MECHANISM AND ANALYSIS OF MORPHING WING FOR CONTROLLED WING TWIST[1]

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Abstract :

A new concept for actively controlling wing twist is described. The concept relied on introducing warping deformation of the wing skin, which was split at the trailing edge to create an open-section airfoil. An internal screw mechanism was introduced near the trailing edge, so that the load-carrying capability of the wing was maintained while allowing the introduction of warping displacement between the lower and upper wing skins at the trailing edge. Simple structural modelling of the warping wing based on generalized thin-walled beam theory was performed. A demonstration wing was built based on a NACA 23018 airfoil section with a span of 300 mm and a chord length of 120 mm. A maximum peak-to-peak twist of 15 deg was demonstrated, with excellent correlation between theory and experiment. Wind-tunnel tests showed that warping could change the lift coefficient by as much as 0.5 at maximum peak-to-peak twist. Analytical and vortex-lattice models were demonstrated to give accurate predictions of the lift coefficient at smaller absolute twist angles. Furthermore, analytic modeling of the wing drag was shown to be in close correspondence with the drag measurements and showed that wing warping could be used to influence the lift induced drag. In general, it was demonstrated that at lower angles of attack, a more positive twist resulted in a higher lift-to-drag ratio. This study proved that a twist-active wing can have sufficient gain to control the rolling motion of an aircraft and to ensure that the lift-to-drag ratio is maximized at various flight conditions.

Keywords-warp mechanism; variable camber, lift to drag ratio

1. Introduction

The concept of morphing is not an idea which has been strictly defined. A morphing aircraft is generally defined to be an aircraft whose shape changes during flight to optimize performance. Types of shape changes include span, chord, camber, area, thickness, aspect ratio and plan form. The morphing can also be applied to a control surface in order to eliminate hinges. Morphing aircraft are multi-role aircraft that change their external shape substantially to adapt to a changing mission environment during flight. This creates superior system capabilities not possible without morphing shape changes. The objective of morphing activities is to develop high performance aircraft with wings designed to change shape and performance substantially during flight to create multiple-regime, aerodynamically-efficient, shape-changing aircraft. Compared to conventional aircraft, morphing aircraft become more competitive as more mission tasks or roles are added to their requirements.

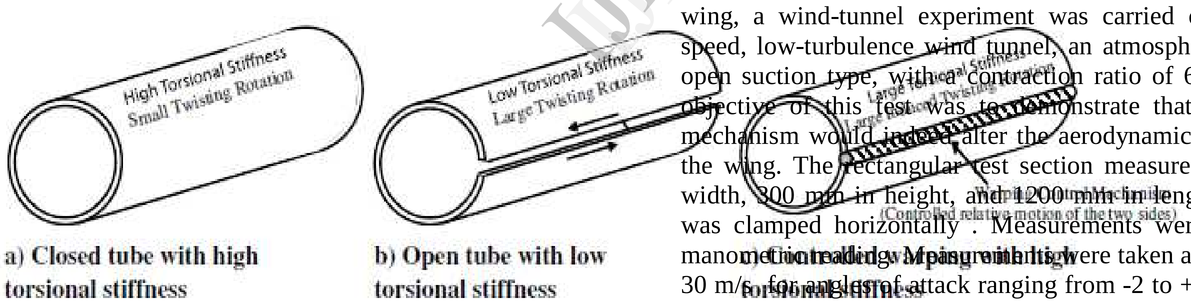
For certain project, morphing is limited to changing the shape of the wings, not of the entire airframe. This type of morphing can be studied with the use of biologically inspired techniques. The different ways that birds change the shape of their wings during flight is studied and compared with morphing techniques. These birds typically change the shape of their wings depending on the types of maneuvers that they need to perform. Certain techniques of morphing for aircraft can be designed by studying these birds. There are several morphing techniques which are used by these birds that demonstrate how their flight maneuvers can be changed, such as loitering, diving and take-off.

In the past, different methods and mechanisms were employed to induce wing twisting. The active flexible wing and active aero elastic wing programs investigated the use of leading- and trailing-edge control surfaces to control the wing twist. Although effective, the control system required to achieve these high roll rates was complex and the mechanism could only be employed on relatively thin wings with low torsional stiffness. All aero elastic approaches use energy from the airstream to induce strain in the structure. Inherent in the concept of aero elastic flight control is their higher susceptibility to undesired aero elastic effects (flutter, divergence, and buffet) compared with structures that are designed to suppress these effects.

The torque box structure of a conventional wing is designed to provide a high torsional stiffness to suppress undesired aero elastic effects such as aileron reversal, divergence, or flutter . A conventional torque box is made of two spars, the upper and lower skins of the wing, and a series of parallel ribs. The increased flexibility of a wing box to produce large twisting motion may come at a price of reduced load-carrying capability. To maintain load-carrying capability, positively controlled relative motion of the individual torque box planes needs to be introduced. This can be achieved by either sliding or hinging part of the box structure. By operating this hinging or sliding motion, the amount of warping can be controlled.

2 . Motivation and Scope

The motivation for this work is to obtain a numerical model suitable for studying the morphing wing technology. The vehicle under consideration uses morphing in the form of asymmetric wing twist as a primary means of lift, drag and roll control. Such a model can then be used for future design iterations of the vehicle by considering a numerical procedure wherein various aspects of the vehicle's aerodynamic performance (roll rate, lift, and drag) are optimized by altering the morphing mechanism: thousands of design permutations are admissible. Typically, the vehicle's rolling performance increases with asymmetrical shape change (barring the case of excessive rotation at the wingtips, which may cause tip stall and adverse rolling moments). Placing warp mechanism at the aircraft wing promotes displacement and maximizes aerodynamic performance.



a) Closed tube with high torsional stiffness

b) Open tube with low torsional stiffness

c) Controlled warping with high torsional stiffness

Fig 1- Basic principle of warping mechanism

3. Design and Manufacturing of a Demonstration Model

Based on wind tunnel size, To demonstrate the effectiveness of wing warping, a demonstration wing was designed and built. The design of this proof-of concept prototype is based on a NACA 23018 airfoil with a chord length of c =13cm. The internal structure consists of ribs that can rotate about a fixed solid aluminium rod that serves as a main spar. A aluminium skin (t _ 0:5 mm) that is continuous over the perimeter of the airfoil. Warping is introduced by a thread rod that runs throughout the entire span of the wing near the trailing edge. The present internal structure is tailored to the geometry of the airfoil (NACA 23012). This particular airfoil was chosen arbitrarily to prove the concept of wing warping. However, the identical mechanism can be applied to any airfoil shape with sufficient thickness to store the individual structural components.

3.1 Warping Mechanism

Over the span of the wing a thread rod is positioned near the trailing edge to induce the warping deformation between the upper skin and the lower skin . The thread rod is connected to the upper and lower skins in such a way that it introduces a relative spanwise movement of the top and bottom surfaces at the trailing edge, referred to as the warping deformation. At five trailing-edge stations, equally spaced from each other, the upper and lower skins have three rectangular blocks/houses. The outer two blocks/houses attach to the lower skin and provide guidance of the thread rod. To ensure that the position of the thread rod remains unaltered with respect to the bottom skin, it is kept in place by nuts secured (locked) on the thread rod at the outboard side of each of the sliding houses. The third and middle block attaches to the upper skin and is threaded on the inside.

4. Wind-Tunnel Tests

To determine the lift and drag characteristics of the warping wing, a wind-tunnel experiment was carried out on low-speed, low-turbulence wind tunnel, an atmospheric tunnel of open suction type, with a contraction ratio of 6. The overall objective of this test was to demonstrate that the warping mechanism would indeed alter the aerodynamic properties of the wing. The rectangular test section measured 300 mm in width, 300 mm in height, and 1200 mm in length. The wing was clamped horizontally . Measurements were taken by a manometric reading. Measurements were taken at a velocity of 30 m/s, for angles of attack ranging from -2 to +15 deg. From the obtained data, the relation between the trailing-edge warping displacement _w and lift coefficient CL is plotted for four angles of attack

In general, the wind-tunnel results demonstrated that the warping wing mechanism could provide a substantial amount of lift change. The maximum change in lift that could be achieved by means of wing warping was constant with angle of attack at approximately CL 0:7.

Furthermore, wind-tunnel tests proved that wing warping can play an active roll in decreasing the lift-induced drag on the wing or increasing the lift-to-drag ratio.

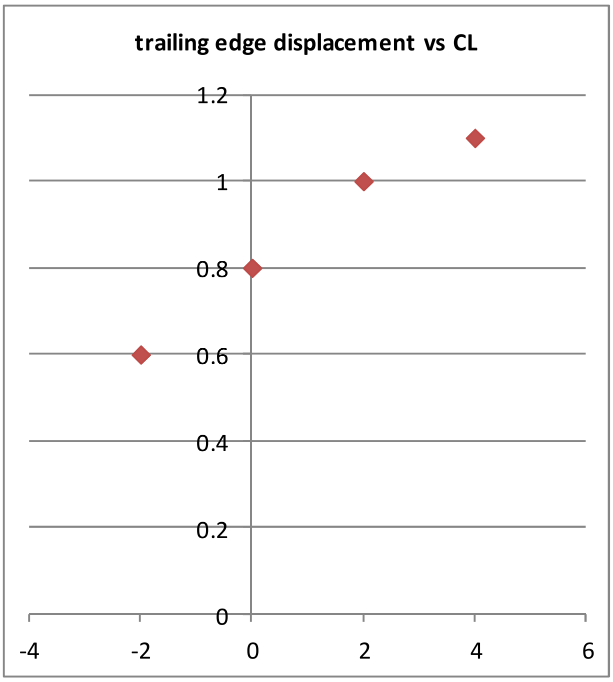


Fig 2 - Relative Trailing Edge Displacement vs. C_L at α=0

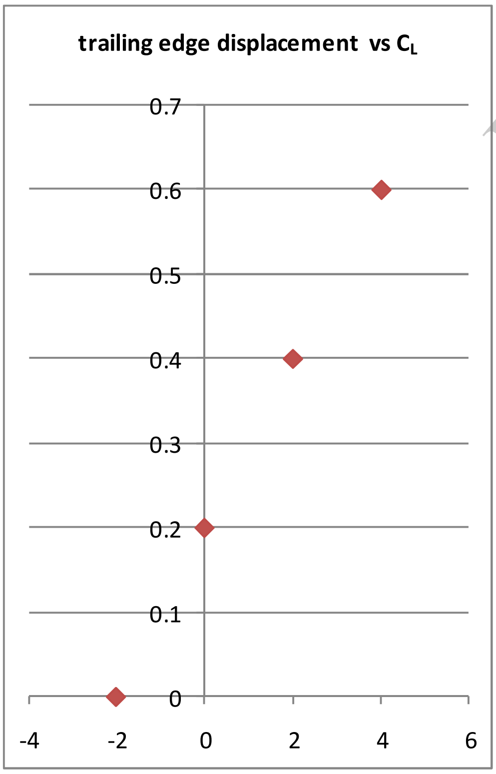


Fig 3 - Relative Trailing Edge Displacement vs. C_L at α=4

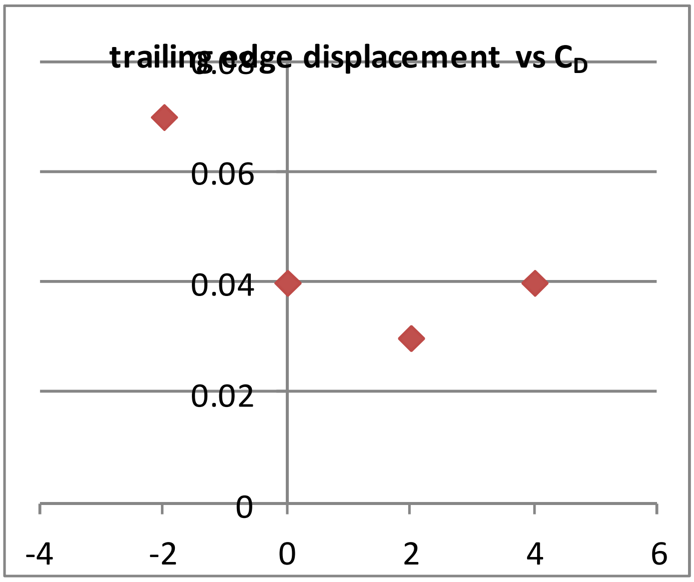


Fig 4 - Relative Trailing Edge Displacement vs. C_D at α=0

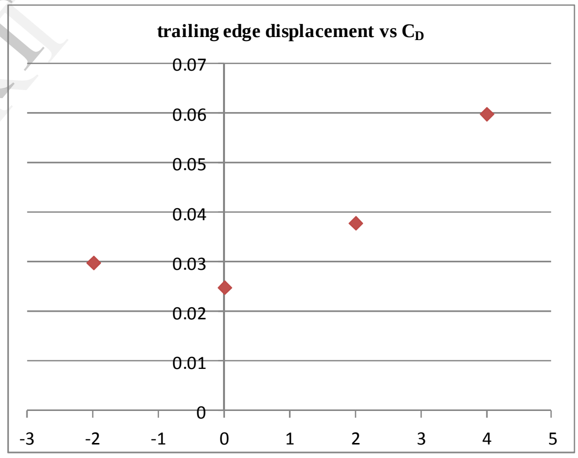


Fig 5 - Relative Trailing Edge Displacement vs. C_D at α=4

5. Results and Discussion

To verify this relationship between twist and warping displacement a bench test was carried out. Warping of the wing was determined by measuring the relative displacement of the upper skin with respect to the lower skin at the trailing edge. The tests showed a linear relationship between the displacement of upper and lower skins, and the amount of twist

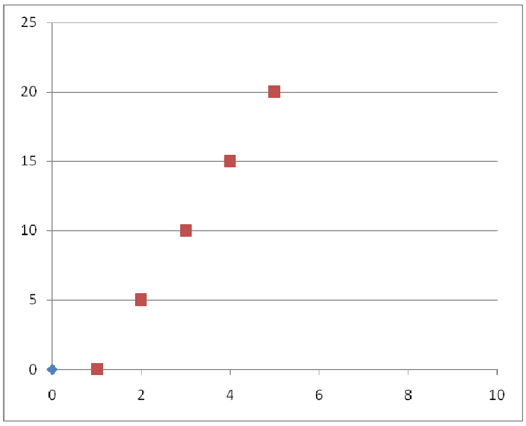


Fig 6 - Results for trailing edge displacement vs. wing twist

5.1. Effect of Camber thickness change

The introduction of variable-camber to this situation eliminates these conflicting interests by allowing the airfoil to change its camber depending on the flight situation. Although these airfoils are conventional, their comparison shows the general effect of camber that will be present no matter how advanced the airfoil.

The second primary benefit of VC wings for subsonic flight is the ability they have to manipulate their spanload. For maximum cruise efficiency, the desired spanload is most likely elliptic, although in some cases the wing-root bending moment of an elliptic distribution forces a structural weight penalty that causes a net loss in total system efficiency. In any case, the wing planform would be chosen so that it comes close to producing the desired cruise spanload for the cruise CL. The planform that would be the most efficient is usually not chosen because the planform must also produce a spanload capable of satisfactory high-lift performance.

ALPHA	C_L	C_D
-2	-0.2261	0.04092
-1	0.1971	0.03956
0	0.4768	0.03329
2	0.6256	0.03148
4	0.7351	0.03583

Fig 7 - Standard datas of naca 23018 for conventional wing

5.2. Comparision of Datas of Morphing Wing and Conventional Wing

Demonstration of a twist-active wing can have sufficient gain to control the rolling motion of an aircraft and to ensure that the lift-to-drag ratio is maximized at various flight conditions, while keeping energy requirements on the flight control actuators at a minimum. From the obtained values we can say that aerodynamic performances (lift, drag and lift/drag ratio) of morphing wing has optimised values than conventional wing.

6. Conclusions

A new concept for actively controlling wing twist based on introducing warping displacement has been discussed. This feature could be integrated in a typical straight wing by creating a slit at the trailing edge that separated the upper and lower skins. A thread-rod mechanism was positioned near the slit to connect the lower and upper skins so that torsional stiffness of the wing was maintained while allowing the relative displacement between the upper and lower skins. This resulted in a linear relation between wing twist and relative trailing-edge warping displacement, which closely correlated to analytic predictions. The maximum peak-to-peak twist angle was measured to be 15 deg. Wind-tunnel tests on a 300 mm-span demonstration wing showed that wing twist could change the lift coefficient by as much as 0.5 for angles of attack ranging from 0–12 deg. Furthermore, analytic modeling of the wing drag was shown to be in close correspondence to the drag measurements and showed that wing warping could be used to change the lift-induced drag. In general, it was demonstrated that a more positive twist resulted in a higher lift-to-drag ratio, especially at lower angles of attack. This study demonstrated that a twist-active wing can have sufficient gain to control the rolling motion of an aircraft and to ensure that the lift-to-drag ratio is maximized at various flight conditions, while keeping energy requirements on the flight control actuator at a minimum.

Acknowledgments

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