A comprehensive review of vertical tail design

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Abstract

Purpose – This work aims to deal with a comprehensive review of design methods for aircraft directional stability and vertical tail sizing. The focus on aircraft directional stability is due to the significant discrepancies that classical semi-empirical methods, as USAF DATCOM and ESDU, provide for some configurations because they are based on NACA wind tunnel (WT) tests about models not representative of an actual transport airplane.

Design/methodology/approach – The authors performed viscous numerical simulations to calculate the aerodynamic interference among aircraft parts on hundreds configurations of a generic regional turboprop aircraft, providing useful results that have been collected in a new vertical tail preliminary design method, named VeDSC.

Findings – The reviewed methods have been applied on a regional turboprop aircraft. The VeDSC method shows the closest agreement with numerical results. A WT test campaign involving more than 180 configurations has validated the numerical approach.

Practical implications – The investigation has covered both the linear and the non-linear range of the aerodynamic coefficients, including the mutual aerodynamic interference between the fuselage and the vertical stabilizer. Also, a preliminary investigation about rudder effectiveness, related to aircraft directional control, is presented.

Originality/value – In the final part of the paper, critical issues in vertical tail design are reviewed, highlighting the significance of a good estimation of aircraft directional stability and control derivatives.

Keywords CFD, Aircraft design, Stability and control, Vertical tail, Wind tunnel tests

Paper type General review

Definitions, Acronyms and Abbreviations

CFD	□	Computational Fluid Dynamics;
DATCOM	□	Data Compendium;
EASA	□	European Aviation Safety Agency;
ESDU	□	Engineering Science Data Unit;
FAA	□	Federal Aviation Authorities;
GRT	□	Generic Regional Turboprop;
NACA	□	National Advisory Committee for Aeronautics;
RANS	□	Reynolds-averaged Navier–Stokes (equations);
USAF	□	United States Air Force; and
VeDSC	□	vertical tail design, stability and control.

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Introduction

The aircraft vertical tail is the aerodynamic surface that must provide sufficient directional equilibrium, stability and control. Preliminary sizing is determined by critical conditions as minimum control speed with one engine inoperative (for multi-engine airplanes) and landing in strong crosswinds.

The airborne minimum control speed V_{MC} is the calibrated airspeed at which, when the critical engine is suddenly made inoperative, it is possible to maintain control of the airplane with that engine still inoperative and maintain straight flight with an angle of bank of not more than 5° (EASA, 2015). The airborne minimum control speed may not exceed 1.13 the reference stall speed. Thus, this parameter affects the take-off field length, which must be kept as low as possible otherwise the payload could be reduced when the aircraft is operating on short runways. The V_{MC} involves large rudder angles $\square_r$ to keep a small angle of sideslip □. See Figure 1, left. This requires a certain vertical tail area for a given rudder effectiveness □, which must be the highest possible to keep control authority at 25° or more of rudder deflection. F1

A crosswind landing requires a sufficient vertical tail area to ensure aircraft directional stability in this delicate phase, which involves large sideslip angles □ in full flaps conditions and possibly large rudder angles $\square_r$ to keep the airplane at the desired flight path. Because the rudder deflection is usually opposed to the sideslip angle, the vertical tail lift curve is in the linear range, like a plain flap at negative angle of attack, as reported in Figure 1, right.

Another condition not critical for safety, but important for flight quality, is the ratio between directional and lateral static stability derivatives, which should be less than unit for transport aircraft to avoid the annoying dutch roll phenomenon. For general aviation and military aircraft this requirement may be different, especially for the carrier-based airplanes, where large lateral control in landing is vital.

Design of the vertical tail is not a simple task due to the asymmetrical flow behind the wing-fuselage combination and lateral cross-control forces causing rolling moments. These aerodynamic issues must be addressed in both the linear and non-linear range of the lift curve, and aerodynamic interference must be accounted for. Some indications come from aircraft design books (Gudmundsson, 2013; Hoerner,

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