Aerospace Composite Structure Testing Using Commercially Available Laser Ultrasound Systems

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Composite airframe structures are evolving towards greater complexity with increased use of materials and assemblies utilizing honeycomb core, foam core, bonded joints instead of fasteners, ceramic matrix composites (CMC's), and metallic/organic additive manufactured (AM) components. Water-coupled ultrasound (UT) and contact UT have traditionally served as primary inspection methods for carbon-fiber reinforced polymer (CFRP) laminate components in high-rate aircraft manufacturing environments. However, water-coupled UT has limited inspection utility for many of these more complex materials and structures. Water-coupled UT often cannot penetrate septumized honeycomb, foam core, or porous laminates and adhesives. Exposed core, either open or through perforated skins, cannot get wet. Bonded joints exhibit rough and uneven surface texture and geometry that prevent reliable UT signal transfer via contact coupling methods. The surface roughness, porosity, and acoustic impedance of oxide and non-oxide CMS's prohibit efficient signal transfer of water coupled UT. Also, in many instances during manufacture, CMC's cannot get wet for necessary inspections. Finally, the necessity for high-rate manufacture of complex assemblies will drive reliance on increased in-process inspections rather than waiting for final inspections, since final assemblies may become too complex to inspect or too costly to repair or scrap. In-process inspection of green materials, such as during fiber lay-up, will require inspection methods that are non-contact and do not rely on coupling fluids. In order to meet these emerging inspection demands, the aerospace manufacturing NDI "toolbox" must expand to include various non-contact technologies such as thermography, shearography, air-coupled UT, laser UT, electromagnetic methods (millimeter wave, GHz, THz), digital radiography methods, etc. Although many of these technologies have been available for decades, they have not reached widespread manufacturing maturation due to lack of universal industry demand or relatively high systems cost. As argued above, the demand for these non-contact technologies may be on the rise driven by material-complexity requirements. Also, with advancements and proliferation associated with suppliers, the barriers-to-entry associated with high costs are declining. Laser ultrasound provides a viable alternative to water-coupled and contact ultrasound while offering several potential advantages: it is non-contact; it requires no coupling fluid; it overcomes many surface coupling issues; it is inherently frequency-broadband; it is requires reduced geometry contour following; it can provide improved resolution; finally, it may provide increased scan rates. Historically, laser ultrasound inspection equipment was very large and expensive. Gas CO2 laser source systems cost several millions of dollars, and occupied hundreds of square feet of factory floor space with large scanning heads. Over the last few years, solid state laser sources and novel optical-acoustic receiver technologies have become commercially available that offer compact cabinet-size systems an order of magnitude cheaper than these previous laser UT systems. Furthermore, the availability of higher frequency laser systems have provided the option of transmission and reception via fiber optics. This allows compact scan head distribution over several meters in confined spaces, and provides the added benefit of increased portability. These developing features are making laser UT a competitive alternative for the aerospace manufacturing environment. In order to demonstrate manufacturing relevance, we will present the results of testing performed on aircraft components and materials using commercially available laser ultrasound systems. Comparisons will be made to traditional water-coupled as well as air-coupled ultrasound to demonstrate equivalence and benefits of the laser ultrasound approach. Results will highlight advantages of laser UT frequency bandwidth, signal-to-noise, defect resolution, and contour following. Our laboratory testing efforts act as a precursor for transitioning laser UT to fully-automated robotic scanning systems for use in high-rate manufacturing environments. In addition to test results, we will briefly describe system requirements needed to integrate the relevant technologies with production scanning systems.