Titolo tesi di dottorato: GNC subsystem definition for astratospheric hybrid platform

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Abstract: A renewed interest in the stratospheric environment has emerged in recent years, driven by its unique atmospheric conditions and its potential for long-endurance missions in Earth observation and telecommunications. Among the various high-altitude platform solutions, hybrid airships -- combining both aerostatic and aerodynamic lift -- offer a promising trade-off between payload capacity, energy efficiency, and structural layout. This doctoral research addresses the design and implementation of the Guidance, Navigation, and Control subsystem for a hybrid stratospheric airship capable of autonomously following commanded trajectories.

The present study is carried out within the framework of the STOPP project ("Strumenti e Tecniche di Osservazione in Prossimità e Persistenza"), coordinated by the Italian Space Agency (ASI), and involving key national research institutions including CIRA (Italian Aerospace Research Centre) and Politecnico di Torino. The platform under consideration was initially defined by CIRA through a mission-driven preliminary design, which provided a CAD model and a detailed mass breakdown. Based on this, a comprehensive dynamic model of the airship is developed, encompassing aerodynamic, propulsive, gravitational, buoyant, mass, and inertial properties.

The aerodynamic modelling approach involves three-dimensional CFD simulations, conducted using the commercial software STAR-CCM+, for the characterisation of the entire platform, whereas two-dimensional inviscid analyses using XFoil are used to characterise the aerodynamic control surfaces. The complete model is implemented in MATLAB/Simulink. The GNC subsystem design is based on established methodologies and features a two-loop PID control architecture, consisting of an inner-loop Flight Control System and an outer-loop Autopilot. The guidance algorithm relies on the Artificial Potential Field method to achieve path-following capabilities. As far as the attitude, position and velocity estimation is concerned, an Unscented Kalman Filter was adopted to address model nonlinearities and combined with a Complementary Filter to estimate the heading angle. The simulation environment also includes models of typical onboard sensors such as accelerometers, gyroscopes, GPS, and magnetometers in order to take into account the effect of realistic uncertainties.

Key outcomes include: a) the full dynamic characterisation of the hybrid platform; b) a centre-of-gravity optimization procedure for determining the trim condition at cruise altitude and speed; c) the development of a complete GNC loop enabling stabilisation and trajectory tracking. By addressing the specific control challenges posed by a hybrid stratospheric configuration -- an architecture that received limited attention in the existing literature -- this study offers a contribution to the advancement of autonomous high-altitude flight.

Overall, this thesis documents the design approach adopted to model, control, and autonomously operate an innovative platform using mature techniques. The results support further research on advanced navigation and control approaches, and provide valuable insight for refining the early-stage design of hybrid high-altitude airships. The findings contribute to the broader goal of enabling persistent and flexible stratospheric observation systems for environmental and strategic applications.