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LOW-SPEED AEROELASTICITY OF ROTOR BLADES AND SLENDER WINGS WITH ADAPTIVE AIRFOILS

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ABSTRACT

Integral shape change of the airfoil is regarded as a more aerodynamically efficient mechanism for wing control than the classic trailing edge flap. It could be achieved by either embedding smart actuators, such as piezoelectrics, in the wing structure [1], or by design of compliant substructures [2]. However, low-order aeroelastic analyses of slender wings and rotorcraft blades are typically carried out using beam models and strip aerodynamic models that are based on rigid-section assumptions and therefore are not suitable for adaptive airfoils. To model morphing airfoils, the approach has been to represent the structure using plates or solid elements so as to include the airfoil deformations. In this work, we present a novel aeroelastic model for fixed and rotary slender wings with deformable airfoils that extends the classical low-order aeroelastic formulations to account for the deformation of the airfoil. The 1-D finite-element modeling of the structure is preserved, but with additional degrees of freedom (finite-section deformation modes) to model the elastic deformation of the cross sections [3]-[4]. Figure 1 shows the finite-section mode for airfoil camber deformation. This is used in conjunction with a 2-D unsteady aerodynamics model that also includes airfoil deformations through a Glauert expansion of the pressure and inflow-velocity fields [5]. A finite-state approximation finally provides a time-domain representation of the aerodynamic equations, which are solved with the 1-D structural elements to provide the transient aeroelastic response of the system either to varying flight conditions (gust encounter, manoeuvres, etc.) or to a geometric change induced by the embedded actuation. The proposed approach results in a natural extension to the conventional way of analyzing slender wings, with very little additional complexity.

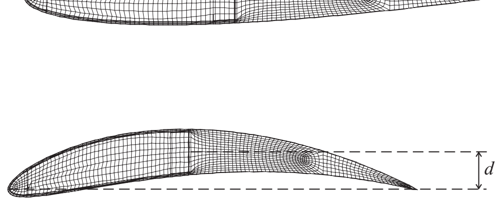

Figure 1. Typical airfoil deformation through change in camber line

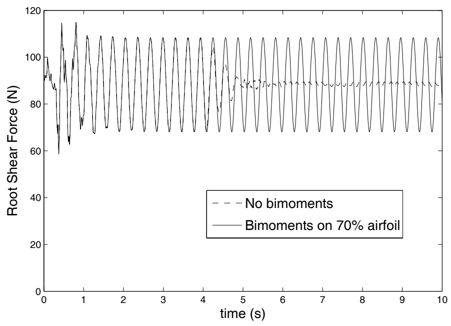

Figure 2. Stabilization of a clamped plate in uniform flow with camber bimoments

The control effectiveness of camber deformation has been numerically investigated in some simple situations. Figure 2 shows the vertical shear force at the wing root of a 2000×200×6 mm Aluminum plate clamped at one end and in a sea-level 25-m/s uniform airstream. A finite-section mode of quadratic shape defines the camber deformation, and 8 inflow states are used in the unsteady aerodynamics. After an initial perturbation the slender wing shows very-lightly damped oscillation, which were removed by appropriately tuning a local applied bimoment at the 70% section of the plate (the actual mechanism to apply that load is not discussed). The amplitude of camber deformation needed at the 70% section was d=4.79% of the chord (with d as in Figure 1).

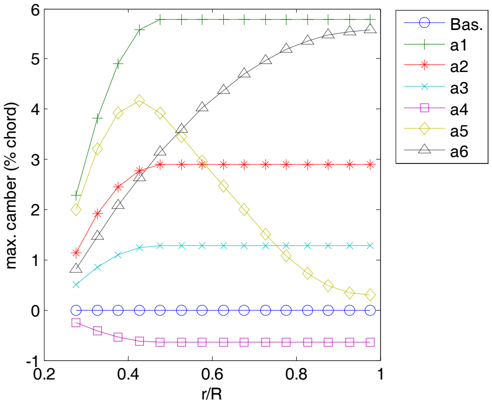

Figure 3. Local camber distribution along a rotating blade in hover

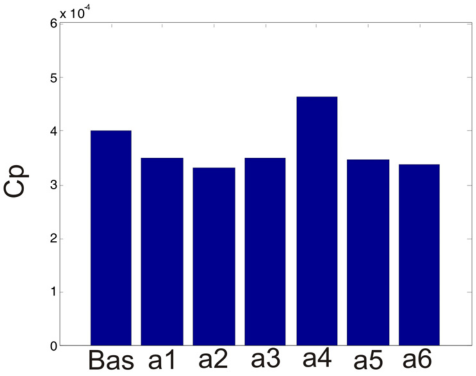

Figure 4. Power coefficient for different distributions of camber deformation

A similar investigation has also been carried out on a rotating blade modeling the 2-m-long Bo105 scaled-model rotor of the HART II experiments [6]. An assumed finite-section mode of quadratic shape has been included to estimate the effect of camber-bending. The resulting model has therefore five elastic degrees of freedom, corresponding to extension, twist, and bending about all three axes. Numerical results were obtained for the rotor in hover at Ω=109 rad/s at sea level conditions. In this case, the blade was deformed in camber by different distributions of applied bimoment along the blade, which result in the camber distributions shown in Figure 3. Figure 4 shows the power coefficient corresponding to each of those cases. The largest reduction (17%) was achieved with a maximum camber of 3% and constant bimoment (case a2). A significant reduction of 12% was already obtained with only 1% maximum camber.

These results illustrate the suitability of the present methodology for the preliminary estimation of the aeroelastic characteristics of slender wings and rotor blades with deformable airfoils.

REFERENCES

[1] Cesnik CES, Shin S, Wilbur ML (2001). “Dynamic response of active twist rotor blades.” *Smart Materials and Structures* **10** (1) 62-76.

[2] Santer M, Pellegrino S (2007). “Topology Optimization of Adaptive Compliant Aircraft Wing Leading Edge.” AIAA Paper 2007-1714.

[3] Palacios R, Cesnik CES (2005). “Cross-Sectional Analysis of Non-Homogeneous Anisotropic Active Slender Structures.” *AIAA Journal* **43** (12) 2624-2638.

[4] Palacios R, Cesnik CES (2008) “A Geometrically-Nonlinear Theory of Active Composite Beams with Deformable Cross Sections.” *AIAA Journal* **6** (2) 439-450.

[5] Peters DA, Hsieh MA, Torrero A (2006). “A State-Space Airloads Theory for Flexible Airfoils.” *Proceedings of the 62nd Annual Forum of the American Helicopter Society*, Phoenix, AZ, USA.

[6] van der Wall BG, Burley CL, Yu Y, Richard H, Pengel K, Beaumier P (2004), “The HART II test - measurement of helicopter rotor wakes,” *Aerospace Science and Technology* **8** (4) 273-284.