Non-Destructive Testing Techniques for Aerospace Applications

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Abstract

Any Health/Condition Monitoring system depends on the input of accurate and appropriate data. Non-destructive testing (NDT) techniques such as ultrasound and eddy current have been used for many years in the aerospace industry to detect, measure and monitor problems including corrosion and cracking. Phased Array Ultrasound (PAUT) and Eddy Current Array (ECA) are developments which can offer increased probability of detection, fast scan rates and encoded inspections.

This paper describes some specific examples where PAUT and ECA methods have significantly reduced inspection times on aircraft and also provided easy to analyse displays and encoded data for Condition Monitoring. PAUT methods for composite materials are also discussed.

Keywords: support & maintenance, corrosion & fatigue, safety

Introduction

Conventional ultrasound (UT) and Eddy Current (EC) techniques have been used successfully in aerospace applications for many years. However, both have their limitations; for example, both require trained and experienced operators for the most reliable results. With conventional UT, the same inspection may have to be performed at several angles, increasing the time taken. The displays of conventional instruments, and EC flaw detectors in particular, can be non-intuitive and require experience to interpret. The probes used may be small, requiring skill to hold correctly and taking a long time to cover large areas. Although most modern UT and EC flaw detectors have data loggers, the amount of information stored can be limited. For some inspections Phased Array (PA) or Eddy Current Array (ECA) can greatly increase inspection speed, provide clear visual displays that highlight defects, increase probability of detection (POD) and offer more options for storing data.

Equipment and Terminology

Omniscan

The results presented in this paper were obtained using the Olympus NDT Omniscan flaw detector. The Omniscan consists of a mainframe which can be used with a number of different modules to perform conventional UT, PAUT, conventional EC and ECA inspections. Data can be recorded either as a time-based scan or encoded in one or two axes. Data can be analysed on the spot, or saved for recall later on the Omniscan. An advantage of the Omniscan is that it stores a great deal of data; not only are the screen images saved, but also

the data from which the images are created. This data can also be exported into software such as Tomoview for later or more extensive analysis. From Tomoview, Omniscan data files can be exported in csv format for import to condition monitoring software such as Technical Tools.

Terminology

In both conventional and PAUT, an A-scan refers to a display which plots signal amplitude on the x-axis against time or depth on the y-axis. An example is shown on the left in Fig 1. In the image on the right, the A-scan has been turned to align with the S-Scan beside it so that in both cases depth is shown on the horizontal axis. The S-scan (sectorial or azimuthal scan) can be described as a "stacked A-scan". It displays all the A-scans over a range of angles (40 to 70 degrees in this case) with the signal amplitude colour-coded. The highest amplitude signals show as red and low amplitudes as white, as shown on the colour bar on the right of the display.

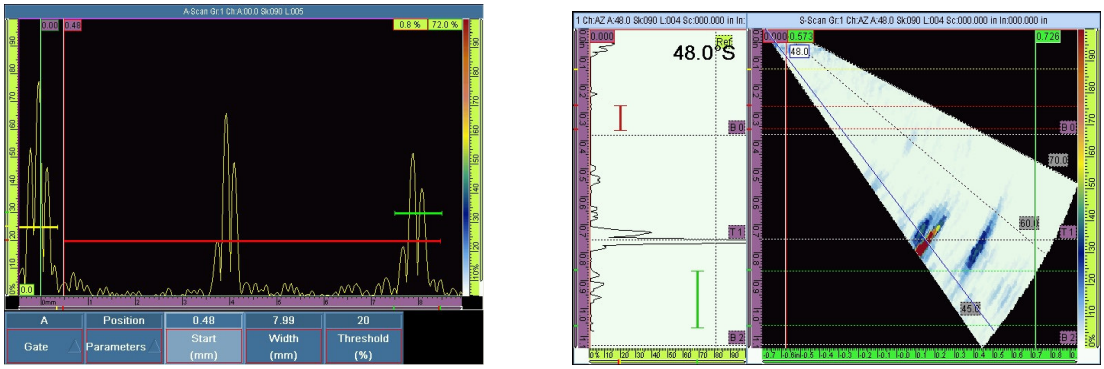


Fig 1: A-Scan and S-Scan displays

The other type of displayed referred to in this paper is a C-scan, which is used in both PAUT and ECA and can be thought of as a plan view from the top of the part as shown in Fig 2.

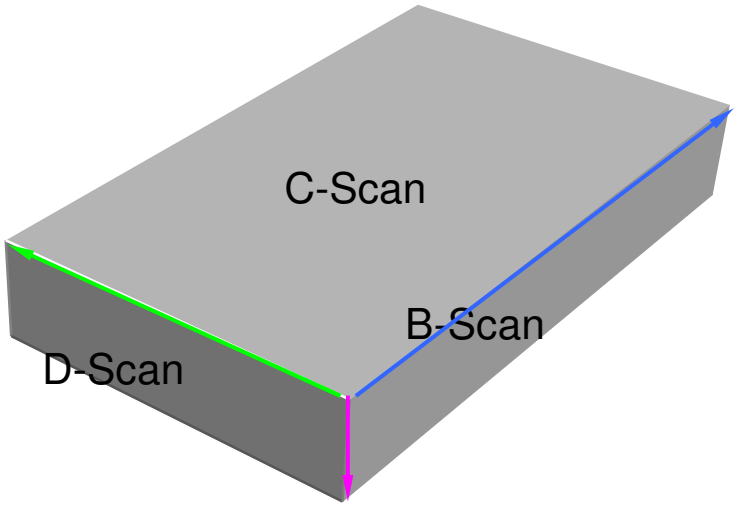


Fig 2: C-Scan display

Phased Array Ultrasound

A PAUT probe is an assembly of ultrasonic transducers with individual connectors. The benefit of PA is that the same probe can be used to generate different types of ultrasonic beams by controlling the time at which each element is pulsed - for a more detailed description, including animations, see Ref 1. Although probes can be produced in a variety of geometries, including 2-D matrices and annular, in practice the probes most often used are linear. Beams can be generated to scan over a range of angles (sectorial or azimuthal scans as shown in Fig 1) or a beam at one angle (linear scans can be moved along the length of the probe electronically (e-scan) without moving the probe itself. Focussing can also be controlled.

Although a PA probe is more versatile than a conventional probe and can generate different ultrasound beam, is important to note same laws of physics apply as in conventional ultrasound. Beams can only be focussed in the near field, the higher the UT frequency the higher the attenuation, and beam spread will still limit sizing capability.

Examples of maintenance procedures already qualified with Omniscan PA:

- Boeing DC-9 inspection of landing gear (NTM DC9-32A350, Dec 2004)
- Boeing 737, 747, 757, 757 fuselage skin scribe mark (CMN NDT part 4, July 2008)
- Airbus A340-500-600 centre wing box (NTM-A340 57-18-16, July 2007)
- Airbus 300-600 inspection of gear rib forward attachment lug for main landing gear
- Airbus 380 general PAUT procedure for the inspection of GLARE structures (NTM A380-51-10-23, Sep 2008)

The first two examples will be described below.

DC-9 landing gear inspection:

In 2003, Northwest Airlines experienced two landing gear failures due to cracking in the outer cylinder near the trunnion arm radius. Analysis at NTSB and Being Long Beach found that these cracks were the result of grain boundary separations forming along inclusion in the cylinder forging.
The initial inspection plan required:

- Stripping the paint, primer and cadmium plating
- Performing spot fluorescent magnetic particle inspection with portable magnetic yokes
- Reapplying the cadmium plating, primer and paint

Some issues with this process were:

- Long (up to 40 hours)
- Paint curing time alone was 12 hours
- Hazardous
- Removing the hydraulic brake lines for access was problematic

Conventional UT was considered. It performed well but required the use of at least 5 different angles, and it was considered too difficult to do all these separate UT inspections with too high a risk of error. PA trials on a notched test sample showed that the notches could be clearly detected with one 45 to 70 degree sectorial scan. As there was no need to move the hydraulic lines for access or to remove the paint, there was a huge time saving; 2 hours for the inspection instead of 40 hours.

A curved wedge was used to conform to the shape of the landing gear cylinder and before each inspection, validation is carried out on a calibration sample as shown in Fig 3 below.



Fig3: PAUT probe and wedge on landing gear calibration sample

Fig 4 shows the indication from the notch in the calibration piece on the S-scan (top image) and A-scan (lower image). The A-scan is that for the 59 deg beam, which is shown by the blue horizontal line in the S-Scan.

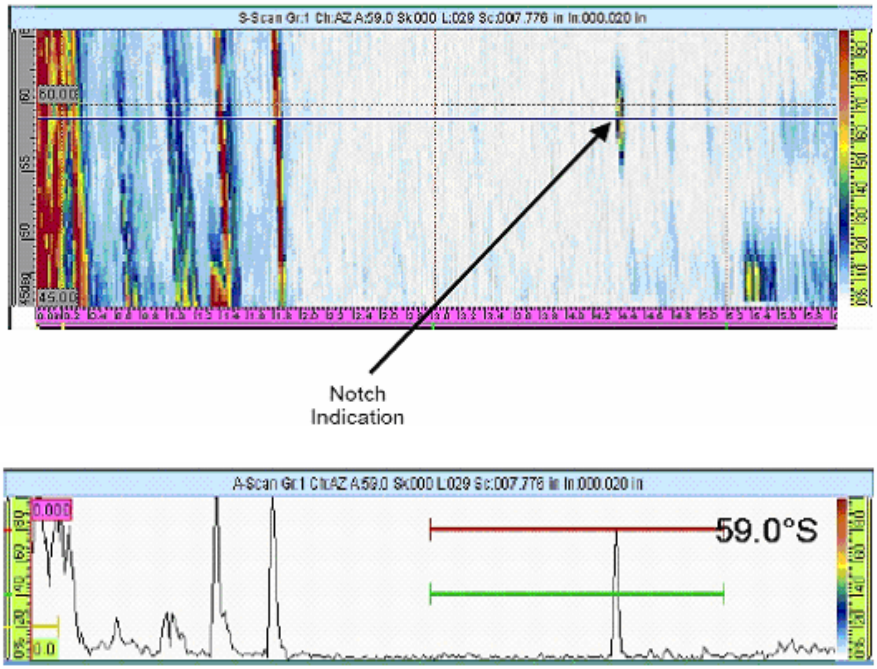


Fig4: S-scan and A-scan of calibration notch

The PAUT inspection is performed manually (see Fig 5 below). The image on the Omniscan screen is then frozen and analysed on the spot.

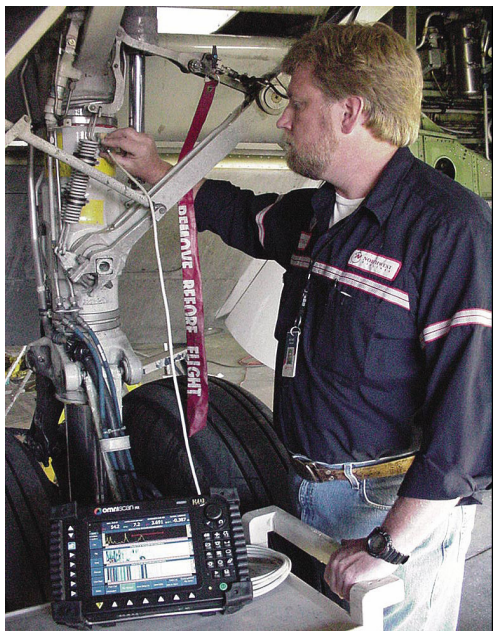


Fig 5: PAUT landing gear inspection

737 Scribe Mark Inspection

The use of sharp tools to remove paint and sealant caused damage along the fuselage skin lap joints, butt joints and other areas of several Boeing 737 aircraft (ref 2). If undetected, these marks in the pressurized skin could lead to cracks and potentially wide spread fatigue damage. All commercial aircraft that have been repainted and had sealant removed could have this type of damage.

Typically defects are > 5mm long, as shown in Fig 6. Those of concern are 50% of the skin thickness in skins from 0.81 to 1.1mm thick. The probe used is a standard 10MHz probe set up for a shear wave sectorial scan from 60 to 85 deg.



Fig 6: example of scribe line damage

Results:

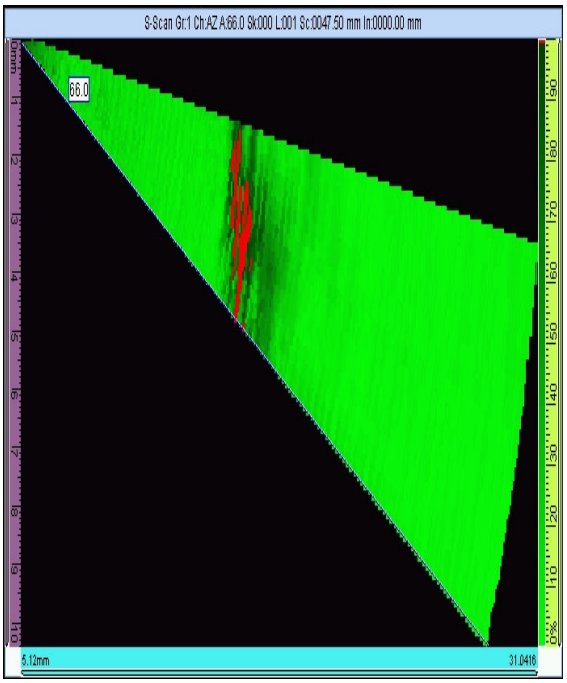


Fig 7: S- Scan showing scribe line damage

Fig 7 (above) shows an S-scan with a typical scribe line damage indication. These indications can easily be differentiated from signals from the fasteners. Again an advantage of using PAUT was that the inspection could be done without having to remove the paint, a huge time-saver. This resulted in an extremely fast payback on the cost of the PA equipment and training.

Composite materials:

As with conventional UT, PAUT transmits only through liquids and solids. The fact that it cannot transmit through air is an advantage when trying to detecting voids, but can be a problem with foam materials. Some fibreglasses can be successfully tested with both UT and PAUT, depending on the size and orientation of the fibres and quality of resin. These materials usually need to be tested to determine whether UT or PAUT are suitable.

Both UT and PAUT can work well on carbon-fibre reinforced polymers (CFRP) and glass - reinforced metal fibre laminate (GLARE). For flat panels, as delaminations are parallel to the top surface, inspections are normally done with zero degrees longitudinal waves (see Fig 8).



Fig 8: Two-axis encoded flat panel inspection

While delaminations can also be detected by a conventional UT 0-degree scan, this is time-consuming when large areas need to be scanned and if a grid pattern is used, some regions will not be inspected. With an encoded PAUT scan, the entire area can be scanned quickly.

Fig 9, below, shows typical displays from a CFPR inspection. In the image on the left, the Omniscan screen shows an. A-scan, S-scan and a depth C-scan. Note that in a 0 degree scan, in the S-Scan the reflections from the backwall appear as straight lines. The horizontal cursor in the S-scan is over a delamination indication. In the image on the right, the display shows an A-scan and both a thickness and a Time-of-Flight (TOF) C-scan. As the scan is encoded, the length of defects can be quickly and simply measured using cursors on the C-scan displays.

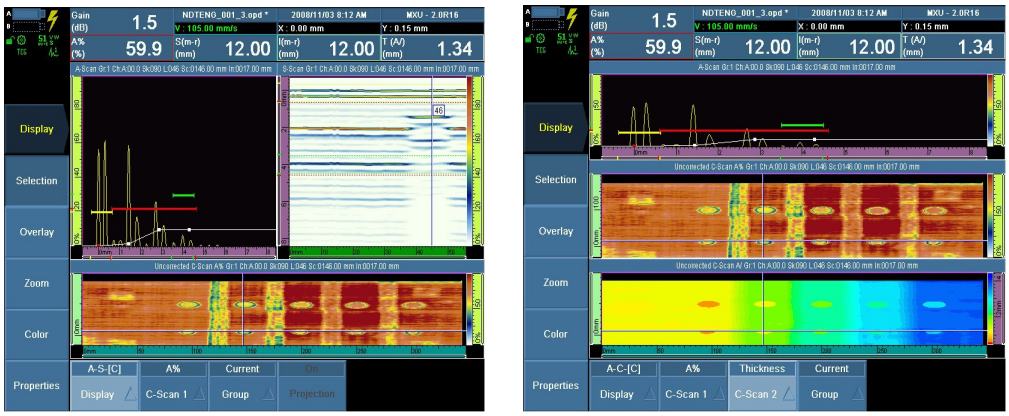


Fig 9: CFRP inspection displays

Eddy Current Array

ECA technology can be defined as the ability of electronically drive several eddy current sensors (coils) placed in the same probe assembly (fig 10). Data is acquired by multiplexing the EC sensors to avoid mutual inductance between the coils. This

- Allows large coverage in a single probe pass while maintaining resolution
- Reduces the need for complex robotics to move to the probe – a simple manual scan may be enough
- Allows for inspection of complex shapes either with probes made to conform with the profile of the part, or with flexible probes

Most conventional EC techniques can be used with ECA probes.

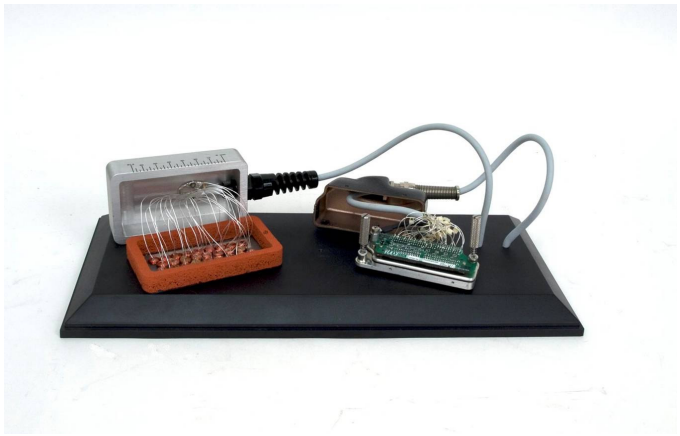


Fig 10: Eddy Current Array probe

As the ECA probe is moved over a flaw, each coil will produce a signal. The amplitudes of these signals are colour-coded and merged into a C-scan view, which can be considered as a "map" of the part looking from above as shown in Fig1 below.

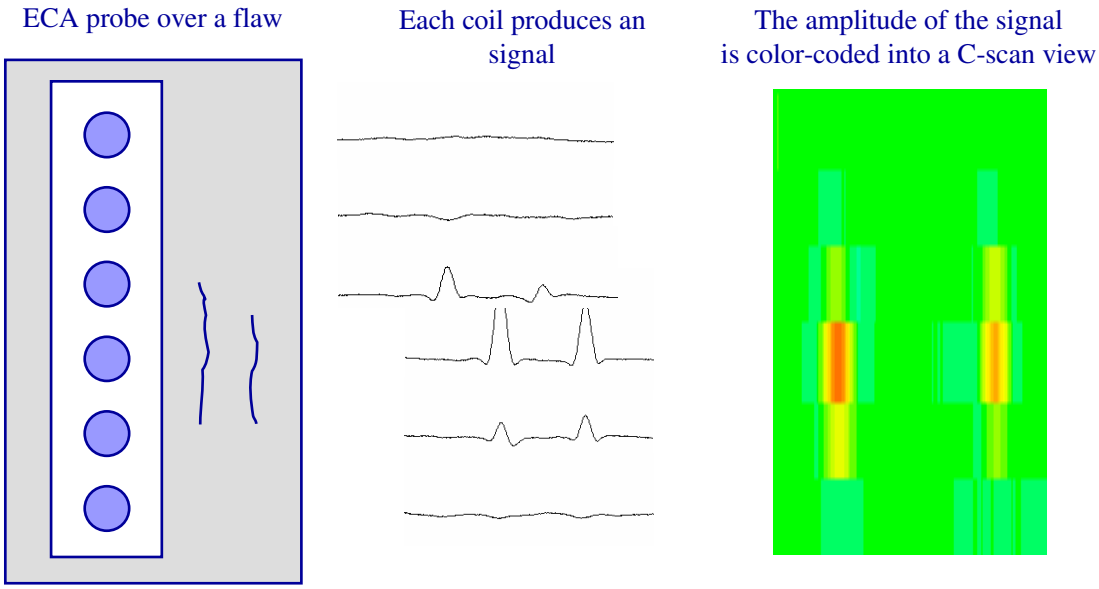


Fig 11: ECA flaw detection and display

Four examples of ECA aircraft inspections will be described below.

1. Boeing 737: Inspection of doubler edge

Shear and compression loading causes subsurface cracks at the doubler edge. These cracks must be detected at an initial stage, when they are small as 6mm long by 0.24mm deep. Otherwise they grow until they can be detected visually on the fuselage skin outer surface. Once this happens, the aircraft must be removed from service and the repair is extremely expensive.



Fig 12: Example location of doubler edge damage on 737 (left). On the right is a close- up view from the inside.

Using a low-frequency ECA probe, the inspection is done from the outside. The probe covers 67mm in one pass and the penetration depth in aluminium is 1.0 to 3.5mm. It is a simple manual inspection that does not require complicated scanners or robotics.

Results:
The C-Scan image allows easy location of the doubler edge for fast, simple detection of small cracks (see Fig 13, below). The colour transition from light to dark green indicates the doubler edge. Fasteners appear in light green. Defects above the rejection level show up in red.

The inspection time is only 48 hours compared with 200 hours with conventional EC, which again is a substantial saving. The results were reliable and reproducible and the scans can be encoded. This inspection is referenced in NTM7 NDT 53-30-25 part 6, Dec 2—4.

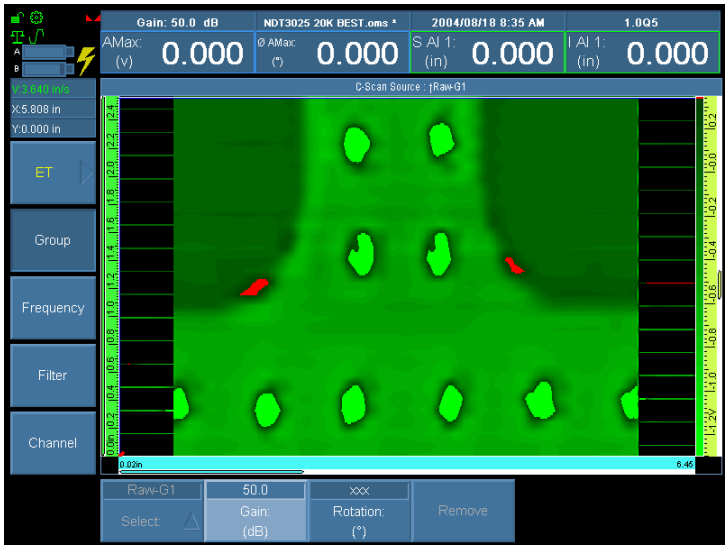


Fig 13: ECA C-scan of Boeing 737 doubler edge showing subsurface cracks

2. Boeing 757 : lap splice inspection at upper row of fasteners in the outboard skin.

This is an optional procedure to Part 6, 53-30-06, released Jan 2008. A high resolution surface ECA probe is used to inspect the upper row of fasteners of the skin lap splices for near surface cracks. The probe has at least 32 channels, a head to scan an area >22mm but less than 37mm and a frequency range of 200 kHz to 400 kHz. It is calibrated on a standard with an EDM notch through the first skin, positioned 0.1 in from the rivet shank, to represent the type the cracks to be detected.

Results:

- C-Scan image is easy to interpret (see Fig 14)
- Compared to conventional EC probes, positioning is not critical
- Absolute coil can detect notches in any direction
- Fast and reliable; data can be encoded.

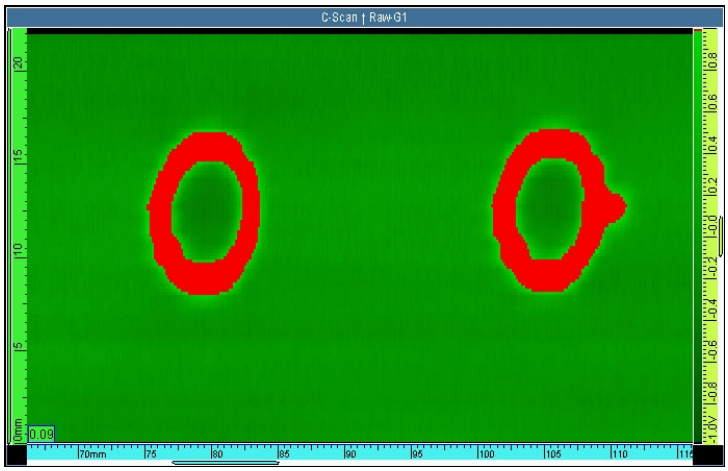


Fig 14: ECA C-scan of lap splice fasteners. A good rivet is shown on the left. The notch on the river on the right shows up clearly

3. Airbus A330-200 – corrosion detection on fuselage internal skin underneath acoustic insulation panels

A low frequency (1 to 20 kHz) ECA probe is used for this application. It has 32 elements and a coverage of 128mm with a resolution of 4mm. Penetration depth in aluminium is 3.0 to 6.0mm.



Fig15: ECA Corrosion inspection on Airbus A330-200

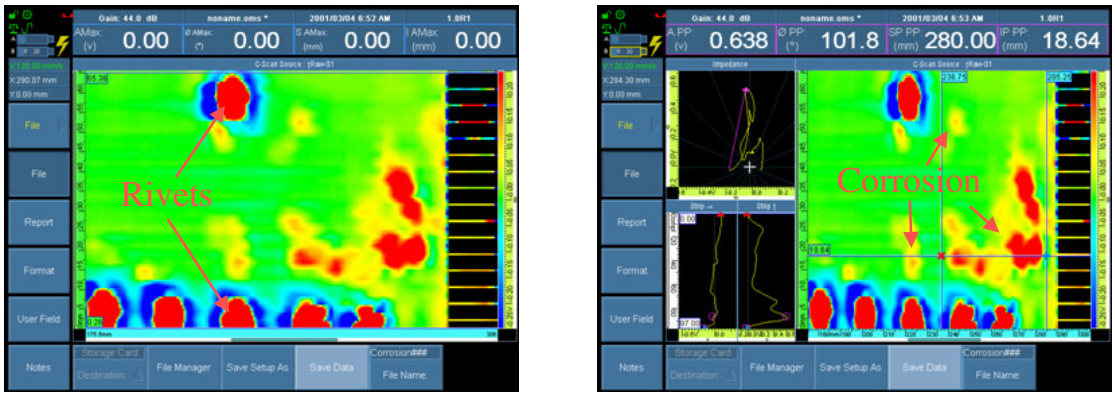


Fig 16: C-Scans of corrosion inspection.

Fig 16 shows typical scan from this inspection. On the right is the display from the Omniscan while in acquisition mode; a scrolling C-scan shows in real time a map of the part being inspected. In analysis mode (on the right), cursors are used to select which data points to show in an impedance plane and/or strip chart display. Analysis can then be done using all three displays.

Results:

- Easier detection of small regions of corrosion in large areas
- Detection capability: 10% corrosion under 5mm with a diameter of 12.5mm
- Better reliability and reproducibility than with small conventional EC probes
- Time saving: for an area of $12m^2$, 1 hour with ECA compared with 9 hours with conventional UT.

For large area inspections, as with PAUT probes, ECA probes can be used with scanner that attaches to the surface being tested. Using encoders on both axis will record the x,y location of discontinuities. This can be used to monitor non-rejectable defects, or if serious defects are found, to know where to inspect other aircraft to check for similar damage.

Conclusion

PAUT and ECA inspections can provide substantially reduce inspection times as well as intuitive displays and data storage for later re-evaluation.

References

1. http://www.olympus-ims.com/en/ndt-tutorials/phased-array/
2. Flight Standards Information for Airworthiness (FSAW 03-10B), *Fuselage Skin "Scribe Mark' Damage on Boeing 737 Aircraft*, November 2003
3. http://www.olympus-ims.com/en/ndt-tutorials/eca-tutorial/

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