



Smart NDT Tools: Connection and Automation for Efficient and Reliable NDT Operations

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Abstract. Efficiency and reliability of NDT operations result from the combination of at least three factors: the NDT procedure, the NDT toolset and the operator. Classically, maintenance manuals provide relevant NDT procedures, NDT tools are powerful and accurate enough to play the procedures, and operators are trained to apply the procedures with the tools and interpret the results. However, taking care of each component independently may yield to inefficiency in the operations realization and/or scattering in the obtained results. The approach presented here is to make NDT devices following the idea of smart devices (ex. smartphones): connected tools with dedicated easy-to-use software applications. Following this idea the Smart NDT Tools integrate procedures with dedicated – step by step – user interfaces to minimize the possibility of making mistakes, wrong choices, getting lost in the menus... These simplified GUIs are combined with automation algorithms and signal processing routines to further reduce the error rate and thus maximize the efficiency and reliability of inspections. This paper presents examples of applications both with ultrasound and eddy currents. Potential use as connected NDT tools in an internet of things perspective is also discussed.

Introduction

In this paper we will present various NDT applications for which the traditional procedure and generic system have been replaced by dedicated acquisition kits embedding automated signal processing, defect sizing and reporting software modules. Although each system has been designed to address one specific NDT problem the resulting modules and algorithms (automatic sizing, 3D tracking, per shot coupling, dead element detection, ...) can be adapted and combined to resolve new challenges.

1. Impact damage detection and sizing on CFRP

This application deals with the detection and sizing of delaminations in Carbon Fiber Reinforced Polymer (CFRP) fuselage after impact. In this typical in-service scenario we assume something hit the fuselage leaving a visual indication. In this case a NDT inspection is required to evaluate if the impact has generated any damage and if the resulting damage within the structure is above the allowable damage size. Traditionally a



certified NDT level 2 operator would apply the relevant NDT procedure and manually assess the size of the defect.

The goal of the “Automatic Sizing” kit is to simplify the data acquisition and fully automate the defect extraction and sizing.

The kit is made of the following components (see Figure 1):

- 1) Ultrasonic Testing Phased Array 5 MHz 32 elements wheel probe fitted with two lasers;
- 2) Plastic stencil to draw lines on the fuselage and a pen;
- 3) Ruggedized tablet (Panasonic FZG-1) running our software connected with a 8x32 multiplexed UT data acquisition card.

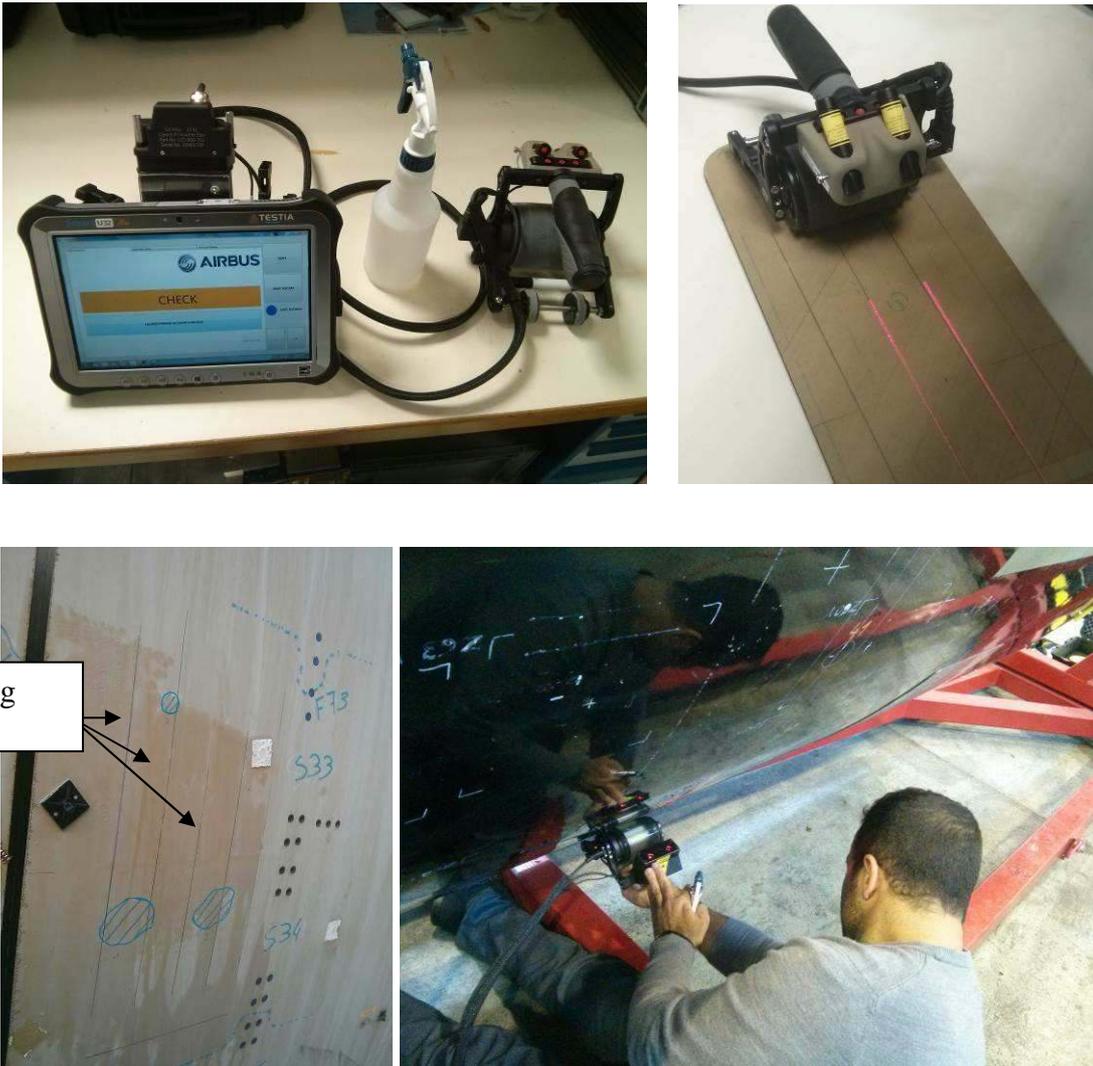


Figure 1: Automatic delamination sizing kit (top), inspection lines on the fuselage (bottom left) and operator scanning (bottom right)

1.1 Graphical User Interface

A dedicated software user interface has been developed for the application (Figure 2). On the first screen the operator launches the probe calibration and dead element check to detect (if any) faulty piezo-electric elements and normalize the amplitude response. When the “check step” is ok, the operator is allowed to switch to the c-scan acquisition screen. On

this second screen the operator can view the c-scan, reset each c-scan pass independently and adjust for inter-pass backlash using two arrows. The central button when clicked launches the automated post-processing and report building.

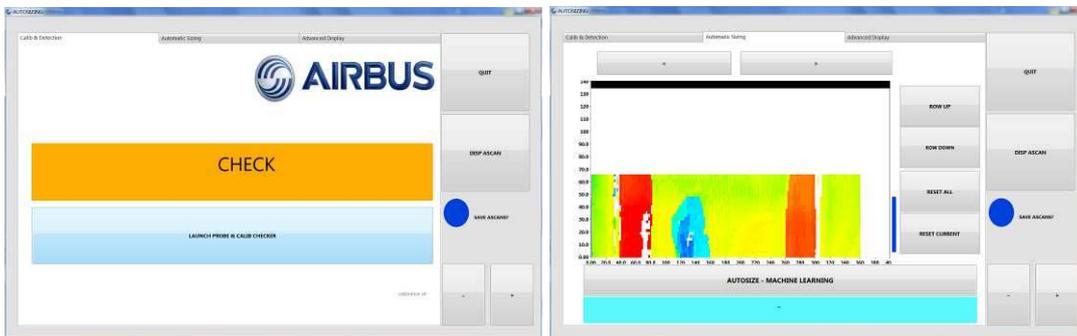


Figure 2: User interface with 2 screens: calibration/probe check (left) and c-scan acquisition (right)

The user interface is inspired by the NDT procedure and the operator is guided step by step.

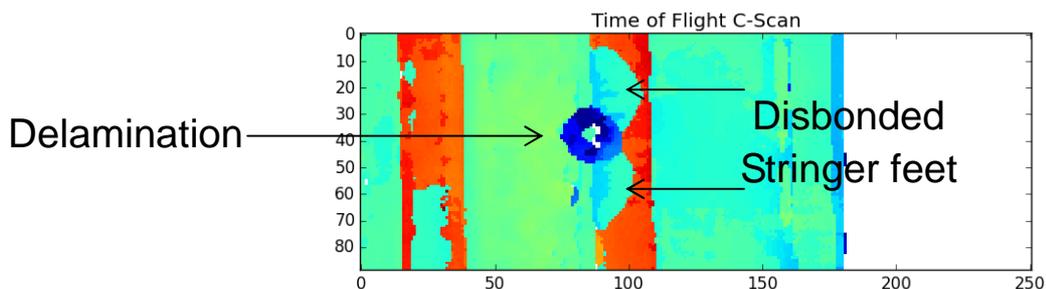
1.2 Algorithms

The added value of the presented application lies in the fact that the operations are very easy and require a low level of NDT expertise from the operator. This can only be achieved because the intelligence is embedded within the tool. For this particular application we have developed algorithms to:

- i) Ensure the quality of the acquisition.
- ii) Evaluate the size of the impact damage.

The acquisition quality is monitored in real time by testing the good coupling of the probe. It guarantees the data aggregated into the c-scans is coming from a well coupled transducer. The damage size evaluation is performed using a combination of machine learning algorithms found in the literature [1]. It computes the real size of the defect from any given amplitude and time of flight (tof) c-scan pair after the acquisition is finished. The algorithm has been trained using a data set made of impact damage data from various sources to cover the spectrum of possible structural configurations found on the A-350 fuselage including:

- Constant thickness areas
- Variable thickness areas
- One or multiple stringer feet on the cartography
- Thin and thick areas
- Delamination with and without stringer disbond



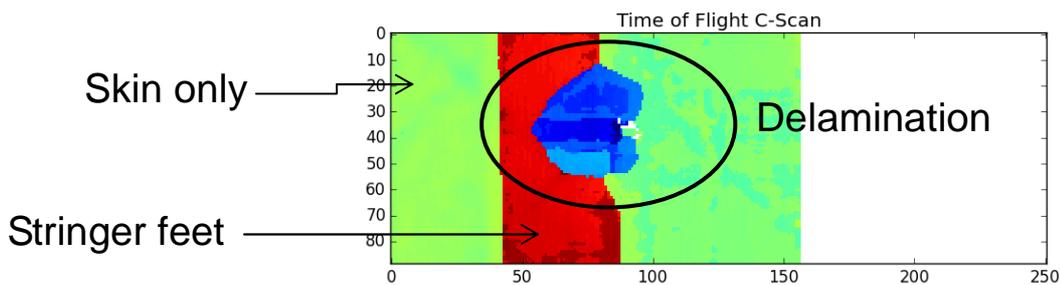


Figure 3: Remarkable features on Time of Flight C-Scans

We gathered data acquired using phased array wheel probes either in a single pass or in a multipass scan with sum ascans and a Time Compensated Gain (TCG) curve. Certified level 2 NDT specialists isolate the defects on every c-scan using a per pixel binary label (true = defect, false = not a defect) as shown on Figure 4.

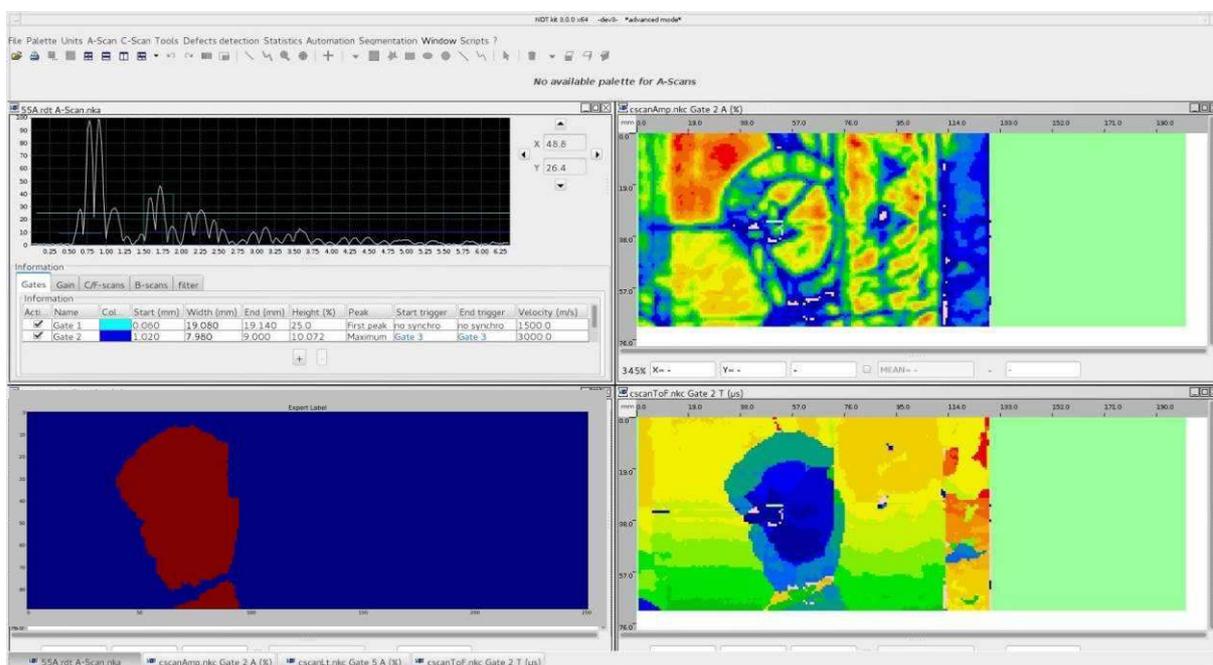


Figure 4: Ascan (top left), amplitude c-scan (top right), tof c-scan (bottom right) and binary label (bottom left) in NDT kit software.

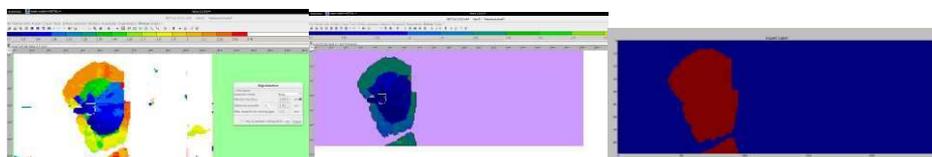


Figure 5: Using NDT kit to label the c-scans

This labelled dataset has been used to design a machine learning pipeline using cross-validation scores to drive the choice of the models and their parameters. The final algorithm takes amplitude and time of flight c-scans as input and outputs a binary “c-scan” of defect state for every pixel. The following figures show examples of defect extraction on various types of delaminations from our test set.

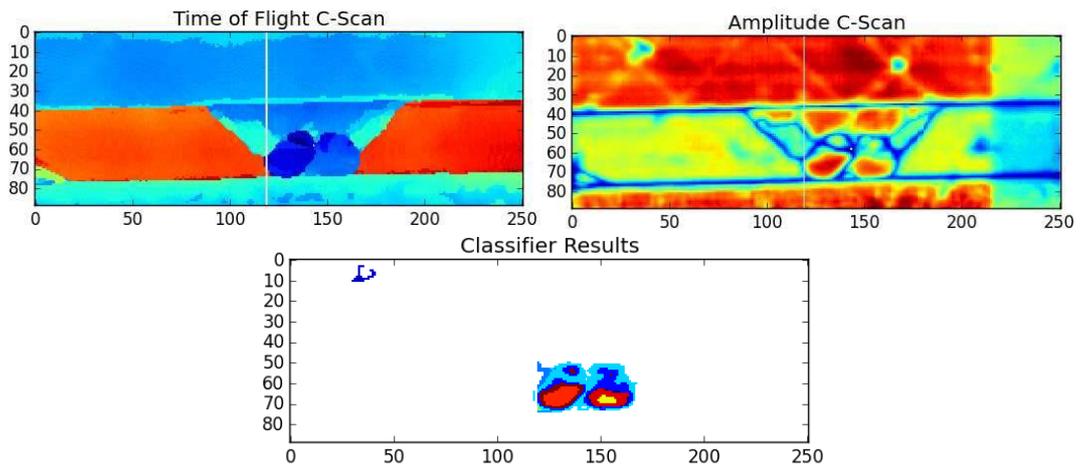


Figure 6: Defect extraction of delamination above stringer feet (stringer disbond is excluded)

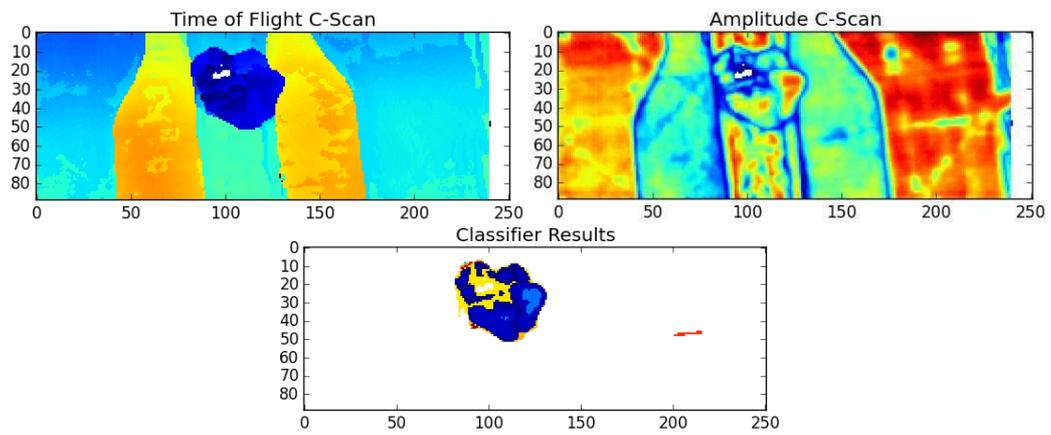


Figure 7: defect extraction between stringer feet

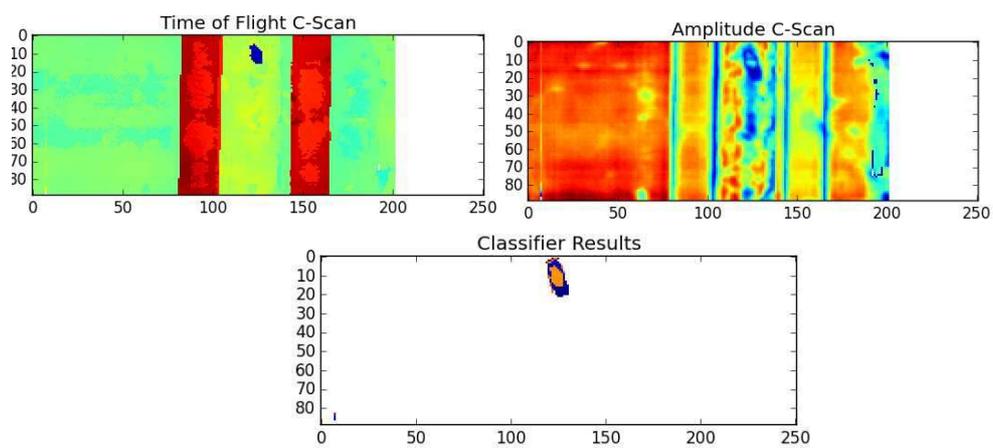


Figure 8: defect extraction of a "tiny" delamination

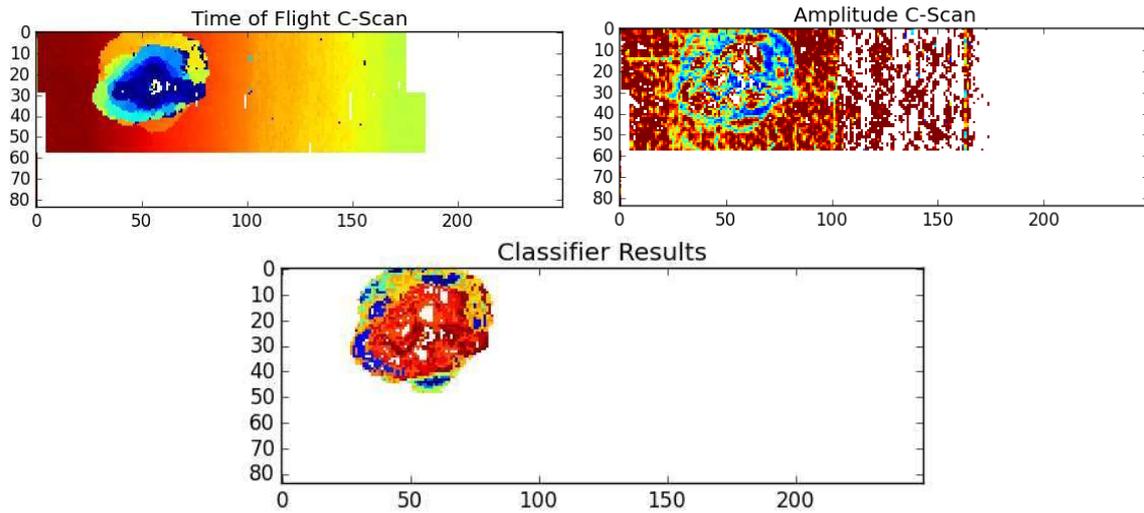


Figure 9: Defect extraction from a saturating backwall + variable thickness

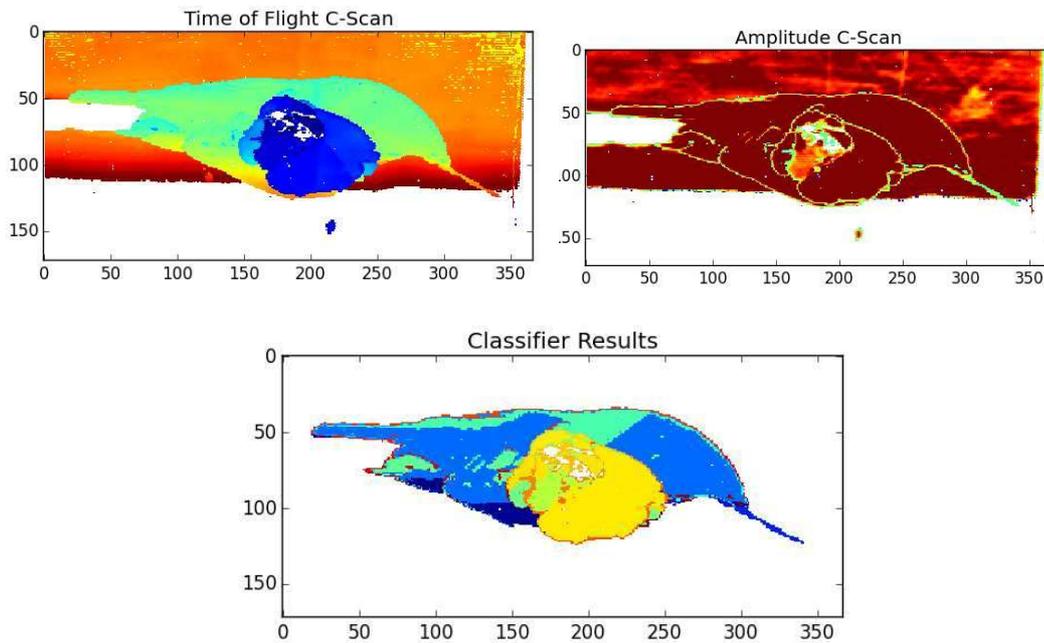


Figure 10: defect extraction from a saturating backwall + multi-thickness delamination

Finally, the binary c-scan created by our algorithm is used by NDT kit® analysis software to apply the NDT procedure proximity criteria and defect grouping rules to output a pdf report of the inspection as shown on Figure 12. As described in the Airbus procedure we use the rectangular bounding box surface of each defect group to output a slightly overestimated defect size as shown on Figure 11.

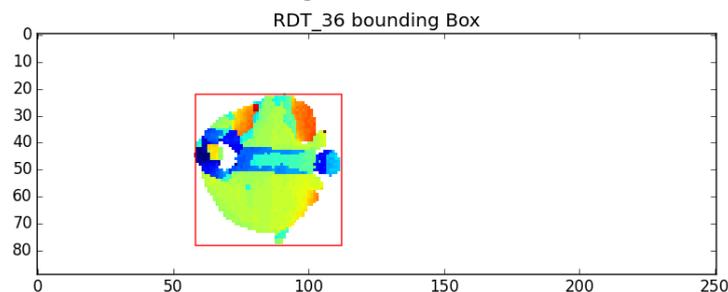


Figure 11: Rectangular bounding box to overestimate defect size

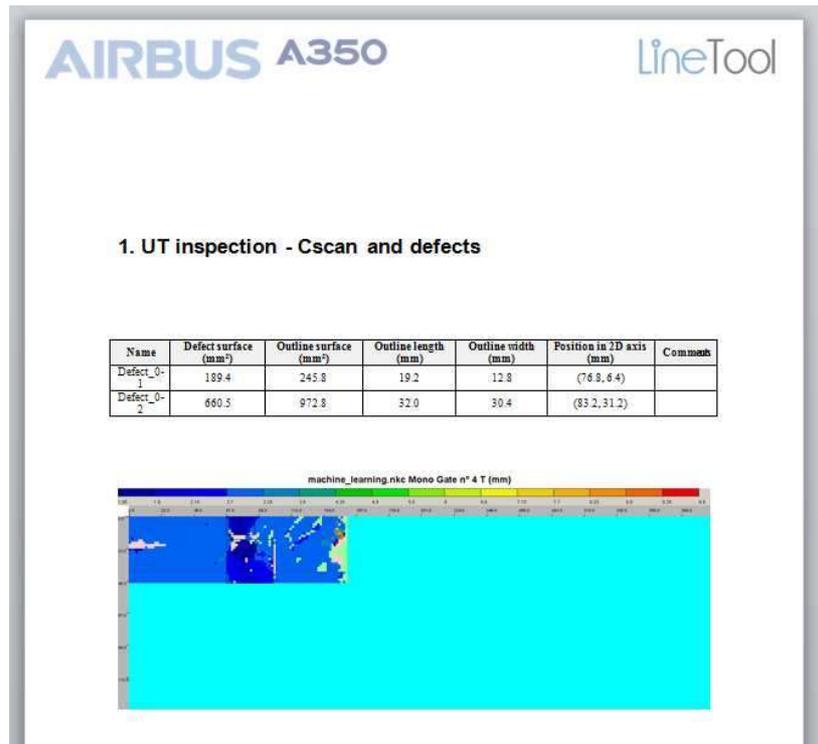


Figure 12: Final report generated by NDT kit with both raw defect surface and bounding box surface

This “automatic sizing” system could be adapted to other use-cases provided enough data is available to train the underlying classifier.

2. Improve scanning speed and reliability with phased array and 3D tracking

The goal of this application is to increase reliability and reduce inspection time of Glass Fiber Reinforced Polymer (GFRP) parts on the production line. Today the inspection is performed using a manual single crystal UT transducer: it is time consuming and operator dependent. The diagnosis is made on the fly by the operator who applies complex criteria on the A-scans signals to detect delaminations and porosity.

The application we are developing replaces the mono-element UT by a manual phased array UT probe with C-scan construction and automated diagnosis. Fully encoded manual scanning is the best compromise we found with our customer to keep the versatility of this working station and to avoid the installation of an expensive robotized system. C-scans building and storage make the diagnostic more robust and improve traceability. For this application we combined a 2.5 MHz 32 elements phased array probe with an innovative soft silicone wedge from Sonaxis and a 3D electromagnetic tracking device [2] to be able to produce C-scans. The final system provides a “painting like” experience to the operator. The tracking technique presented here cannot be used as-is on metallic parts due to potential interferences with the electromagnetic positioner.

The ultrasonic data acquisition system is a Smart NDT Tool U32 triggered by the 3D position tracker synchronization output at 240 Hz.

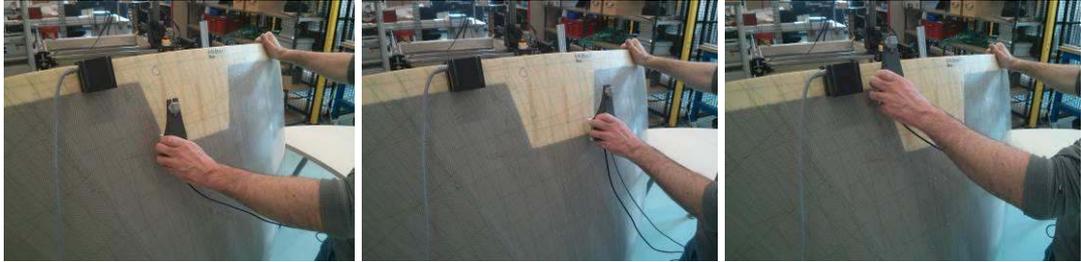
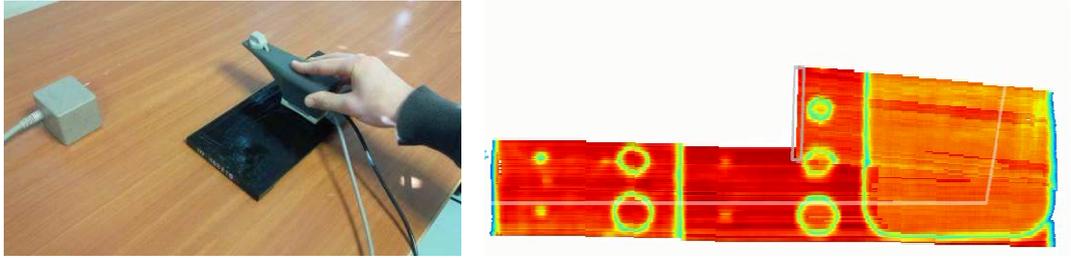
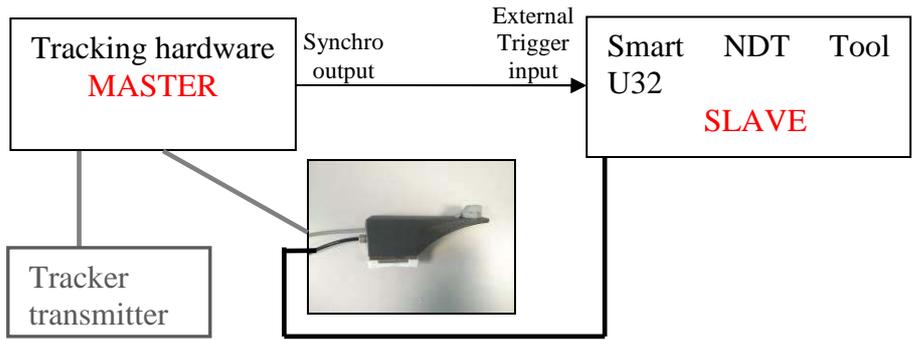


Figure 13: Ref block scan and 3 steps projection plane capture

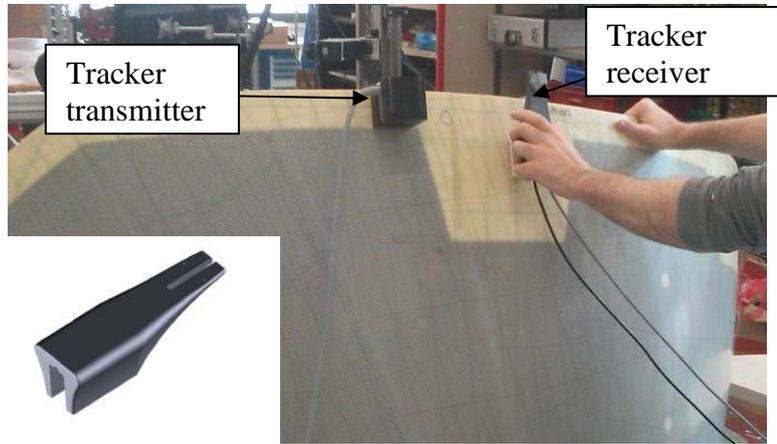


Figure 14: Operator scanning the part

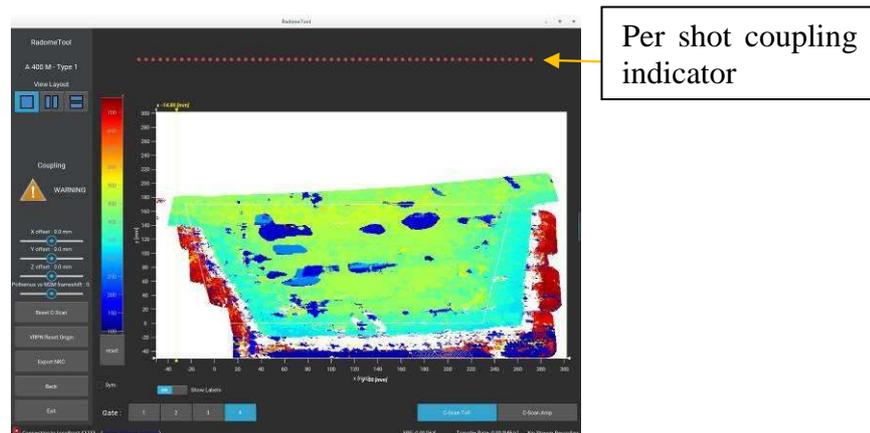


Figure 15: Time of flight c-scan with delaminations

The part to inspect is prepared by applying a coupling gel and the operator proceeds with a 3 steps projection plane capture by positioning the probe over remarkable features of the part. Once the plane is defined the operator scans the part like a painter since the tracking system allows us to compute the probe orientation in the projection plane. A dedicated coupling algorithm has been designed to ensure C-scan quality. Our next objective is to implement automated defect extraction and sizing using these cartographies.

3. Clad Tool: automated cladding removal detection

The cladding is a corrosion protection layer made of “pure” aluminum applied on the surface of the aluminum alloys constituting the aircraft parts. The cladding layer electrical conductivity is nearly twice the conductivity of the aluminium substrate. The clad removal testing principle is therefore to measure variations of the eddy-currents response due to conductivity variations in the above layer of the tested area. For this we use high frequency eddy-currents (> 1MHz) to be sensitive mostly to the upper layer.

The Clad Tool is a dedicated software application implemented on a Smart NDT Tool UE1. The software interface is made such that it is usable by non-NDT specialists. The user follows the step by step procedure on the screen.



Figure 16: Clad Tool hardware kit



Figure 17: Clad Tool user Interface

Conclusion

Several applications have been developed using the Smart NDT Tools software and hardware modules to address a variety of NDT use-cases both in production and in service. Smart NDT Tools are made for quick application development to solve problems and bring simplicity to the end users on the field and make phased array UT accessible to non-expert operators. Simplicity for the operator also means dedicated applications and powerful automation algorithms. Our next step will be to benefit from the high connectivity of these tools to gather more data and increase the performances and scope of our algorithms. These systems are designed by Airbus Group Innovations with Testia providing industrialization, support and sales.

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References

- [1] F. Pedregosa, G. Varoquaux, A. Gramfort, V. Michel, B. Thirion, O. Grisel, M. Blondel, P. Prettenhofer, R. Weiss, V. Dubourg, J. Vanderplas, A. Passos, D. Cournapeau, M. Brucher, M. Perrot, and E. Duchesnay, "Scikit-learn: Machine Learning in Python," *Journal of Machine Learning Research*, vol. 12, pp. 2825–2830, 2011.
- [2] D. K. Hsu, V. Kommareddy, D. J. Barnard, J. J. Peters. and V. Dayal, "AEROSPACE NDT USING PIEZOCERAMIC AIR-COUPLED TRANSDUCERS", *WCNDT, 2004*, http://www.ndt.net/article/wcndt2004/pdf/non-contact_ultrasonics/410_hsu.pdf