https://doi.org/10.31256/Ec2Na5W

Futuristic Martian Aerobot Design

Vishal Youhanna
PhD Researcher,
Centre for Autonomous and Cyber-Physical Systems.
Cranfield University
Cranfield, UK
Vishal.Youhanna@cranfield.ac.uk

Dmitry Ignatyev
Senior Research Fellow,
Centre for Autonomous and Cyber-Physical Systems.
Cranfield University
Cranfield, UK
D.Ignatyev@cranfield.ac.uk

Leonard Felicetti
Lecturer,
Centre for Autonomous and Cyber-Physical Systems.
Cranfield University
Cranfield, UK
Leonard.Felicetti@cranfield.ac.uk

***Abstract*— NASA's Ingenuity Helicopter has proved that flight is possible on Mars with its ingenious yet elementary design, but it lacks long-range endurance and the capacity to carry any dedicated scientific instruments. In this paper, we propose a preliminary study for an innovative development in the series of Martian drones. The Futuristic Mars Aerobot Design (FuMAD) proposes a foldable winged drone based on Ingenuity's rotors design for enhancing long-range endurance and payload capacity.**

Keywords— Martian Aerobot, Ingenuity, Mars Drones, UAV

I. INTRODUCTION

Planet Mars was only closely explored via unmanned orbiters, landers, and rovers, until recently. The thought of using unmanned aerial vehicles has been around for decades [1] as it has offered numerous benefits such as improved speed, range, avoidance of obstacles, and field of view over a classic surface rover. The future aerial exploration missions on Mars rely on the practicable designing, developing, testing, and manufacturing of an aerobot adapted for the low-pressure atmosphere. Previously, planetary exploration research interest majorly has been limited to light-than-air airships or fixed wings planes, due to the greater technical complexity of the rotating wing aerobots. However, based on the technological advances made in the development of a variety of terrestrial drones for commercial use in recent years, the first and only aerobot was constructed, launched, and landed on Mars in 2021, which is currently in an operational state. This paper proposes a new design study of a futuristic Martian drone inspired by the success of the first Mars Helicopter.

II. BACKGROUND

Mars being different from Earth, offers a unique set of design challenges for a rotorcraft, mainly because of its atmospheric conditions. Even though Martian gravity is only about 38% of Earth's gravity, the average atmospheric density is about 100 times lower than that of Earth [2]. Therefore, the rotors would be operating at extremely low Reynolds numbers, even lower than 5000 for a small-scale helicopter. However, the Mach number (ratio of local flow velocity to the speed of sound in that medium) will be significantly higher (M>0.4) because of the higher tip speed required (due to lower density) and the speed of sound on Mars is only about 72% of the speed of sound on Earth. This low-Reynolds-number, high-Mach-number flow condition on the blade imposes severe constraints on the rotor design. Another critical ability needed to sustain the flight of a Martian drone is to minimise the heat produced by the propulsion system while producing the required lifting thrust, which is extremely difficult considering the low Reynolds numbers involved [3]. Added to the above constraints is the size limitation of the aeroshell (a protective heat shield that encapsulates spacecraft has a 4.5m diameter max) that would transport the aerobot to Mars [6]. However, NASA's Ingenuity Mars Helicopter has overcome all these challenges for flying a rotating wing aerobot on Mars by landing on the planet in February 2021; and as of June 2022, it has completed its short autonomous pre-commanded 29th flight, covering a ground distance of 179m at an altitude of 10m with a max ground speed of 5.5m/s for a duration of 67s. During these test flights, Ingenuity has transitioned from the Technology Demonstration phase to the Operations Demonstration phase, to showcase how future rovers and aerial surveyors can work together [4].

III. RESEARCH GAP, MISSION STATEMENT, REQUIREMENTS, AND POSSIBLE VTOL DESIGN

Ingenuity Helicopter has showcased the flight ability of an unmanned aerial vehicle for in-situ exploration of Mars, but the design of the helicopter has limitations such that it lacks the endurance, range, and science payload capacity due to its small size and elementary design. These limitations reduce its ability to perform science exploration missions that would require long-distance flights, higher scientific payload, a sophisticated communication system, or a powerful propulsion system for high altitude flights.

We propose a new enhanced rotorcraft design for a set of more challenging requirements for a Martian aerobot mission, which is realistically sized to fit into the maximum aeroshell, to land and explore the largest canyon system of Mars called Valles Marineris. An aerobot will aim to generate a high-resolution aerial mapping of the area and can mark potential experimental/sample collection points for future rover missions. Operationally it will be designed to last at least 90 Martian days. The generic aerobot design requirements are that the subsystem must withstand the extreme negative temperature on Mars (range from 20 °C to -153 °C), dust storms, radiation dosage of 66.6 mSv/lifetime, and must have a certain degree of redundancy to minimize risk due to impacts. The propulsion system requires robust rotors that can spin over 2400 RPM to generate lift and thrust. The structure must be a lightweight and strong material such as carbon fibre, that could resist shear stresses due to launch and face windspeeds of up to 9.9 m/s.

One possible solution to enhance the capability of Ingenuity Helicopter is to add fixed wings to the design. In the past, several fixed-winged aircrafts with VTOL capability has been proposed for Mars Exploration, which had either rigid [7-10] or foldable [11,12] body configurations, and recently one VTOL Inflatable winged configuration has been researched on as well [13]. Winged aircraft have better endurance due to increased lift per power unit, which in return prolongs the range of the mission. This would increase the size of the aerobot, which could benefit in terms of carrying bulkier science payloads and in providing increased surface area for solar panels. However, the downside of a larger aerobot is that it would need to have a folding mechanism to be either transported as a standalone payload in the spaceship to Mars or be packaged with a smaller rover/lander, due to the limitation of the current aeroshell size.

IV. Futuristic Mars Aerobot Design (FuMAD)

One such design, called Futuristic Mars Aerobot Design (FuMAD), is conceptualized for a preliminary study, which is a monoplane with foldable wing and landing legs, a conventional tail, nose propeller, and co-axial rotor embedded in between the wings at the center of the fuselage. A not-to-scale conceptual Computer Aided Design (CAD) model of this concept design is shown in Fig. 1.

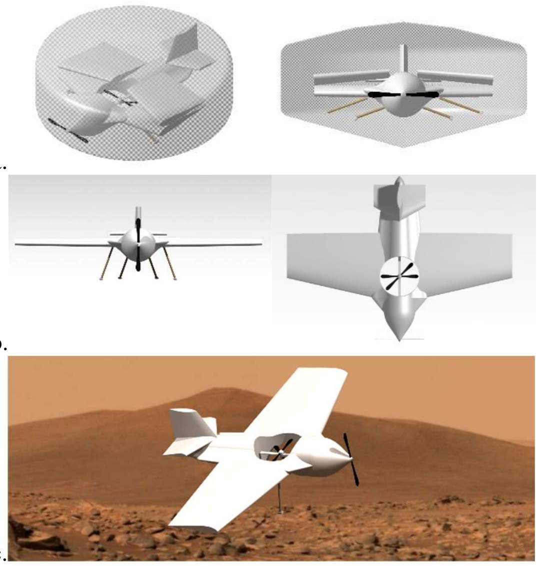
a. b. c.

Fig 1. Conceptual rendered CAD model of FuMAD. The views a) Folded and packed in the Aeroshell. b) Deployed on the Ground. c) Flying

A dedicated VTOL co-axial rotor, based on the rotor blades of Ingenuity or the optimized airfoil of the advanced Mars Science Helicopter [5], will serve its purpose of take-off from the ground and will continue to produce lift during flight along the wings to compensate for the lack of high air density on Mars. A single mainplane is used for this design for its lighter weight and efficient lift-to-drag ratio when compared to a configuration of biplane or tandem wing. The wings are made tapered and positioned in the middle of the fuselage as these minimize drag by better wing load and lift distribution along the span and aerodynamic streamlining, respectively. A high aspect ratio wing (the ratio between the wing span and the wing mean aerodynamic chord) increases lift to drag ratio, therefore the wingspan is kept long with a one-fold mechanism to be fitted in the 4.5m diameter aeroshell that would be deployed on the Mars ground using stored elastic potential energy, Fig 1a. Horizontal landing gears are preferred in comparison to tail-sitter configuration, as it provides more ground stability in a rocky and windy environment, and these will also be deployed using a similar folding mechanism. Due to the low density and slow velocities on Mars, special airfoils are required for low Reynolds numbers. The wings, horizontal stabilizer, and top fuselage are covered with solar panels. The electronic system and the observational surveillance system (position in the nose) would be placed inside the fuselage with a heating system and insulation. The performance of the proposed design can be analyzed based on Computational Fluid Dynamics (CFD) to guarantee that it meets the requirements. Further optimization of the geometry will improve the design characteristics and performance.

V. Conclusion

History of the Mars exploration by an aerial drone was shared briefly, with a focus on the current operational rotorcraft on Mars called Ingenuity Helicopter. Using a system engineering approach, goals and requirements for a future Martian mission are formulated. To accommodate more challenging requirements a novel design of VTOL foldable winged Futuristic Mars Aerobot Design (FuMAD) is proposed. In future work, a thorough analysis of the aerodynamics and performance of the aerobot using the CAD and CFD tools will ensure that the proposed design meets the stated goals.

Reference

[1] Hassanalian, M., Rice, D., & Abdelkefi, A. (2018). Evolution of space drones for planetary exploration: A review. *Progress in Aerospace Sciences*, *97*, 61–105. https://doi.org/10.1016/J.PAEROSCI.2018.01.003

[2] Overview | Mars – NASA Solar System Exploration. (2022) Retrieved June 09, 2022, from https://solarsystem.nasa.gov/planets/mars/overview/

[3] Radotich, M., Withrow-Maser, S., Gelhar, S., & Gallagher, H. (n.d.). A Study of Past, Present, and Future Mars Rotorcraft.

[4] Mars Nasa. (2022) Mars Helicopter - NASA Mars. Retrieved August 09, 2022, from https://mars.nasa.gov/technology/helicopter/#Flight-Log

[5] S. Withrow, W. Johnson, L. A. Young, H. Cummings, J. Balaram, and T. Tzanetos, "An Advanced Mars Helicopter Design," in ASCEND 2020, American Institute of Aeronautics and Astronautics.

[6] Johnson, W., Withrow-Maser, S., Young, L., Malpica, C., Koning, W. J. F., Kuang, W., Fehler, M., Tuano, A., Chan, A., Datta, A., Chi, C., Lumba, R., Escobar, D., Balaram, J., Tzanetos, T., & Fjaer Grip, H. (2020). Mars Science Helicopter Conceptual Design. http://www.sti.nasa.gov

[7] Young, L. A., Chen, R. T. N., Aiken, E. W., & Briggs, G. A. (2000). *Design Opportunities and Challenges in the Development of Vertical Lift Planetary Aerial Vehicles*.

[8] Aguirre, J., Casado, V., Chamie, N., & Zha, G. (2007). *Mars Intelligent Reconnaissance Aerial and Ground Explorer (MIRAGE) AIAA 2007-244*. https://doi.org/10.2514/6.2007-244

[9] Forshaw, J., & Lappas, V. (2012). Architecture and Systems Design of a Reusable Martian Twin Rotor Tailsitter. *Acta Astronautica*, *80*(0), 166–180. https://doi.org/10.1016/J.ACTAASTRO.2012.05.008

[10] RM Zubrin. (2012). *The mars gashopper - Concepts and Approaches for Mars 2012*. https://ui.adsabs.harvard.edu/abs/2012LPICo1679.4069Z/abstract

[11] Underwood, C., & Collins, N. (2017). Design and Control of a Y-4 Tilt-Rotor VTOL Aerobot for Flight on Mars. *Proceedings of the 68th International Astronautical Congress (IAC)*, 25–29. https://openresearch.surrey.ac.uk/esploro/outputs/conferencePresentation/Design-and-Control-of-a-Y-4-Tilt-Rotor-VTOL-Aerobot-for-Flight-on-Mars/99511131102346

[12] The Team Of. (2022) Ukrainian invention to feel the ground for Mars colonization (GRAPHICS) - Jun. 06, 2016 | KyivPost. Retrieved May 29, 2022, from https://www.kyivpost.com/article/content/ukraines-it-edge/ukrainian-invention-to-feel-the-ground-for-mars-colonization-graphics-415570.html

[13] Fathepure, M., Booker, A., Wang, N., Abouzahr, O., Tikalsky, D., Kheong Loh, W., & Jacob, J. D. (2021). *Design and Construction of an Inflatable-Winged VTOL Mars Electric Flyer*. https://doi.org/10.2514/6.2021-2578