

Rapid Ultrasonic Inspection of Ageing Aircraft

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Abstract

The requirement for rapidly detecting corrosion and disbonds in large areas of lap joints in transport aircraft has prompted the development of various new NDT methods and large-area imaging systems. QinetiQ has developed ultrasonic array technology in collaboration with Diagnostic Sonar Ltd and evaluated the inspection performance and the potential speed of inspection. The crucial factors in this development were the achievement of high speed as well as high spatial and depth resolution to allow interrogation of sealant and adhesive layers and the characterisation of corrosion.

A highly-innovative ultrasonic array probe has been developed that is capable of the high frequency response and broad bandwidth required for lap-joint inspection of ageing aircraft. The array covers a 124 mm swathe and scans at a speed of 4 m (13 ft) per minute with a 1 mm scan pitch.

Scanning software was developed to allow scanning at the maximum pulse-repetition frequency allowed by the ultrasonic flaw detector. Another critical issue was the coupling of a long array into the structure. Data on the latest focused array will be presented, with images scanned on real aircraft structure.

Technology transfer of the array has been a successful part of this project. The ultrasonic array is commercially available from Diagnostic Sonar Ltd, an NDT manufacturer in the UK, and the software to control it is available as an upgrade of current commercially-available equipment.

1. Introduction

This project commenced during a period when life extensions of aircraft in the fleets of various air forces were being implemented. Certain high-profile incidents related to ageing civil aircraft and their poor maintenance had recently rocked the civil aviation world. Large programmes of research in the USA had commenced, relating to both civil and military aircraft types.

The particular inspection problems in ageing aircraft relate primarily to the effect of ageing mechanisms, such as corrosion, modifying the fatigue performance predicted for the aircraft. Generally the fatigue life will have been calculated without allowing for the increased likelihood of crack initiation from a corrosion site. Hence the only way of preventing corrosion from shortening the life of these aircraft has been to adopt a policy

of non-destructive testing (NDT) and removal of all corrosion that is detected, however light.

Corrosion sites are many and varied and a whole 'toolkit' of NDT methods is required. Work carried out by QinetiQ (then DERA)⁽¹⁻²⁾ identified the most promising techniques for development into rapid inspection tools, in particular for the large areas of lap joints and other multi-layered structures in metallic transport aircraft.

The requirement for rapidly detecting corrosion and disbands in large areas of lap joints in transport aircraft has prompted the development of various new NDT methods and large-area imaging systems. One option is to speed up conventional methods, such as eddy-currents and ultrasonics, using automated or semi-automated scanners. Currently there are several systems available that scan either a single transducer in a raster scan, or several single-element transducers simultaneously⁽³⁻⁵⁾. Another method for increasing scanning speed even further is to electronically scan through a linear array of transducer elements and manually move this array along the lap joint. QinetiQ has developed both ultrasonic and eddy-current arrays and evaluated their inspection performance and the potential speed of inspection.

Recent years have seen the development of piezo-composite ultrasonic transducers which, by their very nature, are highly suitable for use as arrays and there have been several moves to introduce these arrays into NDT^(6,7). In addition, piezo-composite arrays can be flexible⁽⁸⁻¹⁰⁾ and this could prove essential because the most obvious problem with using array technology on in-service structures is that of maintaining ultrasonic coupling or eddy-current stand-off on uneven and curved surfaces. Thus a substantial part of QinetiQ's development program has been looking at this problem.

The prime technique for inspection of lap-joints is thickness gauging. Transducers have to be high frequency and wide bandwidth to produce the short duration pulses needed to achieve acceptable depth resolution for the thin aluminium alloy sheet of the lap-joint. The ultrasonic spectroscopy technique developed by QinetiQ⁽⁶⁾ for surface roughness measurement makes use of the preferential scattering of high frequencies. Measurement of the loss of these high-frequency components also requires a wide bandwidth transducer. Early single element probe investigations suggested that a focused acoustic field could offer improved tolerance to variations in angle of incidence. Any array implementation should therefore ultimately provide the capability for focused operation.

The width of the lap-joint requires a C-scan swathe of over 100mm and it is desirable to be able to inspect this in a single pass. The aim was to inspect on a 1mm pitch and to try to achieve a symmetrical acoustic beam profile in each direction.

This paper concentrates on the development of an ultrasonic array with a sufficiently high frequency range for lap-joint inspection, and a rapid scanning system to plot the C-scan results.

2. Array Development

The Mk I array has been described previously^(12,13), and used a poly-vinylidene fluoride (PVDF) piezoelectric sheet sandwiched between a backing block and the aluminium stand-off material. Aluminium was chosen partly to try to minimise peak-frequency downshift due to attenuation in the stand-off medium, and partly to act as the front

electrode. A water stand-off would also have had minimal attenuation but would have required a recirculating system with quite a high flow rate.

The array comprised 64 electroded elements of size 4 mm x 2 mm (or 0.16" x 0.08"), spaced at 2 mm (0.08") centres, fired as a triplet and receiving on a pair. After each firing either the transmitting triplet or the receiving pair are alternately incremented along by 2 mm (0.08"). Thus the result is 128 scan-lines spaced at 1 mm (0.04") centres.

The ultrasonic performance of the Mk I array was assessed and the centre frequency of approximately 12 MHz was sufficiently high to enable bond inspection and depth scans of corrosion sites. However, the initial attempt to maintain the high frequency through using an aluminium stand-off medium had failed due to the dominant reflections in the thin coupling layer between the probe and the structure. Hence the bandwidth was not as wide as is desirable for these inspections.

When scanning with the Mk I array it was found to be highly sensitive to alignment relative to the structure. As maintaining this alignment would be very difficult in practice, it was decided to re-design the probe to be a focused probe, thus reducing the sensitivity to alignment. Some development work was carried out at QinetiQ into a suitable rubber material to use as a low-reflecting membrane to retain a water column. The Mk II array was a focused array and used this water stand-off method.

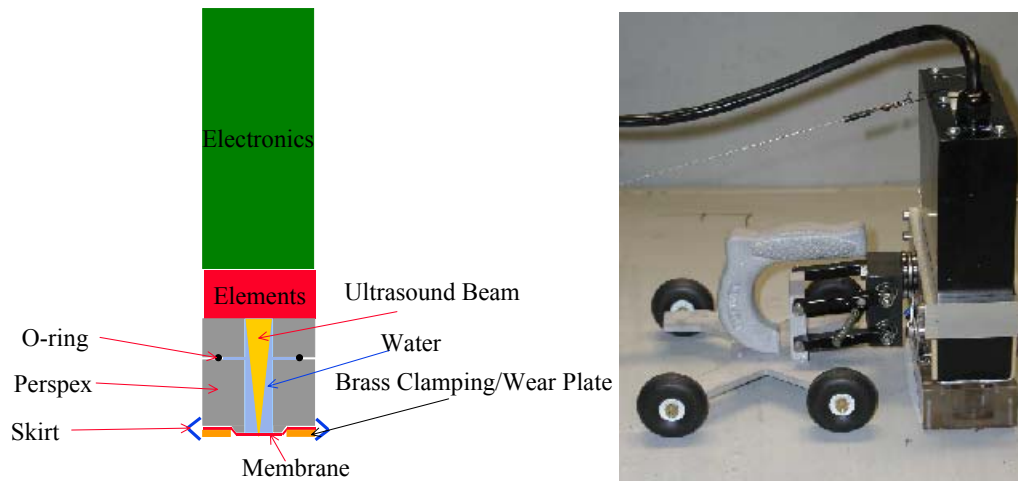


Figure 1. Schematic diagram (left) and photograph (right) of the Mk III array in the trolley designed to keep it upright and normal to the surface.

Fixed focusing in the plane perpendicular to the array was achieved by curvature of the elements. Electronic beam-forming is used to focus in the plane of the array by providing differential delays between the signals to and from adjacent elements. Focal length can be varied by altering the delays. However the constraint of matching the beam profiles in each direction means that a fixed focal length is satisfactory. The Mk III array was similar but used piezo-composite elements as in the table below.

Array	Beam	Piezoelectric	Stand-off	Centre Freq.	B/W
Mk I	Planar	Polymer	Aluminium	11.5 MHz	2 MHz
Mk II	Focused	Polymer	Water	10 MHz	8 MHz
Mk III	Focused	Piezo-composite	Water	14 MHz	8 MHz

3. Speed of Coverage

There are many different factors affecting speed of coverage and, during the period of this project, each factor was tackled, as it became dominant. For example, the asynchronous data acquisition method was initially the limiting factor but when that was improved the PC card acquisition rate dominated. When a new faster card was used the software became the limiting factor.

The current situation is that the latest ANDSCAN[®] software, PC-card, computer and multiplexer are all fast enough to acquire at up to 12 kHz PRF. However, the flaw detector used for this work will not allow a PRF of more than 8.5 kHz for the path length required when going through nearly 50 mm of water, so this is the current limiting factor

The final factor to be considered is the effect of coupling the array to the scanning surface. If the operator is not confident in maintaining coupling then he will not be able to move the probe fast. This factor begins to dominate between 3 and 8.5 kHz.

The acquisition speed of the Mk I array was limited initially by the data acquisition PC card and software to PRF of 600 Hz. This gave only five frames per second from the array and the speed was limited to 360 mm (14") per minute, achieved with a 1 mm spot size, or 720 mm (28") per minute, achieved with 2 mm spot size.

An improvement in ANDSCAN[®] software speed used with the Mk III array allowed the use of a 12 kHz PRF, giving a coverage of 5.7 m (18 ft) per minute with a 1 mm spot, or 11.4 m (36 ft) per minute with a 2 mm spot. However, with a 50 mm water stand-off the flaw detector would only allow 8.5 kHz giving a speed of 4 m (13 ft) per minute with a 1 mm spot, or 8 m (26 ft) per minute with a 2 mm spot.

At these speeds the limiting factor will be the confidence in maintaining coupling. Hence the issues of pumping sufficient water will need to be addressed.

4. Results

Figure 2 shows the improved lateral spatial resolution resulting from focusing the array.

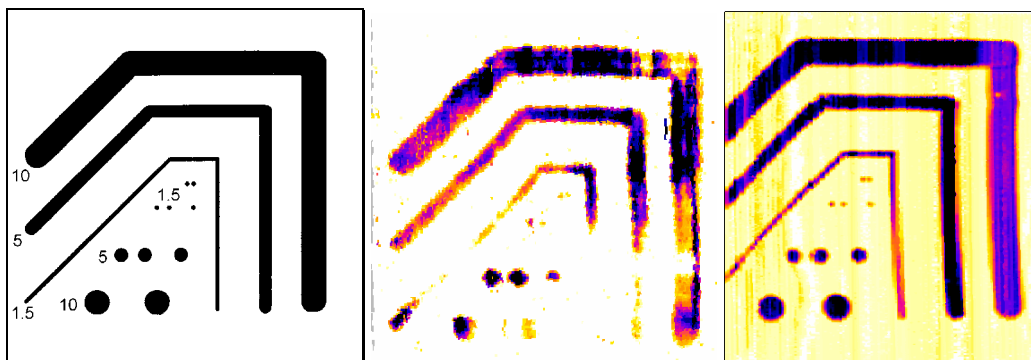


Figure 2. Diagram (left) of a 10 mm-thick aluminium resolution test-block. Amplitude C-scans are from the Mk I array (centre) and the Mk III array (right).

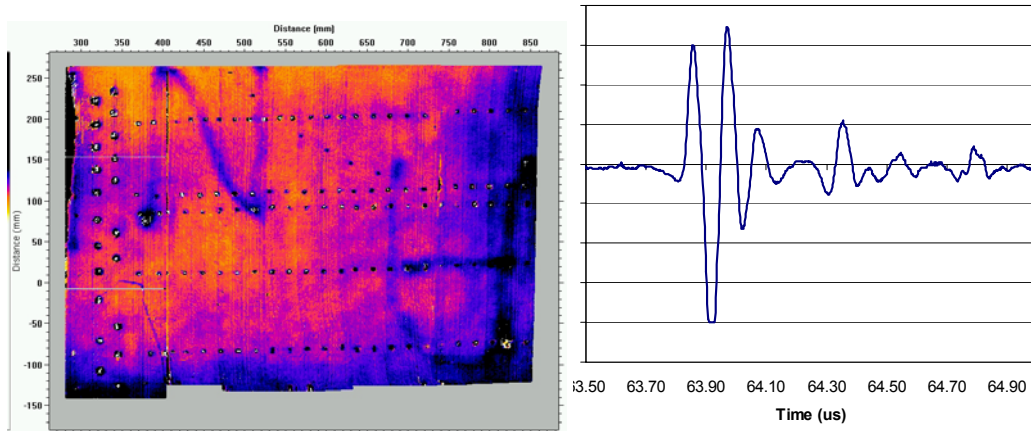


Figure 3. Example of a depth scan (left) performed with the Mk III array on a large fuselage panel. The waveform (right) shows the reflections from the painted front and back of the top skin and from the back of an adhesive layer.

Scanning time for the 0.22 m² shown in Figure 3 was approximately 30 seconds at 3.5 kHz PRF. The upside-down ‘N’ and ‘A’ that can be seen had been spray-painted on the outer surface using an aerosol so the depth scan has detected the extra paint thickness.

5. Conclusions

A large-area multi-element array probe has been developed that is capable of the frequency response required for lap-joint inspection of ageing aircraft. This is highly innovative as it has pushed the technology forward beyond the frequency range used for medical ultrasound.

A focused phased-array was found to be the most suitable because it allows a greater tolerance on alignment of the probe normal to the surface. The focal length can be adjusted electronically if required.

The issues of coupling the array to the real surfaces on ageing aircraft have been addressed and a water column held in by an acoustically-transparent rubber membrane successfully allows good coupling to the surface. The length of the water column can be changed to match the focal length of the probe and allow the focal plane to coincide with the appropriate interface in the structure.

The Mk III array was able to multiplex at up to 12 kHz PRF, and the speed at 12 kHz PRF is 5.7 m (18 ft) per minute with a 1 mm spot, or 11.4 m (36 ft) per minute with a 2 mm spot. This PRF is only possible with a shorter water path than the 50 mm used in the current array. However, 8.5 kHz was possible with this water path and this would give a speed of 4 m (13 ft) per minute with a 1 mm spot, or 8 m (26 ft) per minute with a 2 mm spot. At these speeds the limiting factor will be the confidence in maintaining coupling.

The work reported in this paper has assumed the use of a separate flaw detector to process the ultrasonic waveforms. Unfortunately this means that the system is reliant on the performance of that flaw detector. If acquisition of full-waveform data could be rapid enough then it would be possible to trigger the array from the computer and acquire and store full waveforms.

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