DRONES FOR PLANETARY EXPLORATION: MODELING CHALLENGES

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During the last decade the efforts in space exploration have increased massively and led to the need of new ways to examine planets and other celestial bodies. The modern tendency is to create spacecrafts able to scout the surface from a higher point of view, where drones have shown to be most useful. In general, drones are known for their agility, speed, hovering capability, obstacle avoidance, target tracking and following. It is reasonable to consider any class of drones suitable for space application, since they all have benefits that can meet the requirements of the mission. The design choices in the space field are deeply affected by some limitations, such as maximum dimensions, total weight, cost, environment, temperature. Furthermore, it is also necessary to consider the basic requirements to make the platform able to carry out the mission, which are usually secured by various subsystems: thermal, communication, on-board data handling, electrical power, propulsion, and guidance, navigation and control. The main focus for space exploration has been Mars and rotorcraft concepts: in fact, a great example is offered by the Ingenuity helicopter, shown in Fig. 1, which performed the first flight on the Red Planet in 2021. Mars atmosphere is different from Earth's, translating in peculiar aerodynamic challenges. A first great variation is found in the low atmospheric density, which, together with the limited dimensions of the drone, results in very low chord-based Reynolds number flows ($10^3 - 10^4$) [1]. These flows are more characterised by viscous forces than by inertial forces, causing a decrease in the efficiency of the airfoil performance. This aspect affects the lift force, which is slightly compensated by the low acceleration of gravity ($3.71\ \mathrm{m/s^2}$). Various studies have been conducted in this field since 1930s and it is possible to identify three regions describing the behaviour of the flow: subcritical ($Re < 10^5$), critical ($Re \sim 10^5$) and supercritical ($Re > 10^5$). For Mars studies, the focus lies on the subcritical region, where the laminar boundary layer is inclined to separation, causing large drag coefficients and reduction of lift coefficient. The instability of this laminar separated flow causes transition to a turbulent flow, which can induce reattachment, hence creating Laminar Separated Bubbles, which affect the performance of the foil. There are various approaches that can be followed to carry out an aerodynamic analysis: for example, consider the flow fully laminar flow [2] or use RANS, LES or DNS. For the modeling of the Mars helicopter Ingenuity, the SA 1-equation turbulence model has been used [1].

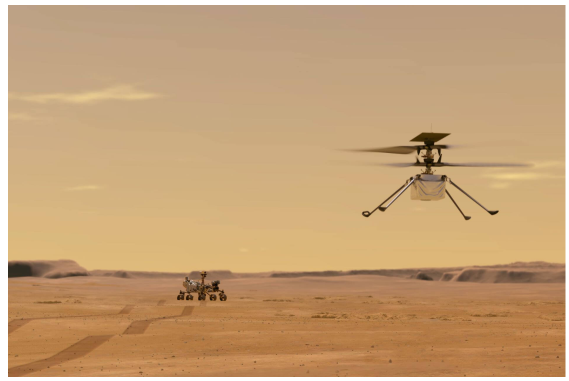

Figure 1: The Ingenuity helicopter ©[2021]NASA/JPL

In the present study, the gap of knowledge for aerodynamic modeling for Martian conditions is identified: in fact, a proper understanding of the aerodynamics is crucial for the control framework design. The control of the body is performed by the GNC subsystem, together with determination of the states and generation of optimal trajectories. Making the drone autonomous is fundamental, though the difficulties caused by the lack of infrastructures in space. Since all the concepts developed up to this time are based on the presence of atmosphere, the use of thrusters would enable to extend the exploration to other celestial objects, like moons and asteroids. The adoption of this technology would allow to pass the limits of planetary exploration, giving a new, faster, and efficient way to explore any astronomical body.

References

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