Comparison span-wise and camber morphing for performance and efficiency

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Introduction

An aircraft experiences a wide variety of flow, and in-turn loading conditions over its operational envelope. The optimum geometry of the aerodynamic boundary varies over the envelope, and so it is postulated that by allowing parameters closely related to aerodynamic performance, efficiency and structural loads (and hence weight), that the overall mission performance, efficiency or capability can be improved. Generally, aircraft undergo only minor configuration or geometry modifications during flight. Examples of conventional systems that provide significant modifications to adapt to a flight phase are leading and trailing edge flaps (that extend the chord and modify the camber) for take-off and landing. Conventional devices are generally discrete geometric entities, with limited structural homogeneity for example between flap and the primary structure of a lifting surface. Under generic descriptions of morphing wings, these can be considered a form of morphing. A contemporary description considers morphing to involve the use of compliant structures or mechanisms that enable significant modification to a lifting surface cross-sectional and/or planform parameters/geometry.

Various novel structural designs and development of mechanism to actuate the geometric changes, which conform/comply to this contemporary description of morphing, have been developed. The fundamental types of morphing can be categorised as follows; twist, camber, chord, span, sweep and dihedral/ cant. De Breuker et. al. [4] further sub-categorises these variable geometry types into inter (twist, camber and chord) and intra (span, sweep and dihedral/ cant) section morphing. Each of these morphing parameters affects the vehicular system pressure and therefore lift distribution, which influences both the aerodynamic performance as well as the structural design. It is shown by Beaverstock et. al. [2] that a span morphing concept can be used to reduce structural bending moments and marginally improve aerodynamic performance for a speed range at constant altitude. It is postulated that allowing the span to vary allows sufficient control over the spanwise lift distribution to optimise for minimum drag (induced + skin friction drag), or reducing bending moments. It is supposed that control over the spanwise lift-distribution can be provided by camber morphing. It is proposed in this investigation to study an aircraft example, employing either a span morphing concept or a camber morphing concept to optimise the bending moments and/or aerodynamic efficiency over a representative mission.

The example will be a small/ medium UAV, with a mass of 25 kg, designed for a loiter mission. Two systems are to be compared, namely a span morphing concept and a camber morphing concept. This will be followed by a discussion of the implications of the results, in terms of both aerodynamic performance and efficiency, as well as structural implications in developing each concept.

A brief background

Barbarino et. al. [1] presents a review of morphing aircraft, including historical record of the interpretation of morphing, in addition to classical and contemporary morphing projects and concepts under investigation/ development.

The MAK-10 is a classical example of a span morphing concept which employs a systems, whereby a telescopic spar extends discrete wing sections with sliding skins in the span-wise direction. A sliding skin used in this example refers to a discrete skin in each section, where no strain between discrete sections is required to be overcome. The advantage of such system is observed in their relative simplicity in design, and lack of actuation energy required to overcome the stiffness of structural members to modify the shape. However, because of the discrete step changes in the geometry, this does not provide the best aerodynamic boundary shape. Other methods to modify span include passive methods such as polymorphing cant [6] like the XB-70, whereby span is modified through applying dihedral deflections to partitions at the tip of the wing, or concepts such as the MFX-1. It is proposed to employ a span morphing system which uses a straining skin to form the aerodynamic boundary with the structure. The proposed substructure is then a telescopic spar with 'floating ribs' to enable the span to morph.

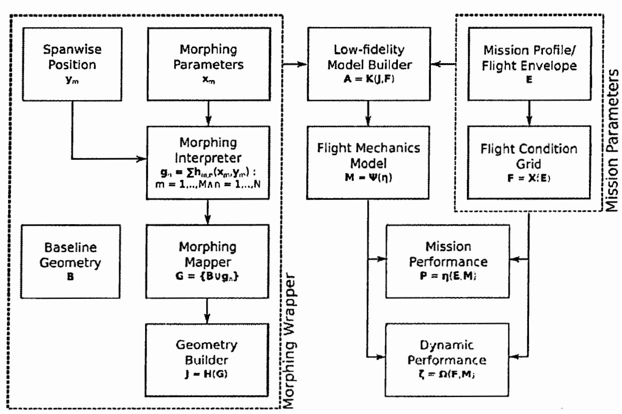
A number of camber morphing systems have been proposed to enable camber variation along a span. The simplest system is a classic rigid, discrete trailing edge flap. This mechanism has the advantage of simple design, and limited applied stress/strain in the structure to actuate a 'camber' variation. However, trailing edge flaps have associated disadvantages, which include; a discontinuous break in profile of the aerodynamic boundary, and a discontinuity in the structure and the flap is typically only capable of a constant fixed flap deflection along the span of its hinge line. The break in the aerodynamic boundary is shown in a NACA-0012 study by Woods et. al. [8] to be a source of significant drag (profile) increase when compared to a concept that employs a continuous varying camber change for equivalent load.

A more contemporary interpretation of what a morphing concept is have been developed that enable effective control of the cross-sectional camber, using concepts that maintain an unbroken aerodynamic boundary, and continuous camber change.

Solutions have been proposed that either modify the leading edge, or the trailing edge. Leading edge devices have included the concept developed at DLR [5], which using a 'compliant' leading edge skin, an internal structure mechanism is designed using topology optimisation to enable active control of the leading edge shape. A number of trailing edge concepts have been proposed to enable active control of the camber. These include split trailing edge to enable torque applied to deflect the trailing edge [9], [8]. Alternatively, Woods et. al. [9], [8] presents a system that uses a concept of distributing stiffeners along a spine centred along the camber/chord line of the aerofoil, where a stress bearing skin is replaced by an elastomer to enable large amounts of strain to achieve the required deflections for camber change. The concept considered for camber morphing in this investigation is the FishBAC developed by Woods et. al. [9], [8].

Analysis software framework

The analysis framework used is based on that presented by Werter et. al. [7] and Beaverstock et. al. [3], summarised in the figure below. This will investigate aerodynamic advantages, and structural loads to compare span and camber morphing concepts. A vortex lattice code is used to generate the aerodynamic data, which enables investigation into the aerodynamic performance, efficiency and structural loads experienced by the aircraft over the operational envelope. From this, systems level performance parameters can be computed, which includes mass, range and endurance.
The analysis shall investigate the two concepts, span morphing and camber morphing. The investigation shall include a variation in span and camber morphing parameter, where a representative mission profile is used and each configuration is optimised to complete the mission with the best performance.



Morphing software overview

Sensitivity and robustness

Sensitivity to inertial changes, as well as deficiencies in predicting the aerodynamic derivatives will be investigated. This will include modifying parameters related to the inertial properties, including aerodynamic derivatives to investigate the effect of these on the comparison, and ascertain the consequent effect on the results and conclusions.

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