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Evaluation of Dynamic Characteristics of an Optimized Conceptual Active Smart Wing

C. Nae[1]

[1] INCAS – National Institute for Aerospace Research "Elie Carafoli",
Iuliu Maniu 220, sect.6 Bucharest, ROMANIA, cnae@incas.ro, www.incas.ro

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This paper is on the smart wing conceptual design for future regional aircraft, where basic knowledge derived from extensive empirical and experimental work on birds led to some valuable knowledge to be exploited in proposed integrated technologies. The new smart/active wing concept integrates a set of advanced technologies inspired from bird wings, mainly in respect to their capability to control the flow and overall dynamic evolution.

Birds have long time been considered very efficient in using energy for flying, mainly due to the very obvious impact of their performance in nature. Historically speaking, birds have been used as a model proposed for heavier than air vehicles, including most of the basic principles for flight dynamics. From many theoretical and experimental studies[1] performed in this respect (Tucker, 1973; Greenewalt, 1975; Rayner, 1979, Whiters, 1980), the aerodynamic performance of different bird species is highly dependent on their wing morphology, which in turn would reflect many ecological and physiological constraints. This clearly shows the trade-offs between lift and drag performance required by various bird species as generated by the great variety of shape, size and aerodynamic performance of bird wings. However, integrating this knowledge in modern aircraft designs is not as straightforward as aviation pioneers considered in the past. This is mainly due to the technical specificity of each aircraft concept and proposed operational environment where various bird models could be considered as reference.

Using basic aerodynamic characteristics of the bird wings, in rigid shape, as a reference is not very challenging. The drag of bird wings is considerably greater than that of conventional aerofoils for a variety of reasons. Skin friction drag is higher because of the lower Re, and whether air flow over bird wings is laminar or turbulent makes little difference to the value for skin friction drag. Pressure drag is high for bird wings because the Re is subcritical and so separation occurs immediately after the thickest part of the wing; it also appears to be high because bird wings are twisted. Feathers may also result in some additional drag compared to a smooth aerofoil. Induced drag appears to be greater for bird wings, which have lower aerofoil efficiency factors. The maximum lift coefficient for bird wings (in rigid shape) varies up to about 1.3 for a very comprehensive bird population, depending upon boundary layer adherence as influenced by thickness, Re number, camber, cross-sectional shape of the wing and shape of the leading and trailing edges. This is much lower compared to conventional aerofoils at similar Re, as it also the case CL/CD ratio, close to 17, compared to more than 20 on modern aerofoils.

The real challenge for a future aircraft concept is on the capability to control the dynamic behaviour on a wide extent in the mission profile, as it is the case with birds. This is an area for new developments where birds clearly have proven capability in advanced control Take-off/ landing and cruise should be a clear focus, but soon to be extended to gust alleviation and special manoeuvres, integrating valuable concepts already analysed on various birds.

Optimization in this work is intended for a highly efficient laminar flow conceptual wing, integrating morphing technologies and flow control devices in order to achieve low speed imposed performance. Major focus is on the capability of the active wing to achieve requested dynamic characteristics for the reference regional aircraft, as expressed by the longitudinal control and lateral dynamic stability in low speed evolutions.

The active smart wing integrates flow control devices with requested authority to achieve requested flow structure. Morphing concepts are used for leading edge and trailing edge areas as standard high lift systems, also able to be used for roll control in high lift/high incidence configuration. Such morphing devices are able to operate independently with respect to overall aircraft requirements. Flow control active devices are used in a dual mode: as boundary layers control devices in cruise/low incidence evolution and as separation control devices in high incidence evolution.

Fig. 1 – Wind tunnel model w/ active smart wing

A dynamic model of the aircraft integrates various controls on the conceptual wing. Performance of various controls is integrated in the overall formulation and dedicated optimization is analytically performed in order to set-up a reference model. This was then used for a dedicated experimental program [2], where the wing is analysed with respect to controls efficiency. Based on a preliminary set of data obtained on this dedicated model for a highly efficient regional aircraft in INCAS Subsonic Wind Tunnel, a global optimized wing concept is finally presented with associated control model. The predicted dynamic performance is compared to state of the art airworthiness regulations and evolutions of some representative birds.

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