Simulation of unsteady aerodynamic characteristics of aircraft at high angles of attack using neural networks.

Ignatyev D.I.
Central Aerohydrodynamic Institute (TsAGI),
Zhukovsky, Russia

According to the Commercial Aviation Safety Team, a government/industry partnership formed to address aviation accidents, loss-of-control is the main reason of the fatal accidents. Attention on study of aircraft dynamics and pilot training in the prevention of and recovery from upsets, including stall and spin, has been increased. Consequently, there is a growing need for models describing unsteady aerodynamics in flow separation conditions suitable for study of aircraft dynamics, upset recovery and use for flight simulators.

CFD has progressed significantly in recent years and shows very good results. However, solving of simultaneous equations of fluid dynamics and aircraft motion is very resource consuming and cannot be used in aircraft dynamics applications since a great number of parametrical investigations are required for aircraft dynamics analysis and control design. Moreover a real-time modeling is required in flight simulators.

Mathematical models of unsteady aerodynamics covering the full flight envelope can be identified using the experimental data. To obtain the data a set of wind-tunnel tests are used. Each experiment corresponds to one-type motion in the restricted region of flight parameters, for example, forced oscillations with small amplitudes for investigation of aerodynamic damping derivatives, forced oscillations with large amplitudes and free controllable motion for investigation of dynamic phenomena of nonlinear aerodynamic characteristics, etc. So the experiment results can be considered as different-type data set that complicates mathematical model identification in the whole region of the studied parameters.

It was shown that traditional approach for unsteady aerodynamics simulation based on the damping derivatives failed to describe nonlinear phenomena observed in the large-amplitude test. At the present paper a neural network approach is used to obtain the models of pitching moment coefficient of a delta wing and a model of passenger airliner Transonic Cruiser (TCR) with canard.

Neural networks have advantages as compared to the conventional techniques. It was shown that any continuous function can be approximated to any desired accuracy by a network of one hidden layer of nonlinear units and one layer of linear output unit. In addition no simplifying assumptions are required to identify the model. For dynamic system simulation recurrent neural networks are usually utilized.

Recurrent neural network NNARX (nonlinear autoregressive network with exogenous inputs) is used in the paper. The neural network (NN) output is pitching moment coefficient C_m, the inputs of the neural network are angle of attack α and its time derivative $\dot{\alpha}$. To simulate output value of $C_m(t)$ at the time instant t the neural network uses not only current kinematic parameters $x(t) = \big(\alpha(t), \dot{\alpha(t)}\big)$ but also the preliminary history of motion, namely the previous kinematic parameters $x(t - \Delta t_K)$ and neural network simulation results $C_m(t - \Delta t_C)$

$$C_m(t) = NN\big(x(t), x(t - \Delta t_K), C_m(t - \Delta t_C)\big).$$

The experimental data of small- and large-amplitude pitch oscillation tests were utilized to train the neural network. About half of data was used to train (training set) and about half of data was used to test the generalization ability of the neural network (testing set).

Nonlinearities in the unsteady longitudinal aerodynamic characteristics of the delta wing at high angles of attack are due to vortex breakdown dynamics; otherwise unsteady nonlinear phenomena of TCR model are caused by the canard flow separation dynamics. Nevertheless the neural networks revealed good precision for both delta wing and TCR model for training and testing sets. The neural network is shown to simulate with acceptable precision the pitch moment coefficient hysteresis, obtained using the wind-tunnel dynamic experiment of forced pitch oscillations with large amplitudes and also dependencies of the aerodynamic derivatives on oscillation frequency.

To increase the neural network precision the special training algorithm was developed. The technique is based on Bayesian regularization and takes into account that the experiment results can be considered as different-type data set. The proposed training technique enables the neural network error to be decreased almost by 50 %.