CAMBER SETTING OF A MORPHING WING WITH MACRO-ACTUATOR FEEDBACK CONTROL

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Abstract. This paper relates the camber control of a morphing flap actuated by a macro-actuator composed by five electromechanical actuators. Controlling the camber of the flap could provide fuel consumption by reaching specific aerodynamic profiles. Due to their reliability, electromechanical actuators are used for the macro-actuator. They are located and integrated to resist to realistic aerodynamic forces. Their control is determinant to ensure the flap mission. Based on a simplified model using Lagrange principle leading to macro-actuator feedback control, the strategy deals with the interconnection of the five electromechanical actuators. Flow simulations are computed around the flap to have more pressure distribution data. Finally, feedback control simulations are provided.

Keywords: Camber control, morphing flap, electromechanical actuation, feedback control, aerodynamic force, flow computation.

Introduction

In the context of an energy efficiency improvement, especially within more electrical aircrafts, the morphing of structure could provide many benefits [1]. The shape of morphing structures can be optimized to improve their aerodynamic performance [2]. For instance, adaptive morphing flap could reduce aircraft fuel consumption thanks to a shape adaptation to flight conditions. Reducing fuel consumption is a high environmental and economic challenge: 2% of CO2 emissions were due to civil aviation in 2008 [3] and one kilogramm of fuel saved represents a 1000 $ savings [4].

The work presented in this article is a part of a European project called Smart Morphing and Sensing (SMS), which is a multi-disciplinary upstream project that employs intelligent electro-active actuators that will modify the lifting structure of an aircraft and to obtain the optimum shape with respect to the aerodynamic performance (high lift and low drag). This paper focuses on a specific part of the projet, the design, control and test of a Large Scale (LS) prototype. The LS prototypes will be fully equipped with both integrated sensors and actuators for use in laboratory and wind-tunnel experiments. The overall goal of this prototype is the design of a flap for shape optimization of realistic full-scale aero structures, in order to increase the aerodynamic performance of the smart wing in a realistic scenario both in terms of aerodynamic loads and structural constraints.

The feasibility of this principle has been proved in [5] where Shape Memory Alloy (SMA) actuators were used to control the camber of a small flap. Indeed, SMA actuators properties are particularly suitable for slow motion in high force conditions, [6]. However, SMA actuation is not as reliable as electromechanical actuation. Electromechanical actuators (EMA) have many applications in aircrafts [7][8] and even as primary flight control actuator if reliability is ensured [9] That is why we propose here to focus on an electromechanical actuation for the morphing flap, which as been well detailed in [10], and especially on the camber control of the flap through its actuation system control.

The specifications and the designed flap description are first described and the control strategy with flow computations and feedback control simulations are detailed in the second part of the article.

1 Large Scale prototype for morphing flap description

1.1 Technical specifications

Based on an Airbus commercial aircraft, this section deals with the morphing flap design. The flap profile has been adapted from industrial specifications: 1m chord and 2m span. A chordwise loading is specified, equivalent to 1.5 tons of aerodynamic upward forces. An idea of the force distribution is represented in Figure 1. Only the shape of the flap is adapted to flight conditions, with a morphing profile. The flap profile evolves between two extreme shapes, a high cambered shape and a low cambered shape, as presented in Figure 2. The proposed solution is detailed below.

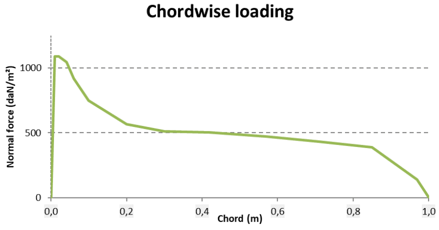

Fig. 1. Aerodynamic force distribution

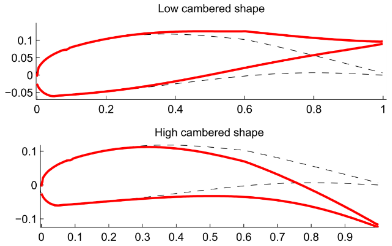

Fig. 2. Wing profiles

1.2 Proposed solution

In order to reach the desired profile, the flap is divided into 6 parts connected with five hinges (Figure 3). The locations of hinges are determined by optimization, for SMA actuators [11]. Actually, the SMA actuators appear as a smarter way to articulated the flap, but they remain hard to control, to integrate and are not as reliable as EMA. The optimization results with SMA are used for EMA in order to provide a comparison between the two solutions in the future.

Then, EMA provide linear forces, using leverage around hinges. A block of five EMA (one for each hinge) forms a macro actuator. To ensure the shape in realistic fligth conditions, four macro-actuators are needed along the flap span, as described in Figure 4 (the fourth macro actuator is hidden under the wing skin on the figure).

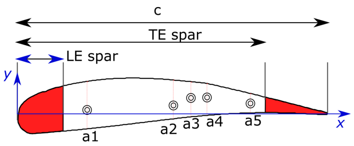

Fig. 3. Articulated profile with hinges

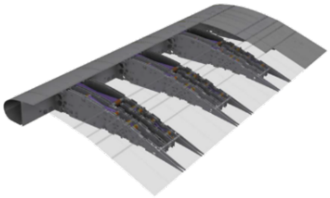

Fig. 4. Morphing flap with 4 macro-actuators

1.3 Actuation system: EMA

The EMA design is well documented in [10] and mainly consists in a permanent magnet motor connected to a screw nut through a gearbox as presented in Figures 5 and 6. The EMA are located to respect the right leverages and to manage space: the macro-actuator (Figure 7) cannot be larger than 50cm. Indeed, the 2m span flap requires four macro-actuators.

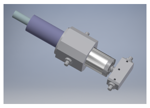

Fig. 5. The EMA

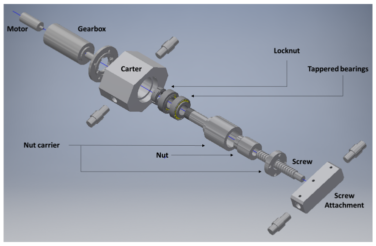

Fig. 6. Detailed view of the EMA

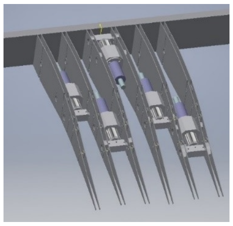

Fig. 7. The macro-actuator

2 Modelling of the system and feedback control design

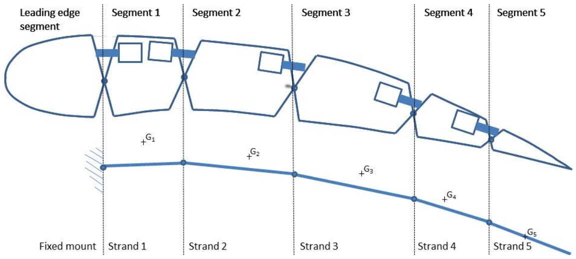

Fig. 8. Scheme of the simplified morphing wing used for the Simulink simulation

From the mechanical draft, a dynamical model of the camber actuation is designed using MATLAB and Simulink. The morphing wing is simplified as 5 strands, connected by pivots around parallel axis. The overall model is presented in Figure 8. Each strand k is defined by its mass m_k, length l_k, centre of gravity G_k, inertia J_k and articular parameter q_k (corresponding to angles expressed in the global referential). Hypotheses are chosen for this simplified model: rotations are considered two dimensional and around parallel axis, strands non-deformable and pivots perfect. The description of the dynamical equilibrium of the system is therefore performed using the Lagrange principle:

$$\mathcal{M}(q)\ddot{q} + \mathcal{N}(q,\dot{q})\dot{q} = F_g(q) + F_a(q) + \Gamma(q) \tag{1}$$

with $F_g(q)$ moment of the gravitational force, $F_a(q)$ moment of aerodynamical forces, $\Gamma(q)$ moment applied by the actuators at the pivot, $\mathcal{M}(q)$ inertia matrix and $\mathcal{N}(q,\dot{q})$ gyroscopic effects, here neglected due to the slow motion of the morphing wing.

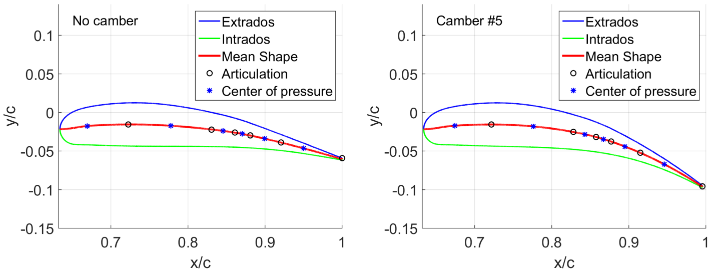

Fig. 9. Results of the flow simulation for different cambers of the wing, here (a) minimal and (b) maximal angles tested.

A proper knowledge of the aerodynamical forces and moments F_a applied on the morphing wing is crucial and could be challenging. A simulation of the flow over the morphing wing is used here to obtain the pressure distribution for different cambers. Details of the simulation can be found in the SMS project. Minimal and maximal cambers of the wing are presented in Figure 9. Contributions of the pressure for suction side (top) and pressure side (bottom) are separated. Positions of the articulations are brought back to the mean line of the wing (obtained as the mean position between extrados and intrados). Forces and moments applied on each articulation, and their center of pressure are eventually obtained from the pressure distribution. A more complete database of simulations will be available soon with a bigger camber deformation for the large scale wing, in order to improve the aerodynamical model.

The simplified model of Figure 8 is then used to design feedback controllers. An objective of angular morphing is fixed by the global flows and pilot demands parameters. The closed-loop control goal is to achieve this objective with precision and speed as in [12]. A proportional-integral-derivative (PID) regulator is first considered as a reference closed-loop controller in order to achieve the performances previously detailed.

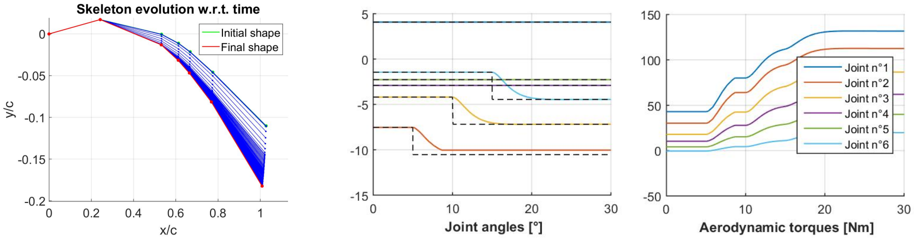

Fig. 10. Results of the feedback control simulation to achieve target skeleton. (a) Skeleton evolution w.r.t. time, (b) evolution of joint angles (full line) compared to the targets (dotted), (c) aerodynamic torques applied on the joints.

Preliminary results of the feedback control of the structure are presented on Figure 10. The full skeleton shows a global convergence of the complete system. Targets of the joint angles are partially or totally reached by the controller.

For the next steps of the present study, the full model will be improved by more mechanical and aerodynamical informations. Some specificities of the system could perturb the proper control, like the hysteresis behavior of the EMA and saturations of actuators. A consideration of these phenomena and a more sophisticated approach of the feedback control synthesis will also be considered in order to counter these difficulties.

3 Conclusion

The full control of the camber was performed by a multidisciplinary approach between mechanics, electronics and automatic science. It allows a global integration of the control in order to fit the camber with specific profiles, allowing a decrease of the drag and, therefore, the fuel consumption.

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