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Design and Testing of Multi-Element Airfoil for Short-Takeoff-and-Landing Ultralight Aircraft

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The design and analysis of a new airfoil to be employed on a ultralight aircraft with short takeoff and landing is presented. An inverse design philosophy has been applied and is described; the numerical analysis performed used XFOIL, MSES, and TBVOR computational codes and the effects of airfoil shape on complete aircraft performances were taken into account. A high-lift configuration, including slat and single-slotted flap geometries, has been developed and is illustrated in this paper. Exhaustive wind-tunnel tests were performed at the Department of Aerospace Engineering and the experimental results are described here. To validate numerical results and to analyze the effect of laminar bubbles on airfoil performance, the pressures on airfoil surface and in the wake were measured and flow visualizations were done using fluorescent oil. The landing configuration was also tested and an experimental optimization of flap and slat positions was carried out to obtain a high maximum lift coefficient.

Nomenclature

α = angle of attack
c = airfoil chord
$C_{D\mathrm{eq}}$ = complete aircraft trimmed drag coefficient
C_d = drag coefficient
$C_{d\,\mathrm{min}}$ = airfoil minimum drag coefficient
$C_{L\mathrm{eq}}$ = complete aircraft trimmed lift coefficient
C_l = lift coefficient
$C_{l\,\mathrm{max}}$ = maximum lift coefficient
$C_{\mathrm{mc}/4}$ = moment coefficient with respect to 25% of the chord
C_p = pressure coefficient
Lh = tail load
$\mathrm{RC}_{\mathrm{max}}$ = maximum rate of climb
V_{max} = maximum speed
V_s = clean configuration stall speed
V_{sff} = full flap configuration stall speed

I. Introduction

THE design of a new STOL (short takeoff and landing) ultralight aircraft was carried out at the Department of Aerospace Engineering (DIAS) by the Aircraft Design and Aeroflightdynamics Group; a general view of the aircraft is shown in Fig. 1. The commercial success of the STOL aircraft depends mainly on the capability of combining good cruise performances with excellent short takeoff and landing. However, some STOL light aircraft with quite low maximum speed performances, such as the well-known Zenith CH701 (see Fig. 2), have received worldwide recognition, thus demonstrating that STOL capabilities can be a key to commercial success in the category of light and ultralight aircraft. Recently, other ultralight aircraft have been modified and sold in an STOL version. The Savannah ADV (see Fig. 3) produced by ICP was put on the market in 2005. These aircraft are usually characterized by a fuselage that is not very well streamlined and by a wing employing classic airfoil shape. For example, the Savannah ADV employs a NACA 5-digit airfoil and a very simple flap shape. Some STOL aircraft in this category are characterized by a fixed slot at the leading edge (see Fig. 4) penalizing parasite drag and flight speed in cruise conditions. The initial idea on which the EasyFly project was based was to design a STOL ultralight aircraft made of composite material with good drag characteristics and very low stalling speed. The wing high-lift system (flap and slat) was specifically designed to have low-drag characteristics in cruise conditions and a very high maximum lift coefficient in full-flap configuration; to achieve this, both leading-edge slat and slotted flap were designed to be retractable.

The general design of the aircraft was presented in previous papers [1–3]. The aerodynamic design of both the main airfoil and high-lift system, performed through aerodynamic numerical analysis and wind-tunnel tests, are illustrated in the present paper.

The high-lift system includes a retractable slotted flap and a retractable slat. Most of the reports about three-element high-lift airfoils reported in current literature [4–7] refer to applications at a high Reynolds number and to airfoil shapes commonly used for general transport transonic aircraft. This paper presents the research work undertaken on high-lift devices to be applied for low-speed light and general aviation aircraft. A Reynolds number of about 1×10^6 at landing speed usually characterizes these applications. For this reason, particular attention has been paid to this factor in both the numerical analysis and in experimental tests, and the optimization of gap and overlap has been performed both numerically and experimentally. The final results in terms of maximum achieved lift coefficient are particularly promising because they were obtained for a relatively low Reynolds number.

II. Airfoil Design

A new airfoil was designed at the DIAS. The aerodynamic requirements were a $C_{l\,\mathrm{max}}$ of no less than 1.6 at a Reynolds number 1.7×10^6, a $C_{d\,\mathrm{min}}$ less than 0.006, and $C_{\mathrm{mc}/4}$ greater than -0.08 at a Reynolds number 4×10^6; a 13.5% chord referred thickness was chosen to obtain a good compromise among wing weight, low drag, and high lift. Requirements regarding transition were also taken into account. In general, a certain amount of laminar flow is well accepted to reduce drag in cruise condition; in the present design, however, high-lift requirements have to be considered, and this means that instead of large extent of laminar flow, a moderate laminar flow is preferable if a very gradual asset-related change in transition point can be achieved at the same time. In this way, it should be possible to avoid abrupt stall, often connected with laminar bubble and/or transition instabilities.

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