Robotic Exploration of Titan with Dragonfly, a Multi-rotor Relocatable Lander

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Dragonfly Flight System Engineer
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We do not know how life came to form on Earth and cannot go back to study our own prebiotic history.
Unique and Compelling Scientific Opportunity

- We do not know how life came to form on Earth and cannot go back to study our own prebiotic history.

- Places elsewhere in our Solar System provide pieces to the puzzle of the chemical processes that led to life.
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Places elsewhere in our Solar System provide pieces to the puzzle of the chemical processes that led to life.

Titan is the most like the early Earth and holds keys to understanding our chemical origins.
• Outer water-ice shell
• Global subsurface ocean
• Inner ice layer
• Silicate core, ~4000 km diameter
Titan is the Largest of Saturn’s 62 Moons

- Diameter = 5150 km
  - 1.48x larger than Earth’s Moon (3474 km)
- Surface gravity = 1.35 m/s²
  - 14% of Earth’s surface gravity
- Surface atmospheric pressure = 1.45 atm
- Surface atmospheric density = 5.3 kg/m³
  - 4.3x density of Earth’s atmosphere at sea level (94.3% nitrogen, 5.6% methane and 0.1% hydrogen)
- Atmospheric height = 1270 km
  - ~10x Mars atmospheric height
  - ~10x column density of Earth
- Surface temperature = 94 K = -179°C = -290°F
  - Bedrock composition = water ice
Exploration of Titan

Voyager 2
23 August 1981
Cassini-Huygens Exploration

4.0-m (13.1') HGA

2.7-m (8.9') Huygens Probe

6.8-m (22.3') Tall
Cassini-Huygens Exploration

- Launch October 15, 1997 (VVEJGA)
- Saturn arrival, July 1, 2004
- Huygens Titan descent and landing, Jan. 2005
- Cassini in Saturn orbit 2004 – 2017
  - 126 close Titan flybys

Titan’s orbit
Huygens Atmospheric Descent, January 14, 2005

European Space Agency
Cassini's Imaging Science Subsystem (ISS)

ISS
22 August 2005 (T06)

Titan spectrum

CB3
Cassini's Imaging Science Subsystem (ISS)

ISS
22 August 2005 (T06)

Titan spectrum

CB3
Combined VIMS and ISS map of Titan's surface (Seignovert et al. 2019)
Organic Sand Dunes
North-polar Lakes & Seas

RADAR SAR

ISS, 1 Jan 2014
Clouds and Weather Patterns

- Methane cycle like Earth’s water cycle
Key Ingredients Necessary for Life

- **Energy**
  - Sunlight, photochemistry

- **Organic material**
  - Abundant complex organics

- **Two liquids**
  - Water
    - available at the surface in Titan's past
    - interior ocean
  - Methane
    - active methane cycle like Earth’s water cycle
    - liquid methane could support development of alternate biological systems

On Titan alone, can we study prebiotic chemistry in the full context of a planetary environment and Earth-like surface processes.
Previous Exploration Strategies

- Helicopter (Lorenz 2000)
- Airship (helium or hydrogen; Levine & Wright 2005; Hall et al. 2006)
- Montgolfière hot-air balloon (Reh et al. 2007)
- Airplane (Levine & Wright 2005; Barnes et al. 2012)
- Sea lander (TiME proposal to NASA Discovery Program, Stofan et al. 2013)
- NASA Titan Explorer Flagship study (Leary et al. 2007)
  - Lander + Montgolfière-type balloon
  - Two landers
  - Montgolfière + lander

*With both landed and aerial capability, Dragonfly accomplishes science objectives of multiple concepts using current technologies.*
Mission Elements

Spacecraft = Cruise Stage + Entry Vehicle

Entry Vehicle = EDL Assembly + Lander

Rotorcraft Lander
Flight configuration with HGA stowed

EDL assembly includes aeroshell (heatshield and backshell), parachutes, ESL, and support equipment.

Launch June 20, 2027 – Arrival November 26, 2033
Landed Configuration and Payload Accommodation

- Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) power
  - Charge battery used for flight and science activities
  - Waste heat maintains nominal thermal environment in lander

- Direct-to-Earth (DTE) communication
  - High-gain Antenna (HGA) articulation used to target cameras to build up panoramas of surrounding terrain

- Science measurements on surface and in flight
  - Aerial imaging
  - Atmospheric profiles
Initial Landing Site Provides Access To Multiple Geologic Settings

- Dunes
- Interdunes
- Impact crater deposits
- Access to sample organic sediments and materials with a water-ice component
Environment Models

Cassini RADAR

Namib Terrain Analog
Mission Timeline and Exploration Strategy

• “Leapfrog” exploration strategy to scout future landing sites
• 16-day Titan Tsols → relaxed operations schedule
  - 99.9% of time is spent on the surface making science measurements
Dynamics Model

- 14-Degree-of-Freedom (DOF) lander model
  - 6-DOF lander
  - 8-DOF rotors
- Aerodynamic database
  - 6-DOF vx, vy, vz, yaw, pitch, roll
Earth-based Wind Tunnel Testing

- NASA/Langley Transonic Dynamics Tunnel (TDT)
  - R134a heavy gas at ambient temperature
  - Does a good job of duplicating Titan flow conditions at full scale
  - Mach, Tip Mach, Advance Ratio, Reynolds & Lock numbers

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*Geometrically scaled, same rotor material.
Rotor Pair and Semi-span Testing

Example of Tilt-rotor Semi-span Testing in the TDT; Dragonfly is also planning semi-span testing with 4 rotors.

Full-scale Rotors in the TDT 16’x16’ Test Section
Mobility and Science Sensors

- Forward Science Cameras (2 ea.)
- Navigation Cameras (2 ea.)
- Lidars (2 ea.)
- Down Science Cameras (2 ea.)
- Micro-imagers and LED lights (2 ea.)
Sensor Suite

- **NavCams (including a Titan lighting model)**
  - Navigation coprocessor used to offload the CPU
- **Flash Lidars**
- **Miniature IMUs (MIMUs)**
- **Radar Altimeter/Velocimeter**
- **Ultrasonic Altimeters**
- **Pressure Sensors**

**Nav Cams**: panchromatic 90° FOV, 1024x1024p resolution after binning,

**Lidars**: 10 Hz, 15° FOV & 128×128p res. <175 m, 7.5° FOV & 64×64p res. <350 m, 0.25° FOV & 2×2p res. alt. <10,500 m, accuracy 10 cm 1-σ, precision 5 cm, 10 mJ 1064 nm laser, albedo 0.15.

**MIMUs**: 200 Hz rates & accels., isometrically oriented w.r.t. gravity for optimal initialization

**Ultrasonic Altimeters**: 50 kHz, 0.5-3.0 m ±3 mm, >10 m range.

**Radar Altimeter/Velocimeter**
Antenna temperature is maintained behind RF transparent Rohacell insulation.
Safe Landing Site Identification

Ideal Landing Site

Safe Site Thresholds

(Conservative)
Selected Sites

Site #1 (Best):

- Nominal site
- Nominal footprint
- 6 m radius
- 8 m radius
- 10 m radius
- Hazards
Multidisciplinary Science Measurements at Dozens of Potential Landing Sites

- **DraMS**: Mass Spectrometer
- **DrACO**: Drill for Acquisition of Complex Organics
  - GSFC, Honeybee – *MSL SAM, ExoMars MOMA*
- **DraGNS**: Gamma-ray and Neutron Spectrometer
  - APL, LLNL – *MESSENGER GRNS, Psyche GRNS*
  - GSFC, Schlumberger – Pulsed Neutron Generator
- **DraGMet**: Geophysics & Meteorology Package
  - APL sensor suite + JAXA *Lunar-A* seismometer
- **DragonCam**: Camera Suite
Titan is Large Enough to be a Planet

Venus
12,104 km
7,521 mi

Earth
12,760 km
7,926 mi

Mars
6,796 km
4,214 mi

Titan
5,150 km
3,193 mi

Mercury
4,878 km
3,024 mi

Earth’s Moon
3,476 km
3,155 mi

Pluto
2,274 km
1,413 mi

Titan’s day ~16 Earth days
Titan’s year 29.5 Earth years
Gravity 1/7th of Earth’s
Surface Pressure 1.5 the surface pressure on Earth