Nondestructive Evaluation for Damage Tolerance Life Management of Composite Structures

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Polymer matrix composites (PMCs) are experiencing a growth in their use for civilian and military aircraft. However, the certification process for PMCs as a function of application can leads to new requirements for nondestructive inspection/evaluation (NDI/E). For example, in metallic structures current practice as defined in MIL STD 1530Dc1uses slow crack growth analysis which requires the NDI technique to have a defined probability of detection (POD) curve to enable risk calculations. However, certification processes used to date for PMCs are closer to safe-life methods where the need for validated NDI is different. Much of the development of NDI methods for PMCs has been focused on the inspection during production to ensure the composite does not have defects larger than the set detection thresholds, or in response to events while in use, such as impacts. However, there is a desire to alter the approach for managing PMCs structures in the US Air Force to follow slow damage evolution criteria as is done for metallic structures today. To realize this desired capability, the use of NDI must evolve from the detection of fatigue cracks above a certain size, as with metallic structures, to a detailed characterization of the geometry of defects found in PMCs.

The presentation and affiliated paper provide an overview of the predictive modeling required to realize damage tolerance based on slow damage evolution in PMCs, followed by much greater detail on the development of NDI-based methods for metrics of damage that are required for these models. The use of ultrasound for nondestructive evaluation (NDE) is explained in much greater detail. The nature of the scattering and mode conversions of ultrasound in typical PMC structural elements presents an expanded domain of parameters that must be addressed. The technical approach has explored conventional pulse-echo methods, including resolution of tip diffractors from delaminations at the individual ply level. The amplitudes of these responses are quite small, leading to an alternative approach based on localized single-sided pitch-catch methods that evaluate the ultrasound that propagates through and around a damaged region, such as the typical damage field resulting from an impact event. The current approach uses the signal transmitted through damaged regions to extract features indicating matrix cracking or internal geometric attributes of delaminations that supplement the conventional one-sided pulse echo measurement. Current efforts to realize this capability, including model-based methods and feature extraction approaches, are addressed and progress to realize the objective are summarized. In addition, verification of the damage state is addressed by destructive methods to ensure the ground truth for the measurements is known and used a reference for any metrics in the performance of this approach. With this capability, the Building blocks are in place to realize slow damage growth damage tolerance for PMC structures.

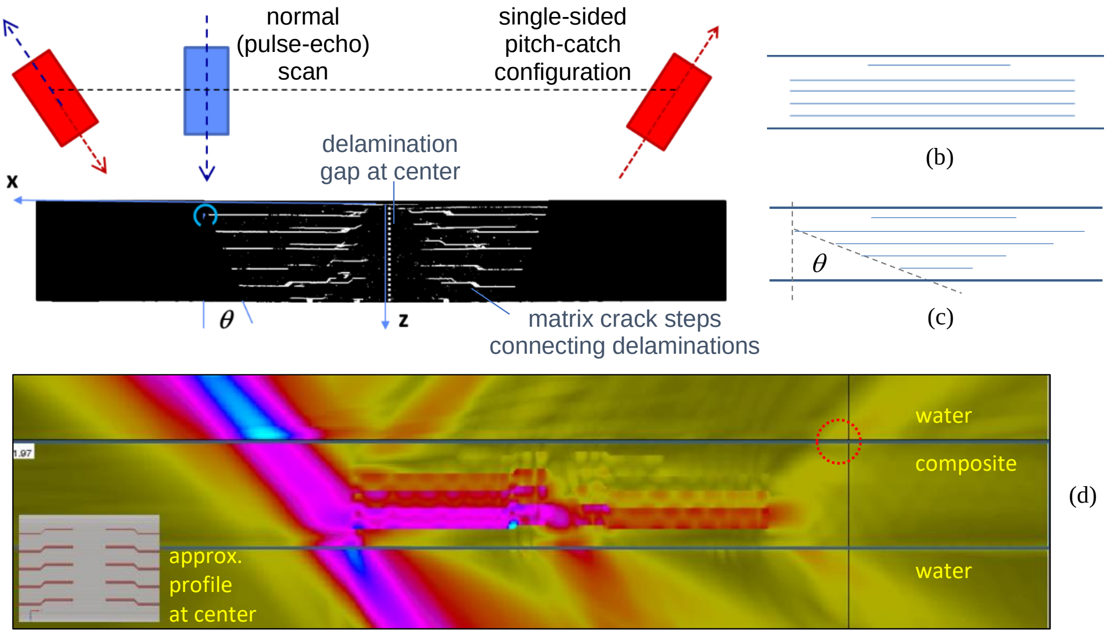

Figure 1: (a) Diagram of single-sided pitch-catch configuration for inspection of hidden delamination region of impact damage, showing micrograph of example cross-section. Diagrams of impact damage (b) columnar and (c) diamond profiles showing hidden damage angle. (d) Maximum ultrasonic response in 2D cross-section of columnar delamination profiles with insert showing approximate real impact damage profile at center of test sample.