46th Annual Review of Progress
in Quantitative Nondestructive Evaluation
QNDE2019
July 14-19, 2019, Portland, OR, USA

QNDE2019-6892

CASE STUDY OF MODEL-ASSISTED PROBABILITY OF DETECTION (MAPOD) EVALUATION FOR MANUAL ULTRASONIC INSPECTION OF FASTENER SITES FOR FATIGUE CRACKS

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ABSTRACT

This work investigates the application of model-assisted probability of detection (MAPOD) capability evaluation for manual ultrasonic inspection. Forward models are used to generate data that is incorporated into fast surrogate models for Monte Carlo simulations. Example evaluations highlight the value of the process to quickly assess performance sensitivity relative to varying inspection assumptions.

Keywords: cracks, fastener sites, model-assisted probability of detection, probability of detection, ultrasonic NDE.

NOMENCLATURE

MAPOD	model-assisted probability of detection
NDT	nondestructive testing
POD	probability of detection
UT	ultrasonic testing

1. INTRODUCTION

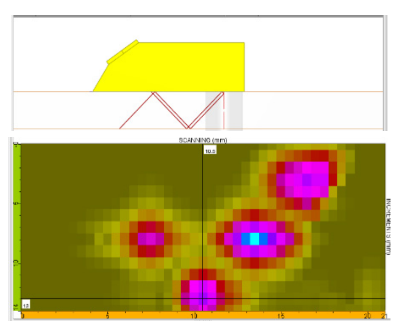
There is the potential for the growth of nondestructive testing (NDT) using portable, hand-held instrumentation to detect defects in multi-layered metallic structure and composites. However, challenges exist with manual NDT due to complexity and variability of typical aircraft structures [1]. Early large-scale probability of detection (POD) evaluations demonstrated considerable variability in repeated measurement by inspectors for the same crack, and significant variability between cracks of the same size [2]. Any evaluation of NDE performance must consider all key factors that influence reliability. Often, 'human factors' have been used as a label for issues with manual inspections that are not under control [3]. It is critical for a POD evaluation to address these limitation of inspection techniques.

The model-assisted POD (MAPOD) approach proposes to supplement empirical data with simulated results from physics-based model [4-5]. Variations due to the crack state and test conditions are ideally represented in the model as probability distributions of the input variables. Hybrid models incorporating both empirical and physics-based components can also be implemented, to address all key factors including those that cannot be adequately simulated [6]. Some recent work has considered model-assisted POD evaluation for manual NDT [7-8], studying the accuracy of the process. This work builds on prior work, demonstrating a process for generating synthetic POD assessments for varying inspection assumptions.

2. MATERIALS AND METHODS

2.1 Key Factor Assessment and Forward Model

Assessing the key factors is a critical step in any POD evaluation. For UT of fastener sites, considerable prior work has studied the key factors that influence the measured response [1,4,9-10]. CIVA UT has shown to be a promising tool for simulating automated UT scans of fastener sites [9-10]. Figure 1 shows an example simulated response for an angled-beam shear wave inspection using a contact (wedge) transducer, for a



(a)

(b)

FIGURE 1: (a) CIVA UT MODEL FOR FASTENER INSPECTION, (b) EXAMPLE C-SCAN MAP FROM CORNER CRACKS AT NEAR AND FAR SURFACE LOCATIONS.

fastener site with 3 mm near and far-surface corner cracks. For manual inspections, the evaluation must also consider the real-world sensitivity to manually positioning and orienting the hand-held transducer with respect to the fastener hole and crack site.

2.2 Model-assisted POD Evaluation Process

A diagram of the MAPOD evaluation process is shown in Figure 2. For this study, a surrogate model fit using empirical data was developed for the POD evaluation. The model considered varying crack location (both near-surface and far-surface cracks, shown in Figure 1), varying cracks size, and varying crack angle about the hole. Fast surrogate models using n-dimension interpolation were subsequently used for Monte Carlo simulations, enabling sampling of the model input parameters over different input parameters distributions. Lastly, of interest for manual inspection, the effect of degrading scan resolution was also considered in the study.

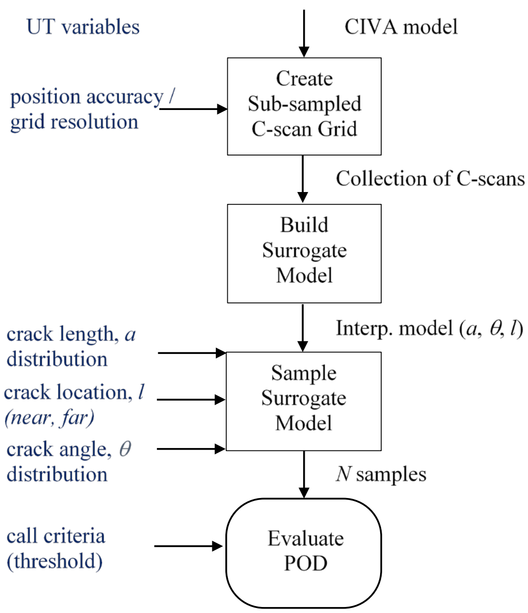


FIGURE 2: MODEL-ASSISTED POD EVALUATION PROCESS ADDRESSING VARYING SCAN RESOLUTION AND VARIABILITY IN CRACK SIZE AND ANGLE.

3. RESULTS AND DISCUSSION

Results are presented in Figure 3 for a model-assisted POD evaluation, considering both near and far crack detection, for varying crack size (up to 3 mm) and crack angles of (a) uniform distribution from -10° to 10°, and (b) uniform distribution from -20° to 20°. Monte Carlo simulations of 100,000 samples were used to form the detection estimates, for a series of fine crack length steps. Note, confidence or uncertainty bounds are not included in the plot since the data is entirely sampled from the model, and uncertainty on the input parameter distribution was not yet considered in the analysis. Scanning resolution was also studied (results not shown), comparing a fine scan resolution from 1 mm step size up to a rougher 3 mm resolution. Varying crack angle was shown to be a more significant factor on POD performance, with degrading performance with increased angle range to -20° to 20°. Note, the small step in the POD curve at 0.5 is associated with the difference in detection sensitivity for near and far crack locations. Scan resolution was found to not make much difference in terms of POD, where larger cracks can still be detected well with a rough 3 mm index resolution.

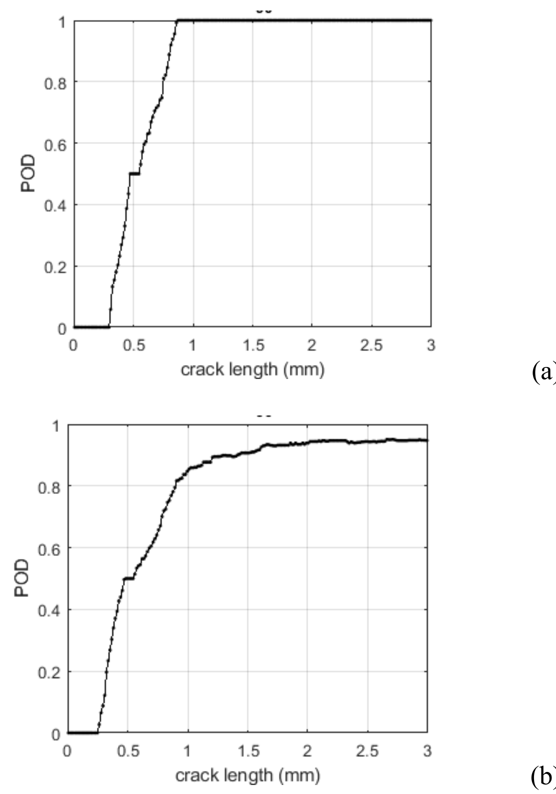


FIGURE 3: Model-assisted POD evaluation of near and far crack UT inspection for varying crack size and angles of (a) uniform distribution from -10° to 10°, and (b) uniform distribution from -20° to 20°.

4. CONCLUSION

This work investigated the application of model-assisted probability of detection (MAPOD) capability evaluation for manual ultrasonic inspection. Forward models were used to generate data that was incorporated into fast surrogate models for Monte Carlo simulations. Example evaluations highlight the value of the process to quickly assess performance sensitivity relative to varying inspection assumptions. Continued work is planned to refine the evaluation process, add additional parameters such as multiple layers and sealant conditions, and ideally verify the accuracy of the MAPOD results with empirical data using multiple inspectors.

ACKNOWLEDGEMENTS

Portions of this work were supported through a USAF Phase I SBIR Award to TRI/Austin entitled, "Assisted Data Analysis

for Portable Nondestructive Inspection” (Topic AF181-50).

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