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Structural and shape optimization in aerodynamic airfoil performance: literature review

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Aerodynamic airfoil performance has been subject to research from the beginning of aviation itself. Oversimplifying, airfoil shape generates the lift and drag forces, and the goal of airfoil design consists in to minimize the drag force (under certain conditions) while achieving an appropriate lift without massive flow separation (boundary layer shedding) fulfilling possible limitations on the lifting force, pitching moment, and structural requirements.

Airfoil design approaches can be classified into two groups: (a) the direct problem in which given a specific geometrical shape the dynamic of the fluid around is analyzed, and (b) an inverse problem where it is intended to find a specific geometry, which must be compatible with the behavior of the fluid around it satisfying certain boundary conditions. Inverse problems are based on nonlinear differential equations and require expensive computational requirements, while the former direct problem requires cheaper simulation procedures but repetitive analysis on several scenarios.

In this revision paper, we concentrate our efforts in commercial aircraft's airfoils at subsonic flight (Mach Number < 0.8) and transonic flight (0,8 $>=$ Mach Number $<=$ 1,2). In some cases, fluid compressibility and viscosity can be neglected (constant density and zero friction) and this hypothesis helps to simplify the governing equations of the system.

Many scientific publications with different approaches to the study of the design and optimization of aerodynamic shapes of airfoil elements have been selected and analyzed. Among them, two are revision papers [6, 15] where the papers are classified following the strategy of resolution and the optimization method, respectively.

In this paper, we focus the analysis to make a classification based on three different kinds of approaches: (a) the first approach is structural, where the physical and geometric characteristics are the main focus of the study; (b) a second approach is about the discretization criteria which is used to characterize the fluid behavior and its parametrization; (c) a third approach corresponds to the optimization of shapes and the different optimization methods used for it.

A total of 40 papers have been selected and analyzed (between the years 1987 to 2021). Most of them emphasize the mathematical and numerical methods to characterize the airflow around the profile and the curve parameterization technique that is used to build the airfoil shape [4, 5, 7, 8, 10]. Other papers focus on the optimization process through the use of evolutionary algorithms, as fundamental optimization tools to deal with the aerodynamic analysis-design problem [1, 2, 9, 13]. However, since 2010 a new trend can be observed within the structural approach to the problem known as "Morphing Wings", which basically consists of the development of variable geometry profiles [3, 11, 12, 14]. Such innovations are made possible due to the advances in new

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materials technology, digital control tools, and modern optimization techniques, which enable the development of profiles that are tailored to the flow characteristics and performance requirements of the airfoil. In this way, we conclude that new approaches arise to the structural design and optimization of aerodynamic shapes based on the development of variable and adaptive geometries.

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