Aerodynamic Interference Issues in Aircraft Directional Control

Fabrizio Nicolosi[1]; Pierluigi Della Vecchia, Ph.D.[2]; and Danilo Ciliberti[3]

Abstract: This work investigates the aerodynamic interference among airplane components caused by rudder deflection for a typical turboprop aircraft geometry through the computational fluid dynamics technique. At no sideslip, an airplane is in symmetric flight conditions. The rudder deflection creates a local sideslip angle close to the vertical tailplane, and this effect is increased by fuselage and horizontal tail. Typical semiempirical methods, such as USAF DATCOM, do not take into account for these effects, proposing the same corrective parameters both for pure sideslip and rudder deflection conditions. Numerical analyses executed on several aircraft configurations with different wing and horizontal tailplane positions show that the interference factors are smaller than those predicted by the USAF DATCOM procedure, providing guidelines for a more accurate aircraft directional control analysis and hence rudder preliminary design. **DOI:** **10.1061/(ASCE)AS.1943-5525.0000379.**

Author keywords: Aerodynamics; Aircraft; Computational fluid dynamics technique; Directional control; Tailplane.

Introduction

The scope of the work is to describe the aerodynamics of the vertical tailplane of a typical general aviation and regional transport aircraft and to evaluate the aerodynamic interference factors that are involved with a rudder deflection δ_r.

The rudder is the aerodynamic control surface of the vertical tailplane. Tail surfaces provide, in general, for aircraft equilibrium, stability, and control. Directional control and vertical tail design requirements account for minimum control speed with one engine inoperative, extreme out-of-trim conditions, and maximum crosswind capability. Also, control forces must be sufficient to achieve static equilibrium in all flight conditions but limited to prescribed values to be acceptable to the pilot or the actuators (Hoerner and Borst 1985; Obert 1992; Perkins and Hage 1949; Raymer 1992).

Semiempirical methods, such as USAF DATCOM (Finck 1978), are commonly used in linear aerodynamics (i.e., at low angles of incidence). Roskam (2000) follows this approach (described in Finck 1978, Sections 5.3 and 6.2) and calculates the control derivative $dC_{yv}/d\delta_r$ (variation of the vertical tailplane lateral force coefficient C_{yv} caused by the rudder deflection δ_r) through a corrective factor, named *effective* aspect ratio A_{veff}, of the vertical tailplane lift curve slope $C_{L\alpha\mathrm{v}}$. This effective aspect ratio accounts for the aerodynamic interference of fuselage and horizontal tailplane on the vertical tailplane, and it derives from the results of National Advisory Committee for Aeronautics (NACA) wind tunnel tests of the first half of the twentieth century, which were performed on fighter aircraft geometries (elliptical bodies, swept wings, and tailplanes) investigated at several angles of attack and sideslip, without rudder, as Brewer and Lichtenstein (1950) and Queijo and Wolhart (1950) described.

Thus, USAF DATCOM considers an aerodynamic interference factor evaluated for the whole airplane in sideslip conditions, hence neglecting the *local* asymmetric flow generated by the rudder deflection. Coupling the vertical tail with fuselage and horizontal tail enhances the effects of this local flow. The computational fluid dynamics (CFD) technique is very useful to investigate such interference effects; see for example Park et al. (1999).

The following sections describe the numerical analyses, geometries involved, setup of the simulations, configurations analyzed, and numerical results.

Numerical Investigations

It is possible to calculate the side force coefficient of an airplane as

$$C_Y = C_{Y_\beta}\beta + C_{Y_{\delta_r}}\delta_r \tag{1}$$

at small angles of sideslip and rudder deflection (i.e., in the linear range). The objective of the CFD analyses presented in this paper is to provide some guidelines for the evaluation of the second term (rudder control) at the right of Eq. (1), whereas for the calculation of the first term (sideslip), treated with the same approach, see Nicolosi et al. (2013).

At no sideslip, the airplane is in symmetric flight conditions. The deflection of the rudder generates a local angle of sideslip (i.e., the flow symmetry is lost) in the rear part of the airplane. The contribution of the airplane's components in this condition is quite different from the sideslip condition, in contrast with the formulation provided by USAF DATCOM (Finck 1978), and the effects of the local angle of sideslip induced by the rudder deflection are *conserved* at sideslip conditions. Thus, the effects of sideslip angle and rudder deflection can be summed in the linear range as predicted by Eq. (1).

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[1] Associate Professor, Dept. of Industrial Engineering, Università degli Studi di Napoli "Federico II," 21, Via Claudio, 80125 Napoli, Italy. E-mail: fabrizio.nicolosi@unina.it

[2] Dept. of Industrial Engineering, Università degli Studi di Napoli "Federico II," 21, Via Claudio, 80125 Napoli, Italy (corresponding author). E-mail: pierluigi.dellavecchia@unina.it

[3] Ph.D. Student, Dept. of Industrial Engineering, Università degli Studi di Napoli "Federico II," 21, Via Claudio, 80125 Napoli, Italy. E-mail: d.ciliberti@studenti.unina.it

Note. This manuscript was submitted on February 8, 2013; approved on August 23, 20[redacted] period open until 0, 0; se-parate discussions must be submitted for individual papers. This paper is part of the ***Journal of Aerospace Engineering***, © ASCE, ISSN 0893-1321/(0)/$25.00.