Progress Report 
on 
Innovative Revolutionary Airspace Designs: Advanced Aircraft Wing Concept with Micro- and Macro-Morphing Capability
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May 16, 2003

1. Introduction

The overall objective of the project is the development and wind-tunnel demonstration of an aerodynamically self-actuating telescoping wing concept that will allow large changes in wing span, wing area, and wing aspect ratio. A key feature of the concept is the actuation of the telescoping wing using just aerodynamic forces, thus avoiding the need for potentially large and heavy actuators. In addition, the concept involves the use of segmented trailing-edge flaps (TE flaps) on all portions of the wing. These TE flaps, in combination with pressure sensors and a unique aerodynamic sensing algorithm recently developed at NCSU, allow for the modulation and tailoring of the local lift and profile drag at all sections of the wing in addition to control of overall span load distributions and thus the induced drag. The use of the TE flaps on the winglets allows for control of the side force on the winglets, and thus enables the aerodynamic self-actuation of the telescoping wing. The proposed research will involve computational study, adaptive airfoil/wing design methodology development as well as the design and fabrication of a test bed wing model for use in the NCSU subsonic wind tunnel. The wing will be used in follow-on efforts for development and demonstration of the concept.

The idea encompasses both "micro-morphing" (small-scale wing shape adaptation by multiple trailing-edge flaps for span load variation) and "macro-morphing" (large-scale wing shape change by changing the span to adapt the wing for a variety of flight conditions from high-speed cruise to low-speed landing).

Motivation

A variable-span wing provides significant advantages over a wide range of flight conditions – thus resulting in a flight vehicle that has the advantages of both a small wing and a large wing. Having the capability to change from a large to a small wing in flight provides the advantages of both worlds, with the ability to switch between the two configurations at will, namely, high speed cruise and maneuverability, along with long-range and endurance mission segments.

The retracted wing is to be used for high-speed cruise, dive, maneuvering at high speeds and with high “g”s or load factors. Low span results in avoidance of unnecessary wing area at high speeds and results in low drag, reduced wing root bending moment and the capacity for high-speed maneuvering capability, and low roll damping that increases aircraft roll rate.

The extended wing is beneficial for takeoff and landing with larger payload carrying capability, climb, long-range and long-endurance cruise, and loiter. The larger wing area provides significant benefits at low-speed flight conditions decreasing takeoff and landing distances. The larger span provides induced drag reduction that is critical for low fuel consumption when long range and endurance are important. The induced drag reduction also improves climb and service ceiling.
2. Progress and Results

Concept Development for the Morphing Wing Capability

Preliminary development of the concept has been carried out. Figure 1 shows a conceptual illustration of the self-actuating telescoping wing, with 75% increase in span, 45% increase in wing area, and 110% increase in wing aspect ratio for this particular example. Figure 2 shows the use of variable side force on the winglet to actuate the telescoping portion.

![Figure 1: Conceptual illustration of the self-actuating telescoping wing.](image)

![Figure 2: Illustration of the use of aerodynamic side force for retraction and extension of the telescoping wing.](image)

Vortex-Lattice Analysis of Morphing Effectiveness

In order to assess the reduction in induced drag, a vortex lattice code was used to analyze three configurations: (1) the retracted wing configuration in Fig. 1, (2) the extended wing configuration in Fig. 1 with all TE flaps set to zero deg, and (3) the extended wing configuration with TE flap angles adjusted as per Fig. 3 to obtain a smooth lift distribution. Going from configuration (1) to
configuration (2), a significant 64% reduction in induced drag was obtained owing to the increase in span. To offset the effect of the step change in the planform shape of configuration (2), a step change in the segmented TE flap deflection was examined in configuration (3) as per Fig. 3. Figure 4 compares spanwise lift distributions for configurations (2) and (3). It is seen that use of the TE flaps smooths out the lift distribution – reducing the vortex that forms at the junction of the fixed and telescoping wings and reducing induced drag by a further 6%. Thus, the use of segmented TE flaps can be used to offset the step change in planform by reducing lift in the fixed inboard portion and increasing lift in the telescoping outboard portion.

Figure 3: Segmented TE flap angles deflected by varying amounts to compensate for step change in chord distribution.

Figure 4: Effect of the TE flap deflection on the spanwise lift distribution.

Wind Tunnel Model Design

The design of a wind-tunnel model for demonstration of the telescoping wing concept in the NCSU low-speed wind tunnel has been initiated. The solid model is being designed using the SolidWorks CAD software. Figure 3 shows a view of the solid model geometry. The internal structure for the wing spars are being designed along with the telescoping mechanism and the load-transfer platform. The plan is to use stereolithography (STL) for fabricating the outer geometry with built-in pressure taps and multiple flaps. The STL outer geometry will be supported on the structural framework fabricated out of aluminum. Detailed design of the model and feasibility study of the use of STL fabrication is targeted to be completed by the September 2003.
Inverse Design Methodology for Adaptive Airfoils

Morphing wing concepts will benefit by taking into consideration the adaptive capability during the design stages. Towards this objective, an inverse airfoil design method (PROFOIL) is being modified to design airfoils with TE flaps. The inputs to this method will include desired aerodynamics for the airfoil as well as the specifications of the aircraft for which the airfoil is being designed.

3. Publications