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Array Eddy Current for Fatigue Crack Detection of Aircraft Skin Structures

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ABSTRACT

Fatigue cracks growing rate in an aircraft skin structures is difficult to predict, therefore early detection is very important to avoid structure failure. Small fatigue cracks originating deep in these structures, or in the second layer of the skin and in the region of the fastener holes, are hard to detect using standard driver-pickup eddy current probes. The difficulty lies in the fastener length and spacing, which reduce test sensitivity. This paper explains the development of array eddy current probe and signal interpretation technique designed to detect and visualize fatigue cracks in fasteners holes and at multilayer level.

In this study, an array eddy current probe was evaluated and a new eddy current array coil design is suggested. Several tests were conducted with the developed array on an aircraft lap-joint sample having simulated fatigue cracks. With the improved array design, the results show great potential and enhanced detection capabilities of relatively small size fatigue cracks in fasteners.

1) INTRODUCTION

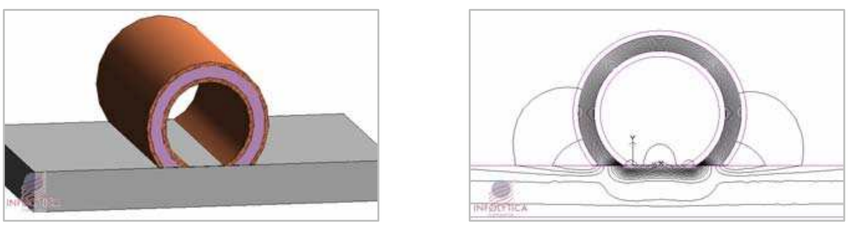
Airframe manufacturers and airline companies use nondestructive techniques such as eddy current to detect hidden fatigue cracks and skin structure corrosion. With conventional eddy current technique, the basic component is a sensor coil. When the coil is excited by an alternating current and put on or near a conductive material, a resultant eddy current is created on the skin of the material. After the coil passes over a defect, the impedance of the coil will change and this impedance variation is directly illustrated on the screen in a view called the impedance plane (Lissajous). However, such interpretation is not simple task and requires a considerable amount of operator skill and knowledge. A good way to facilitate the interpretation of eddy current signals is to present them in a C-scan view. This kind of representation is made possible with the use of eddy current array (ECA) probes. Furthermore, with the use of ECA probes, a C-scan view can be built with one single of scan, which reduces inspection time tremendously. This paper presents a new ECA probe designed for the detection of deep fatigue cracks which are immediately adjacent to fasteners in relatively thin and multilayered structures.

2) ECA PROBE PRESENTATION

The designed ECA probe represents a transmitter-receiver probe that provides a quick and reliable solution for the detection of fatigue cracks in lap joint structures.

2.1 Transmitter

The investigated ECA probe was first designed and modeled using commercial finite element software (MagNet from Infolytica) to analyze and optimize the probe.



(A) (B)

Figure 1: Transmitter coil modeling results

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Figure 1 (A) shows the general appearance of the probe transmitter and figure 1 (B) shows the magnetic field distribution produced by the coil. Measurements were made to quantify the produced magnetic field. Such probe configuration provides a powerful transmitter allowing a large magnetic field generation in the inspected material.

2.2 Receiver

The following figure illustrates the configuration of the designed eddy current array probe receiver. The probe is used with an ECA unit (OmniScan), which has an internal multiplexer that activates four pick-up coils at the time. The receiving configuration is composed of 16 coils. Four coils are activated in four acquisition time intervals (or time slots) to activate the complete probe in a very short period of time.

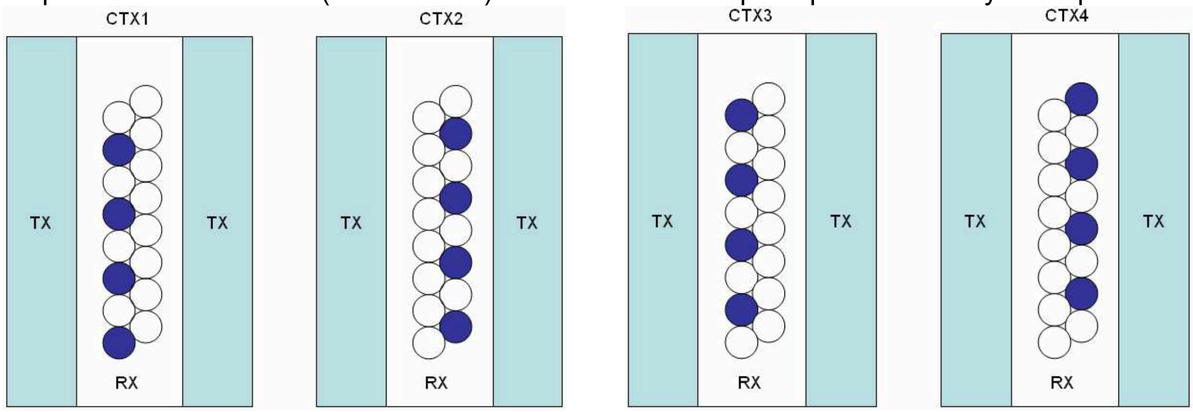

Figure 2: Receiving coil multiplexing

This multiplexing technique provides a large coverage in a single inspection pass while maintaining high scanning resolution. Also, it reduces the need for complex robotics to move the probe; a simple manual scan is often enough when using ECA. R/D Tech (Olympus NDT Canada) was the first NDT instrument manufacturer to use this revolutionary multiplexing technique.

3) SIGNAL INTERPRETAION

This section describes the signals that are produced when the eddy current probe passes over a defect. Figure 3 shows how a C-scan image can be built when an ECA probe passes over a defect. In this case, the coil located just over the flaw produces a strong signal. The further the coil is from the defect, the weaker is the produced the signal. The C-scan view is color coded to represent the amplitude of the close and far coil signals.

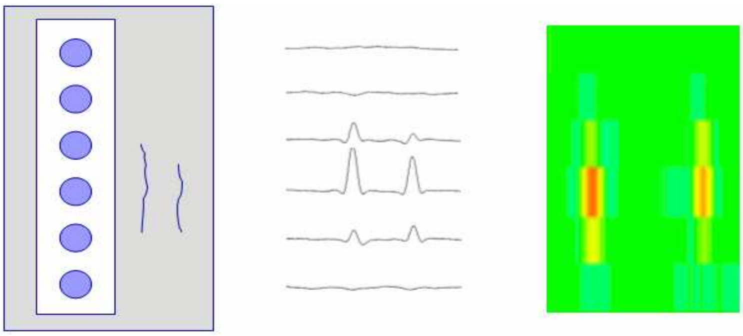

Figure 3: ECA probe C-scan representation

The same principle is used in the inspection of a fastener. When the probe passes over a fastener free of defects, we obtain a signal in the impedance plane as shown on the left of Figure 4. In order to facilitate the interpretation, the signal is rotated until it reaches a horizontal position.

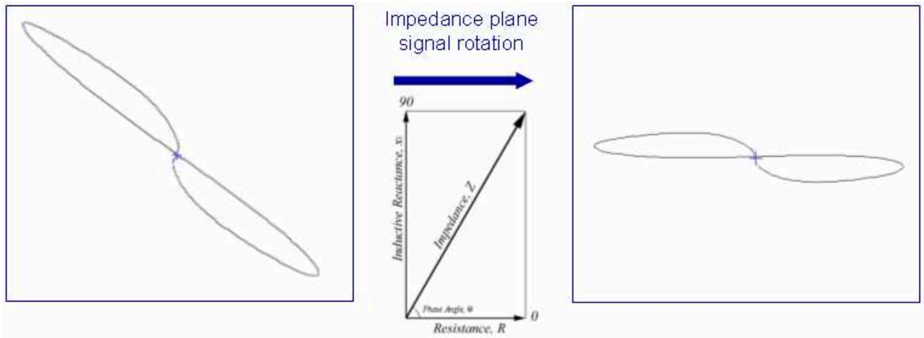

Figure 4: Fastener signal processing

This rotation makes it easy to set an alarm threshold on the Y-axis, which is usually the component affected by a defective fastener (see Figure 5).

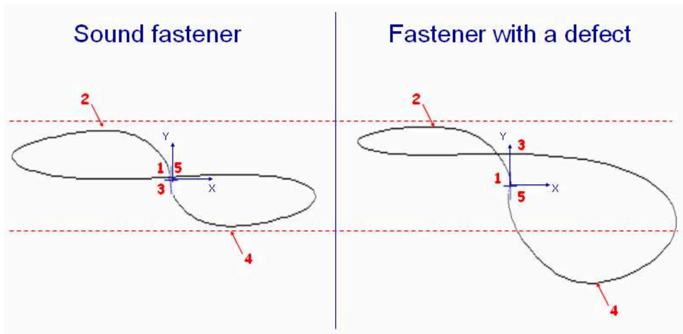

Figure 5: Defect detection signal interpretation

When the probe passes over a fastener with a crack, the signal crosses the alarm threshold and the C-scan of the Y-axis clearly shows the defect. Figure 6 presents the strip chart and C-scan representation of that Y-axis (the X-axis is not used at this moment).

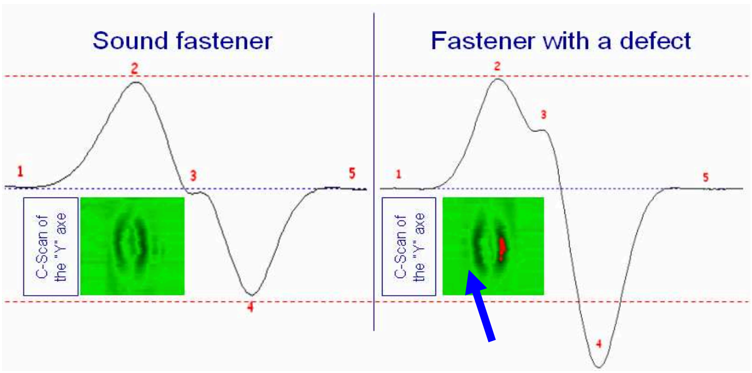

Figure 6: Y-axis strip chart and C-san signal representation

Each line forming the C-scan represents the measured signal of each receiving coil. It is possible to obtain a smoother C-scan if we use an interpolation processing between each received line.

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4) EXPERIMENTAL EQUIPMENT SETUP

The experimental equipment needed for this demonstration is shown in Figure 7. This is a setup built around the user-friendly equipment produced by R/D Tech. The equipment includes the ECA OmniScan unit and software, an ECA probe prototype, and a small position encoder.

Figure 7: Experimental equipment

5) APPLICATION RESULTS

5.1 First experimentation

The first simulated specimen is aluminum machined three-layer thick lap-joint structure. The cracks are located in the third layer of the structure (each layer is 2 mm thick). It is important to mention that such sample configuration represents a considerable thick structure for the eddy current technique. As a matter of fact, the crack is located under 4 mm of aluminum plates.

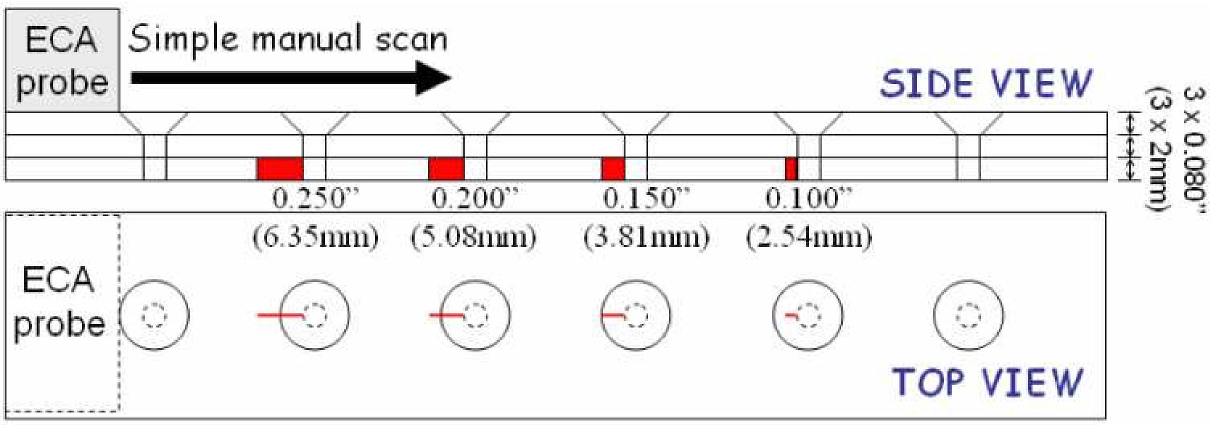

Figure 8: Experimentation 1 configuration

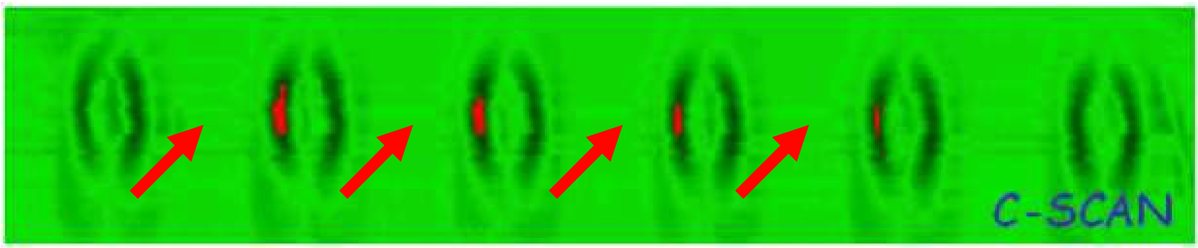

Figure 9: Experimentation 1 C-scan results, frequency of 1 kHz

Scanning with the designed ECA probe, figure 9 shows that we were able to cracks down to 0.100" (2.5-mm) located in the third layer of the simulated lap-joint structure. Another important point is that the ECA probe had very low sensitivity to lift-off.

5.2 Second experimentation

The second application is a machined, three-layer thick lap-joint sample like the first one, but the defects were located in different layers of the structure. Each layer is 1 mm thick.

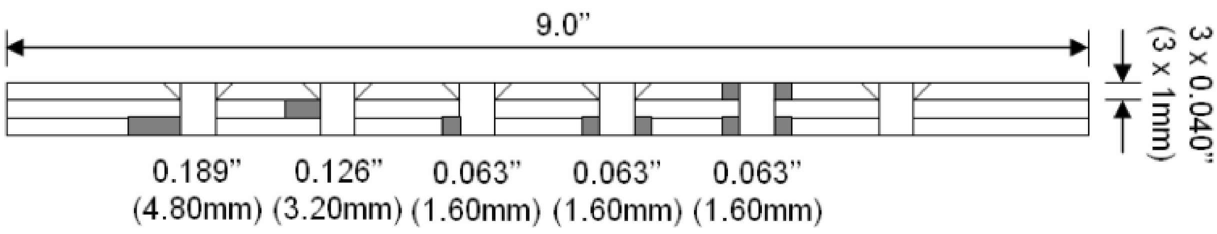

Figure 10: Experimentation 2 configuration

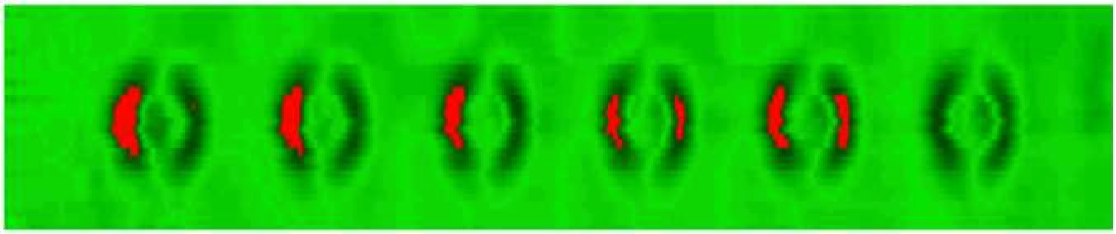

Figure 11: Experimentation 2 results, frequency of 2 kHz

This above results (figure 11) demonstrates that we have been able to detect cracks in the third layer as small as 0.063" (1.6-mm). This setup also allows the detection of defects located in different layers of the structure without any false calls.

5.3 Third experimentation

Figure 12 shows the sample configuration with the different location of the cracks.

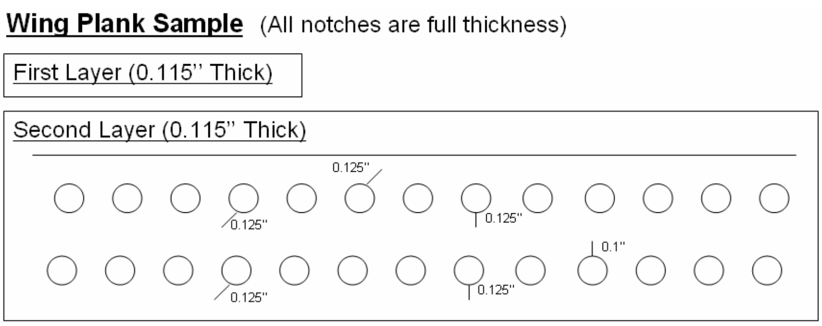

Figure 12: Experimentation 3 configuration

Normally, the fastest way to inspect the plate would be to move the ECA probe along the fastener line. However, since the designed probe has a better sensitivity to the type of cracks oriented along the scanning axis, scanning along the fastener is not really recommended for defects with orientation between 5 and 7 o'clock such the above sample. With such defects, a perpendicular scan or an oriented 45 degrees scan of the fastener line would provide much better results. The following section shows the results obtained for different scan orientations.

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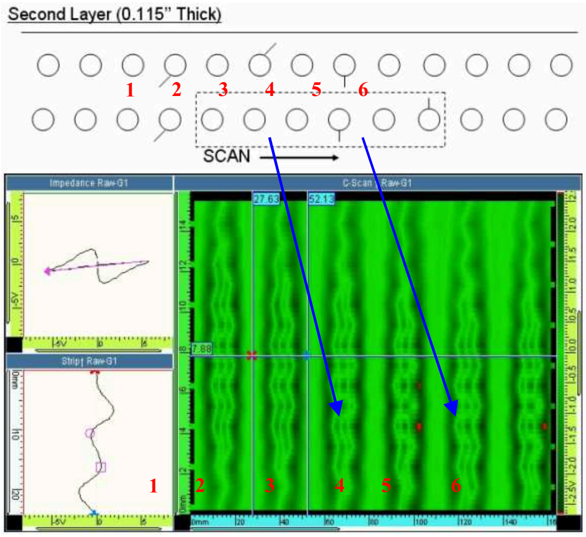
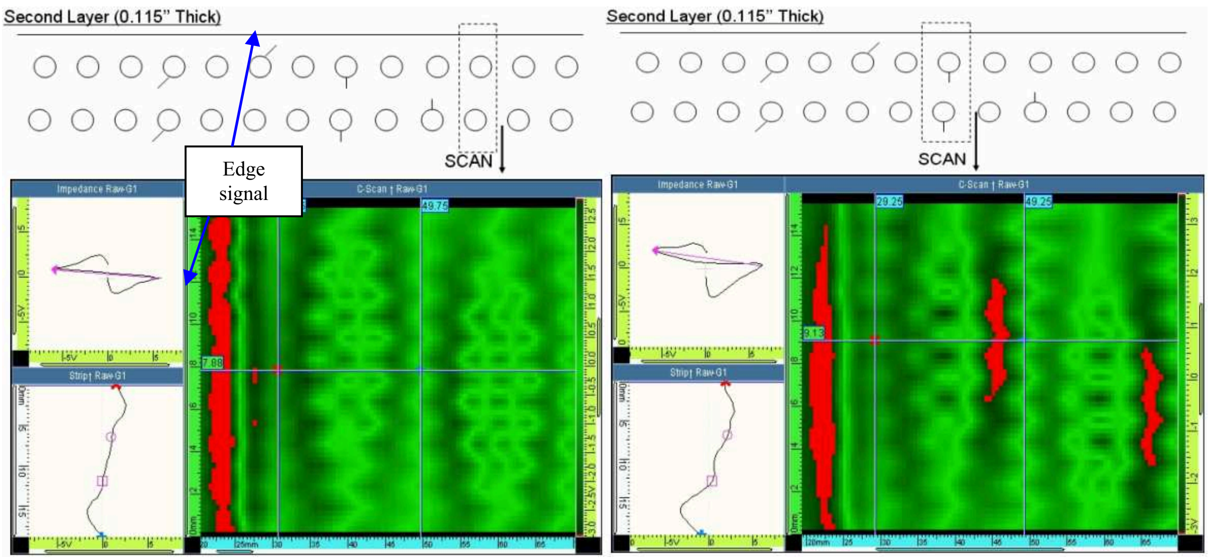
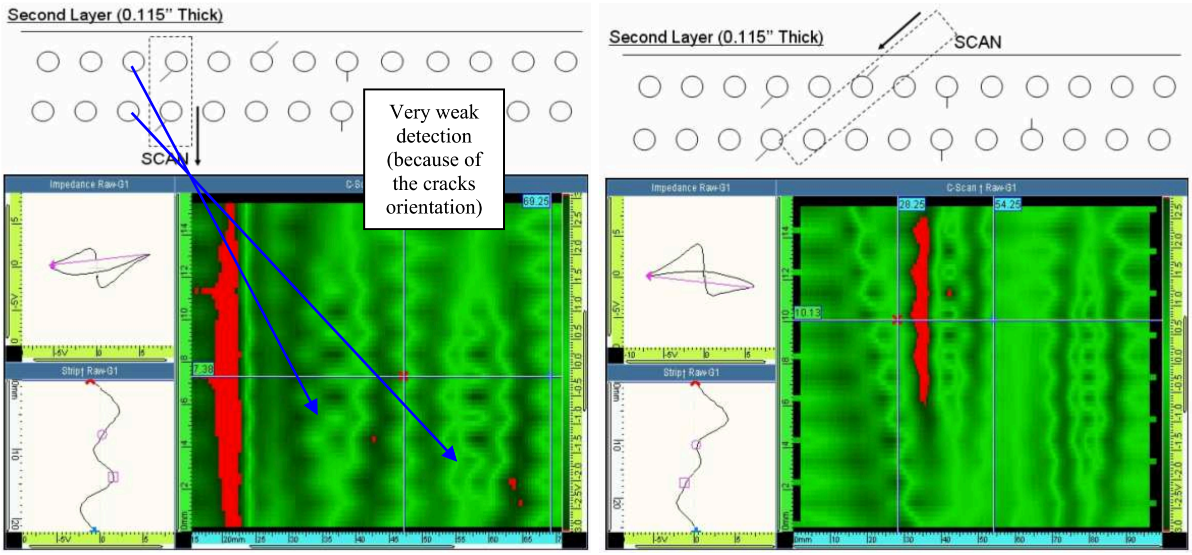


Figure 13: Parallel scan, very weak detection (because of crack orientation)

With the probe moving parallel to the fastener line, it is very difficult to adjust the C-scan color palette to obtain good detection of the cracks. Figure 13 shows two small indications that correlate with the plate defects. However, the signal amplitude that we get from those defects is relatively small and could easily be confused with a good fastener. With this type of parallel scan, the minimum detectable flaw would vary between 0.160”-0.180”.



(A) *(B)*



(C) *(D)*

Figure 14: Experimentation 3 Results: frequency of 1.5 kHz –A) Response of good fastener - B) Response for defective fastener with crack at 6 o'clock – C) Response for crack located at 8 o'clock – D) Response for crack located at 8 o'clock (good scan orientation)

When the scan is made perpendicular, the signal response to a crack located around 6 o'clock becomes much stronger. Figure 13 (A) and 13 (B) shows the results from two scans, one made on good fasteners and one made on fasteners with cracks. When the crack is located at 8 o'clock like in the Figure 13 (C), the defective fasteners are more difficult to detect. They can still be detected but the difference with a good fastener response is very small.

Figure 13 (D) shows the scan result for a 45-degree orientation. This type of scan is clearly optimized for defect around 7 and 8 o'clock. The first fastener gives a big signal represented as a deviation in the positive plane of the impedance plane and as an important color change in the C-scan.

To conclude with this third experimentation, the new ECA probe design was able to detect all the fatigue cracks located in the second layer of the simulated lap-joint samples. However, this probe has some limitations:

- A parallel scan can provide very fast scan but the detection level is expected to be more around 0.160" to 0.180".
- Optimum response is obtained when the probe is scanned in the same orientation as the defect. In this case, a crack as small as 0.125 in. can be detected. To cover all direction at this level of sensitivity, a total of four scans are required.

6) FUTURE WORKS

Based on these results, it is possible to confirm that the ECA probe design can be successfully used for fatigue crack detection. However, to be able to obtain a better detection capability, some future work is required:

- Improve the resolution of the probe
- Add real-time calculation of the signal surface inside the impedance plane
- Using modeling for optimization
- Characterize defects and identify their depth using multi-frequency inspection

7) CONCLUSION

In this paper, an ECA probe and practical inspection procedure were demonstrated for fatigue crack detection in multilayered lap-joint structures. The prototype probe showed better detection capabilities compared to the standard ECA probe for crack detection presently on the market. We have demonstrated a very good detection level with a uniform sensitivity on both sides of the fastener. The next steps are: make a standard probe of this prototype and characterize the detection capability with regard to the crack orientation.