Dragonfly: Flying the NASA New Frontiers mission on Titan

Jack W. Langelaan
The largest of Saturn’s 62 moons
Exploration of Titan

Cassini, Saturn orbit 2004 – 2017
• 126 close Titan flybys
What science?

- Chemical composition and processes at Titan’s surface
- Meteorological sensing
- Geological feature characterization
- Seismic studies
- Atmospheric profiling
- Aerial imagery
Science instruments

DraMS (GSFC): Mass spectrometer
DraGNS (APL & GSFC): Gamma-ray and neutron spectrometer
DraGMet (APL): Meteorology, seismic, and other geophysical sensors
DragonCam (MSSS): Camera suite
Mobility (or, why fly a rotorcraft?)

Dunes and craters and lakes, oh my!
Initial landing site
Initial landing site

- Organic Sand
- Interdune Materials
- Ejecta Blanket
- Impact Melt

approximate landing ellipse
Exploration and science targets

3 years of exploration

- >70 Tsols (Titan days) of science operations
- Traverse distance up to ~180 km
- Exploration of ≥24 unique sites

approximate landing ellipse
### Titan's atmosphere

<table>
<thead>
<tr>
<th></th>
<th>Mars</th>
<th>Titan</th>
<th>Earth</th>
<th>Titan/Earth</th>
</tr>
</thead>
<tbody>
<tr>
<td>density</td>
<td>r</td>
<td>0.013 kg/m³</td>
<td>5.4 kg/m³</td>
<td>1.2 kg/m³</td>
</tr>
<tr>
<td>dynamic viscosity</td>
<td>m</td>
<td>1.422 x 10⁻⁵ Pa.s</td>
<td>6.7 x 10⁻⁶ Pa.s</td>
<td>1.8 x 10⁻⁵ Pa.s</td>
</tr>
<tr>
<td>kinematic viscosity</td>
<td>n</td>
<td>1.08 x 10⁻³ m²/s</td>
<td>1.24 x 10⁻⁶ m²/s</td>
<td>1.5 x 10⁻⁵ m²/s</td>
</tr>
<tr>
<td>sound speed</td>
<td>a</td>
<td>245 m/s</td>
<td>195 m/s</td>
<td>330 m/s</td>
</tr>
<tr>
<td>gravitational</td>
<td>g</td>
<td>3.71 m/s²</td>
<td>1.35 m/s²</td>
<td>9.81 m/s²</td>
</tr>
</tbody>
</table>

### Diagrams

- **Left Diagram:**
  - Graphs for density (ρ) vs. height (h) for Earth, Mars, and Titan.
  - X-axis: ρ (kg/m³) on a logarithmic scale.
  - Y-axis: h (km).

- **Middle Diagram:**
  - Graphs for temperature (T) vs. height (h) for Earth, Mars, and Titan.
  - X-axis: T (K).
  - Y-axis: h (km).

- **Right Diagram:**
  - Graphs for sound speed (a) vs. height (h) for Earth, Mars, and Titan.
  - X-axis: a (m/s).
  - Y-axis: h (km).
Implications for flight

The power required to hover on Titan is 1/40 the power required on Earth:

\[
\frac{P_{\text{Titan}}}{P_{\text{Earth}}} = \frac{g_{\text{Titan}}^3 \rho_{\text{Earth}}}{g_{\text{Earth}}^3 \rho_{\text{Titan}}} = 0.0247
\]

Hover power:

\[
P_{\text{hover}} = \frac{1}{FM} \sqrt{\frac{m^3 g^3}{2 \rho A}}
\]
Aerial exploration of Titan

Helicopter (Lorenz 2000)
Airship (helium or hydrogen; Levine & Wright 2005; Hall et al. 2006)
Montgolfière hot-air balloon (Reh et al. 2007)
Airplane (Levine and Wright 2005; Barnes et al. 2012)
Sea lander (TiME, Stofan et al. 2013)

Flagship mission studies:
NASA Titan Explorer Flagship (Leary et al. 2007)
  • Lander + Montgolfière-type balloon
  • Two landers
  • Montgolfière + lander
Dragonfly mission elements

- **MMRTG**
  - Charges battery to power flight and science activities
  - Waste heat maintains nominal thermal environment in lander

- **Direct-to-Earth communication**
  - HGA articulation used to target cameras for panoramas of surrounding terrain

- **Measurements on surface and in flight**
  - Aerial imaging
  - Atmospheric profiles

Spacecraft = Cruise Stage + Entry Vehicle
Entry Vehicle = EDL Assembly + Lander

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

Rotorcraft Lander
Surface configuration with HGA deployed
Mission concept

Parachute entry and descent

Powered flight to landing site

Science operations, battery recharge
(1 Tsol = 16 Earth days)

Fly to new science target
Constraints: Atlas V-411 launch vehicle
Calculating flight performance: trimmed flight

\[ T \sin \alpha = -D - mg \sin \gamma \]
\[ T \cos \alpha = mg \cos \gamma \]
\[ \tan \alpha = \frac{-D_{\text{body}} - mg \sin \gamma}{mg \cos \gamma} \]
\[ T = \sqrt{m^2 g^2 + D_{\text{body}}^2 + 2Dmg \sin \gamma} \]

A flight condition is deemed feasible if:

\[ \omega_i > 2v_a \sin \alpha \]
\[ \theta < 75^\circ \]
\[ \mu < 0.3 \]
Power in trim

Required power ultimately determines range and endurance... and if a particular flight condition can be achieved.

\[ P_{\text{aero}} = P_{\text{parasite}} + \kappa_{\text{ind}} P_{\text{induced}} + P_{\text{profile}} + P_{\text{gravity}}. \]

\[ P_{\text{parasite}} = D_{\text{body}} v_a = q S C D_{\text{body}} v_a \]

\[ P_{\text{induced}} = T w \]

\[ P_{\text{profile}} = \rho A v_a^3 \frac{\sigma c_{\text{d,blade}}}{T} \left(1 + 3 \mu^2 \right) \]

\[ P_{\text{gravity}} = m g v_a \sin \gamma \]

- \( P_{\text{aero}} \): aerodynamic power
- \( \eta \): drivetrain efficiency (battery to shaft)
- \( P_{\text{hotel}} \): hotel power (thermal management, avionics, etc.)
- \( q \): dynamic pressure (0.5 \( \rho v^2 \))
Level flight power

Pre-Phase A values: mass and power undergoing refinement

Langelaan et al., IEEE Aerospace 2017
 Science/flight operations paced by day/night cycle

Titan day (Tsol) is 15.95 Earth days long, so lander is out of contact for ~9 days (~200 hrs)

MMRTG* output ~70W. Battery is recharged overnight with background science (weather, seismic monitoring)

Each Tsol starts with downlink of overnight science data

Flights for scouting and relocation start with a fully charged battery, with real-time monitoring from Earth (two-way light time is ~1.5 hrs)

Lorenz et al, APL Tech Digest, 2018
Navigation

Navigation sensors
- IMU
- radar
- LIDAR
- nav cameras
Optical navigation

Navigation and flight operations

![Graph showing flight operations across different sites]

- Current Landing Site
- Previously Scouted Site
- Planned Candidate Site