Aerospace Science and Technology 55 (2016) 332–343

Contents lists available at ScienceDirect

Aerospace Science and Technology

www.elsevier.com/locate/aescte

Fuselage aerodynamic prediction methods

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ARTICLE INFO

Article history:
Received 19 January 2016
Received in revised form 9 June 2016
Accepted 10 June 2016
Available online 16 June 2016

Keywords:
Aircraft design
Fuselage aerodynamics
Turboprop aircraft

ABSTRACT

A reliable estimation of the aerodynamics of the fuselage of an airplane is crucial in order to carry out a well-designed aircraft. About 30% of an aircraft zero-lift drag source is due to the fuselage. Its aerodynamic instability is impacting wing and horizontal tail design, as well as aircraft directional stability characteristics. This paper proposes methods, developed through CFD analyses, to estimate fuselage aerodynamic drag, pitching, and yawing moment coefficients. These methods are focused on the regional turboprop aircraft category. Given the fuselage geometry, several charts allow to evaluate its aerodynamic characteristics. Numerical test cases are shown on several fuselage geometries and a comparison with typical semi-empirical methods is presented.

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1. Introduction

This paper presents new preliminary design methodologies to estimate the aerodynamic coefficients of transport aircraft fuselage. Methods have been developed by numerical aerodynamic analyses performed with STAR-CCM+® (Ref. [1]) and they have been focused on the estimation of aerodynamic drag, pitching moment, and yawing moment coefficients. A similar approach to develop a preliminary design method has already been carried out by the authors, which have deeply investigated the aerodynamics of the vertical tailplane and the aerodynamic interference among airplane components asymmetric conditions [2,3]. The result of these studies is a methodology which effectiveness is not limited to the turboprop air transport category, but it has also been exploited for the preliminary design of a new general aviation commuter aircraft [4,5]. Fuselage design is particularly critical for commuter aircraft and general aviation categories, concerning drag and static stability contribution, which can strongly affects the tailplane sizing, as outlined in Ref. [5]. Especially for general aviation category, the choice of fuselage tailcone angle is also critical to achieve the best vertical location of the horizontal tailplane [4–6]. CFD calculations performed on bodies and wing-body combinations show in general a very good agreement respect to experimental data obtained through wind-tunnel tests performed by the authors [6].

The aerodynamic design of the fuselage of a regional transport aircraft is a crucial item in airplane preliminary design. About 30% of zero lift drag is due to the fuselage [7]. Aircraft cruise performance, such as maximum flight speed or fuel consumption, are mainly dependent from the zero-lift drag coefficient and they could be improved with a more accurate aerodynamic design. Moreover aircraft longitudinal and directional stability characteristics are strictly related to the fuselage contribution, thus an accurate estimation of the latter could lead to a better tailplane design and aircraft stability characteristics.

In a previous article [7], the authors have also highlighted the importance of a good aerodynamic design of the wing–fuselage junction or "karman" as usually defined for high mounted wing regional transport aircraft.

Aircraft preliminary design usually relies on semi-empirical methodologies, based on heritage aircraft geometries and wind tunnel tests mainly conducted by NACA [8–12]. Semi-empirical methods consider the drag coefficient as the sum of different contributions that can be evaluated by relations obtained from wind tunnel test data, most of which are collected in the USAF DATCOM database [13,14]. The total drag coefficient of an aircraft can be expressed as the sum of the zero-lift drag coefficient and the drag-due-to-lift coefficient. This assumption is valid when the approximation of a parabolic drag polar is used in order to estimate the drag coefficient for low incidence, such as cruise and climb, that is until the lift coefficient becomes greater than 1. The zero-lift drag coefficient is also known as parasite drag coefficient and it includes skin friction (function of wetted area), windshield angle ψ, upsweep angle θ, and base drag contributions [13–15].

Moreover, semi-empirical methods are also used to predict the moment coefficients. One of the most used is the *strip-method* where the fuselage is divided into strips, each of which gives a

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http://dx.doi.org/10.1016/j.ast.2016.06.012
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