**Ultrasonic array imaging for composite materials using reverse time migration**

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ABSTRACT

Composite materials such as carbon fibre reinforced polymers (CFRP) have seen increased usage as structural materials for their light weight and mechanical properties. Ultrasonic phased arrays are commonly used for the non-destructive evaluation of those materials and structures to ensure safe operation, due to their ability to image subsurface defects. In most scenarios, only single-sided access is needed for ultrasonic phased array inspection, which is important for large structures such as aircraft fuselages and structures having complex geometries.

Conventional delay-and-sum imaging such as the total focusing method (TFM) obtains the image intensity by estimating the travel time of the ultrasonic signals, assuming that rays from the source go in straight lines. However, for complex media such as CFRP which is strongly anisotropic and multi-layered, the straight ray assumption is only valid when the anisotropy is homogeneous and translationally invariant. Therefore, it is not always straightforward to apply TFM to obtain an accurate representation of the internal structure, particularly in scenarios where ray curvature and/or refraction are involved as occurs in, for example, curved components, thick sections with ply drops and tapers, and defects such as wrinkles.

This work investigates the use of reverse time migration (RTM), a common imaging technique in geophysics for multi-layered media, for defect detection in CFRP. Unlike ray-based imaging such as TFM, RTM does not require the assumption of straight ray paths or explicit ray-tracing, and can work with any wavefield propagation model including, for example, numerical methods such as finite element (FE). The image intensity of RTM is obtained by cross-correlating a forward wavefield, which propagates the excitation signal from the sources in FE, and a reverse wavefield, which backpropagates the time-reversed measured signal in the same FE model. RTM and TFM are compared in several representative scenarios with various degrees of material complexity, and their relative merits are discussed. It is shown that the RTM and TFM results are equivalent in the case of a single point target in a planar CFRP laminate when the RTM process uses an analytical, single-mode wave propagation model. It is also shown that while FE can be used to provide a more general RTM wave propagation model, this potentially comes at the expense of increased imaging artefacts due to the implicit inclusion of multiple wave modes.

**Keywords:** ultrasonic testing, reverse time migration, total focusing method, composite materials