1. Introduction

An accurate method of measuring the thickness of paint on composite aircraft parts is important from a weight standpoint, but more importantly, due to damage that can occur from lightning strikes on composite parts with excessively thick paint coatings. When the lightning strikes the aircraft, the embedded conductive wires (which are made up of aluminum) evenly spread the current over the surface of the aircraft. The current generated due to the lightning reaches the different layers of the aircraft skin depending on the paint thickness or, in general, coating thickness. If the paint is thick, the current generated by lightning cannot spread and burns a hole in the aircraft. This project was charged with a task of looking at a method to improve the accuracy and ease of operation of a commercial paint thickness measurement system that analyses the reflection pattern of an acoustic pulse echo (time domain reflectometry).

2. Signal Processing Technique and Intelligent Algorithms

2.1) Present method and its bottlenecks

The present method used by many aircraft companies in calculating paint thickness is called "pulse-echo method". In the industry it is used for flaw detection, cracks, thickness gauging etc. A local aircraft manufacturer used the pulse-echo method to test the paint thickness on composite aircrafts. The pulse-echo method consists of a pulser, a transducer, a receiver and an oscilloscope. The pulser sends the electric pulses into the transducer and the transducer converts these electric pulses into acoustic pulses. These acoustic signals travel through different layers of aircraft skin and the receiver records reflections from discontinuities between the surfaces. These are captured with the oscilloscope and later processed with different techniques to calibrate the thickness of the material. The problem with this method is it requires a highly qualified technician to interpret the data. In this project, we tested the efficiency of Artificial Neural Networks in measuring the thickness of the paint on composites by using the data that was processed using a signal processing technique, Fast-Fourier Transform (FFT).

2.2) Elimination of bad data

The data, which was in time-domain, was obtained from a local manufacturer (Cessna). To remove the front surface reflections, since they play no major role in measuring the thickness of the paint on the composite panel, first 4mil of the time-domain data was removed before proceeding to any further steps. This data was then normalized by first dividing all the points of the amplitude with the largest magnitude and then referencing the start of the signal to a common point, the peak of the reflected signal. These normalized data points were processed using Fourier transformations.

2.3) Fast Fourier Transform (FFT)

A Fourier Transform (FT) is an analytical method used to convert a signal between time-domain and frequency-domain. The reflectometry signal used to calculate paint thickness is initially in the time domain. This domain is not always the best for signal processing related applications. In many cases, the most distinguished information is hidden in the frequency content of the signal. The frequency spectrum of a signal is basically the frequency components (spectral components) of that signal.

The Fourier Transform of a signal $f(t)$ is given by

$$F(\omega) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(t)e^{-i\omega t} dt$$

Where $\omega =$ frequency

$t =$ time

The time-domain reflectometry data produced by the measuring instrument is in a discrete form due to sampling of the data. For this, a Discrete Fourier Transform (DFT) is used. The FFT is merely an algorithm for efficient computation of the discrete Fourier transform [1].

Plots in figure 1 represent time-domain plot before chopping off first 4mil, normalized time-domain plot after
chopping off the first 4mil and its Fast Fourier Transform (FFT).

Since the signal was concentrated in the first 50 frequency bins of the FFT data, these were provided as inputs to neural networks.

2.4) Artificial Neural Networks (ANN)

An Artificial Neural Network (ANN) is a powerful tool that is able to interpret and classify data. The true power and advantage of neural networks lies in their ability to represent both linear and non-linear relationships and to learn these relationships directly from the data being modeled [2]. In the present project, we tested the ability of an ANN to calculate the paint thickness on composite panels using a signal-processing method known as FFT. Backpropagation algorithm was used in the present project.

Time-domain reflectometry data, which was taken by Cessna on paint over composite panels, was obtained in March 2004 and processed using FFTs. These were given as inputs to ANN to test their ability in approximating the paint thickness on composite aircraft. Neuralworks Professional II software was used and the details of the network architecture is as below:

<table>
<thead>
<tr>
<th>Network architecture</th>
<th>#PEs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input layer</td>
<td>50</td>
</tr>
<tr>
<td>Hidden Layer1</td>
<td>7</td>
</tr>
<tr>
<td>Hidden Layer2</td>
<td>3</td>
</tr>
<tr>
<td>Hidden Layer3</td>
<td>0</td>
</tr>
<tr>
<td>Output</td>
<td>1</td>
</tr>
</tbody>
</table>

Learning Rule: Norm-Cum-Delta
Activation Function: Sigmoid
The rest of settings used were default values.
After training the network, the test rms error was 0.0945.

3. Conclusions

Using time-domain reflectometry data, provided by Cessna, paint thickness was calculated to within ±9% maximum error using FFT preprocessing and artificial neural networks. If this method is integrated with the existing pulse-echo method in the form of software, paint thickness can be approximated using the already trained ANN by feeding the processed data into a computer.

4. References