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The Adaptive Aspect Ratio morphing wing: Design concept and low fidelity skin optimization

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ABSTRACT

This work introduces a new aircraft wing span morphing concept. Known as the Adaptive Aspect Ratio wing, this concept couples a compliant skin to a mechanism based internal structure to create a morphing wing capable of significant changes in span and aspect ratio. The technologies of the concept are first introduced and discussed. The compliant skin is established to be the dominant component in the design of this concept, requiring balancing of in-plane and out-of-plane stiffnesses. An initial skin design optimization exercise is performed using analytical models, providing insight into the interplay between the various parameters of the skin design.

1. Introduction

The Adaptive Aspect Ratio (AdAR) wing is a compliant skinned morphing wing concept under development at Swansea University. The word "adar" is Welsh for "bird", and connects this concept to its inspiration; the smoothly adaptive aspect ratio and span change achievable by bird wings. As with the case of avian flight, it is useful in manmade craft to be able to change the aspect ratio of a wing to find the optimal tradeoff between induced drag and wetted area drag. While the flight speeds and Reynolds numbers of birds and aircraft are significantly different, the driving forces are the same. Operation at high lift coefficients, for example during low speed flight or maneuvering, leads to significant lift-induced drag, which is best mitigated by increasing the aspect ratio of the wing. However, in direct contrast to this, operation at low lift coefficients, for example at higher flight speeds or lower operating weights, leads to significant profile drag on the wing, which is best mitigated by reducing the wetted area of the wing, through reduction in the span for example. Currently, aircraft wings are designed with a shape which provides a compromise between these competing considerations given the particular mission profile expected of that aircraft. Generally speaking this approach works well, particularly for aircraft such as long haul commercial airliners which spend most of their flight time in one particular operating condition. For these aircraft a compromise wing design weighted heavily towards the cruise portion of the flight will provide good overall performance. However, there are many aircraft which are expected to operate over a more widely varying set of conditions. One example is aircraft that are used for surveillance type missions where it is desirable to travel between locations at a maximum possible speed and then slow down once on station to a more efficient loiter speed to increase time on station. There are many other mission profiles which also require changes in operating condition, and indeed the use of morphing may allow for entirely new mission types not currently possible. However, the dash and loiter conditions of a surveillance aircraft provide a useful range of operating conditions for the current discussion.

2. Adar wing concept overview

The AdAR concept combines four key technologies to create a span morphing concept capable of a 100% increase in the span of its morphing section; a compliant skin made from elastomeric matrix composite (EMC), a telescopic rectangular box spar, sliding ribs, and a strap drive system. While other span morphing wings have been built and tested in the past [2,3,6,7], the AdAR wing has a unique combination of technologies and properties. First and foremost, the change in length required of the skin surface is achieved in this concept through material compliance. The elastomer matrix of the EMC composite is capable of achieving the high levels of strain required with a single continuous skin surface, removing the steps and discontinuities found with rigid sliding skin designs. A mechanism based solution consisting of a telescopic sliding spar is chosen for the primary load bearing

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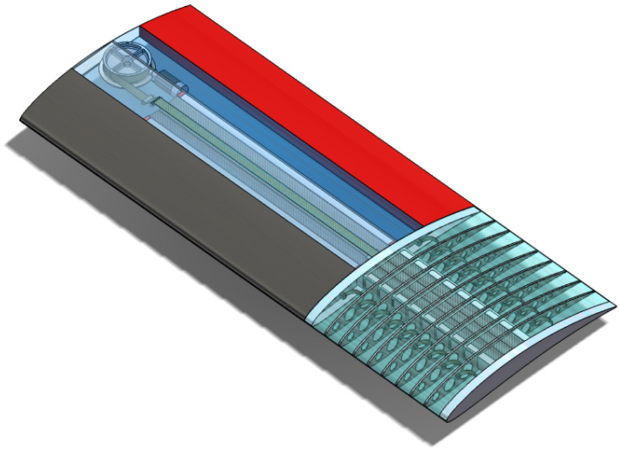

Fig. 1. Isometric view of preliminary AdAR wing design – span retracted.

structure due to its simplicity and low impact on actuation requirements. Furthermore, if carefully designed, the discontinuous geometry of a telescopic spar does not have the same negative impact on aerodynamic performance as a discontinuous skin surface. In order to provide an effective interface between the compliant skin, which strains continuously along its length, and the telescopic spar, which increases its length in a more discontinuous manner, the AdAR wing concept incorporates sliding ribs. These ribs are bonded to the skin surface at regular intervals, creating a distributed network of support for the skin. However, the ribs are free to slide over the outboard portion of the telescopic spar, allowing them to maintain equal but increasing spacing as the spar extends. The sliding ribs of this concept incorporate features intended to increase the reliability and safety of their actuation, namely spaced bearing surfaces and mechanical separation limits, which will be discussed in more detail below. The final aspect of the concept is a strap drive system. This is a tension driven actuation system which connects the inner moving portion of the telescopic spar to the outer fixed portion using a high strength fabric strap traveling around redirection pulleys in a manner which produces extension of the spar using tension in the strap. This approach has several benefits, including the mitigation of buckling concerns which would exist with a compression based actuation system (such as a lead screw or a telescoping piston), and the ability to spool the strap onto an actuated drum with a high degree of packaging efficiency.

The specifics of these four design aspects and their integration into the AdAR wing design will be discussed further in turn. A preliminary design model, seen in Fig. 1, has been created to show how these different components integrate. In this example, the compliant skin in its retracted state covers 33% of the span of the wing. The fixed inboard portion of the telescoping spar also forms the main spar for the rest of the wing while the moving outboard portion of the spar slides inside of it. The specifics of the wing geometry seen here are given in Table 1. Note that the specifics of the dash and loiter conditions are listed here as well, including the maximum aerodynamic pressures predicted to exist in these two conditions. These values are taken from computational fluid dynamics analysis of the wing, as discussed further in Section 3.3.1 below.

The same design model is shown from above in Fig. 2 in its extended state. Here the overall length of the compliant skin portion has increased by 100%, which represents a 33% increase in total span. Given the fixed chord, this is also a 33% increase in aspect ratio. Note that the compliant skin in this state covers 50% of the total wing span. It can be seen in Fig. 2 that the moving portion of the spar still retains some overlap into the fixed spar even at maximum span extension to allow for effective transfer of the outboard loads into the inboard spar.

Table 1
Wing geometry and operating conditions.

Parameter	Value	Units
Retracted semispan, h_0	1.5	m
Max extended semispan	2	m
Initial morphing length, L_{m0}	0.5	m
Chord	0.6	m
Airfoil	NACA 6510	n/a
Dash velocity	30	m/s
Loiter velocity	15	m/s
Max aero pressure (dash)	521	Pa
Max aero pressure (loiter)	129.5	Pa

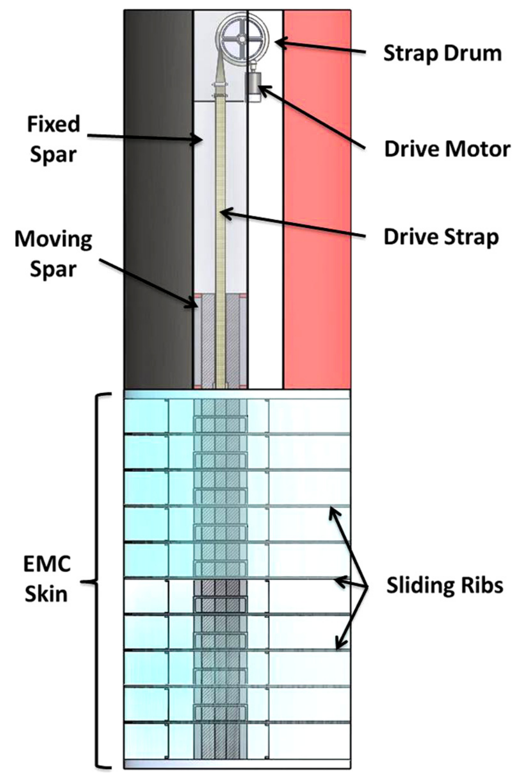

Fig. 2. Top view of AdAR wing design – span extended.

2.1. Elastomeric matrix composites

Elastomeric matrix composites consist of fiber reinforcement, typically carbon fiber, embedded in an elastomer matrix, typically silicone or polyurethane. With careful material selection, these composites are able to achieve over 150% recoverable in-plane strains. Furthermore, a very small volume fraction of unidirectional fiber reinforcement perpendicular to the primary strain direction (called transverse fibers here) allows the large Poisson's ratio of the elastomer matrix to be effectively eliminated. Due to Poisson's ratio effects, large levels of strain in a compliant skin without transverse fiber reinforcement lead to highly undesirable necking-in in the chordwise direction, creating variations in chord along the span and an undulating skin surface which suffers from a higher drag penalty. Previous work has shown experimentally that small amounts of transverse fiber will virtually eliminate necking in of the skin, resulting in constant chord with span extension [7].

The EMC technology used here is a further development of that used in previous work [4]. The EMCs are made in-house using an improved laminating process which provides better control over