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The transformer: A multimission UAV capable of symmetric and asymmetric span morphing

Rafic M. Ajaj *, Girish K. Jankee

Aerospace Engineering, University of Southampton, Southampton, SO17 1BJ, UK

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ABSTRACT

This paper presents the development and extensive testing of the Transformer aircraft, a multimission UAV capable of symmetric and asymmetric span morphing. The UAV utilises a novel actuation based on a rack and pinion mechanism to achieve span extensions up to 50%. The Transformer can morph symmetrically to enhance flight performance and asymmetrically to provide roll control. Extensive mechanical testing followed by wind-tunnel testing in the RJ Mitchell Wind-tunnel at the University of Southampton were conducted to ensure structural integrity and assess the behaviour of the UAV. Finally, a series of flight-testing were performed and the flight mechanics aspects associated with both symmetric and asymmetric span morphing were investigated.

1. Introduction

Large wingspans offer enhanced flight performance but reduce the manoeuvrability margin. On the other hand, low aspect ratio wings offer higher margins of agility but lack the aerodynamic efficiency [8]. A span morphing wing can combine the advantages of both design allowing one aircraft to effectively perform different types of missions [1]. The idea of span morphing is not new. Ivan Makhonine, a Russian expatriate, developed one of the earliest span morphing wing designs. The MAK-10 was an aircraft that flew in the 1930s with a telescopic span morphing wing. He used pneumatic actuators to morph the telescopic wing and his design was capable of achieving up to 60% span extension [12]. In recent years, there have been some promising work on span morphing wings. For example, Blondeau and Pines [9] developed a telescopic wing and they used hollow fiberglass shells to preserve the aerofoil shape and reduce storage size of the wing. To reduce the weight, they used inflatable actuators instead of rigid spars to support the aerodynamic loads on the wing. On the other hand, Bae et al. [7] conducted static and dynamic studies on the wing of a long-range cruise missile and identified some of the difficulties associated with the design of a morphing wing capable of span change. Their studies concluded a drag reduction of 25% and a range increase of 30%. Furthermore, the authors developed a number of wing designs that facilitate changing the span. These designs include the Zigzag Wingbox concept [6], the Compliant Spar concept [3], and the Gear driveN Autonomous Twin Spar (GNATSpar) [2]. Most of the concepts developed by Ajaj et al. [6,3,2] used a hybrid structural design philosophy where the wing structure is at the same time the mechanism and the actuator. The structure was then covered by flexible material (mainly elastomeric) to provide and maintain the aerodynamic profile. A more extensive review on span morphing technology (applications and concepts) for both fixed-wing and rotary-wing aircraft is given in Barbarino et al. [8]. This paper aims to experimentally assess the impact of span morphing on the flight performance (when operated symmetrically) and on its ability to enhance roll control authority (when operated asymmetrically). Therefore, an electrically powered, span morphing mini-UAV is designed, built and tested. A telescopic mechanism, that facilitates both symmetric and asymmetric span morphing, is developed. The paper provides an overview on the design, sizing and manufacturing of the UAV and it details the wind-tunnel and flight testing performed.

2. The morphing UAV

2.1. UAV's configuration

A conventional UAV configuration was selected to simplify the integration of the span morphing wing and to minimise unwanted couplings between the different axes. In addition, a conventional UAV configuration may allow scaling some of the results of this study to large aircraft with similar conventional configurations. This scaling might not be feasible if unconventional UAV configurations (such as flying wings) were used. The UAV's maximum

* Corresponding author.
E-mail addresses: r.ajaj@soton.ac.uk (R.M. Ajaj), g.jankee@soton.ac.uk (G.K. Jankee).

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take-off weight must not exceed 15 kg and therefore it will be electrically powered using one powerful electric motor driven by a series of on-board batteries. The UAV's configuration is shown in Fig. 1. A tractor propulsion system (attached to the nose of the UAV) is selected due to its ability to reduce prop strike on take-off whilst allowing for a lighter single-boom empennage configuration. A conventional, fixed tricycle landing gear arrangement is used where the nose and main landing gears are mounted to the bulkheads of the fuselage to minimise the impact of landing loads on the span morphing wing and maximise the internal volume of the fuselage (central wingbox) to house the morphing mechanism/actuation system. The baseline wingspan, when fully retracted, is 2 m.

2.2. Morphing mechanism

There is a number of span morphing mechanisms available in literature. However, the telescopic span morphing mechanism is most popular due to its relatively simple design, high reliability and durability, and minimal actuation requirements. Telescopic mechanisms can achieve high morphing rate due to their low actuation force requirement (when compared with non-telescopic or hybrid telescopic (those covered by elastomeric material)) which is necessary for utilising span extension for roll control. Therefore, it was decided to utilise a telescopic mechanism to vary the wingspan. To achieve both symmetric and asymmetric morphing, two independent actuators will be used. A study by Ajaj et al. [4,3] concluded that for flight performance and roll control purposes only span extensions of up to 50% are required. Therefore, this paper focuses on span extension (symmetric and asymmetric) of up to 50% even though the span morphing mechanism that is developed here allows achieving span extension up to 100%. The maximum wingspan studied here is 3 m (50% extension). To maximise the effectiveness of the vehicle (in case of jamming or failure of the morphing mechanism), it must be able to fly effectively throughout all the flight phases (take-off, cruise/loiter and landing) with the wing fully retracted which necessitates the need for flaps and ailerons. Since the extension is stored in the main wing when fully retracted, both the flaps and ailerons are attached to the fixed partition (non-morphing part) of the wing. This will ensure that the extension/retraction path is kept clear regardless of the wing configuration as shown in Fig. 2a and b. To simplify the integration of the morphing mechanism with the wing, wing dihedral, sweep, taper and twist were avoided and a mid-wing configuration was selected to easily house the actuation system needed. Due to the telescopic nature of the morphing mechanism used (discussed in the next section), the extending part of the wing has a smaller chord and is set at a geometric incidence angle (to prevent tip stall) relative to the main wing section as shown Fig. 2c.

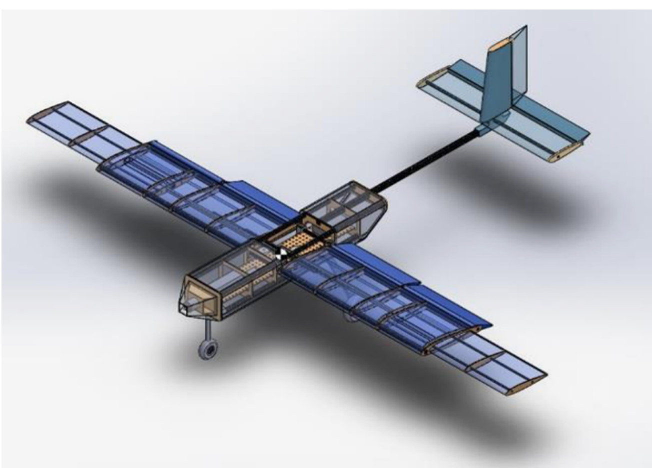

Fig. 1. The UAV platform.

2.3. Design, manufacturing and integration

2.3.1. Wing geometry

This paper focuses on the impact of span morphing on aerodynamic and flight mechanics of the UAV. Therefore, a rectangular, unswept, untwisted wing with no dihedral is selected. The UAV is expected to take-off from a 50 m long grassy runway. It was decided that the UAV must be able to take-off with wing fully retracted and flap fully deployed (30°). As such, the main wing geometry was defined mainly by the take-off performance of the

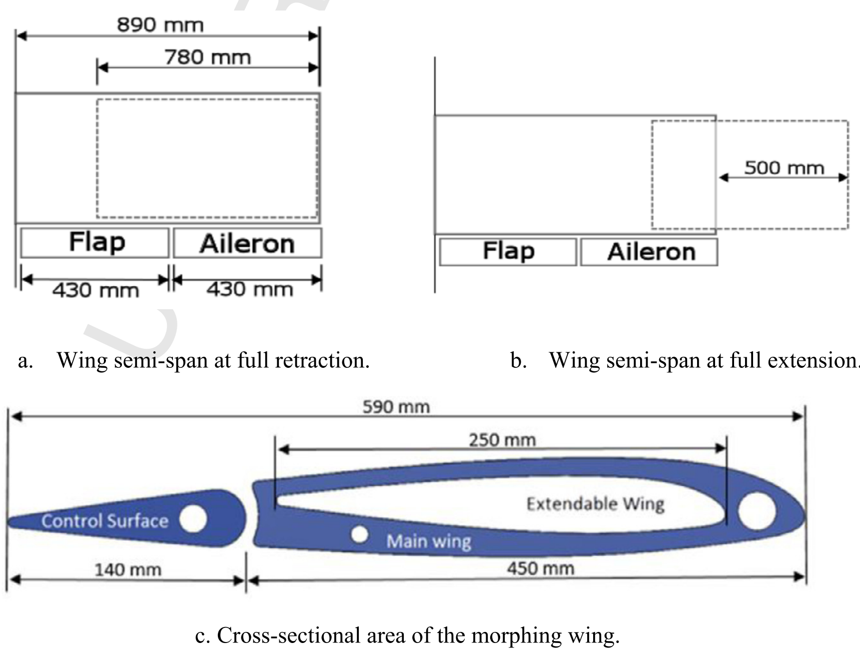

Fig. 2. Final control surface configuration concept.

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