Hybrid UAS Design for Investigation of Saturnian Moon Titan

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Introduction

With past explorations by NASA to other parts of the solar system, Titan's emerged as a subject for investigation considering its characteristics and its resemblance to earth in some respects; however, many facts about Titan were not explored in detail. This project will investigate a detailed design of a fixed wing hybrid Unmanned Aircraft System (UAS). The UAS should meet a set of requirements to prove its functionality and be within the constrains for research purposes. The goal of said UAS is to explore, research, map, and investigate the surface and atmosphere of Titan as well as other details that it may hide.

Major Design Requirements

- Capable of vertical takeoff and landing (VTOL)
- Redundant system(s)
- Fixed wings
- Wireless charging system
- Science data retrieval
- Survey capabilities
- Instrumentation space
- Preliminary design dimensions include wingspan of 4.5 meters maximum based on rocket fairing
- Maximum flight time: 75 minutes
- Preliminary weight of 450 kg (dragonfly mission reference)
- Cruise speed of 13 m/s minimum*

Aircraft Specifications

Wing Specifications	Value	Units
Wingspan, b	2.50	meters
Chord Length, c	0.22	meters
Lift coefficient, C_L	1.04	Unitless
Max Lift Coefficient, $C_{L,max}$	2.75	Unitless
Drag Coefficient, C_D	0.0336	Unitless
Lift to Drag Ratio, L/D	6.19	Unitless
Wing Loading, W/S	925.32	N/m^2
Aspect Ratio, AR	5.09	Unitless
Thrust to Weight Ratio, T/W	0.162	Unitless

Rotor Specifications	Rotor
Blades, b	3
Solidity	0.38197
Rotor Radius, R (m)	0.300
Disk Area, A (m^2)	0.2827
Rotational Speed (rad/s)	100
Tip Speed (m/s)	30
Chord (m)	0.12

Overall Specs	Value
$W_{takeoff}$	163.24 kg
V_{cruise}	13 m/s
$V_{\infty,min}$	11 m/s
MP 176065 xlr	36

Applied Equations

Hovering Flight

$$P = \frac{kW^{3/2}}{\sqrt{2\rho A}} + \rho A V_{tip}^3 \left(\frac{\sigma C_{do}}{8}\right)$$

Climbing Flight

$$\frac{P}{P_h} = \frac{V_c}{2v_h} + \sqrt{\left(\frac{V_c}{2v_h}\right)^2 + 1}$$

Heat Transfer

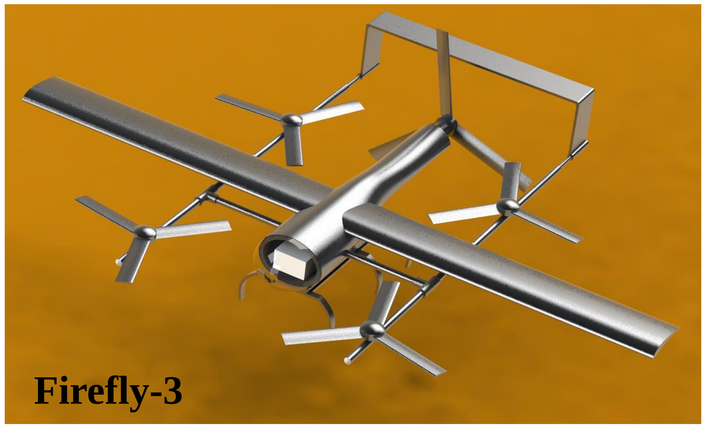
$$R_{cyl} = \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi Lk} \qquad \dot{Q}_{cond,cyl} = \frac{T_1 - T_2}{R_{cyl}}$$

Blade Element Theory

$$B = \frac{\rho c C_l}{2}$$

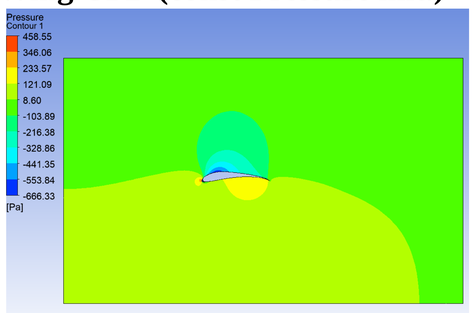
$$L = B\left(v_h^2 y_f + \Omega^2 \frac{y_f^3}{3}\right)$$

Final Model

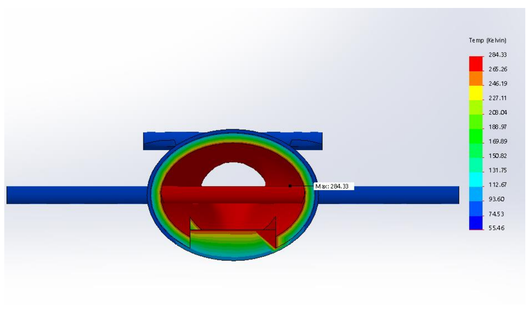


FEA/CFD Analysis

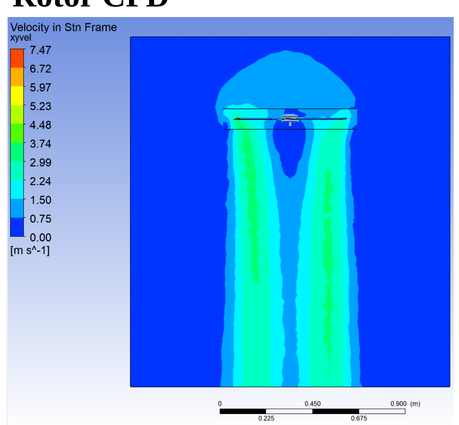
Wing CFD (const Pressure init.)



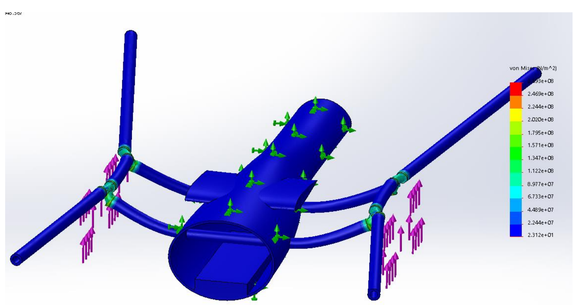
Insulation Thermal FEA



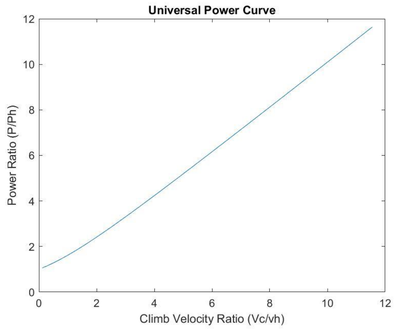
Rotor CFD

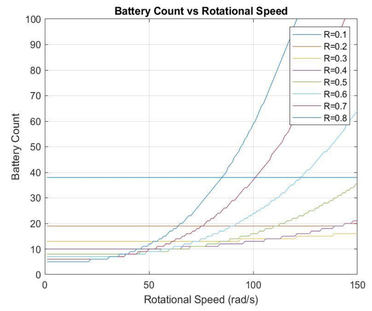


Fuselage Static FEA



Power & Energy Analysis





Configuration (Batteries Required)	Loiter (Fixed Wing)	Loiter (Hover)	Prop (Forward)	Climb (Rotors)	Total Batteries
Configuration 1	0	18	10	8	36
Configuration 2	2	0	10	8	20

Design Solution

Compared to the budget of the Dragonfly mission for the year of 2018 it was deemed that based on the cost analysis the project was on budget ($ 4 million vs $698,000). The CFD simulations converged to the performance values that were evaluated such as the drag force on the aircraft, cruise velocity, and lift coefficient. The desired cruise velocity was achieved allowing for long distance travel on Titan's surface. The Firefly-3 weighs in at 169 kg which is less than the weight restriction of 450kg. The total mission range was found to be 77 km which stands up well against the Dragonfly's hop distance of 8km. Compared to the wingspan restriction of 4.5m an adequate wingspan was determined at 2.5m. A battery count of twenty was found to sufficient based on power analysis. The trade studies performed guided the design points selected and ultimately resulted in the successful completion of the project and a demonstrable design solution.

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