

A New Approach for the Estimation of the Aerodynamic Damping Characteristics of the ETF Demonstrator

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ABSTRACT

Nautilus S.p.A. and the Polytechnic of Turin, in cooperation with Blue Engineering, have developed a very versatile product, the ELETTRA Twin Flyers [6] (ETF), which consists in a very innovative remotely-piloted airship equipped with high precision sensors and communication devices. This multipurpose platform is particularly suitable for border and maritime surveillance missions and for telecommunication, both in military and civil area.

To assess the actual maneuver capabilities of the airship [14], a prototype of reduced size and complexity has been assembled [16]. Before the flight tests a further assessment on the flight simulator is needed, because the first version of the software is tuned on the full scale prototype.

Steady state performance and static stability of the demonstrator have been evaluated with CFD analysis. The dynamic stability have been evaluated using CFD as well, because the classical methods to calculate dynamic derivatives, using USAF Datcom or wind tunnel tests, are not accurate enough, for unconventional shaped aircrafts in particular. Moreover, these methods refer to body pitch and plunge motion: it follows that derivatives are affected to a great extent by the frequency [17] and these derivatives are not suitable for aircraft model. To overcome all of these shortcomings, an innovative approach, based on looping and heaving motion has been used to calculate the dynamic derivative in order to update the flight simulator and thus to train the pilot with a realistic mathematical model.

1. INTRODUCTION

Over the last decade, the interest of various market sectors, involving military, civil and private organizations (security, commercial, defense, prevention, etc...) has more and more focused on unmanned aerial vehicles able to perform extremely different tasks, such as monitoring, telecommunications, advertising and surveillance. In addition, concern in environmental impact has grown particularly in those areas where these vehicles should operate. Among the several topologies of unmanned aerial vehicles, remotely-piloted airships certainly represent the most interesting solution for low speed, low altitude exploration and monitoring missions and, at the same time, they can be easily arranged to have high performance and respect the environmental compatibility. In fact, their aerostatic lift makes them noiseless, non-obtrusive, ecological and useful for environmental applications [1], such as oceanographic [2-3] and agricultural studies, traffic monitoring, ecological and climate research, inspection of endangered ecological sites as well as long-term variability studies. Moreover, airships have already been employed as camera and TV platforms for specialized scientific tasks and feature remarkable advantages over the other transport means in civil applications [4]. The innovative Lighter-Than-Air platform (Fig. 1) patented by Nautilus S.p.A and the Polytechnic of Turin [6], has been designed trying to fulfill some important requirements, such as controllability and maneuverability, low speed and hovering capabilities, operativity in severe weather conditions, noise emissions, ground staff and required facilities, acquisition and operative costs. The final target of the new concept airship design



Fig. 1. Elettra Twin Flyer

consists in achieving a good degree of satisfaction to all the previous requirements, on which fixed-wing aircraft, helicopters and conventional airships undoubtedly present total or partial lacks.

The resulting solution presents many innovative features, which cover many sectors of the aircraft design: almost all the subsystems have been purposely shaped and assembled and have never been tested on aeronautical applications. Hence, great emphasis has been given to the demonstrator phase, which has been considered crucial in the final process of the feasibility assessment. The demonstrator (Fig. 2) is a reduced-scale platform, which has been purposely assembled to test the most critical subsystems, such as the control system and the architectural solution. For this reason, the demonstrator complexity is reduced, if compared to the series- production platform, to concentrate the resources on the most critical issues: limiting costs and assembly time. In order to satisfy these requirements new procedures were used, for example the airship aerodynamics were evaluated using computational fluid dynamics (CFD) without the wind tunnel support, in particular the novel technique is the calculation of dynamic aerodynamic coefficient using CFD alone. The aim of this paper is to show the methodology used for the estimation of each dynamic derivative necessary to set up a flight simulator, using the commercial CFD code STAR-CCM+. In this work an innovative methodology has been used for damping derivative estimation that was validated in a previous work.

2. FLIGHT SIMULATOR (AERODYNAMICS)

To develop an innovative unmanned airship, a complete and refined Flight Simulator is essential. The simulator is necessary to support the whole design process of the platform as well as to provide a valid platform for the pilot training. In particular, the main tasks of the ETF Simulator can be summarized as follows: to assist the airship design process from the early stages in which it is necessary to evaluate the global dynamic behavior of the vehicle, up to the more advanced phases in which the single components and subsystems of the airship have to be correctly analyzed, dimensioned and integrated in the final product; to support the design and test phases of a completely new flight control system, as well as its implementation in the on-board computer through innovative techniques based on real-time rapid prototyping and hardware-in-the loop simulations; to supply a powerful tool for the pilot during the training phase, when the pilot is expected to acquire the ability to fly this non conventional remotely-piloted airship. In fact, even though the piloting has been thought to emulate as much as possible the helicopter concept, a short training phase is necessary in order to get used to the airship response and to obtain the best performance from its great capabilities; to support the design of the ground station, which has to be realized as close as possible to the Flight Simulator in order to maintain the same operational environment used by the pilot during the training phase; to provide an expository platform to effectively highlight the peculiar characteristics and performance of this new concept unmanned airship during marketing operations.

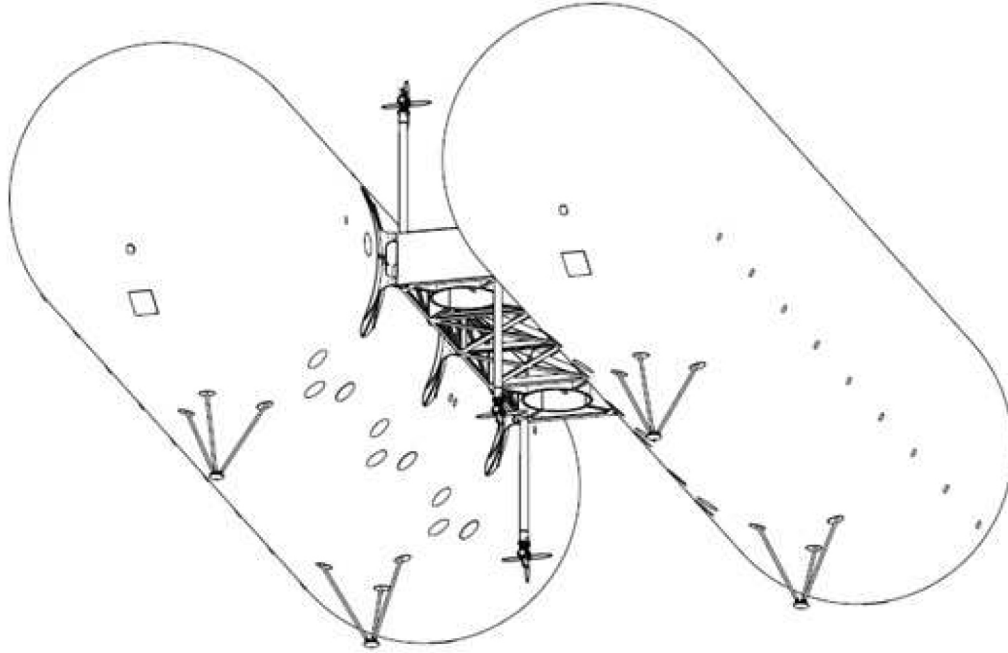


Fig. 2. ETF demonstrator

THE AIRSHIP MATHEMATICAL MODEL

The ETF Simulator is based on a six-DOF airship non linear dynamic model [7-8], in which the airship is considered as a rigid body without aeroelastic effects and symmetric about the XZ plane. This 12-state mathematical model is described by the Newtonian non linear equations of motion, according to the standard dynamic modeling of the conventional aircraft[9]. However, the presence of aerostatic lift provided by a huge gas volume and the large volume of air displaced by the airship motion give rise to significant additions to the familiar aircraft equations of motion, such as the buoyancy force B and the apparent mass and inertia terms. The airship equations of motion are expressed in the non linear *state-space* format and referred to the XYZ body-axes reference frame fixed in the Center of Gravity (CG). In particular, they consist of the six force and moment equations, the three kinematic equations and the three navigation equations[10]. In a matricial notation we can summarize them as follows:

$$\begin{aligned} M \dot{\bar{x}}_v &= \bar{F}_d + \bar{F} \\ \dot{\bar{x}}_K &= \mathbf{f}(\bar{x}_K, p, q, r) \\ \dot{\bar{x}}_N &= \mathbf{g}(\bar{x}_N, u, v, w) \end{aligned}$$

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where M is the total mass matrix, $\bar{x}_v$ is the state vector of linear (u, v, w) and angular (p, q, r) velocities. $\bar{x}_K$ is the state vector of the Euler angles (ϕ, θ, ψ), which define the airship attitude relatively to the Earth-inertial reference frame, while $\bar{x}_N$ represents the state vector of the airship coordinates

(North, East, Altitude) with respect to the Earth reference frame. Moreover, F_d and F represent, respectively, the dynamic contributions and the external force and moment contributions depending on aerodynamics, static buoyancy, propulsive system and gravity. The force (F_X, F_Y, F_Z) and moment (L, M, N) components of these two vectors along the X -, Y -, Z - body axis of the CG reference frame can be expressed as follows:

$$\bar{F}_d = \begin{bmatrix} -m_z w q + m_y r v \\ -m_x u r + m_z p w \\ -m_y v p + m_x q u \\ -(J_z - J_y) r q + J_{yz} (q^2 - r^2) + J_{zx} p q - J_{xy} p r \\ -(J_x - J_z) p r - J_{yz} p q + J_{zx} (r^2 - p^2) + J_{xy} q r \\ -(J_y - J_x) q p + J_{yz} p r - J_{zx} q r + J_{xy} (p^2 - q^2) \end{bmatrix} \quad \bar{F} = \begin{bmatrix} F_{x_a} + F_{x_b} + F_{x_p} + F_{x_g} \\ F_{y_a} + F_{y_b} + F_{y_p} + F_{y_g} \\ F_{z_a} + F_{z_b} + F_{z_p} + F_{z_g} \\ L_a + L_b + L_p \\ M_a + M_b + M_p \\ N_a + N_b + N_p \end{bmatrix}$$

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Where $m_x, m_y, m_z, J_x, J_y, J_z$, etc..., are the airship inertial terms of the total mass matrix M . The airship inertial data have been computed on the assumption that the total mass matrix has to account for three contributions: the mass and inertia terms M_i of all the airship structure components; the inertial properties M_g of the gas inside hulls and ballonets; the apparent mass and inertia terms M_{app} arising from the large volumes of air displaced by the airship motion, especially in non stationary conditions. These three inertial contributions are summed up in the total mass matrix M and inserted in the equations of motion of Equation (1):