Assisted Diagnosis Solutions for Fast Decision Making

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Abstract
Most of the NDT portable instruments cannot be used without the operator being perfectly trained and certified in the method. Only thickness gauges and electrical conductivity indicators can be used by non-certified operators. This situation creates problems for companies who need to meet increasing production rates whilst also maintaining low prices.

Assisted diagnostic solutions were developed to enable non-specialists to make decision and release acceptable components/aircraft rapidly, both in manufacturing plants and in-service. Several software modules are already available depending on the application. These include:

- Accurate thickness measurements after machining or after blending corroded areas
- Automatic sizing of delamination after drilling or impact

Keywords: ultrasound, phased arrays, eddy current, resonance, aerospace, assisted diagnosis

1. Context

2.1 Standards
The reliability of a large share of non-destructive testing (NDT) is guaranteed by the certification of operators. In the aeronautical sector, 4179/NAS410 standards set the rules. To submit to the examination, one must get training courses, but also justify of a practical experience. The following table shows the time required for the three most demanding methods: UT (ultrasonic), ET (eddy currents) and RT (radiography):

<table>
<thead>
<tr>
<th>Certificate level</th>
<th>Training</th>
<th>Experience</th>
<th>French certificates¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>UT1, ET1 or RT1</td>
<td>40 hours</td>
<td>400 hours</td>
<td>1404</td>
</tr>
<tr>
<td>UT2, ET2 or RT2</td>
<td>80 hours</td>
<td>1600 hours</td>
<td>2599</td>
</tr>
</tbody>
</table>

The companies that provide the components or assemblies to the aerospace industry must therefore invest in their future inspectors for many long months (even if these times are expected to decrease).

Two special cases must nevertheless be noted in the above standards:
- Direct readout instruments: “Personnel performing specialized inspections using certain direct readout instruments as determined by a Level 3 certified in the method, do not require qualification or certification”
- Level 1-Limited: “when authorized by the cognizant engineering organization and the employer’s written practice, the performance of a specific NDT test on a specified part, feature, or assembly may be performed by personnel certified to Level 1-Limited. Each use of Level 1-Limited shall be approved by the cognizant engineering organization. Several points shall be documented and be made available for review by the employer’s

customers and regulatory agencies”. The required duration of training and experience are reduced, as shown by the following table:

<table>
<thead>
<tr>
<th>Certificate level</th>
<th>training</th>
<th>Experience</th>
<th>Certificates</th>
</tr>
</thead>
<tbody>
<tr>
<td>UT1L, ET1L ou RT1L</td>
<td>10 hours (25%)</td>
<td>40 hours (10%)</td>
<td>?</td>
</tr>
</tbody>
</table>

2.2 Lack of Inspectors
The relatively high age of inspectors leads to predict a loss of expertise and a shortage in certified staff greater than it is today. Today, the companies that we do business with have difficulty in finding certified inspectors available on the job market. They are therefore trying to anticipate their needs, by offering their employees raise in skills. It is not always obvious to be reactive within the times required by the standards as the development cycles of new aircraft are strongly reduced.

2.3 Resulting Production Ranges
The scarcity of inspectors contributes to the establishment of production ranges which are terminated by a final check, when the components have capitalized the maximum added value.

In large companies (manufacturers/assemblers and outsourcers), which often keep the mastery of the most important parts and sub-assemblies, there is a proliferation of NDT intermediary tasks to ensure that the last operation has been carried out correctly. For Carbon Fibre Reinforced Plastics (CFRP), we can mention for example:
- health control after polymerization,
- edges inspection after trimming,
- thickness measurements after painting,
- peripheral examination of holes after drilling,
- thickness measurements of “aluminium fillers” before assembly, etc.

This approach allows validation of each step, and it avoids keeping parts which normally be rejected. However it requires a greater amount of inspectors...

2.4 NDT perceived as an Extra-cost?
Training effort for companies, combined with the scarcity of certified inspectors can contribute to the perception of NDT being an expensive operation, though it actually increases the products value, so that they are delivered in conformity with the quality requirements.

2. Possible improvements
The compromise between security and profitability concerning NDT can rely on two characteristics of the current standards, in one hand direct readout instruments and on the other hand Level 1-Limited.

2.1 Direct Readout Instruments
These instruments “physically display measurements in dimensional or electrical units (e.g. in, mm or % IACS, etc.) either as digital readout or an analog display, such as a scale/pointer configuration and do not require special skills or knowledge to set up the instrument and do not involve adjusting signal displays such as gates, delays, gain, or phase to obtain measurements. Common direct readout instruments include basic ultrasonic thickness gauges without an oscilloscope display, and eddy current coating thickness gauges”. Another
example is the electric conductivity indicator by ET to sort metals and check thermal treatments.

The range of NDT instruments called “Smart NDT tools” aim at multiplying direct result reading software applications, for aeronautical applications.

2.2 Level 1-Limited
For this employer certification level, the general test contains at least 10 questions, whereas the specific test contains 8 questions (against 40 and 30 respectively in superior levels). Its validity must not exceed a year (against five for superior levels)

“Smart NDT tools” are designed to frame the work of this category of inspectors, reduce the human factor to a minimum and help them to sort what is acceptable and what is not regarding the criteria.

3. ‘Smart NDT Tools’ Characteristics [1], [2], [5]

‘Smart NDT tools’ constitute a range of NDT instruments, developed by AIRBUS Group innovations (previously named EADS Innovation Works), industrialized and commercialized by NDT EXPERT/ TESTIA. They are designed to respond to industry problems detailed above, mostly in the aerospace sector. Their common points are the following:

- Patented electronics, flexible and open to programming, based on field-programmable gate array, and functioning as a peripheral device powered by any computer via a USB (Universal Serial Bus) link
- Software specific to aeronautical applications, including tools to help with the diagnosis, for expert operation or not.

3.1 Integration for Field Application
Two electronics have been the subject of significant efforts of integration:
- The first called ‘Smart UE1’ allows you to implement ultrasonic inspections (with single crystal transducers or resonant probes) or eddy current testing;
- The second called ‘Smart U32’ ensures ultrasonic testing (with single crystal transducers and phased arrays).

Figure 1: ‘Smart UE1’ & ‘Smart U32’ (‘Max’ version)
Both electronics are protected by metal cases, combined with a very light ruggedized tablet. ‘Smart EU1’ weighs 2.0 kg whereas ‘Smart U32’ weighs only 2.7 kg (battery included) which allows a ventral use thanks to the harness especially designed. The 10 inches diagonal touch screen offers unequalled high definition viewing comfort of interfaces designed with an ergonomic concern.

3.2 Evolution Capacities
The evolution of Smart NDT tools is drawn by the growing power of processing capabilities of standard computers. Their compactness and their open programming (firmware with VHDL and software with Labview) enable other integrations, for example:

– The closest to the sensors for the process monitoring systems (polymerization, trimming, drilling, welding, etc.) or for automatic machines [12];
– Held on the wrist of a robot, or carried by a crawler to scan components automatically;
– Inside jackets [6] to interrogate embedded sensors periodically or continuously to monitor structures in-service or in laboratories.
Adaptations are limited to the addition of USB extenders, batteries and/or memory…

4. Assisted Diagnosis for Drilled Holes

4.1 Context
Drilling CFRP laminates is a manufacturing operation which can cause delaminations and flaking defects, if the tools are not sharp enough.
This kind of material is widely used for latest aircrafts. Assembling fuselage sections, wings, and tail planes consists in drilling thousands of holes, which diameter ranges between 4 mm and 25 mm. Most of them are performed with automatic drilling machines which are very reliable, but few of them have to be drilled in a more ‘manual’ mode.

4.2 ‘Percephone’ Solution

Specific daisy arrays were developed to save time while inspecting these drilled holes (see fig. 2). Various replaceable delay lines and centring pins were also designed to fit with the full range of holes diameters. These probes are driven by the ‘Smart U32’ instrument. Dedicated software, called ‘Percephone’ (see fig. 3), activates groups of elements successively to scan electronically the circumference of the holes, and detect any internal discontinuity which
exceeds the acceptable radius. Inspection lasts less than one second, which is much faster than performances obtained with a single crystal transducer. Acoustic coupling quality is also significantly improved since the process is static. Single crystal transducers have to be moved around the holes, which can shear the coupling liquid or gel…

When ‘Percephone’ is started, the validity of the electronic channels and the array’s elements is checked. Then the quality of the coupling and the planarity of the interface between the delay line and the component under test are monitored to avoid any mistake (false calls or miss). As soon as both corresponding Light-Emitting Diodes (LEDs) switch to green, diagnosis becomes possible. It is based on logical conditions in analysis gates positioned on all the A-scans obtained after electronic scanning. The third LED indicates diagnosis results for UT1-Limited operator. Then the cells of the table in the lower side of the interface are filled with the corresponding colour (green: acceptable drilled hole / red: drilled hole to be inspected by UT1 or UT2 certified operators for diagnosis confirmation and characterization). Finally the table can be exported for statistical process control.

This ‘Percephone’ solution is already deployed in the repair stations of the drilling bits at AIRBUS Toulouse and St-Nazaire, where colleagues of us supplied the initial requirements.

![Figure 3: ‘Percephone’ Graphical User Interfaces (GUI)](image)

5. Assisted Diagnosis for Delaminations Detection

5.1 Context in Assembly Lines and In-Service

CFRP laminates used in aeronautical structures are impacts-sensitive. Any visible damage leads to ultrasound testing of the surrounded area to track for delaminations.

Some airplanes manufacturers requested to convert some ultrasound thickness gauge into ‘go/no go’ instruments for allow B1 mechanical engineers to release quickly the impacted aircraft without damage. The principle consists in calibrating the instrument on a flawless area close to the impact. Gates and gain are then automatically adjusted considering the back wall echoes. The operator scans the suspicious area. If intermediate echoes appear, the output message ‘no go’ is displayed. If not, ‘go’ is visible on the screen…

This kind of equipment cannot be used on optimized structures which thickness changes at any point (e.g. thin pockets versus thicker stringers feet).
5.2 ‘Line Tool’ Solution

Its patented principle [8] consists in detecting delaminations only in the sub surface range of depths, since these kinds of damages affect the first layers and propagate with a pyramidal shape. It is based on the same electronic board as the ‘Smart U32’ instrument, which drives one linear flat phased array embedded in a wheel (see fig.4). The acoustic coupling quality between the tyre and the surface of the component under test is monitored to avoid any misinterpretation. Diagnosis is fully automated and the GUI is limited to a few icons which guide the mechanical engineer and indicate the status of the inspection.

![Figure 4: ‘Line Tool’ solution [9]](image)

6. Assisted Diagnosis for Indications Sizing

6.1 Context in Manufacturing Plants

Automatic scanning machines are able to scan nearly 100% of the surface of CFRP components now, including particular areas such as stringers’ webs and radii, bent sides, skins with changing thickness areas because of plies drops, chamfered edges, etc. [12]. But the current process requires that all the indications detected on the C-scans are confirmed with manual instruments. This operation was very time consuming since it was based on the use of single crystal transducers. It could be accelerated by linear phased arrays which offer a wider coverage and C-scans imaging capabilities. There are two blocking aspects however with current phased array instruments: first, they are quite new for most of the operators and difficult to get familiar with; second they do not give the possibility to size easily inner indications according to methods recommended in AITM (Airbus Test Methods) documents.

6.2 Context in Maintenance

The basic version of the ‘Line Tool’ aims to detect delaminations, but it does not enable to size them. When ‘no go’ diagnosis is displayed, one UT2 certified operator has to characterize
the finding and report its position, its surface and its depth. If no specialist is available, take-off delay makes passengers unhappy and causes unexpected expenses for the airline.

6.3 ‘Automatic Sizing’ Solution

The ‘Automatic sizing’ software was prototyped as a solution to the problem in manufacturing plants (see §6.1). It is compatible with ‘Smart U32’ instruments. The icons in the upper part of the GUI correspond to the different steps that operators must follow:

- Open one predefined set-up
- Equalize sequences (which means adjust gain offset values to get the same sensitivity on all the virtual probe apertures)
- Detect discontinuities (see fig.5): in this step, the window is split into four live ultrasound views (1 A-scan + 1 E-scan + 2 scrolling C-scans triggered by the internal clock) and three warning LEDs in the lower part of the display are activated help the operator (1 to monitor the acoustic coupling quality + 1 to detect attenuative porous areas + 1 to detect inner reflectors)
- Acquire C-scans triggered by positions encoder, as soon as one of the ‘Porosity’ LED or the ‘Discontinuities’ LED turns to red
- Run ‘NDT kit’ analysis software (also named ‘Ultis’ [4] [7]) as an invisible task to size automatically the discontinuities and compare them to acceptation criteria

One similar software is being developed for maintenance concern. It requires going further in the diagnosis assistance to make ‘Smart U32’ a real direct reading instrument for this application, whatever the component is.
7. Assisted Diagnosis for Fast Thickness Measurements after Blending Corroded Areas [10]

7.1 Context in Maintenance
When aerostructures get corroded, it is necessary to blend out affected layer. Remaining wall thickness have to be measured then to be sure that it is superior than the minimum value regarding mechanical stress. This operation is performed with conventional thickness gauge currently after drawing check pattern on the structure (see left side of fig. 6). Each cell is 10mm × 10mm, or even smaller (5mm × 5mm). As a consequence, the full cycle (prepare the inspection, measure thickness values and report the results in a document) takes about 5 hours for a surface equivalent to 40mm × 30mm. This job is very tiring especially on extrados faces of the wings for instance, because the transducer has to be held upside down.

7.2 ‘Thickness Grid Measurement’ Solution
It is based on the ‘Smart U32’ instrument and one wheel probe similar to the one of the ‘Line Tool’. Two laser diodes were added to project two lines which correspond to the edges of the recorded C-scan (see right side of fig. 6). The standard acquisition software was simplified to guide the operators. They have to follow the five following steps:
1. Open one predefined set-up
2. Calibrate ultrasound speed
3. Adjust the dimensions of the C-scan
4. Record the strips (they are automatically concatenated after pushing the left button on the wheel probe at the end of each line)
5. Define the minimum accepted thickness value, process data automatically and check the resulting editable report

Data processing consists in extracting thickness values automatically thanks to ‘NDT kit’ / ‘Ultis’ software, running as an invisible task, like to the ‘Automatic sizing’ solution.

The full cycle is reduced by a factor 30 compared to the current procedure.

This solution can be used also in manufacturing plants, for all the applications which require a high density of points which thickness have to be measured, assembly areas for instance.
8. Conclusions & Continuation

Several solutions were developed to assist operators in the diagnosis phase, and release faster components in manufacturing plants and aircrafts in maintenance: detection of delaminations around drilled holes, sizing of damages after impacts, thickness measurements after blending or machining, etc.

These solutions are available on the ‘Smart NDT tools’ which constitute a range of NDT instruments, developed by AIRBUS Group innovations, industrialized and commercialized by NDT EXPERT/TESTIA. They are designed to respond to industry problems, mostly in the aerospace sector:
- lack of certified inspectors,
- human factor affecting inspections reliability,
- use of UT1-L and ET1-L operators for simple inspections after each manufacturing step (in addition to final NDT performed by experts) to repair or reject bad components as soon as possible

Additional software modules are being developed for other applications such as the detection of cladding loss on fuselage panels made of aluminum alloys. Other developments are being carried out also in connection with ‘Smart NDT tools’, keeping in mind the same objective to make inspectors job easier:
- Sort bad components and good components automatically after inspecting with smart machines [12],
- Connect inspectors with remote assistance tools [11], etc.

9. Acknowledgements

Many thanks to all the colleagues from AIRBUS Group who have been contributing to develop ‘Smart NDT Tools’.

10. References


