RAPID PHASED ARRAY ULTRASONIC IMAGING OF LARGE AREA COMPOSITE AEROSPACE STRUCTURES

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Abstract: There has been an increase in the use of composite materials in the aerospace industry which is driving a need for new NDT techniques that can rapidly scan large structures and provide quantitative data on the material integrity. In many applications there are common requirements for the ultrasonic inspection of composites for porosity, delaminations, foreign body contamination and fibre wrinkling. Traditional methods of ultrasonic inspection require the use of a single point probe or a multiplexed group of probes. NDT Solutions have developed new inspection techniques based on ultrasonic arrays housed within a rubber coupled wheel sensor. The wheel can be manually applied or scanned over the structure with an automated scanning system.

Applications for the technology include real time imaging and reporting of impact damage, porosity sizing, delaminations and fibre wrinkles. Examples and case studies from a range of aerospace applications are given including manual and automated inspection of small and large area composites.

Introduction: In recent years the number of applications for phased array inspection has increased dramatically, with many applications for weld and crack detection. Most of the applications utilise a sector scan or a B-scan raster mode to enable imaging of the defect as shown in figure 1.

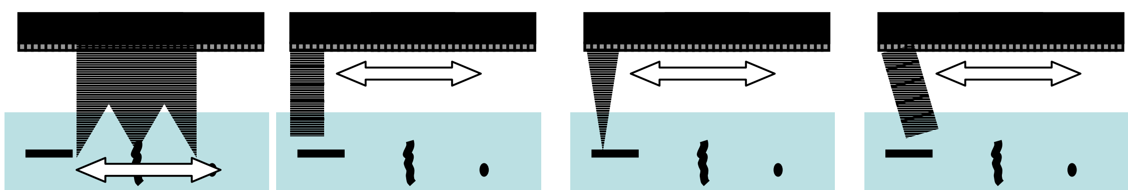


Figure 1: Phased array scan modes with sector scan and raster scans.

Whilst many portable systems have been developed for localised testing of complex shaped parts or for crack detection there have been fewer applications for phased array inspection of large aerospace components in particular composites. This is in part due to the relatively slow acquisition rates that can be obtained with portable equipment (approximately 20 to 50 B-scans per second) and the difficulty in deploying the array sensor for portable inspections where an immersion method cannot be used.

NDT Solutions in collaboration with Airbus UK have developed a unique rapid scanning phased array system that utilises a 128 channel pulser receiver system which can generate beams from up to 32 active channels. This system has been integrated with a custom high speed data capture card which controls the beam forming electronics and processes the raw ultrasound data to deliver high frame rate B-scan and rapid processing for C-scan data[1]. Depending on the number of beams generated and the data density, B-scan frame rates between 100 to 300 times per second can readily be achieved permitting fast, high resolution scanning of large components.

The system operates in B-scan raster mode and utilses a high frequency wheel probe to enable easy scanning of aerospace components[2]. A diagram of the wheel probe and C-scan generation is shown in figure 2.

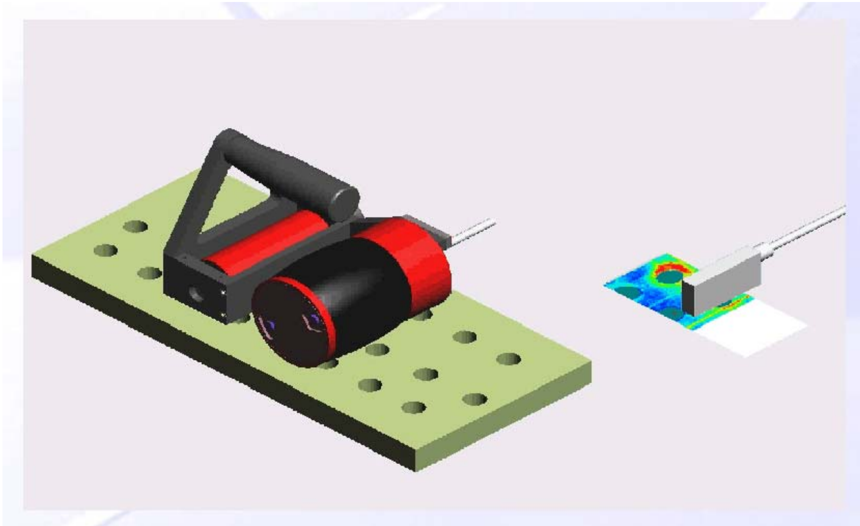
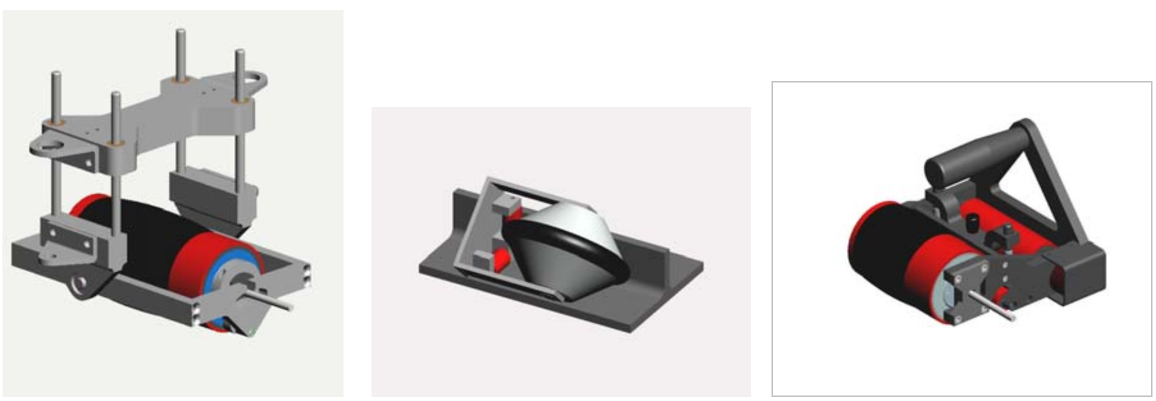


Figure 2: Rapid C-scan generation with an array housed in a water filled wheel probe.

The wheel probe can be used manually as shown in figure 2 or can be mounted on a yoke for automated scanning. Various combinations of wheel probe size, array dimension and frequency can be utilised depending on the applications. The coupling mechanics for the wheel probe can also be modified to enable easy scanning of curved parts such as wing skins or to permit scanning of edges and narrow components such as stringers as shown in figure 3.



(a) Contour following (b) Stringer radius (c) Narrow parts and stringers

Figure 3: Customised wheel probe designs developed for aerospace applications.

In many cases the ultrasonic array wheel probe is replacing an existing inspection based on single or multiplexed conventional ultrasonic probes. To achieve this it must be ensured that the ultrasonic array and wheel probe geometry is carefully selected such that the beams generated by the array are suitable for the inspection. For this reason physical measurements of the sound field from a conventional probe are made with a needle hydrophone and then array modelling software is utilised to design an array that will generate a similar sound field as shown in figure 4.

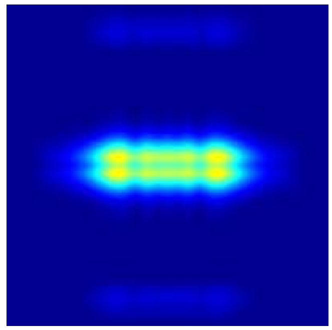
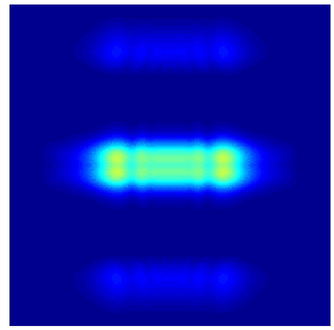
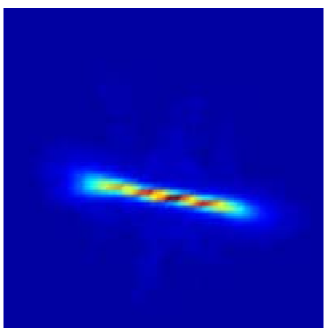
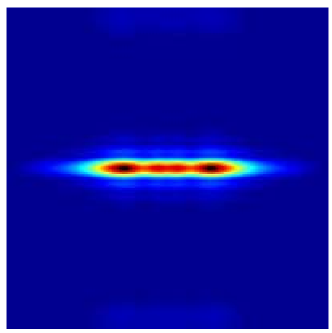
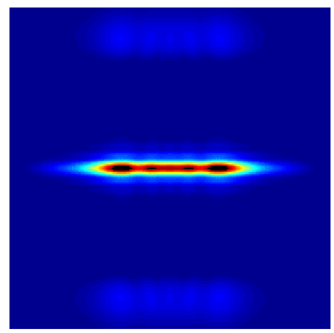
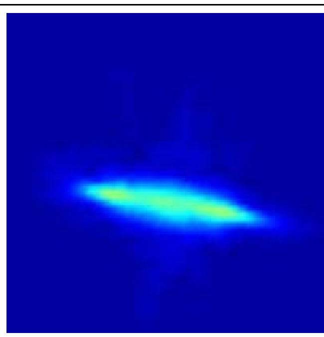
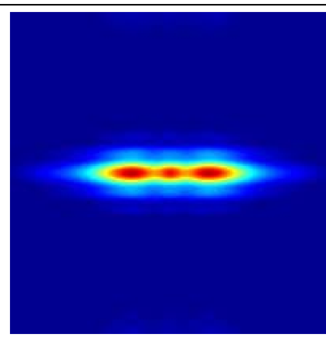
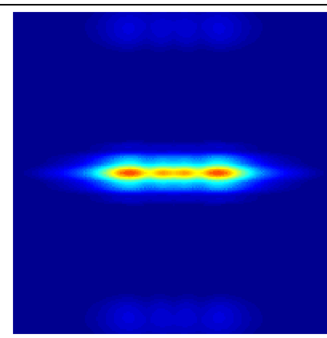
	Standard Probe, 7.5 MHz with mechanical cylindrical focus	32 element array 37.5 mm electronic focus @ 7.5MHz	32 element array 37.5 mm electronic focus @ 10MHz
25mm depth			
35mm depth			
45mm depth			

Figure 4: Comparison between measured sound field for a conventional probe and simulated sound field for two possible array configurations.

Finite element modelling is used to ensure that wheel probe generates a consistent contact patch between the wheel and the part to be inspected. Depending on the application dry coupling of the wheel probe is possible otherwise in most cases only a small amount of water couplant (deployed as a mist) is required to ensure suitable coupling. At the time of writing array lengths of up to 100 mm have been successfully utilised to permit high resolution scans (1.6 mm scan pitch resolution) with full waveform capture, at speeds of up to 200 mms^{-1}.

Array frequencies of 1 MHz, 2 MHz, 5 MHz and 10 MHz have been used in the wheel probe for a wide range of inspections of metallic and composite structures.

The system has been deployed in both manual and automated scanning configurations and a photograph of the manual RapidScan system is shown in figure 5.

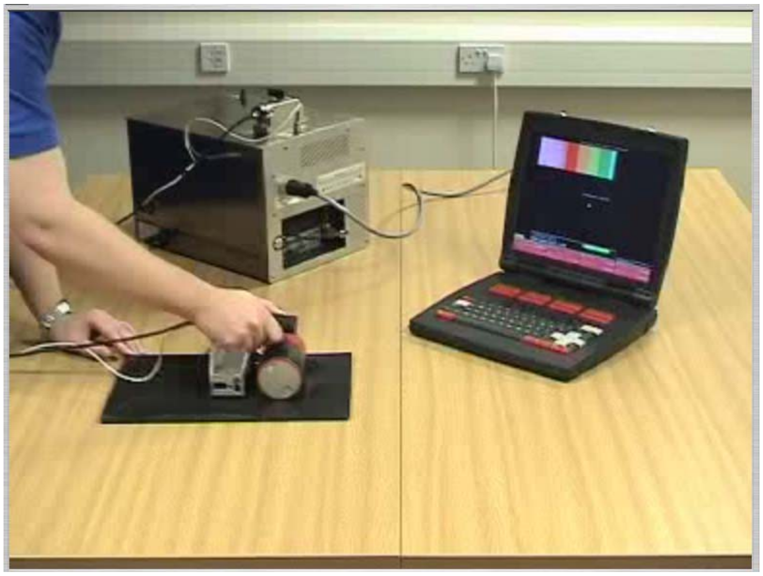


Figure 5: Photograph of RapidScan system.

The following section provides example applications and typical test results from the inspection aerospace components.

Results: The RapidScan system was originally developed for the inspection of wing structure for production quality assurance of wing sealant application and for crack detection around fastener holes for in-service testing. In these applications a 50 mm wide 10 MHz wheel probe was utilised in two configurations; a 0-degree compression wave probe for the sealant evaluation and a 45-degree shear wave probe for the crack detection around the fastener. A typical joint configuration is given in the following figure.

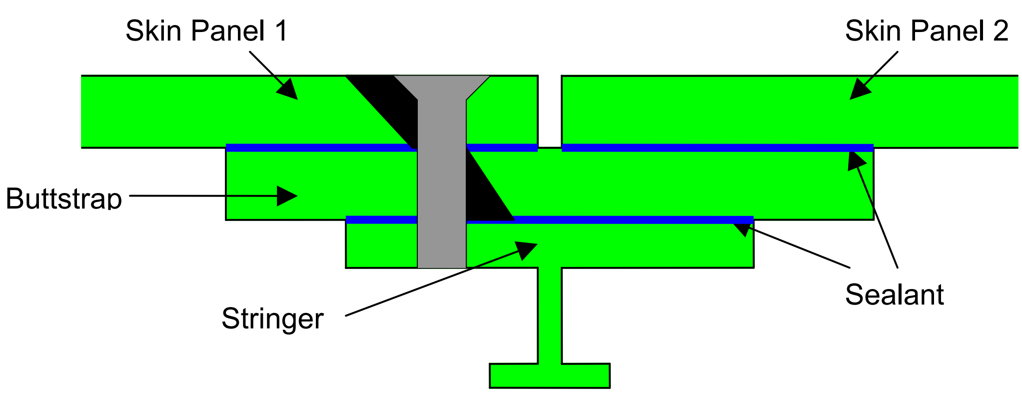


Figure 6: Typical wing skin joint configuration showing sealant and fastener locations. Possible crack locations are shown in black to the left and right of the fastener.

A typical scan result from a test pieces showing successful detection of sealant delamination is given in the following figure. Note that the first C-scan is provided as a coupling check whilst the second C-scan provides a map of the sealant thickness.

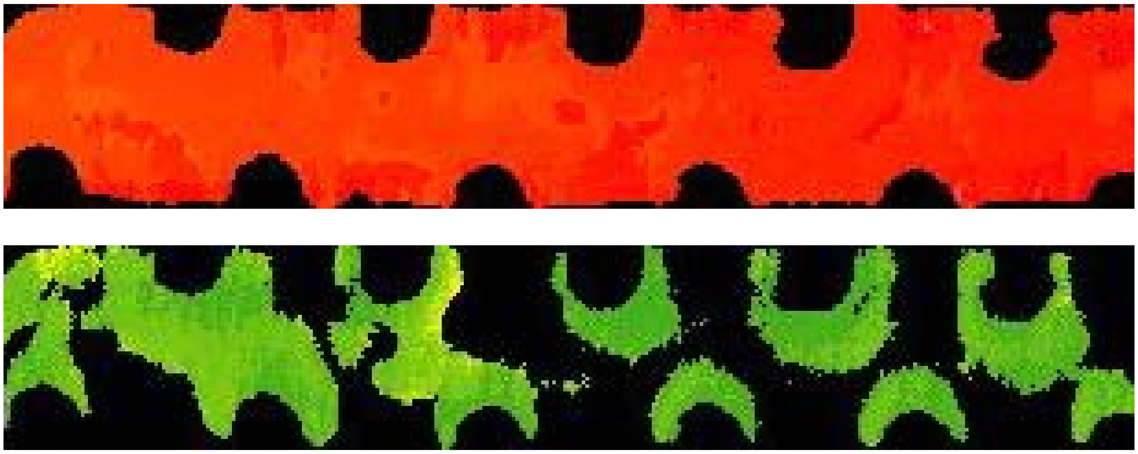


Figure 7: Scan of sealant bonding showing coupling check scan (top) and sealant bonding check (bottom)

Because of the high acquisition speed of the RapidScan system there is time to sweep the shear wave inspection angle between several angles to detect ‘off angle’ cracks. A typical scan result from test pieces showing successful detection of first and second layer cracks is demonstrated in the following figure.

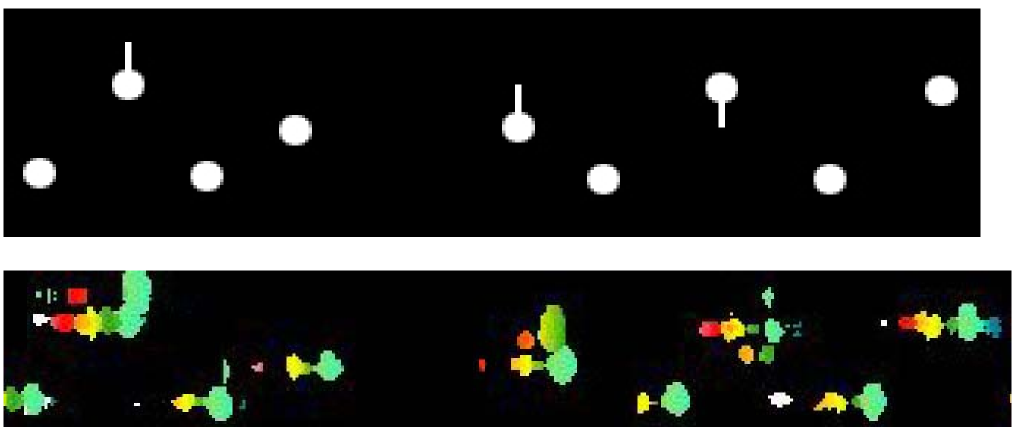
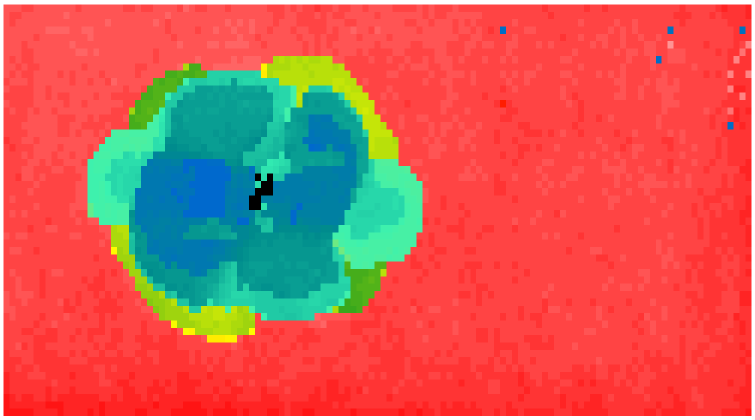


Figure 8: Rapid detection of first and second layer crack locations.

Recently the RapidScan system has been extensively used for the inspection of a wide range of composite materials for the detection and assessment of impact damage, fibre lay-up errors and porosity. In these applications the use of a real-time high frame rate B-scan or subsequent post processing of the C-scan data using B-scan cross-sectional analysis has provided un-precedented structural imaging of the composite material. Two examples of this are given below where a B-scan cross-section is used to image the topology of barely visible impact damage and to provide high resolution images of porosity.



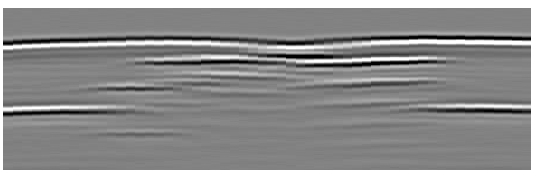
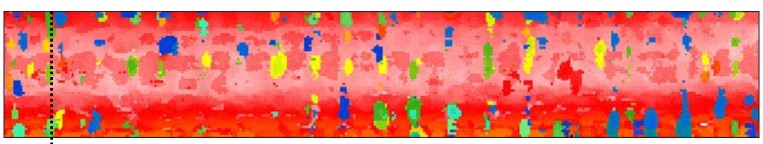


Figure 9: C-scan thickness image of impact damage for a 5 mm thick carbon fibre skin showing cross section B-scan view through central region of impact.



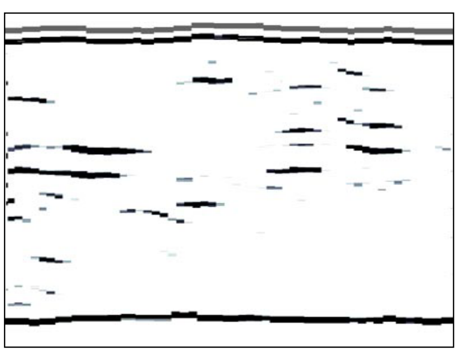


Figure 10: C-scan image of porosity in 5 mm cured pre-preg and cross section B-scan of porosity showing depth and extent of porosity.

In the above example the RapidScan wheel probe was deployed as a manual inspection tool to replace current A-scan single probe inspections. The system has also been successfully integrated with a number of automated scanning rigs to enable large area scanning of composite structures. In these applications high quality C-scans have been generated in a fraction of the time normally taken with single channel scanning systems. Due to the excellent coupling efficiency of the wheel probe these scans are of comparable quality to conventional immersion scans. The following figure shows a scan of a composite wing skin with bonded composite stringer re-inforcements.

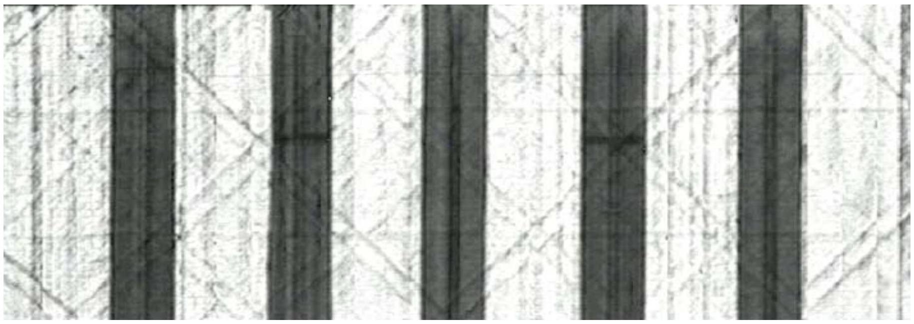


Figure 11: Large area RapidScan image of composite wing skin and bonded stringers.

Discussion: The use of the RapidScan wheel probe for manual C-scan inspection has clear advantages over current manual A-scan inspection methods. For aerospace inspections of stringer components and stringer bonding it is often possible to scan the component in a single pass, without the need for cumbersome scanning rigs, thus reducing the inspection time to a matter of seconds. The ability to perform full waveform capture provides a permanent record of the structure that can be used re-evaluate or re-analyse the structure at a later date.

For large area structures the use of a rapid array based inspection tool can reduce bottlenecks in production inspection and the use of a contour following wheel probe can help reduce the complexity of the scanning hardware.

Conclusions: This paper has presented a novel scanning system utilising phased arrays and rapid data capture to provide a real-time C-scan and B-scan imaging capability for large aerospace composite structures. Results have been presented which clearly show the benefit of high resolution B-scan images for the inspection and analysis of composite features such as impact damage and porosity.

References:

1. A M Robinson, B W Drinkwater and R J Freemantle. An integrated systems approach to automated scanning and analysis of engineering structures, Insight Vol 42, No 11 November 2000, pp 714-719.

2. C. J. Brotherhood, B. W. Drinkwater and R. J. Freemantle, 2003, An ultrasonic wheel-array sensor and its application to aerospace structures, Insight Vol 45 No 11 November 2003, pp 729-734.