Integration of Robotics and Surface-Adaptive Phased-Array UT to Achieve Fully Automated Inspection of Complex Composite Parts

M. Brassard, TD NDE, Montreal, Canada

D. L. Hopkins, BERCLI Corp., Berkeley, CA 94703

Jean-Noel Noiret, EADS Composites Aquitaine, Salaunes, 33160, France

Abstract: *Achieving high-speed inspection rates for complex composite parts requires versatile and integrated systems that meet the challenges of automated part handling and NDT for ship sets that can include hundreds of different parts. Cost-effective integrated solutions are presented that are being successfully used to inspect composite parts for fully automated aerospace applications. The most appropriate solution for a given ship set depends on factors that include detection and sizing requirements, the range of sizes and geometries of the parts, the required inspection speed and cost constraints. The challenges of optimizing different technologies and integrating them into a single system are described for a recently implemented industrial solution. Lessons learned from the project are presented both in terms of technology integration and implementation of a new ultrasonic software algorithm. Surface-Adaptive Ultrasound (SAUL) is a very recent advancement in phased-array technology that is being used to overcome inspection challenges that include highly contoured surfaces; parts with small radii such as those often found on blades and stiffeners; rough and irregular surfaces including regions of ply dropoff and lap joints; and parts with varying shape, curvature, and thickness with length. Although vision systems and robots can be used to achieve highly accurate part following, the part-to-part variability that is typically encountered with composites creates problems for automated part and probe positioning, as well as accurate part tracking. This paper demonstrates the performance of a cost-effective inspection solution for complex geometry composites in a high-volume production environment achieved by combining advanced UT technology with industrial robotics and vision technologies.*

Introduction

Aeropace composite manufacturing facilities face the fact that traditional approaches to inspecting their parts are inefficient. The integration of NDE to the manufacturing process is the solution to this problem. The ultrasonic inspection of complex parts using CAD drawings and teach and learn methods is common in automated NDT of aerospace components, but it is uncommon for these systems to have to rapidly inspect a large number of parts with various geometries. An added difficulty, frequent with composites, is that actual part geometry may slightly differ from the CAD drawing.

In today's competitive environment, NDT must become part of the design process. From the CAD drawings, for aerospace purposes CATIA drawings, we need to inspect rapidly and efficiently. CAD import to the NDT system, or teach and learn on a prototype, is not sufficient, to deal with increased use of CAD data with greater geometric part complexities. As manufacturing was integrated into CAD/CAM system some years ago, next generation inspection systems must be fully integrated to meet these challenges.

Implementation of Processes

Fully integrated Computer-Aided Design and Manufacturing Systems are referred to as CAD/CAM. Computer-aided design (CAD) involves creating computer models defined by geometrical parameters. Computer-aided manufacturing (CAM) uses geometrical design data to control automated machinery. CAM systems are associated with computer numerical control (CNC). CAD/CAM systems differ from older forms of numerical control (NC) where in that geometrical data had to be encoded mechanically. The analogy to current automated NDT systems is evident; we are commonly still encoding our system in a close vase without interaction with other departments.

The system described in this paper is a CAD/CANDT system in which design processes and non-destructive testing are highly integrated. Making the analogy to CAM systems, the NDT is fully integrated and human intervention is not required prior, before and during the inspection. Implementation of a CAD/CANDT offers a number of benefits such as: reducing new part scanning plan design, reducing cycle time and integrating NDT into the manufacturing process.

Other integration objectives are sharing information, avoiding duplication of work, reducing wasted effort, eliminating non-value activities, standardizing software suites which as a consequence free up valuable NDT resources to perform NDT evaluation.

The processes to perform an inspection are schematically shown in Figure 1. These processes are no different than what is done for a part that needs to be machined.

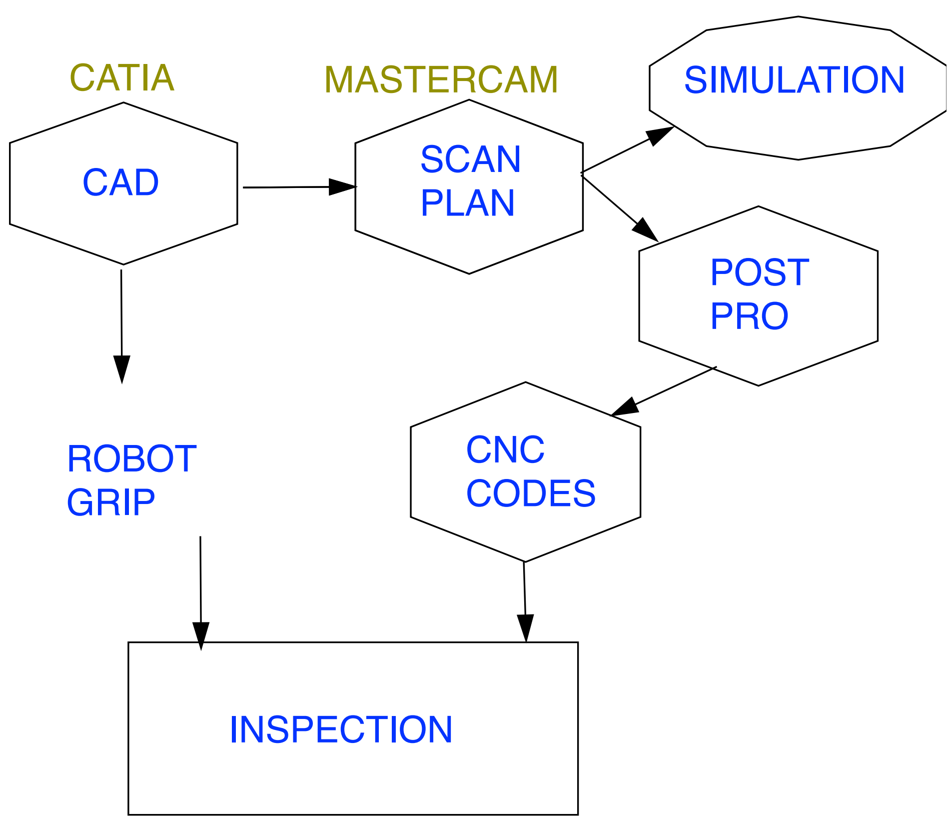

Figure 1 - Process Schematic

The CAD model used is a CATIA drawing because they are common in the aerospace. The CATIA drawing is imported into a path generating software (Mastercam) to create a tool path or for an NDT perspective; a scanning plan. The scanning plan is converted into CNC codes to inspect the part. Conversion is done using a post processor that translate tool path information from Mastercam into CNC information that a controller such as the Siemens SInumerik can interpret. (G codes). These codes are what the operator sees when the machine is inspecting. G-code includes instructions on where to move to, how fast to move, and through what path to move. Practically, the system becomes a machine tool. We, therefore, embrace machining technology, without performing manufacturing.

For example, the following figure shows a practical implementation of a system that is using the above technology to automatically plan, load, inspect and unload composite parts. This is what can be called a CAD/CANDT system.

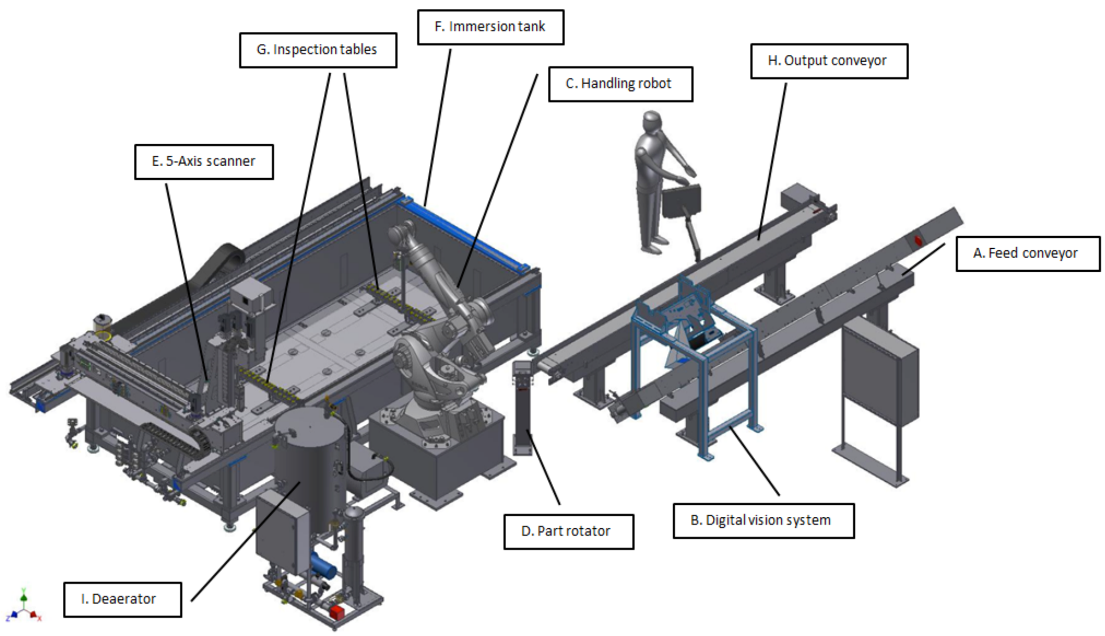

Figure 2 - CAD/CADNDT System

Integration Problems

Integrating various technologies into a single system is a complex and challenging operation. Leaning how to make effective use of existing CAD/CAM technologies and adapting them to NDT requires some planning as processes are different. A machining program, by definition, does everything from the front surface. However, in NDT when we perform internal operations, for example, when inspecting a radius the coverage of the back surface is quite different than what is covered on the front surface. We must therefore take into consideration the NDT physic s when planning our scanning plan. The challenges that we face are:

I. Limited Unfamiliarity. CAD/CAM technicians and engineers are usually not proficient in NDT. Similarly, NDT personnel are not familiar with CAD. This is a major stumbling block in technology integration. It is difficult to exchange information when each party does not understand the other party field of competence.
II. Software. NDT is a small field, and not the main objectives of the software. Tools developed were not part of the developer original mission and customization is more difficult but still doable.
III. Time. To successfully incorporate beneficial technology requires investment of time for production and planning. At the end, the NDT system cycle is much faster and its the machine utilization is fully dedicated to inspection.
IV. Training- NDT personnel are not used to machine codes. The same way that machinist have learned to interpret and used these tools to their benefit, NDT personnel must therefore be trained to become familiar with these tools.

It is well known that NDT is often considered as an after-fact or if you wish a necessary devil which may not inherently be part of the design. While design engineers may say otherwise, the increased difficulty of some of the parts today demonstrate otherwise. Some questions, we in the NDT community, must ask ourselves:

- Why is that our scanning plans made on the machine, is the machine time used efficiently?
- Why is it that the tool path on a machine tool is done by the CAM office and that our tool path (scanning path) is done by NDT personnel?
- Why are we using the system to simulate inspection and not commercially available software commonly used for machine tools?

Functionally, for integration we need to look at the points of failures/weaknesses of the system. Technologies can work together, to the benefit of all, if CAD, CAM and NDT personnel work in closer cooperation.

Ultrasonic Inspection

All the tests were done in immersion. The parts that must be inspected have 3D shaped and includes tight radii. To inspect these parts, using a conventional Phased Array approach requires a curved and a flat probes. As reported by Hopkins and Al [1], part positioning is critical. A 3 mm offset of the probes were sufficient to loss the reflection of the backwall as shown in Figure 3.

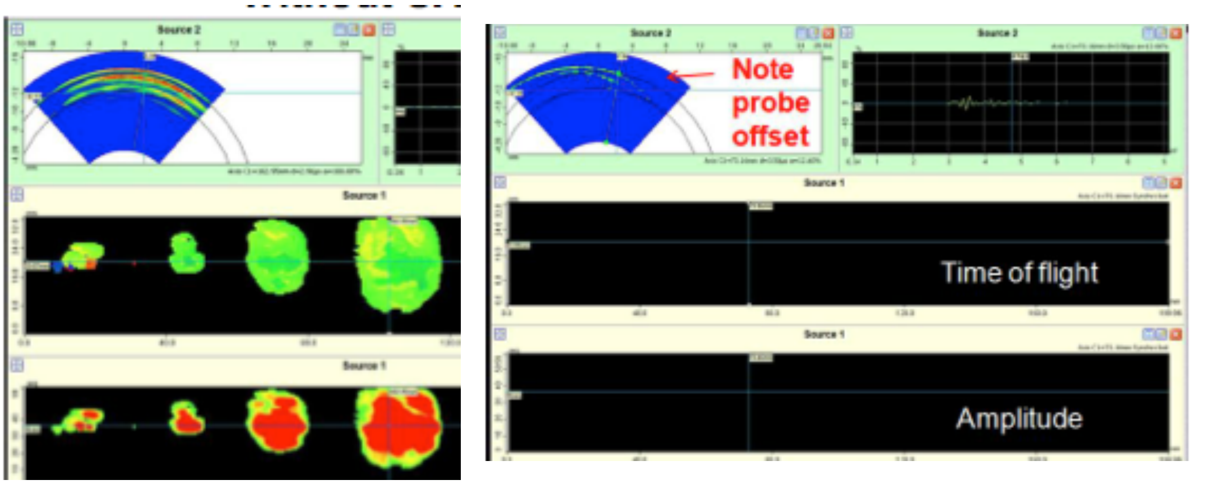

Figure 3 - Scans on the left shows amplitude and TOF scans without offset. Scans on the left shows the same inspection with a 3 mm offset.

One can not fully automate the process if the system can not adapt to part positioning and part variations. A fully automated system will not be complete without an ultrasonic solution adapted to these needs. Solution to automate this process would be to have a very precise positioning system. This is possible and remains important in these types of systems. However, part to part variabilities are not solved. Often, systems have features to reposition the scan part in the space or to adapt to areas where scan plans may differ. This, however, requires times, and actions that must be performed in the tank, leading to an increased of cycle time and loss of availability of the system to inspect parts.

The innovative Self-Adaptive Ultrasound (SAUL) technique developed by the CEA and implemented in M2M instrumentation is used as a solution to the above problem(2). An adaptive technique self-adjusts its transfer function according to an optimization calculated from an error signal and the desired processing operation is to equalize the time signal of the front surface reflections. The delay laws are adapted to refine the transfer functions to match the changing parameters(3). Practically, the algorithm is optimized by the user using a few parameters as part of the ultrasonic set-up process. The SAUL technique allows to fire all elements at once rather than firing by groups. On the return signal, the algorithm is applied to compensate for the surface variations. The delay laws are reconstructed on a return signal by a series of 16 elements with a 1 element increment. The figures below schematically represent the delay law correction leading to a wave front normal to the front surface of a flat composite plate angled 5 degrees from the normal. The same principle applies to a curved area where all wave fronts are optimized locally to match the surface.

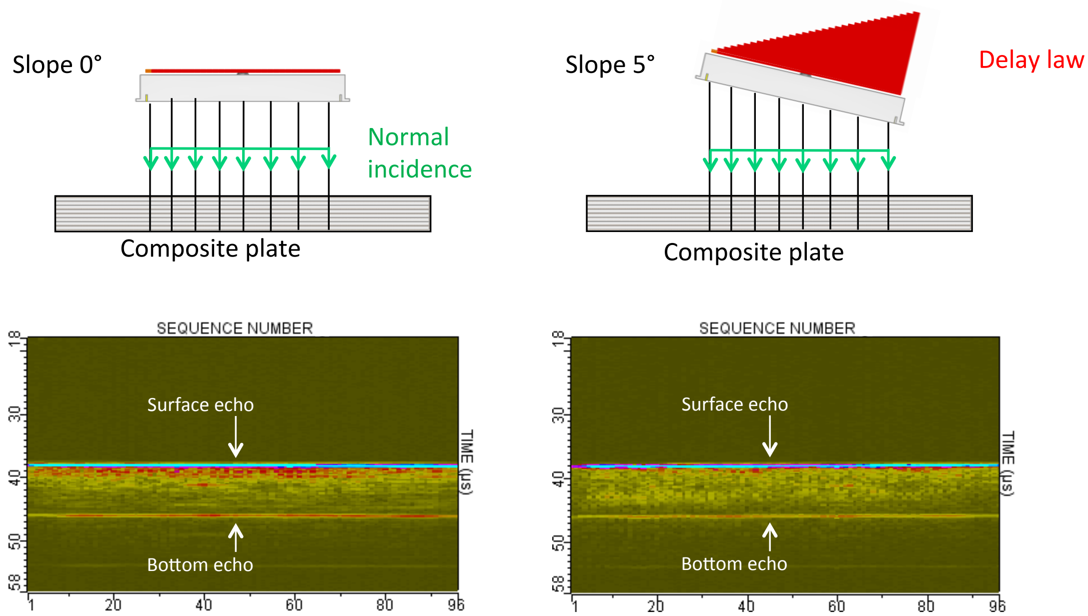

Figure 4 - SAUL Correction

Figure 5 shows the previous part inspected with an offset of 3 mm reinspected using SAUL.

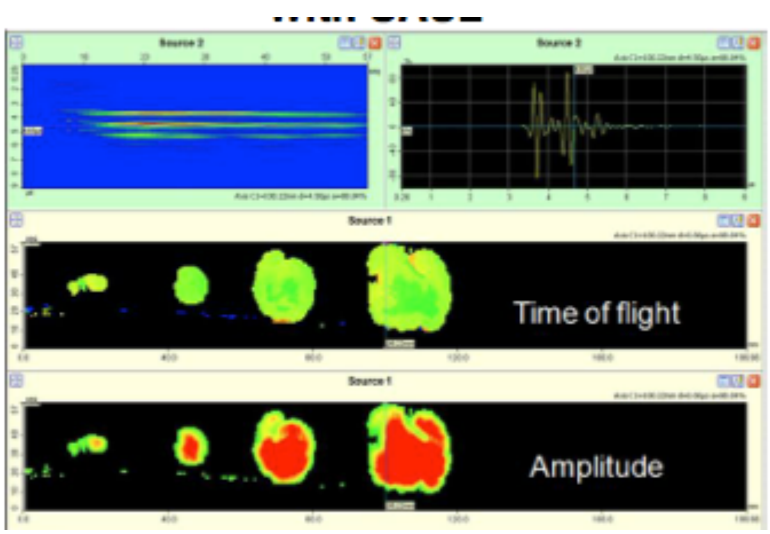

Figure 5 - A 3 mm offset corrected by using SAUL

Comparing the results of Fig 5 to the image displayed in Fig. 3 shows that the scans obtained with SAUL for the probe in the offset position agree very well with the image obtained when the probe was correctly centered on the test specimen.

Extending these results to an aerospace parts, it is possible to use a single flat probe to inspect all shapes, including tight radii. Figure 6 shows a part inspected with SAUL with a 2 D matrix probe. The part is a composite shaped like an L. Top portion is a vertical wall, the middle portion a tight radius and the bottom portion is flat. The middle and top portion have a curve in the X-Y plane.

The advantage of this approach is that the same probe is used and that productivity is increased. In addition, and probably more importantly, compensation for part variability is corrected by the SAUL algorithm.

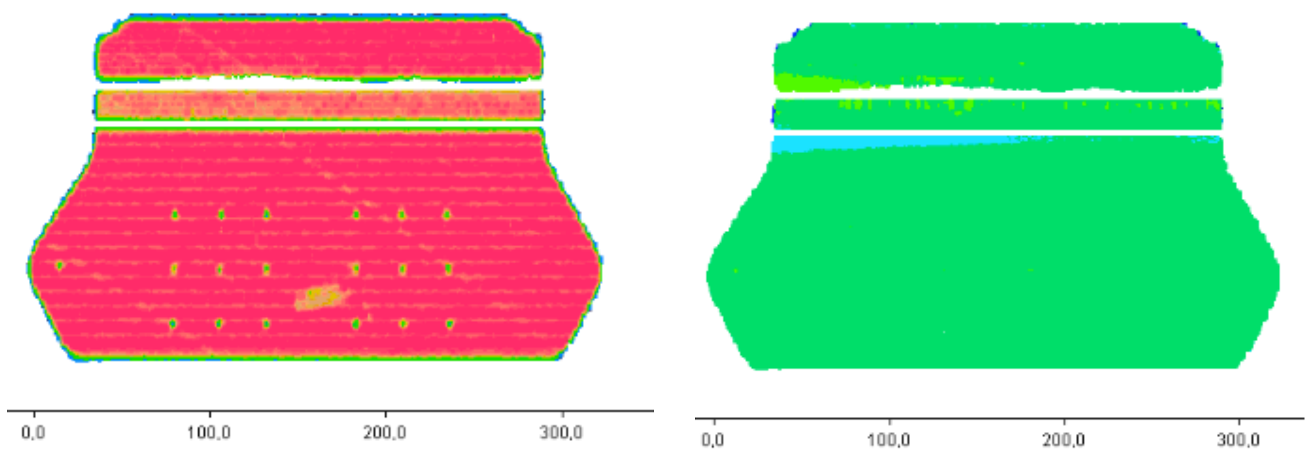

Figure 6 - A part with a tight radius and flat parts inspect with a 2 D probe. LH Image - Amplitude C-Scan, RH Image TOF C-Scan

Simulating the effect of part variability or poor positioning, the part is displaced by 5 mm in the X direction, and reinspected. Figure 7 shows that the results are similar in amplitude and that compensation has taken place. The Time-of-Flight C-Scans shows that part position is different than what was planned but the amplitude scans remains similar. This is due to the fact that the part has a curve in the X-Y plane and that the position of the probe is different than the scanning plan.

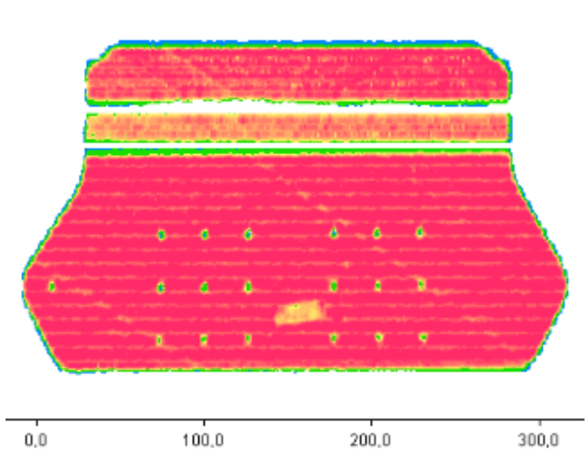

Figure 7 - A part with a tight radius and flat parts inspect with a m2 D probe. LH Image - Amplitude C-Scan, RH Image TOF C-Scan

Conclusion

Great technologies don't necessarily equate to a great system. Integration is the key. Not only the NDT solution must be capable of meeting the inspection challenges but the system must be able to meet the production requirements. Quality and quantity are demanded. CAD/CANDT reduces the entire manufacturing cycle and must be considered part of the process. NDT and CAD personnel must become part of the same team. SAUL has the ability to compensate for misalignment and part variability. Matrix array probe have shown to be useful to compensate for varying geometry in two directions. A CAD/CANNDT system with SAUL is an industrial solution adapted to today's demanding challenges of composite manufacturing.

References

[1] D. Hopkins, G. Neau, W.V. Johnson, L. Le Ber, P. Calmon ¨Surface Adaptive Ultrasound for Phased-Array Inspection of Complex Composite Specimens ¨, QNDE, March 2012

[2] D. Hopkins, G. Neau, L. Le Ber, ¨Advanced Phased Array Technologies for Ultrasonic Inspection of Complex Parts ¨, Proc. of International Workshop Smart Material, Structures & NDT in Aerospace Conference, Nov 2011

[3] S. Mahaut, O. Roy, S. Chatillon, P. Calmon ¨ Modeling and Application of Phased Array Techniques Dedicated to Complex Geometry Inspection ¨, Review of QNDE, vol 21, 2002.