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Design of Artificial Neuro-Fuzzy Based Methodology for Six Component Force Balance

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Abstract

A blunt cone model of 60^0 apex angle and 15^0 flare with internally mountable accelerometer balance has been considered for the present investigation on six component force balance. The finite element method (FEM) has been incorporated at predetermined angles of the applied force to obtain multiple accelerations in three spatial directions so as to replicate a six component force balance system. A novel intelligent soft computing technique, Artificial Neuro-Fuzzy Inference System (ANFIS) has been implemented for accurate prediction of the magnitude and trend of aerodynamic forces and moments from the transient acceleration history. The same method is also used to validate the universal approximation nature of the impulse force by accurate prediction of the hat and ramp forces from the training of the impulse forces. Furthermore, a training algorithm is deduced so as to predict the force and moment magnitude for the three and single component force balance from the six component training data. Henceforth, novelty of this study involves in deduction of a universal training method and successful implementation of it to predict short duration transient force and moment histories.

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Keywords: ANFIS; FEM; Impulse; Transient; Accelerometer balance.

1. Introduction

Hypersonic aerodynamics has been a topic of interest for many researchers. Analysis of the fluid flow in this domain usually requires both ground based and flight based experiments but due to low cost and less risk the ground based experimental facilities seems to be reliable. During ground based experiments the stability and aerodynamic

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behavior of a vehicle can be properly addressed by accurate estimation of forces and moments acting on the body. For an exact estimation of the behavior of the body subjected to certain flow condition can be analyzed fully by a six component force balance system through prediction of the coefficients of forces and moments viz. coefficient of drag, lift, side force, pitching, yawing and rolling moment. The forces and moments on a body during experiment in hypersonic ground based test facilities can be measured with the help of either accelerometer force balance system [1] or stress wave force balance system [2]. A stress wave force balance system incorporates the stiffness based measurements which can represent a system more accurately but accelerometer force balance system is preferred due to its simplicity and less complexity during measurement. Conventionally, de-convolution technique is used for accurate prediction of drag force in a single component force balance system [3]. However, the implementation of this algorithm for three and six component force balance system is a cumbersome task. The extension of this technique is rather more difficult for a complex geometry and as well as involves extensive mathematical formulation and various assumptions. The basic assumption of non-achievement of steady state between the model and supporting system makes the measurement and prediction more complicated.

Hence, present study deals with implementation of ANFIS for short duration transient force and moment prediction for multi degree of freedom system. Soft computing technique has been successfully implemented in many research areas like rapid damage detection in automobile sector [4], flank wear prediction during turning process [5] etc. Artificial intelligent techniques like neural network, fuzzy logic, genetic algorithm and combination of the above stated algorithms are the current research of interest. But comparison of the data prediction type of soft computing techniques like multiple regression, artificial neural network and ANFIS provides an affirmation to outperformance of ANFIS [6]. In view of the wide acceptance of the soft computing technique, an attempt has been made to incorporate it as a part of prediction purpose in hypersonic flow aerodynamics. An accelerometer force balance has been taken into consideration for implementation of ANFIS due to its simplicity. In the succeeding sections a blunt conical model has been considered as it can precisely represent a hypersonic vehicle configuration. The model has been analyzed in FEM under various kinds of loading conditions and transient acceleration responses are measured. Further, these acceleration data are used to obtain a universal training data for ANFIS and a parametric study has been done to obtain the optimum parameters for ANFIS architecture. Then, with the usage of this training data and optimized architecture, various forces and moments has been accurately predicted within certain error bands.

2. Numerical modeling

2.1. Finite element simulation

A Blunt cone model having 60^0 apex angle and 15^0 flare with internally mountable accelerometer based balance is shown in Fig. 1. The model is made out of aluminum and the balance system is prepared from stainless steel rings with circular cross-section (40 mm outer diameter and 30 mm internal diameter). The balance is also comprises of two annular neoprene rubber bushes (30 mm outer diameter and 12 mm internal diameter) having 4 mm thick, which is bonded with inner steel rings as well as with a sting.

Transient finite element analysis has been carried out for the above model using ANSYS 14.5 for a simulation time of 2 ms which corresponds to the range of experimental test time. During meshing for the test model, 10-noded tetrahedral (Solid 187) element is used. After the detailed mesh independence studies, the number nodes are obtained as 58985. The material properties assigned to different parts of the model during simulation is given in Table 1. The boundary conditions for this test model are given as inner surface of the rubber as “fixed”. The detailed mesh of the model is shown in Fig. 2. During simulation, different trend, orientation and magnitude of forces are applied at point ‘P’ on the model as shown in the Fig. 1. Acceleration signals corresponding to the forces are obtained at six discrete points viz. two acceleration in each spatial direction. Some of the acceleration histories are employed for training of the ANFIS network while the other signals are used for prediction purpose. Sample filtered acceleration signals (Cut-off frequency = 12.5 kHz) of 10 N force applied at 100 inclination to both X and Y-axis is shown in Fig. 3.