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Aircraft directional stability and vertical tail design: A review of semi-empirical methods

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ABSTRACT

Aircraft directional stability and control are related to vertical tail design. The safety, performance, and flight qualities of an aircraft also depend on a correct empennage sizing. Specifically, the vertical tail is responsible for the aircraft yaw stability and control. If these characteristics are not well balanced, the entire aircraft design may fail. Stability and control are often evaluated, especially in the preliminary design phase, with semi-empirical methods, which are based on the results of experimental investigations performed in the past decades, and occasionally are merged with data provided by theoretical assumptions. This paper reviews the standard semi-empirical methods usually applied in the estimation of airplane directional stability derivatives in preliminary design, highlighting the advantages and drawbacks of these approaches that were developed from wind tunnel tests performed mainly on fighter airplane configurations of the first decades of the past century, and discussing their applicability on current transport aircraft configurations. Recent investigations made by the authors have shown the limit of these methods, proving the existence of aerodynamic interference effects in sideslip conditions which are not adequately considered in classical formulations. The article continues with a concise review of the numerical methods for aerodynamics and their applicability in aircraft design, highlighting how Reynolds-Averaged Navier-Stokes (RANS) solvers are well-suited to attain reliable results in attached flow conditions, with reasonable computational times. From the results of RANS simulations on a modular model of a representative regional turboprop airplane layout, the authors have developed a modern method to evaluate the vertical tail and fuselage contributions to aircraft directional stability. The investigation on the modular model has permitted an effective analysis of the aerodynamic interference effects by moving, changing, and expanding the available airplane components. Wind tunnel tests over a wide range of airplane configurations have been used to validate the numerical approach. The comparison between the proposed method and the standard semi-empirical methods available in literature proves the reliability of the innovative approach, according to the available experimental data collected in the wind tunnel test campaign.

1. Introduction

The empennages in traditional aircraft configurations (Fig. 1) perform three fundamental functions: (*i*) they provide static and dynamic *stability*; (*ii*) through their movable parts, they enable aircraft *control*; (*iii*) they allow to reach a state of equilibrium in each flight condition.

Tail surfaces sizing and shaping are almost exclusively determined by stability and control considerations. Both horizontal and vertical tailplanes usually operate at only a fraction of their lift capability, since stall conditions should never be achieved. The vertical tail provides directional (i.e. around the vertical axis) equilibrium, stability, and control. The concept of equilibrium is inherent to the absence of accelerations on the aircraft. Directional stability is the aircraft tendency to return to the initial equilibrium condition, if perturbed. Directional control is the aircraft ability to maintain equilibrium at a desired *sideslip* angle, i.e. the angle between the relative wind and the aircraft longitudinal axis [1]. From the dynamic point of view, the role of the vertical tail is to provide *yaw damping*, that is to reduce the oscillations around the vertical axis (dynamic directional stability). If the aircraft directional stability is too small with respect to its lateral stability (i.e. around the

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