**A Statistical Approach to Wrinkling Detection in Composite Materials**

**Matthew G. Chandler1a, Anthony J. Croxford2, and Paul D. Wilcox1**

1Department of Mechanical Engineering

University of Bristol, Bristol, U.K.

aCorresponding author: m.chandler@bristol.ac.uk

ABSTRACT

Ultrasonic inspection is an attractive NDE methodology as it is reliable, cheap, and is not limited to surface inspection. Image processing algorithms such as the total focusing method (TFM) may be applied to ultrasonic array data, providing an insight into how waves are scattered within the component, subsequently enabling the localization of any features of interest. A challenge with this approach is that waves may be scattered by any feature within the sample, so it is often left to an operator to determine which signals, if any, arise from a flaw. In materials such as carbon-fiber reinforced polymers (CFRP), the ultrasonic wave will scatter from each layer within the material, which may obscure signals arising from flaws. The detection of out-of-plane fiber waviness, or wrinkling, is a particular challenge as there is no additional scattering, but rather the displacement of the layer out-of-plane will result in a corresponding change to the location in the TFM image that signals are reconstructed. Here, we seek to address this problem by thoroughly characterizing the local properties of the image at every location within the sample. As the scattered signal is expected to be highly correlated between similar layers in the structure, we calculate the autocorrelation of a small area centered on a given location within the image. In pristine material, this will be consistent across all locations, which is characterized to produce a distribution of acceptable values. Wrinkling is then identified by testing against this distribution: the autocorrelation is expected to change significantly, and may be quantified by identifying the deviation from this distribution. The detection ability of this method is evaluated by using receiver-operating characteristic curves, and the impacts of varying the autocorrelation area are explored. It is then compared to an image processing approach identified from the literature, in which the orientation of the ply layers is extracted from the instantaneous phase of the TFM image. We find an equivalent performance for severe levels of wrinkling, with improved performance at low severities, arising from the use of all of the information in the image, rather than just the phase.

**Keywords:** ultrasonics, total focusing method, statistical analysis, carbon-fiber reinforced polymers, wrinkling detection