LASER ULTRASONIC INSPECTION OF HONEYCOMB AIRCRAFT STRUCTURES

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INTRODUCTION

Ultrasonic methods have been used extensively for the inspection of advanced composite materials and adhesively bonded structures. Conventional ultrasonic inspections usually require couplants to propagate ultrasonic waves to and from the part surface. Delaminations, porosities, and foreign inclusions in composite laminates can be successfully detected by pulsed-echo and through-transmission modes of ultrasonic inspection. Debonds in adhesively bonded structures are most effectively detected by the through-transmission mode of ultrasonic inspection.

The need for coupling media creates considerable inconvenience in the conventional ultrasonic inspection process. Another problem is the requirement to align the incident sound beam to within 3 degrees of the normal to the part surface in the pulse-echo mode. This requirement necessitates the laborious rotation and tilting of the transducers to follow the contour of a part surface with complex geometries. Either the part geometry is pre-programmed into the memory of the controller, or the computerized transducer manipulator must be trained before the inspection to carry out the contour following. This also requires expensive and unique part fixtures to hold the part in a precise location and orientation.

A novel inspection method using lasers for the generation and detection of ultrasound has been cooperatively developed by General Dynamics and Ultra Optec/National Research Council of Canada. The laser ultrasonic method does not require a couplant between the inspection system and the part. Details of the principles and experimental arrangement of the laser ultrasonic inspection systems are contained in Monchalin's papers (References 1 through 4). In this paper, a brief system description will be followed by results obtained on primarily adhesively bonded honeycomb structures with metallic and non-metallic cores.

SYSTEM DESCRIPTION

Two laser ultrasonic inspection systems were used in the honeycomb structure inspections. A laboratory prototype at General Dynamics that uses a retro-reflective coating for signal enhancement and a system at Ultra Optec/Industrial Materials Research Institute, National Research Council in Canada that does not require a signal enhancement coating. Data obtained from both of these systems were analyzed by the data analysis/imaging system at General Dynamics. The system architecture of the prototype systems has been described in Reference 1.

INSPECTION RESULTS

The prototype systems in General Dynamics and Ultra Optec/NRC have been used extensively on a wide variety of composite aircraft parts with severely contoured surfaces and radii. Results from selected adhesively bonded structures are presented in this paper. Some of the bonded specimens were jointly selected by Sacramento Air Logistics Command and NRE Inc. as part of their survey on the capabilities of state-of-the-art ultrasonic inspections. A wedge-shaped honeycomb specimen with implanted defects was fabricated at General Dynamics.

Figure 1 presents LUIS inspection results obtained by using the coatingless prototype on a 5 x 19 x 1-1/8-inch Al honeycomb specimen. The implanted defects in this specimen are located at the bondline between the skin and the Al honeycomb core. Both the amplitude scan and the depth scan in Figure 1 revealed all the implanted defects. Under the depth scan is a B-scan of a line cutting across the implanted defects near the bottom of the specimen. The first vertical line at the left reflects the front surface of the specimen. The second vertical line represents the bottom of the laminate skin and the bondline with the honeycomb core. The presence of the implanted defects is evident from the B-scan by the multiple reflections at those locations. Under the amplitude scan is a cascaded A-scan showing the video waveforms of a horizontal slice cut across the implanted defects near the bottom of the specimen. The defect locations are clearly indicated in the cascaded A-scan.

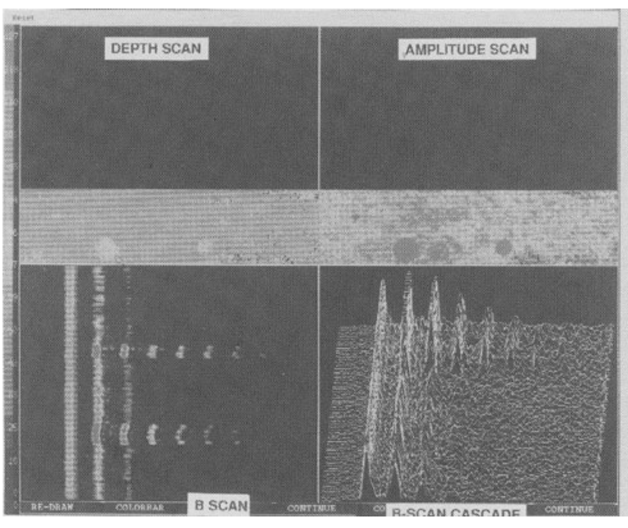

Figure 1. LUIS C-scan of A Specimen With Implanted Defects at Bondline.

Figure 2 presents results obtained by using the coatingless prototype on NRE-27, also a 5 x 19 x 1-1/8-inch Al honeycomb specimen with gr/ep composite skins. Defects were implanted on the skins of this specimen. The upper left corner of Figure 2 shows the C-scan results on one side of the specimen with two defects clearly shown. The upper right hand corner presents an enlarged view of one of the defective areas. A typical video waveform for a defect-free area is shown in the lower right-hand corner while that for a defective area is shown in the lower left-hand corner. The vertical dashed lines in the video waveform displays represent the location of the software gates used for defect discrimination. It should be noted that the amplitude of the signals reflected from the bondline interfaces of a good bond are generally smaller that those from a debonded areas.

The results presented in Figures 1 and 2 show samples of the data acquisition/analysis capabilities of the General Dynamics and Ultra Optec/NRC LUIS prototype systems. Although the specific digital signal processing (DSP) algorithms may vary for different material configurations, the following is a typical DSP procedure performed in real-time by the array processors:

1) Normalization and alignment of data
2) Exponential correction for attenuation
3) Filtering (time or frequency domain)
4) Analytic transformation (rectification with FFT's)
5) Defect discrimination with multiple gates.

System resolution can be judged from the real-time digital video waveforms shown in Figure 2. The A-, B-, and C-scans obtained by amplitude and depth gatings can be imaged with various scales. A-scans can also be presented in a cascaded format to aid in defect discrimination.

The power of digital data acquisition and software gating in the LUIS prototypes can be further illustrated by the inspection results obtained on a wedge-shaped honeycomb reinforced specimen with various kinds of implanted defects. The specimen has gr/ep skins with Nomex honeycomb core and a gr/ep closure. A sketch of the specimen is presented in Figure 3 with the dimensions indicated. The types of defects implanted in the structure simulating typical manufacturing defects are listed as follows:

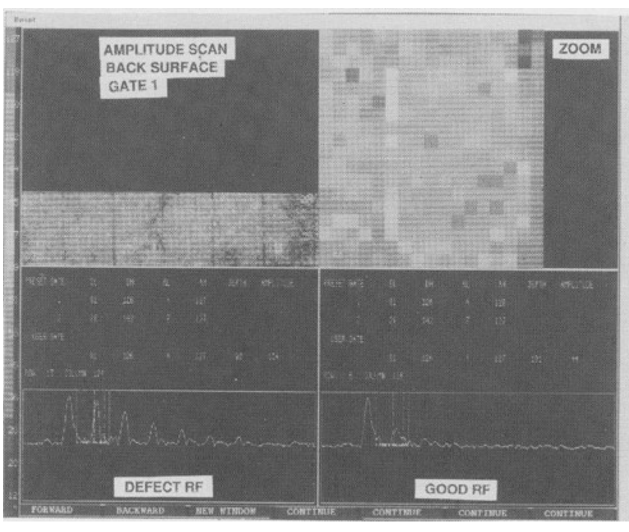

Figure 2. LUIS C-scan for Specimen NRE-27 (LOC-12)

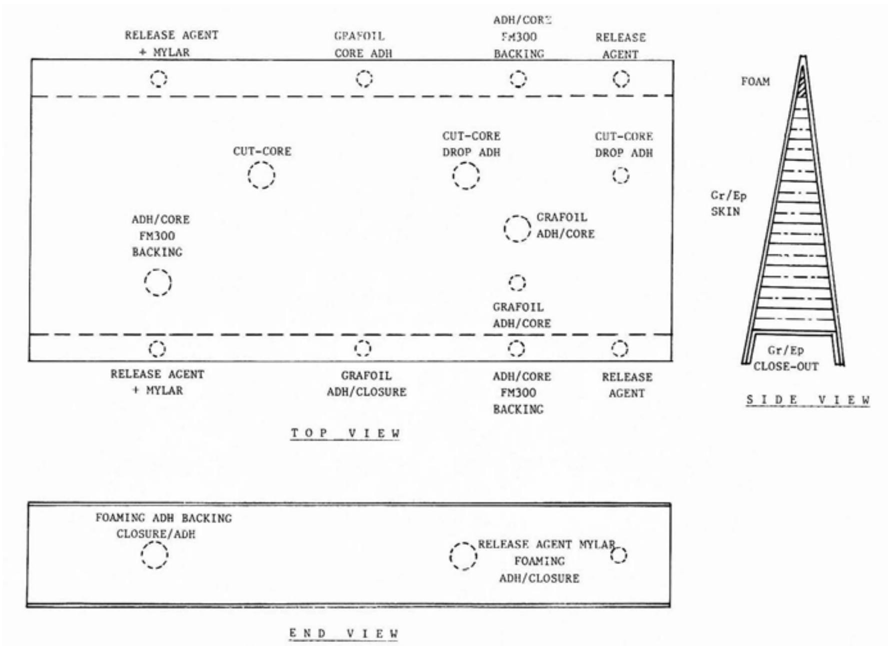

Figure 3. Wedge Specimen Geometry and Defect Locations

Cut-core	- The core is cut to the shape of the defect by approximately 1/16-inch so that adhesive is not in contact with the core.
Cut-core, drop adhesive	- In addition to the cut-core, the adhesive is cut to the same size and placed in the cut-out without touching the inside of the skin.
Release agent	- A release agent is smeared on an area with the shape of the defect on the inside of the skin so the adhesive will not adhere to the substrate.
Adh/core FM300 backing	- A backing material typical of FM300 adhesive is placed at the interface of the adhesive to core.
Grafoil adhesive/core	- A Grafoil cut to the shape of the defect is placed between the adhesive and core.
Release agent + Mylar	- After a release agent is smeared on the inside of the skin, a Mylar cut to the defect shape is placed between the skin and the adhesive to ensure non-adherence.
Grafoil adhesive/closure	- A Grafoil cut to the shape of the defect is placed between the adhesive and the closure.
Release agent + Mylar, foaming adhesive	- "Release agent + Mylar" is applied at the foaming adhesive between the adhesive and closure.
Backing, foaming adhesive	- Backing paper between closure foaming adhesive and closure.

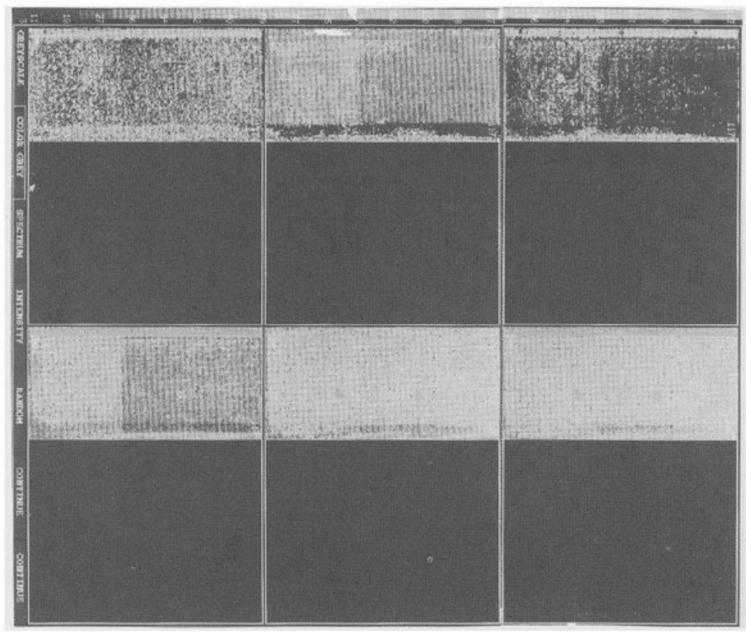

Figure 4. LUIS C-scans for Wedge Specimen

Figure 4 presents inspection results obtained by using the General Dynamics laboratory prototype LUIS with a layer of removable retro-reflective coating sprayed on the specimen surface for signal enhancement. The amplitude and depth scans obtained by using three different software gates are shown in the figure. The original color C-scans of these reproductions show that a complete map of all the implanted defects can be discerned by combining results from the three gates.

DISCUSSIONS

The honeycomb specimens selected in this study encompass a wide variety of core thicknesses, skin and core material types, as well as closure configurations. Defects implanted in these specimens are representative of inclusions, delaminations, and debonds located in either the laminate or the bondline. The results presented in this paper show that the LUIS prototypes with the associated digital data acquisition/analysis module can detect these implanted defects. The majority of these different defects may be detectable by conventional ultrasonic technique using a through-transmission mode of inspection. However, under circumstances where only one-sided access is available, conventional ultrasonic inspection methods with analogue data systems are severely limited when applied in a pulse-echo mode of operation. In fact, some of the specimens used in this study were inspected by conventional ultrasonic methods. Comparison of the results obtained by the two methods indicated that laser ultrasonic inspection using the General Dynamics and Ultra Optec/NRC prototypes is more sensitive than conventional methods for defect detection at the bondline.

Although all the specimens used in this study have flat surfaces with no curvatures, the wedge specimen does provide a situation where the incident laser beam is at an oblique angle with the normal to the surface. Therefore, it may be projected that the LUIS prototypes will be equally effective in detecting flaws at the bondline of contoured adhesively bonded honeycomb structures.

REFERENCES

1. J.-P. Monchalin, J.-D. Aussel, P. Bouchard, and R. Heon, Review of Progress in Quantitative NDE, Vol. 7B, edited by D.O. Thompson and D.E. Chimenti (Plenum Press, New York, 1988), p.1607.
2. J.-P. Monchalin and J. Wagner, Nondestructive Testing Handbook, Vol. 7, Ultrasonic Testing, American Society of Nondestructive Testing, 1991.
3. J.-P. Monchalin, to be published in Review of Progress in Quantitative NDE, Vol. 11, edited by D.O.Thompson and D.E. Chimenti (Plenum Press, New York, 1992).
4. C. Padioleau, P. Bouchard, R. Heon, J.-P. Monchalin, F.H. Chang, T.E. Drake, to be published in Review of Progress in Quantitative NDE, Vol. 11, edited by D.O. Thompson and D.E. Chimenti (Plenum Press, New York, 1992).