Morphing technology for gust alleviation: an UAS application

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Abstract. Atmospheric turbulence can significantly affect aircraft missions in terms of aerodynamic loads and vibration. These effects are particularly meaningful for MALE-HALE UAS because of their high aspect ratios and because of their low speed, sometimes comparable with that of the gust itself. Many studies have been conducted to reach the goal of efficient gust alleviation. A viable solution appears the application of morphing technology. However, the design of morphing aircraft is a strongly multidisciplinary effort involving different expertise from structures to aerodynamics and flight control. In this study, a multidisciplinary wing-and-tail morphing strategy is proposed for attaining gust attenuation in UAVs. The strategy is based on the combined use of: i) an automatic detection system that identifies gust direction and entity and ii) an aeroelastic model stemming from the coupling between a high-order structural model that is able to resolve the motion and the strain and stress distributions of wings with complex internal structures and a Vortex Lattice Method (VLM) model that accounts for the aerodynamics of the wing-tail system. The gust alleviation strategy employs the information from the detection system and the aeroelastic model to determine the modifications of the wing and the tail surfaces aimed at contrasting wind effects, reducing induced loads and flight path errors. Numerical results are presented to assess the capability of the framework.

Introduction

UAS flight is widely affected by atmospheric turbulence for two principal motivations: small dimensions and slow speed. This is more pregnant especially for small UAS because they flight at low altitude and have speed components comparable with atmospheric ones. For the above-mentioned reasons, it is very important to devise an efficient gust alleviation strategy to achieve safe flight conditions. This requires a two-step process: first, wind components need to be accurately identified. Second, suitable actions must be taken on the lifting surfaces to counteract the effect of the gust. Among the various approaches proposed in the literature, morphing appears a viable option to implement the latter step [1, 2].

Morphing covers all those technologies that result in a continuous shape variation of one or more elements of the aircraft during flight, aimed at obtaining maximum performance in multiple flight phases. For example, morphing technologies are increasingly applied in micro unmanned aircraft (MAVs) [3].

Airfoil modifications are morphing technologies that allow to change the camber or the thickness of the wing profile during flight.

This approach could be efficiently applied to gust alleviation modifying aerodynamic surfaces to generate aerodynamic coefficient modification to contrast wind induced ones.

Wind identification algorithm

An accurate non-linear mathematical model based on the classical rigid body equations of motion in body axes has been used [4]. The identification algorithm is based on an Extended Kalman Filter (EKF) [5, 6, 7], in which the corrector employs a set of measurements gathered in turbulent air.

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The measurement vector is composed of the airspeed (V), pitch rate (q), elevation angle (θ) and the spatial coordinate of the center of mass (x; h).

As it is well known, the wind components modify the airspeed (V), the angle of attack (α) and the pitch rate (q) as follows:

$$V = \sqrt{\left(u + u_g\right)^2 + \left(w + w_g\right)^2} \tag{1}$$

$$\alpha = atan\frac{w+w_g}{u+u_g} \tag{2}$$

$$q = q + q_q \tag{3}$$

where (u_g, w_g, q_g) are the unknown wind components in body axes.

To tune the EKF, an optimization procedure, based on the control of prediction errors, has been used. In previous paper [6, 7] authors demonstrated the robustness of the tuning procedure, which allows to identify various kind of atmospheric disturbances with appreciable accuracy. In fact, it has been demonstrated that the algorithm is able to identify either infinite step gusts or finite ones.

Vortex Lattice Method

The aerodynamic model is based on the Vortex Lattice Method (VLM). As it is well known, VLM is a numerical method used in computational fluid dynamics based on the following assumptions:

- the flow field is incompressible, inviscid and irrotational;
- the lifting surfaces are thin, the influence of thickness on aerodynamic forces are neglected;
- the angle of attack and the angle of sideslip are both small, small angle approximation;
- the wing (or tail) is replaced by a lifting surface.

Morphing technology

In this research a combined wing and tail morphing technique is proposed. The morphing approach allows to modify wing and tail camber either simultaneously or not, in terms of both position of maximum camber and camber itself, depending on the gust entity and loads.

In Fig.°1 and Fig.°2 examples of camber modification of wing airfoil are reported.

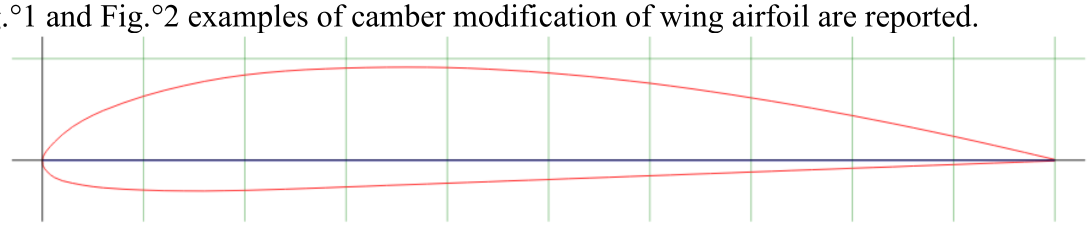

Figure 1: Clark Y wing airfoil

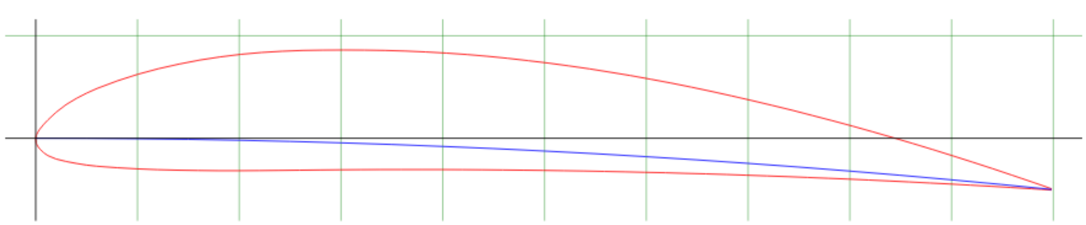

Figure 2: Clark Y wing airfoil with maximum camber variation

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Simulations and results

The proposed procedure has been applied to a UAS that is a 1:5 scale model of a real airplane. Its geometrical and weight features are well known as it is the same model studied in previous applications [5, 6, 7].

Using VLM, various wind-tail geometric configurations have been modeled. These ones can be applied to the UAS during flight with morphing techniques. All obtained data has been analyzed and a polynomial relationship between the C_L and camber has been extracted.

The obtained relationship has been inserted in an algorithm developed in MATLAB environment. Such an algorithm identifies the configuration that UAS needs to reject the external disturbance.

Various simulations have been performed and results show that, when the wind identification procedure identify the external disturbance (in few time steps), the gust alleviation system comes into operation modifying aerodynamic surfaces to reach the goal of the reduction of gust induced variation of angle of attack.

Fig.°3 shows the desired flight path and the real flight path for a landing procedure in turbulent air, while Fig.°4 shows the tracking error.

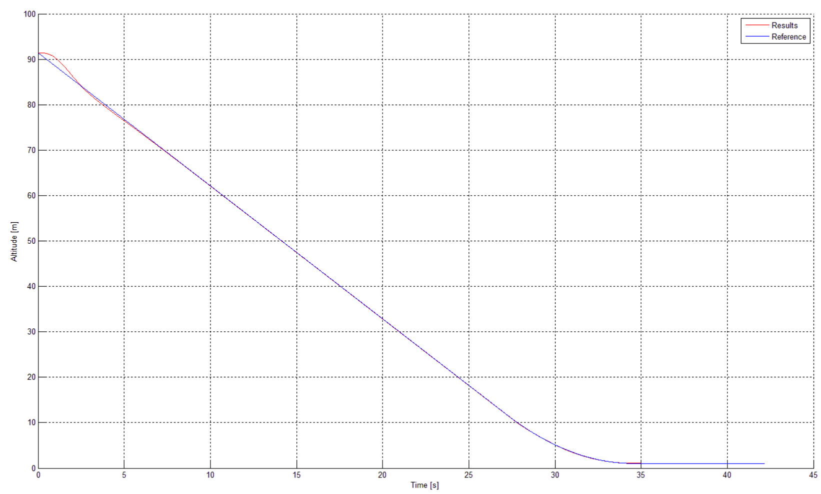

Figure 3: Desired and controlled flight path

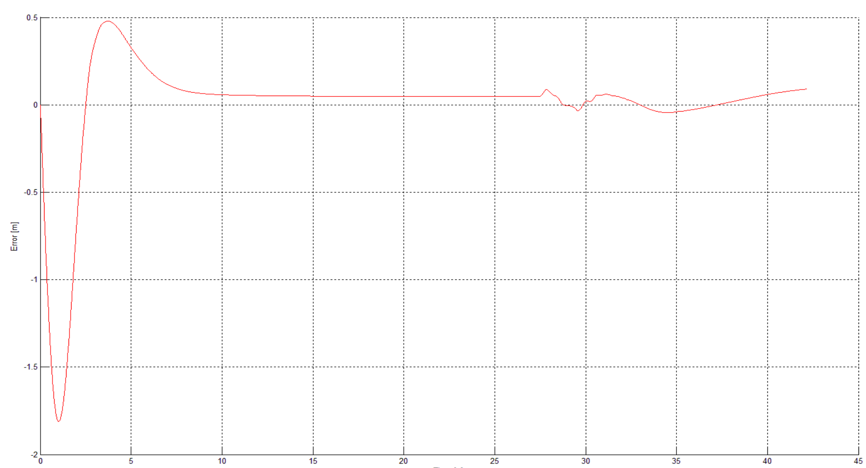

Figure 4: Tracking error

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