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Developing an engineering-statistical model for estimating aerodynamic coefficients of helicopter fuselage

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Abstract The design of the geometric shape of a helicopter fuselage poses a serious challenge for designers. The most important parameter in determining the shape of the helicopter fuselage is its aerodynamic coefficients. These coefficients are determined using two methods: wind tunnel test and computational fluid dynamics (CFD) simulation. The first method is expensive, time-consuming and limited. In addition, estimates in regions away from data can be poor. The second method, due to the limitations of numerical solution, the number of nodes and the used solution, is often inaccurate. In this paper, with the aim of accelerating the design process and achieving results with reasonable engineering accuracy, an engineering-statistical model which is useful for estimating the aerodynamic coefficients was developed, which mitigated the drawbacks of these two methods. First, by combining CFD simulation and regression techniques, an engineering model was presented for the estimation of aerodynamic coefficients. Then, by using the data from a wind tunnel test and implementation of statistical adjustment, the engineering model was modified and an engineering-statistical model was obtained. By spending less time and cost, the final model provided the aerodynamic coefficients of a helicopter fuselage at the desired angles of attack with reasonable accuracy. Finally, three numerical examples were provided to illustrate the application of the proposed model. Comparative results demonstrate the effectiveness of the engineering-statistical model in estimating the aerodynamic coefficients of a helicopter fuselage.

1. Introduction

Models which describe the performance of a physical process are essential for prediction, process control and optimization.[1–3] In general, two approaches exist for the development of these models. The first approach involves the development of models based on engineering/physical laws governing the process, which includes analytical models and numerical

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simulation.[4–7] These kinds of models are called engineering models.[1,8] The other development approach involves the postulation of statistical models and their estimation on the basis of generated data from physical experiments.[9] These models are known as statistical models.[1,2]

Both modeling approaches possess some shortcomings and limitations.[1,2,8] Predictions derived from the engineering models are often not accurate due to some assumptions in modeling,[1,8] limitations in numerical solution, number of nodes and used solution method.[10,11] Statistical models can provide good predictions at points close to the observed data, however, in an attempt to carry out predictions in regions away from the data, the predictions are usually poor. Moreover, the preparation of experimental data required to estimate the statistical models is costly and time consuming.[1,8,10–12] Some researchers began to study various methods in order to discover models by combining engineering models with statistical models, which are useful in adjusting the shortcomings and limitations of the aforementioned models.[1,2,8,13–16] These models are called engineering-statistical models.[1] Engineering-statistical models are expected to provide more realistic predictions than the engineering models, and they are less expensive to estimate than the statistical models.[1,2]

In helicopters, one important characteristic of quality is the shape of the fuselage. The shape of the fuselage is impressive on flight endurance, cruise speed, stability and controllability, altitude, fuel consumption, maneuverability, etc. One of the technical characteristics which determines the suitability of the shape of the fuselage is its aerodynamic coefficients, which is achieved based on macroscopic fluid flow analysis around the helicopter, using Newton's laws of motion and the basic principles of the laws of conservation of mass, momentum, energy and chemical species.[17] Based on the nature of the problem and the desired parameters, these basic concepts can be described as algebraic, differential or integral equations.[17,18] With regards to a body with complex geometric shape, such as helicopter fuselage, there is no exact solution to these equations, and physical experiments (wind tunnel tests) or numerical simulation techniques (computational fluid dynamics) are used to obtain these coefficients.[12,19–22]

Both wind tunnel test and CFD methods used in the analysis of fluid flow around helicopters have shortcomings and limitations expressed in engineering and statistical models. The main objective of this study is to construct an engineering-statistical model in order to accelerate the design process, thereby achieving results with appropriate engineering precision and cost reduction in computing the aerodynamic coefficients of helicopter fuselage which are: the drag coefficient C_D, lift coefficient C_L and pitching moment coefficient C_m. The engineering-statistical model is far more superior to the statistical model and engineering model because it behaves like the engineering model and has values those are close to the data.[1]

Therefore, by firstly using the CFD technique to model different well known helicopter fuselage in medium and intermediate weights, including the Bell 412, Bell 212, Bell 214, Bell 205, Agusta A109, Dauphin SA365N and UH-60 (here, for the ease of reference, they are called F1, F2, F3, F4, F5, F6, and F7, respectively), with the aid of a Fluent software, and running it, the aerodynamic coefficients of a helicopter fuselage are obtained for a number of angles of attack. Therefore, the trend of changes in these coefficients can be understood in terms of angle of attack of a helicopter. Since the observed trends are nonlinear, by using nonlinear regression, a function obtains fitting on the data. At this stage, an engineering model is achieved which estimates the aerodynamic coefficients of helicopters of medium and intermediate weights at the desired angles of attack. To achieve the considered engineering-statistical model, a modified version of the sequential model building strategy of Joseph and Melkote[1] was applied (the JM method). The JM method provides a sequential model building strategy, which helps to identify a prediction model that introduces minimal changes to the engineering model. This prevents additional adjustments which could cause the formation of a model that differs from the concept of the physical phenomena.[1] Lack of a validation process is a shortcoming of the JM method. Hence, the modified version of the JM method is proposed. Therefore, the resultant model will be one which overcomes the shortcomings and limitations of wind tunnel test and CFD methods, and which can also estimate the aerodynamic coefficients with reasonable engineering accuracy.

The rest of this paper is organized as follows. Section 2 presents the data of various helicopter fuselage modeling in Fluent software and engineering modeling method for estimation of the aerodynamic coefficients. In Section 3, the strategy of sequential engineering-statistical model building of Joseph and Melkote[1] is introduced and a validation method of the model is proposed. Section 4 presents three numerical examples to demonstrate the application of the proposed models and the effectiveness of engineering-statistical model in estimating the aerodynamic coefficients of a helicopter fuselage. The conclusions and directions of future work are provided in Section 5.

2. Engineering model develop by combining CFD simulation and regression techniques

The modern helicopter industry requires design tools which are able to accurately and efficiently predict aerodynamic flow.[10,18] In recent years, CFD methods have been increasingly used in the design and analysis of helicopters. This tendency was made by advances in CFD algorithms and the access to more powerful affordable computers. CFD is a virtual simulation technique. A flow can be fully simulated using CFD.[12]

In this paper, at the first step, by CFD technique, helicopters fuselage of F1, F2, F3, F4, F5, F6 and F7 (Fig. 1), were modeled by Fluent 6.3 software. Simulations were implemented in 3D and steady state, using implicit second order method, density based turbulent flow ((with adupion model) K-ω shear stress transport (SST)), the ideal gas model, the Sutherland viscous model, at Mach number $Ma = 0.2$ and the number of meshes for different angles of attack $\alpha = 3.70 \times 10^6$ to 5.43×10^6.

The software output values for aerodynamic coefficients of C_D, C_L and C_m are presented in Fig. 2. As shown in the figure, aerodynamic coefficients in terms of angle of attack, show nonlinear behavior and this trend is similar in almost all helicopters. Fitting a function to a particular data requires a parametric model that relates the response data to the predictor data with one or more coefficients. The result of the fitting process is an estimate of the model coefficients.[23] Through trial and error, and also through the survey of various nonlinear