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PHASED ARRAY ULTRASONIC APPROACH FOR CHARACTERIZATION OF HIDDEN REGION OF IMPACT DAMAGE IN COMPOSITES

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ABSTRACT

This study explores the use of phased array UT for the potential characterization of hidden regions of impact damage in composites. An idealized ray tracing model was developed, demonstrating the sensitivity of transmitted signals to the hidden impact profile angle and asymmetry in the profile. Experimental studies were also performed highlighting the differences in the response from columnar and trapezoidal profiles. FMC processing algorithms were implemented to improve the signal-to-noise for the pitch-catch characterization routine.

Keywords: composites, impact damage, phased array, ultrasonic NDE

NOMENCLATURE

FMC	full matrix capture
PAUT	phased array ultrasonic testing
PTFE	polytetrafluoroethylene
TOF	time-of-flight
UT	ultrasonic testing

1. INTRODUCTION

The increasing use of polymer-matrix composites for aircraft structures has led to an interest in improved lifecycle management through damage tolerance [1]. Normal longitudinal ultrasonic testing (UT) can detect the presence of impact damage; however, this technique does not address the hidden damaged region under the top delamination front. Recent work has investigated pulse-echo angled-beam methods to characterize the profile of hidden impact damage regions [2-3]. Unfortunately, edge delamination diffraction signals are difficult to reliably detect in the presence of typical material noise [4]. To overcome this challenge, pitch-catch configurations are being considered for characterizing the hidden delamination fields [5]. Figure 1 presents a phased array UT (PAUT) concept for characterizing the hidden profile using a pitch-catch inspection. The basic goal of this approach is to discern the angle, θ, of the hidden delamination profile, distinguishing the trapezoidal from columnar profiles. The most promising concept leverages the amplitude and time-of-flight of oblique quasi-waves propagating through the hidden damage region. This PAUT configuration would ensure precise beam steering both laterally and varying angles in the composite part. To carefully position the pitch-catch array elements, knowledge of the top edges of the delamination field is also needed. Thus, a normal phased array inspection is critical to the design, in order to assess the exact position of the top impact damage profile. A full-matrix capture (FMC) approach is proposed for acquiring the necessary pulse-echo and pitch-catch signals for full characterization.

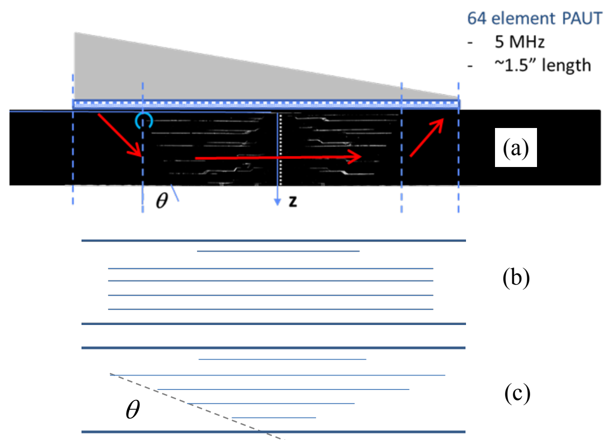

FIGURE 1: (a) DIAGRAM OF PHASED-ARRAY CONFIGURATION TO CHARACTERIZE THE HIDDEN DAMAGE PROFILE: (b) A COLUMNAR PROFILE, (c) A TRAPEZOIDAL PROFILE WITH HIDDEN ANGLE, θ.

2. MATERIALS AND METHODS

2.1 Ray Theory Model for Signal Interpretation

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Due to limitations with many UT simulation packages for this special inspection problem, an idealized ray tracing model was first developed to study the effect of waves propagating through different hidden delamination field profiles. Code was created to track multiple reflection of a set of rays through the pre-defined delamination fields in 2D. The routine assumes an idealized source that can create a series of rays at a fixed angle of incidence from a pitch element location, propagate the arrays through the delamination field, and receive the response at an approximate catch transducer location. Figure 2 presents the spatial location(s) of the received (pitch) signals, and the time-of-flight (TOF) of the corresponding received signal for a columnar profile and a trapezoidal profile with a hidden angle of 25° angle. The promising trend in the model is that there are secondary paths through the delamination field that are sensitive to the angle of the hidden layer. Features are clearly shown both in the location and TOF of signal arrival from varying source location. Several special cases for the delamination field have also been studied addressing asymmetry in the profile and gaps at the center of the profile. For these challenging scenarios, the ray theory model demonstrated the potential sensitivity to hidden impact damage angle and asymmetry. More rigorous finite element method simulations using PZFlex are being performed to better evaluate the expected response from a small array element, the full composite material model, and varying delamination profiles [6].

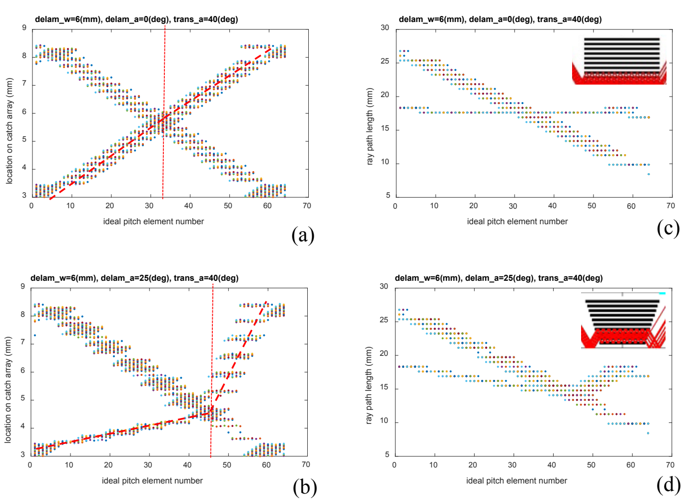

FIGURE 2: SPATIAL LOCATIONS OF RECEIVED SIGNALS FOR VARYING SOURCE LOCATION FOR (a) COLUMNAR AND (b) TRAPEZOIDAL PROFILES. RECEIVED SIGNAL TIME-OF-FLIGHTS FOR VARYING SOURCE LOCATION FOR (c) COLUMNAR AND (d) TRAPEZOIDAL PROFILES.

2.2 Full-Matrix Capture (FMC) PAUT Acquisition and Processing

An experimental test configuration was implemented using a 64 element 5 MHz contact phased array transducer. A test panel with a thickness of 6.4 mm (48 plies) was built with 7 PFTE (Polytetrafluoroethylene) inserts. The shape of the stack-up was created to produce a profile with a trapezoidal shape in vertical direction and a columnar shape in horizontal direction. FMC acquisition was performed across the 64 element array at both low and high gain settings. Progress is underway to implement special FMC processing algorithms to improve the signal-to-noise response for pitch-catch measurement. One concept under investigation is to estimate the mean response for equivalent source and receive element distances, and subsequently evaluate both the average and residual response correlated with the hidden profile.

3. RESULTS AND DISCUSSION

Results are presented in Figure 4, comparing the PAUT pitch response from element 1 at catch elements 1-64 for two different profile scans: (a) across the columnar profile and (b) across the trapezoidal profile. Clear differences are present both the

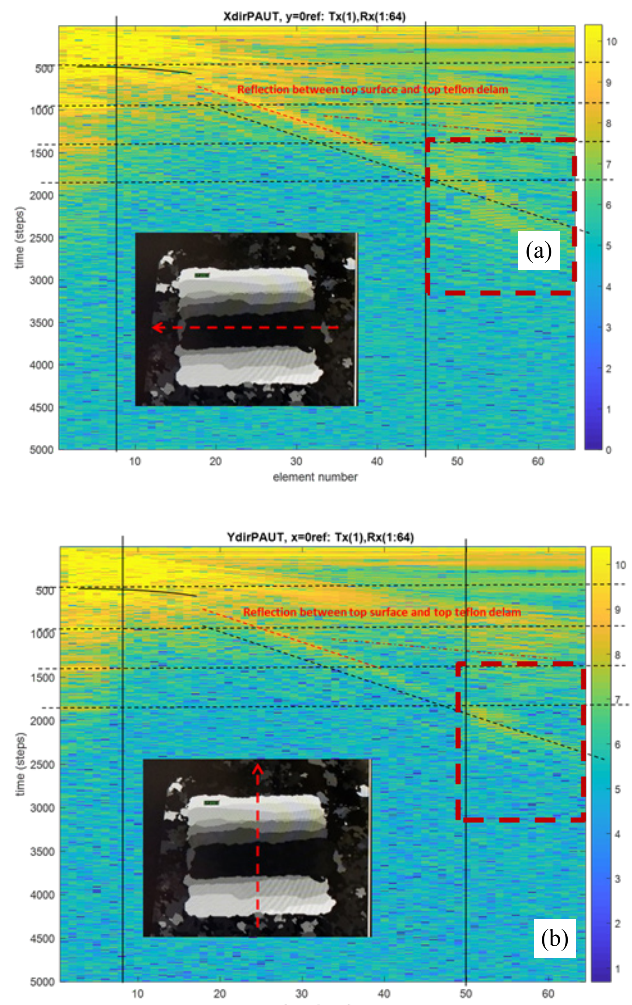

FIGURE 3: PAUT PITCH CATCH RESPONSE, FOR PITCH ELEMENT #1, WITH VARYING ARRAY POSITION CATCH ELEMENTS #1-64 (a) ACROSS THE COLUMNAR PROFILE, AND (b) ACROSS THE TRAPEZOIDAL PROFILE.

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primary path and the secondary signals through the delamination field due to the presence of different delamination profiles. However, more simulated and experiment studies are needed to verify and validate these initial PAUT indications.

4. CONCLUSION

In this work, phased array UT was studied for characterization of hidden regions of impact damage in composites. An idealized ray tracing model was introduced, demonstrating the potential sensitivity of transmitted signals to the hidden profile angle. Experimental studies with FMC processing were performed, highlighting the differences in the response from columnar and trapezoidal hidden profiles. Continued work is planned to use FEM simulation and follow-up experimental studies with more complex profiles, to further validate the hidden damage characterization technique.

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