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Application of Laser Ultrasonics for the Non-Destructive Inspection of Complex Composite Aerospace Structures

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Abstract
Laser Ultrasonics is a non-contact inspection technology that uses lasers to induce and detect ultrasonic waves in a material system. LaserUT™, the Lockheed Martin (LM) developed pulse-echo implementation of Laser Ultrasonics for composite structures, has been used to perform non-destructive inspections of over 22,000 production parts at the LM Aeronautics-Fort Worth facility since the first of two production LaserUT systems went on-line in May 2000. The systems have been approved for use on a variety of aircraft programs including the F-2, F-16, F-22 and F-35. LaserUT was considered a key discriminator for Lockheed Martin by the Joint Strike Fighter selection committee in the JSF competition.
Inspection of complex-shaped composite aircraft parts, such as the inlet ducts of military aircraft or the fuselage stringer sections utilized by commercial aircraft manufacturers, has been very difficult with conventional Ultrasonic NDI systems. LaserUT is highly advantaged for applications with challenging structures that would typically require rigid tooling and custom transducer assemblies, and can be up to 10 times faster than state-of-the-art conventional UT systems. For the most complex of these structures, LaserUT is an enabling technology, allowing the inspection of part configurations previously considered uninspectable by automated systems.
LaserUT greatly simplifies the NDI inspection process. LaserUT typically requires only simple, or no tooling fixtures – most parts can be inspected on a table or on the carts used for transporting them. The system is highly automated, without complicated setup procedures, 3-point alignments/corrections, gain/damping parameters, or most of the other settings and setup time typically associated with conventional ultrasonics. Gates are not required, as the system captures and stores 100% of all waveform data to support advanced data visualization techniques, in addition to standard C-scan images. The end result is an easy-to-use system that acquires the same high quality data regardless whether the operator has 20 years experience in ultrasonics, or was just qualified yesterday.
LaserUT is protected by over 40 domestic and international patents, and has been licensed to PaR Systems, Inc of Shoreview, Minnesota, for commercialization of the technology.
Keywords: Laser ultrasound, LaserUT, pulse-echo, complex, composite, aerospace, tooling

1. Introduction

In 1983, the General Dynamics Corporation's Fort Worth Division began research into the exciting new field of Laser Ultrasonics. At a time when composites were just beginning to see use as large flat wing skins and horizontal / vertical stabilizers, it was understood that one day aircraft would be built mostly from carbon fibre composite [1]. Composites give aircraft designers the freedom to create structures not physically or economically possible with metals.

After years of research, numerous technological advancements, and several prototype laboratory systems – as well as a couple of corporate transitions - the decision was made in 1997 by Lockheed Martin to begin construction of two LaserUT systems (as the laser ultrasonic non-destructive inspection systems were now called). The first system, internally referred to as Alpha, was developed to be a technology demonstrator and test bed for future development. Online in January of 1999, the Alpha LaserUT system was

one of Lockheed Martin's "showcase technologies" during the JSF competition. Thousands of US Air Force, Navy, and Marine Corp officers, Pentagon officials, congressmen, congressional staffers, foreign government representatives, and other dignitaries received a first-hand look at an emerging technology while touring the Alpha facility. Having proven its cost-saving potential to the industrial engineering and quality assurance communities, LaserUT was recognized by the Joint Strike Fighter selection committee as one of the key factors in the selection of Lockheed Martin to build the Joint Strike Fighter.

Even before the Alpha system was completed, work was started on Beta, the second LaserUT system. In May of 2000, after an exhaustive evaluation, LaserUT and the Beta system were cleared to begin full time production use on the F-22 program as a standard pulse-echo ultrasonic inspection system. A second production LaserUT system, Gamma, went online in October of 2004. Together, Beta and Gamma have now inspected over 22,000 production composite parts for Lockheed Martin on the F-2, F-16, F-22, and F-35 programs.

In over 8 years of production use, LaserUT has produced not only significant cost savings versus conventional ultrasonic testing, it has become an enabling technology for Lockheed Martin.

2. LaserUT: An Enabling Technology…

Not long after the Beta LaserUT system entered regular production use at Lockheed Martin, a manufacturing problem arose on the F-22 program. A section of one of the ducts, originally designed to be metallic, was proving to be very difficult to manufacture. The decision was made to construct the part out of composite. Although this was relatively straightforward, the supplier was unable to meet the F-22 requirement of 100% automated inspection with their conventional water squirter system.

2.1 …For Inspection

The first article of the new composite duct section, manufactured at a facility in California, visited several dedicated ultrasonic inspection houses as Lockheed Martin tried to solve the inspection problem. For over a month the automated inspection attempts failed, primarily due to the complex radii and the prominent "bulge" in one of the part's faces. Finally, the duct (Figure 1) was shipped to the LaserUT production inspection system in Fort Worth, Texas.

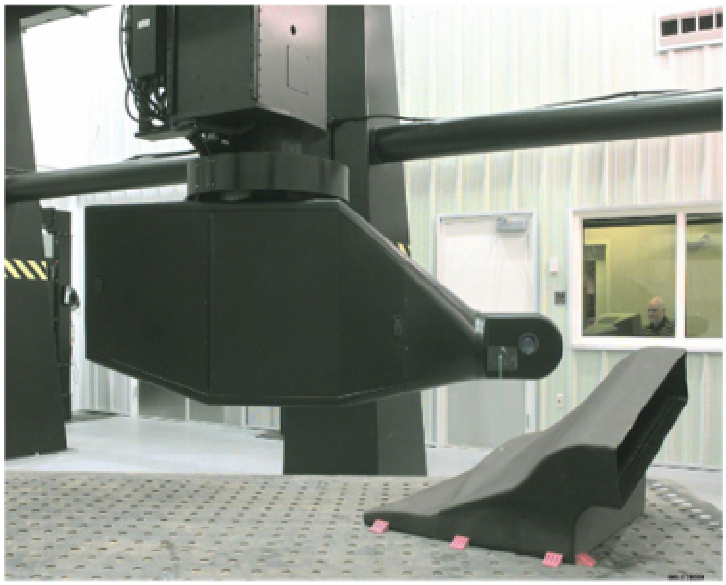

Figure 1. Beta LaserUT System Inspecting F22 Duct Section

Within four hours of arriving at the Beta LaserUT system, the first automated inspection of the duct section was complete. Although difficult even for LaserUT (this part is still the only structure that requires manual repositioning during inspection), Laser Ultrasonics was proved capable of inspecting the most challenging structures. These duct skins are now routinely inspected in an hour.

2.2 …For Process Control

After successful inspection of the duct section with LaserUT, the results showed a problem feared by the designers of the composite tool used to produce the first article – uncontrolled variations in part thickness. Figure 2 shows a C-scan depth image generated by a time-of-flight gate for the portion of the duct section outlined in Figure 3. For defect-free parts, it is essentially a thickness map of the inspected area. Variations in colour represent different thicknesses.

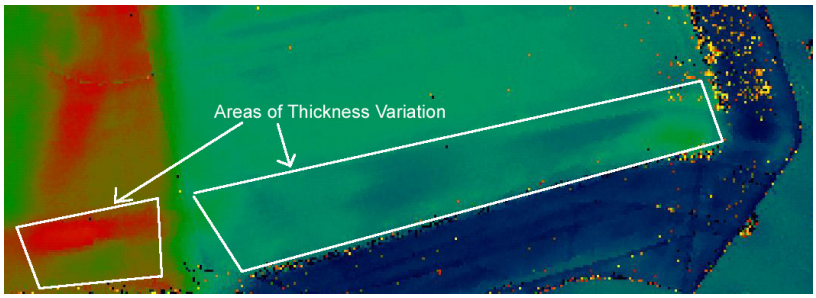

Figure 2. Thickness Map of Lower Radius

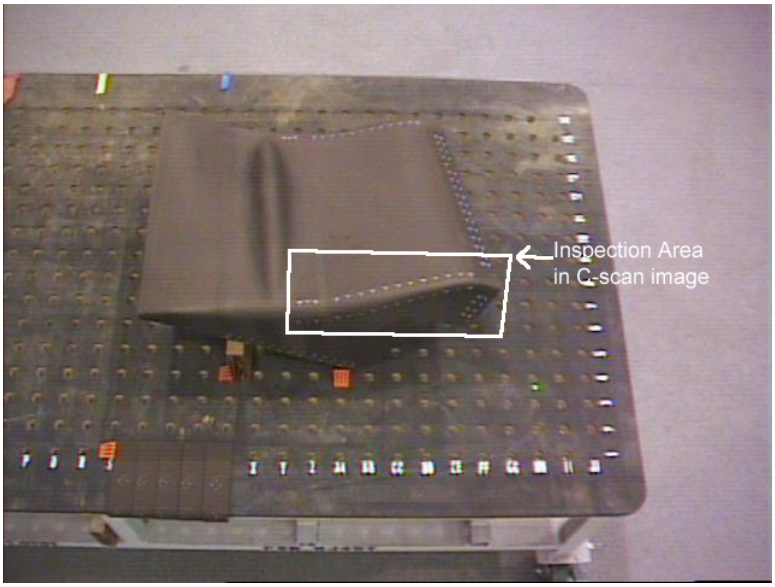

Figure 3. Area Scanned

A B-scan image (Figure 4) of the same area more clearly shows the significant variations in part thickness that were rampant throughout the radii.

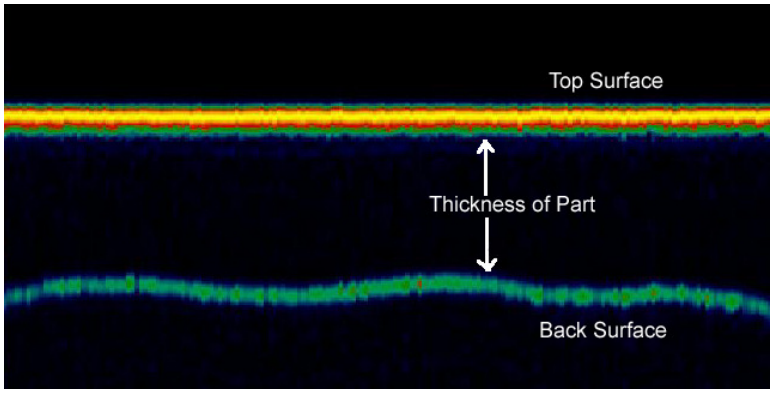

Figure 4. Variations in Thickness along Radii

The radii were composed of a constant number of composite plies and designed to be of uniform thickness. Analysis determined that the variance was caused by resin flow during the cure process. Utilizing maps provided by LaserUT [2], the F-22 composite tool designers and engineers modified the tool to control the resin-flow issue, improve their process, and produce quality parts.

2.3 …For Eliminating Dedicated Tooling

Especially in the case of large structures, conventional ultrasonic inspection systems frequently require dedicated tooling. These components add up-front cost, occupy valuable factory floor-space, and require maintenance, calibration, and tracking. If the

structures are large enough, commercial aerospace manufacturers employ dedicated phased array systems to scan a single component.

LaserUT requires no special tooling. Small parts are placed on a simple peg-board type table (Figure 5). For large parts, the systems at the Lockheed Martin facility are designed to inspect them on their transportation tooling – tools already developed for the purpose of moving the parts through the factory (Figure 6).

Figure 5. Small Part on Simple Table

Figure 6. Large Part Inspected on Transportation Tool

2.4 …For Reducing Cycle Time

LaserUT does not require access to CAD systems or CAD data files. A simple, one-time teach procedure that typically requires less than 30 minutes is all that is needed for a given part configuration. Once completed, there are no '3 point corrections' or other part-specific setup procedures. This reduces the average setup time of individual parts to less than five minutes. For parts that are basically "flat" to LaserUT (i.e. if the part were placed on the floor, no portion of the part would make greater than a 45 degree angle to an overhead viewing position), even the one-time teach procedure is not required. Given only the maximum length, width, and thickness, the LaserUT system can teach the part itself!

All ultrasonics settings are managed by the LaserUT software. There are no transducers to calibrate, nozzles to align, or other buttons and dials to 'tweak'. This reduces cycle time by letting the ultrasonic inspector focus on the task of analyzing data instead of machine setup. It also insures the same quality data will be taken by all inspectors, regardless of their experience level.

3. Conclusions

At the end of the day, the ability to use an inspection system to analyze a particular part, modify a production tool, or eliminate inspection tooling is only significant if that ultrasonic inspection technology helps you to do the things necessary to achieve rate production. For Lockheed Martin, LaserUT accomplishes that mission. Ultrasonic inspection is no longer an impediment to production at the Fort Worth facility.

As of December 18, 2007, Lockheed Martin has exclusively licensed all LaserUT patents and intellectual property to PaR Systems of Shoreview, Minnesota for the express purpose of commercializing the technology.

References

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