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ANN MODEL for ICE SHAPE PREDICTION of AN AIRFOIL

Zhen Tian[1,2] and Kwing-So Choi[1]
1. Faculty of Engineering, University of Nottingham, NG7 2RD, Nottingham, UK
2. Mechanical Engineering, Shanghai Jiao Tong University, 200240, Shanghai, China

INTRODUCTION

The growth of ice on a aircraft airfoil causes a deterioration in aircraft aerodynamic performances, such as a sharp increase in drag and a reduction in lift [1]. From a thermodynamic standpoint of view, two types of ice accretion mechanisms have been identified with physically and geometrically different formations, rime ice and glaze ice [2].

The analysis of icing process on the airfoil requires a detailed knowledge of the physics, thermodynamics, fluid mechanics, heat transfer et al. The experimental and numerical studies have their own advantages, disadvantages, and limitations, which further limit the analysis of anti and de-icing development. Several icing applications have been implemented using ANN (artificial neural network, ANN) [3]. Cao et al. [4] used the ANN to catch the relationships of ice geometry and airfoil aerodynamic coefficients. The ice accretion on the airfoil modeled by ANN is first proposed by Egemen et al. [5]. The results show that the proposed ANN has reasonable capabilities and merits for ice accretion prediction. However, the altitude factor is not taken into consideration.

METHODOLOGY

The ice shape on the airfoil leading-edge can be modeled as a perturbation geometry over a parabola which resembles the airfoil leading-edge, as shown in Figure 1(a). The parabola can be transformed to a straight line and therefore the ice becomes perturbations to the straight line, as shown in Figure 1(b). Ogretim et al. [6] presented the Fourier analysis for modelling complex ice roughness on the leading edge of airfoils, as Eq.(1).

$$f(\xi) = \frac{A}{2} + \sum_{i=1}^{M}\left[B\cos\left(\frac{2\pi i\xi}{\xi_N - \xi_1}\right) + C\sin\left(\frac{2\pi i\xi}{\xi_N - \xi_1}\right)\right] \quad (1)$$

Where A, B, C are coefficients used to regenerate the original geometry; $f(\xi)$ is the analytic roughness expression regenerated by the sine and cosine terms. After the Fourier transformation, the ice characteristics can be used to train the neural network.

Typical three-layer ANN architecture consists of an input layer, hidden layer and an output layer, which are illustrated in Figure 2. The neurons arranged in layers link up to others through adaptable weights. Considering the non-linear units, the logistic sigmoid transfer function (Eq.(2)) is put into service in the hidden layer. The L-M (levenberg-marquardt) algorithm is used in the proposed ANN.

$$f(z) = \frac{1}{1+\exp(-z)} \quad (2)$$

Where, z is the input variable. All these programmes are conducted in Matlab R2013b [7] using artificial neural network toolbox.

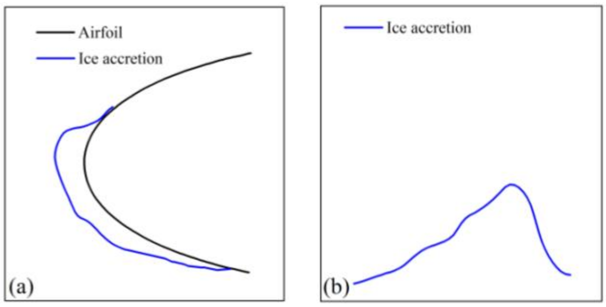

Figure 1: Ice accretion on the airfoil (a) and the transfromed plane (b)

In order to take both the atmospheric and flight conditions into consideration, the Mach number (M_a), the free stream temperature (T_t), the droplet median volume diameter (MVD), the liquid water content (LWC), the free stream pressure (P_a) and the water spray time (t_{spray}) are selected as the input variables. The output variables are Fourier analysis coefficients, A, B and C. After trials and errors, the neurons in the hidden layer were determine as 9.

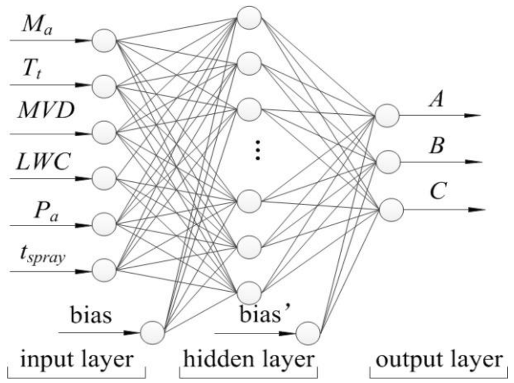

Figure 2: ANN model for ice shape prediction of the airfoil

RESULTS

Three tests with different experimental conditions were selected from Addy's work [8] to test the ANN model, which is showed in Table 1. The ANN prediction results were shown in Figure 3. As can be seen, the ANN showed good performance for test 1, which is under rime ice condition. As for the glaze ice condition, the ANN can predict the ice shape effectively in a shorter time (test 2), while as for longer time (test 3), the ANN need improvement.

Table 1 Input varibales of the experimental ice accretions for the ANN test

Test	M_a	T_t (℃)	*MVD* (μm)	*LWC* (g/m^3)	P_a (psig)	t_{spray} (min)
1	0.28	-11.0	20	0.540	17.0	6.0
2	0.39	-1.3	15	0.600	71.2	7.2
3	0.28	-0.8	20	0.540	17.0	22.5

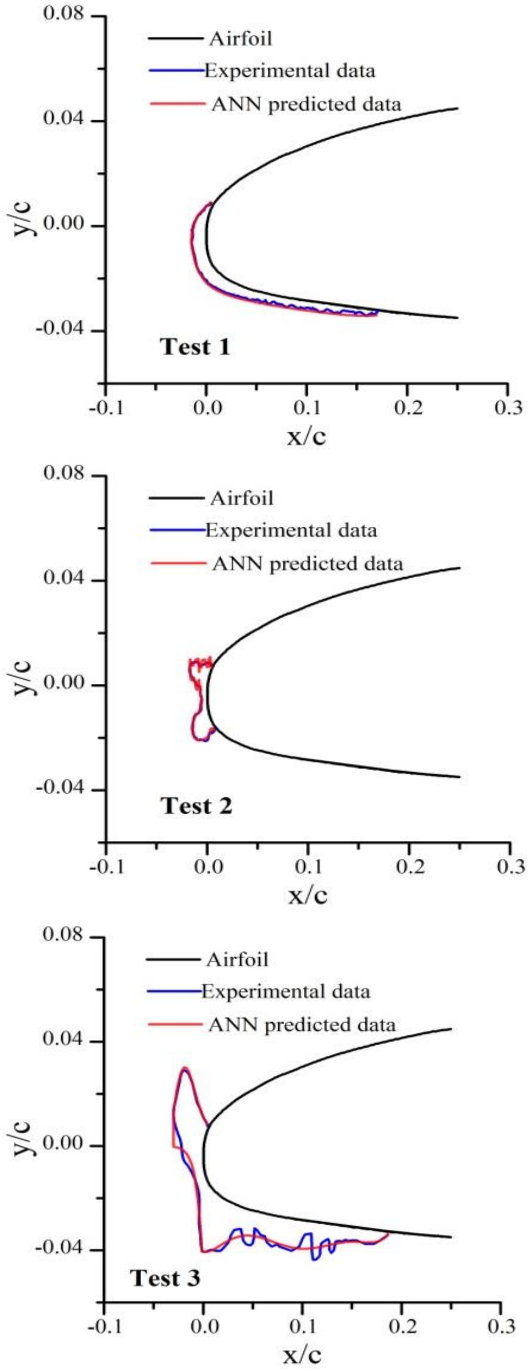

Figure 3: ANN prediction for 3 icing tests

CONCLUSIONS

An Artificial Neural Network (ANN) model is proposed to evaluate the ice shape of an airfoil under icing conditions. 84 data sets from the published leteratures were utilized to traing the ANN with the free stream temperature pressure, Mach number, median volumetric diameter, liquid water content and water spray time as input variables. The ice shape was characterized by the discreted coordinate through Fourier transform. The Fourier transform coefficients were as the output variables of the ANN. After trails and errors, the ANN was determined with 1 hidden layers and 9 neurons. 3 tests were used to test the ANN, which showed good prediction performance under the rime ice condition. As for the glaze ice, the ANN need to be modified.

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