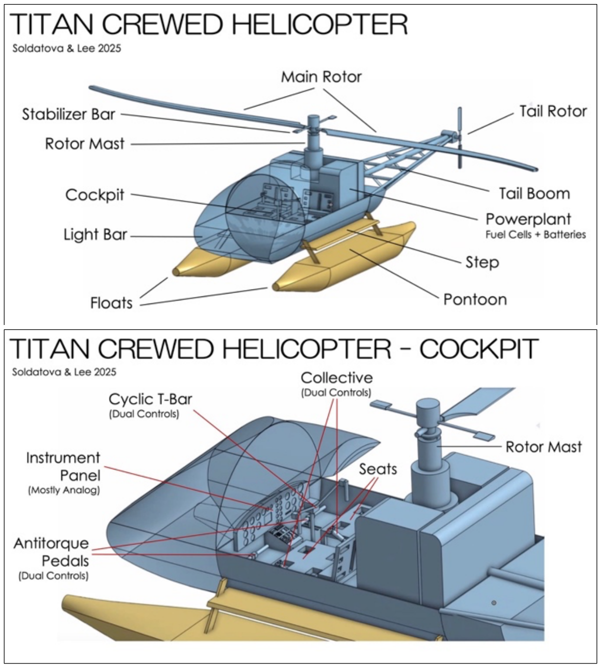

Figure 3. Titan Crewed Helicopter. *Top: Main features; Bottom: Cockpit. (CAD: M. Soldatova).*

Titan Helicopter Design: To keep the Titan helicopter lightweight and efficient to operate, it is unpressurized and operated by astronauts wearing EVA (extra-vehicular activity) spacesuits [2].

Main Features **(Fig. 3 Top):** The Titan helicopter is powered electrically via insulated rechargeable batteries. Its main rotor blades have a swept-back profile and thin tips to maximize high speed performance while minimizing transonic effects and cavitation. The speed of sound on Titan is ~194 m/s, significantly less than on Earth (~343 m/s), so a slower spinning rotor system is not only sufficient, it avoids blade tip transonic effects. Cavitation is also avoided by slower-spinning rotors as methane and ethane are close to saturation levels in Titan's atmosphere. Swept tips also help delay blade stall, which is a risk at slow rotor spin rates. A large cabin body allows for the wide and deep seats needed for spacesuits. Aerodynamic cabin and floats minimize drag, maximize the helicopter's lift and autorotation glide ratio, and help with flotation in case of ditching.

Cockpit **(Fig. 3 Bottom):** The Titan helicopter can be flown by a single pilot but features dual controls, including a T-bar cyclic, for redundancy and workload sharing. The helicopter can also be operated autonomously or teleoperated like a drone. Instruments are duplicated and "analog" to avoid reliance on electronic digital displays in Titan's frigid environment.

A B C D

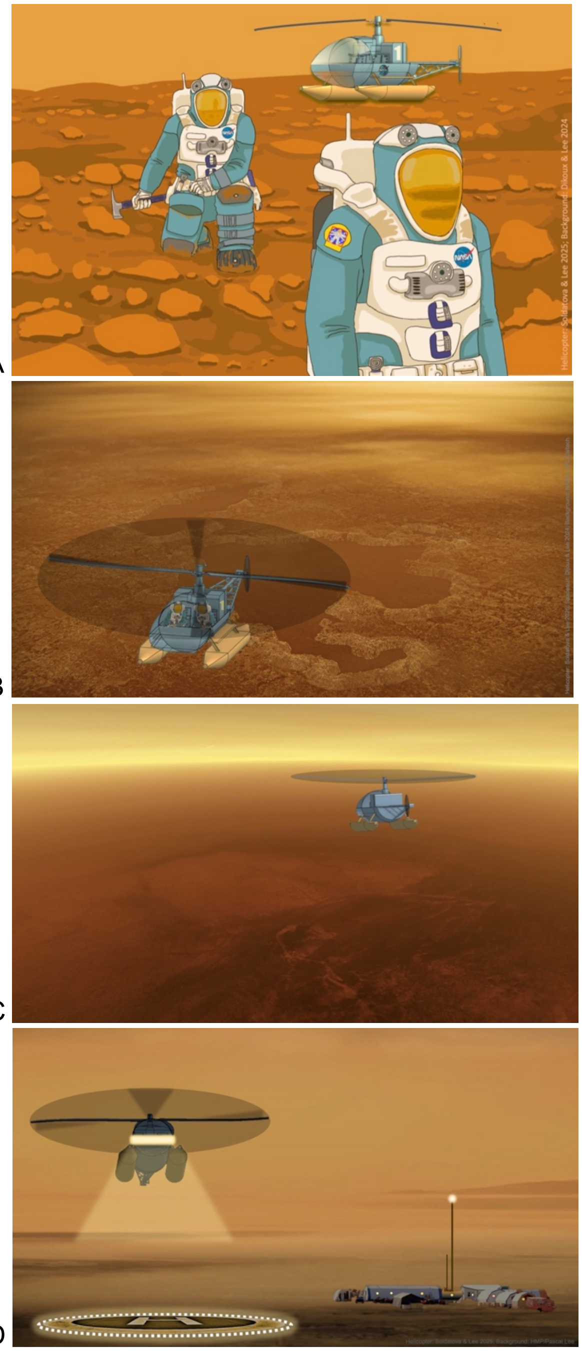

Figure 4. Exploring Titan w/ Crewed Helicopter. *A: Sampling (Spacesuit artwork: J. Dijoux); B: Over lakes; C: Middle atmosphere; D: Returning to base.*

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References: [1] Sofou & Lee. Titan: Surface environmental conditions, chemical toxicity, and implications for future human exploration. *In prep*.; [2] Dijoux, J & P. Lee 2024. A spacesuit for Titan. ISDC-2024, #1001.