Composite Inspection Benefits and Challenges Using Ultrasonic NDT Solutions

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Introduction

Ultrasonic Non-Destructive Testing (NDT) has helped engineers inspect all sorts of composite materials for years. Whether it be traditional aluminium laminates or today's more complex carbon fibre-based composites, the ultrasonic testing (UT) technology has the ability to acoustically see through these parts and create complete inspection maps. Comprehensive volumetric integrity reports can be generated with imaging reports that are as easy to interpret as traditional X-ray.

Over the years, numerous innovations helped improve efficiency, resolution and performance of UT. Nevertheless, specific challenges still exist when inspecting a composite structure using this technology. After a short introduction on UT and Linear Array, this paper will focus on some of the important inspection challenges: the dimensions and geometry of the part, the pressure for higher productivity, the variations of the acquisition conditions, the entire coverage of large surfaces as well as analysis and reporting. Likewise, we'll describe how the newly introduced Sonatest composite inspection solution, the RSflite, a high-end linear scanning instrument, in addition to the WheelProbe2 and the UTmap software, can help. This package offers a fast, portable, battery operated option to assist the NDT professionals facing these inspection challenges, would it be at the time of manufacturing or throughout the lifetime of an equipment requiring maintenance.

1 A Perfect Match between Ultrasonic NDT and Composite Inspection

1.1 Composite and the Industry

Composite materials are made from two or more components, which produce a material having overall performance better than the individual components. For example, the combination of two or more constituents allow the engineers to assemble structures that reach specific mechanical properties, at the same time reducing the overall weight and improving corrosion resistance. The aerospace industry has been an early adopter and heavy user of composites for years. Some of newest aircrafts integrate up to 50% of composite materials within their overall structure. For similar reasons, the trend of using composite materials is also observed in other industries like automotive, marines, drone and train for instance.

Figure 1: Trend in material composition of the latest aircrafts

1.2 How Does Ultrasonic NDT Respond to Composite Inspection?

An ultrasound is a vibration that travels through a medium using a frequency above the range of human hearing. This mechanical vibration can travel inside the material using two propagation modes: longitudinal and shear waves. Because of the typical anisotropic properties of composite materials, the longitudinal wave propagation mode offers the best performances and is the recommended approach.

Figure 2: Sonatest UT equipment used for composite assessment on the Concorde program in the UK, late 1960s.

For more than 60 years, Sonatest has been providing portable and innovative ultrasonic NDT solutions to multiple key industries, including aerospace. The portable manual conventional ultrasonic devices, often named flaw detectors, nowadays remain an efficient for detecting potential defects into composite structures. Flaw detectors echography displays echoes coming back from the component under evaluation in the form of simple "blip" on the screen. The name of this typical, well known simple imaging is the A-Scan.

There are fundamentally two types of information that can be extracted from the A-scan representation: the amplitude of the signal and its position, also named time-of-flight. Thus, a low or attenuated signal amplitude can represent a sign of good bounding quality. However, the presence of an echo crossing the A-scan gate earlier than expected can be interpreted as a layer delamination, a disbond, an impact damage defect or porosities.

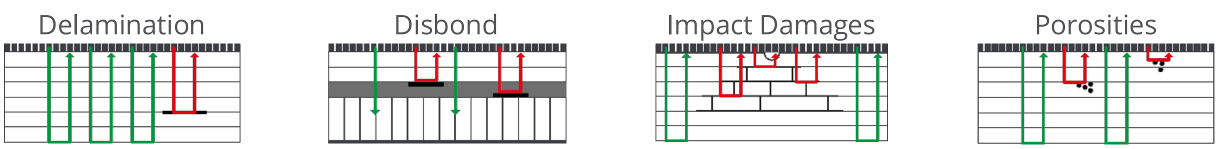


Figure 3: Typical composite defects captured with ultrasonic NDT solution.

1.3 Ultrasonic NDT Evolution for Composite Inspection

Empowered by the latest software and electronics innovations, the new generation of digital flaw detectors can record the A-scan signal with a mechanical encoder device to provide different types of scans, such as the B-scan (1 axis) and the C-scan (2 axes). While the B-scan represents a cross section of the part thickness, the C-scan is an image representing the top view. It is a two-dimensional representation of the part, usually showing defects and indication clearly. Interpretation of this imaging is easier.

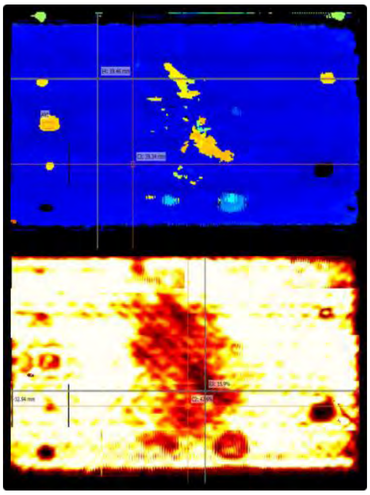


Figure 4: The top image shows a C-scan time of flight and bottom image a C-scan amplitude.

The C-scan can display echoes according to the time-of-flight or the amplitude of each of the encoded A-scan signals. For composite inspection, both information snippets are important because they highlight defect zones differently. Moreover, using colour palettes with adjustable trigger points allows highlighting specific defects, would they be amplitude or time-of-flight based. Therefore, the C-scan mapping is the most performant technique to make fast analysis of a composite structure. As we can see in figure 4, time-of-flight and amplitude-based C-Scan may reveal complementary information.

C-Scans nowadays are usually generated from data gathered using multielement linear array transducer and scan. These concepts are combined into one linear scan solution (L-scan), or sometimes referred to as an electronic scan (E-scan). Referring to the figure 5, the L-scan uses a group of elements to pulse a single straight beam (1). Then it shifts one element and pulses another adjacent beam (2). This sequence is repeated over the full length of the array (3). One of the main advantage for the L-scan is productivity as it generates a high resolution C-scan with only few strips.

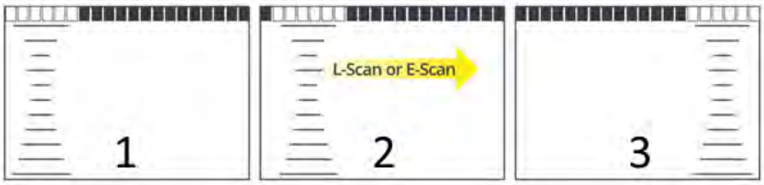


Figure 6: Linear scan or Electronic scan

The example on Figure 5 shows that only four strips are required for the L-scan while it requires more 200 strips of data for a conventional UT scan. Moreover, the L-scan will record the same important information such as: A-scans, B-scans, C-scans, for time-of-flight and amplitude.

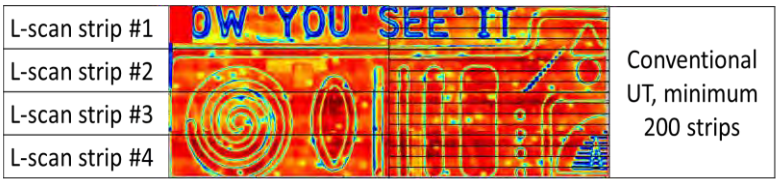


Figure 5: L-scan needs to encode less strips to cover the same area

Figure 7 shows examples of the type of images that can be generated using linear array devices.

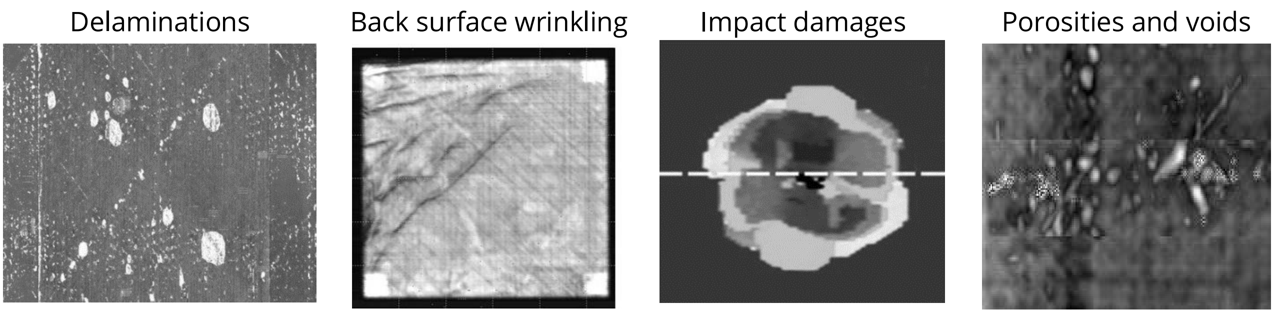


Figure 7 Ultrasonic C-scan imaging made with a Linear Array system over typical composite defects

It is worth mentioning that lately, new signal processing algorithms such as Total Focusing Method have been introduced to the market. Nevertheless, those algorithms require constant 3-Dimensionnal property to ensure a proper image reconstruction. Because of this, the abovementioned approach hasn't yet demonstrated being efficient on composite material.

2 Fast and Optimal Linear Scanning Solution Developed by Sonatest

As explained above, the use of ultrasonic linear array solution can greatly improve composite inspection performances. Typically, Sonatest's **WheelProbe2** linear array made of 64 elements and paired with the new **RSflite** fast acquisition system can inspect a 50 mm (4") wide strip at a rate of 200 mm / second! Remember that in the process, all data is recorded allowing further post scan analysis. The quickness of the scanning represents a tremendous advantage as it can cover large surfaces quickly, hence dramatically improve productivity. Moreover, since the scan resolution of the C-scan mapping can be as high as 0.8mm², defect sizing and positioning are precise. Even better, automated area calculations defined by specific properties can be performed during the analysing phase using Sonatest's post analysis **UTmap** software.

Figure 8: New complete UT solution for the composite industry

3 Overcoming Some Challenges of Using Ultrasonic NDT

3.1 Dimensions and Geometry of the Part

One of the main composite inspection difficulties is the size of a part or its geometry variation. Nowadays, innovative projects also challenge designers to meet strict requirements for dimensions, shapes, strength to weight ratio, fatigue, corrosion and heat resistance.

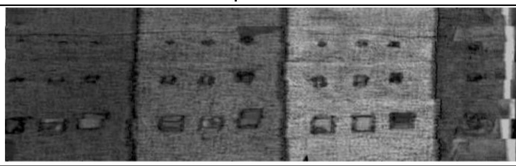
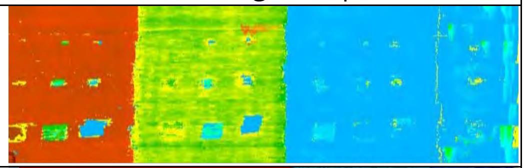
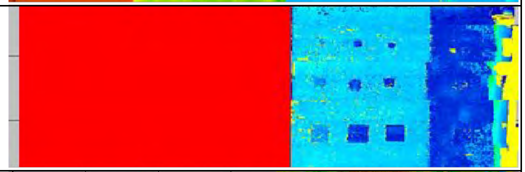
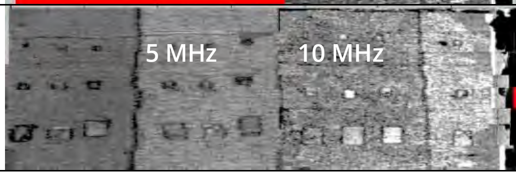
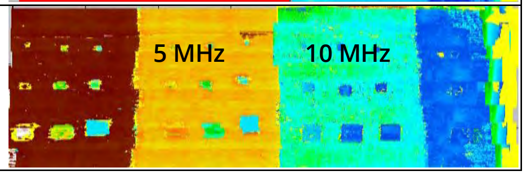
Figure 9: A380 length 73m, wingspan 80m

3.1.1 One Part. Different Inspection Requirements

Large components of composite materials are likely to have thickness variations through the whole design. They are also subject to have different insert depth or other joining device configurations. Along this design, some sections can be more critical than others, requiring enhanced Probability of Detection (POD) or higher sensitivity. Matching the inspection frequency with the part thickness to inspect is a good approach to perform highest inspection requirement.

To visualise this recommendation, a composite step sample with thicknesses of 2.8 mm to 0.6 mm has been inspected. This sample was having artificial Teflon inserts to simulate delaminations. The inspection data were recorded at first using a WheelProbe2 5 MHz and the portable RSflite linear scanning instrument. On the next page, Table 1 shows the C-scan mapping of the sample in amplitude (Left) and time-of-flight (Right). The UTmap software was used to produce all the images.

Table 1: Composite step sample inspected with a multi-frequency analysis approach using Sonatest UTmap

	Amplitude	Time-of-flight (Depth)
5 MHz		
10 MHz		
T-scan stitching using UTmap: left = 5 MHz right = 10 MHz		

The amplitude C-scan produced with the 5Mhz probe successfully detects and highlights most of the artificial delaminations. However, the Time-of-Flight information obtained with this probe frequency didn't have the required resolution to distinguish the artificial delamination's properly in the thinnest part of the sample (all same tonality of blue). In order to improve the sizing and evaluation of the Teflon insert, this section was then re-scan using a 10 MHz probe. This higher frequency greatly helps to successfully detect and differentiate the near surface artificial delamination's of the thin area.

The last row in Table 1 shows a combination of both acquisitions, 5 MHz and 10 MHz data sets, stitched together in the same T-scan. This final reporting assembly was performed rapidly using the unique UTmap stitching facility. By stitching information coming from two different probes, one precise report containing all the information has been generated, saving precious analysis time within the overall manufacturing or maintenance workflow.

3.1.2 Part Size, Shape and Geometry

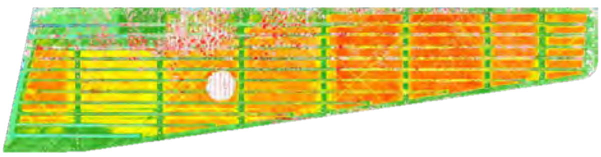


Figure 10: 7 m long rear stabiliser high res. C-scan

Some composite parts can have a lot of geometry changes for aerodynamic constraints. As well, other designs may request major monolithic aircraft sections to be made out of carbon fibre reinforced polymer (CFRP) material for weight economy. In both cases, the need for a proper non-destructive quality assessment is important to mitigate potential failures in operation. Inspection of large areas could be tedious, yet important if not essential. As an example, Figure 10 shows a complete high-resolution C-scan mapping of an aircraft rear stabiliser of 7 metres long performed by the RapidScan, Sonatest's previous generation linear inspection solution. Similar results would be obtained using the new generation solution based on the RSflite, WheelProbe2 and UTmap, with the advantage of faster scans performed using a truly portable piece of kit. As well, UTmap provides even more analysis tools, facilitating detection and measurement of anomalies.

3.2 Productivity is the Key - Save Time. Be More Efficient.

For years, the aeronautic manufacturing sector drove a large portion of the engineering and research associated with composite materials. With ever more demanding requirements, from eco-friendliness to reduced weight, the majority of manufacturers invest heavily in R&D. This results in the development of state-of-art composites. Then, at the manufacturing stage, pressure is high to ensure quality, on time and on budget delivery of goods. Unfortunately, it has been observed that some composite part suppliers struggle to deal with this required productivity increase and, at the same time, maintain the high level of quality expectations of their customers (often called the Tiers 1 partners). The same dilemma is now seen in multiple industries, with the result of having more suppliers facing the same challenge of higher productivity without compromising on quality.

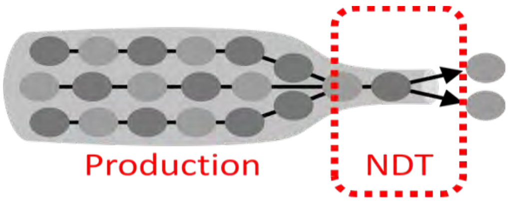


Figure 11: NDT, often at the end of production

3.2.1 Inspection Speed Benchmark Test

In the case of NDT equipment, the recording speed has always been difficult to compare between solutions because the recording performance typically depends on:

- the acoustic travel time (configuration and resolution dependant on the physics);
- the instrument pulse rate frequency (dependant on the physics or electronic);
- the data throughput (dependant on the electronic).

Any of the above parameter could become the limiting factor, setting the instrument maximum recording speed capability. In a configuration where the L-scan resolution, the probe and the part thickness are identical, only the instrument design, including both the electronics and software, makes a difference on the recording speed. For this test, we used 0.8mm resolution, WheelProbe2 and a material thickness of 50mm and velocity of 2900 m/s. In Table 2 below, a pulse generator has been used to simulate an encoder running at a constant rate for a short distance of 1000 mm. The rate has been raised until each instrument reaches its limit and starts to do miss frames.

Table 2: Top acquisition speed benchmark test using similar test condition

Speed Test	RSflite	Veo	RapidScan+	Prisma	MX2
Max speed	230 mm/s	180 mm/s	101 mm/s	65 mm/s	159 mm/s
Max Pulse Rate Frequency (PRF)	17 600 Hz	18 000 Hz	17 600 Hz	5000 Hz	11390 Hz
Comparison		RSflite is 28% faster	RSflite is 128% faster	RSflite is 254% faster	RSflite is 45% faster

Boosted by impressive recording capabilities, the Sonatest RSflite lightweight battery-operated equipment is two times faster than the previous generation. Being able to handle equally well small or large probes (up to 128 elements) and with almost no file size limitation, one can scan and inspect large surfaces quickly. Moreover, this inspection can be realized with one data set, and analyzed using a single data file, thanks to UTmap. This solution offered by Sonatest is definitely a productivity breakthrough.

3.2.2 An Optimised Workflow for Composite Materials Inspection

The RSflite, equipped with a responsive P-Cap touch screen, offers a much-simplified user interface. This simplicity provides significant savings in terms of training costs, namely when compared to more complex instrument offering advanced phased array ultrasonic testing (PAUT) concepts. By optimising the complete inspection workflow, Sonatest is convinced to deliver a game changer solution that helps tackle difficulties related to the quality and productivity challenges of the fast-growing and fast-changing composite industry.

Figure 12: Complete solution proposing an optimised workflow

3.3 Save Time with High Value Post-Acquisition Features

The RSflite and UTmap solution workflow has been designed to ease the post acquisition data management. It often happens that during the acquisition of a data set, the acoustic parameters might change due to a multitude of reasons: variation in the coupling, a different surface conditions, a change in the thickness are a few examples. As we will see below, Sonatest understood the above limiting factors that impact the quality of the data acquisition and came with innovative solutions to compensate for this situation.

3.3.1 Individual Re-gating and Sensitivity Adjustments of Each Strip

Compared to other software solutions, UTmap allows individual C-scan re-gating and post acquisition sensitivity adjustments of each strip of data using the soft gain feature. Those changes could be made just before the extraction information in the T-scan area in order to produce uniform and seamless mapping. Those adjustment features are especially useful when dealing with composite ultrasonic testing using amplitude assessment-based solution.

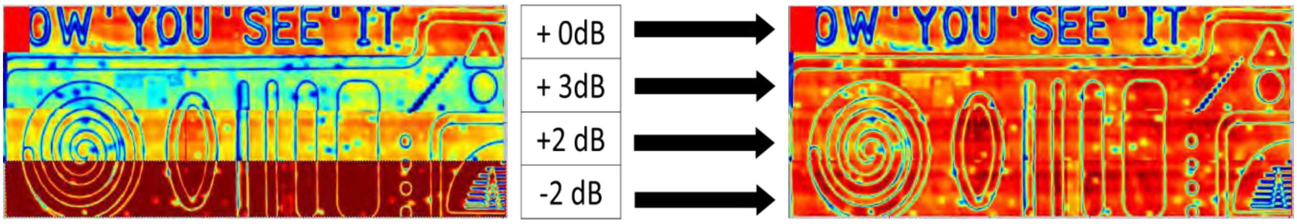


Figure 13: Left image, the strips in original data set do not all have the same sensitivity level. Right image, the sensitivity of each strip has been manually adjusted creating a homogenous C-scan image.

3.3.2 Adjust the Position and Coverage of the Inspection Data

For large specimens, lines are often drawn on the part to facilitate probe guidance. As well, small overlaps in between individual scan stripes are required to avoid unscanned areas. However, with classic merged C-scan workflow, it is difficult to keep the same start possition for every acquisition strip. Therefore, the data analysis will not be optimal, resulting in lower quality report.

Figure 14: WheelProbe2 and part grid

Within UTmap, each individual C-scan can be repositioned or rotated. The band overlapping can also be managed as well, by choosing which strips presents the best information. This strip is then "brought to front" of the mapping.

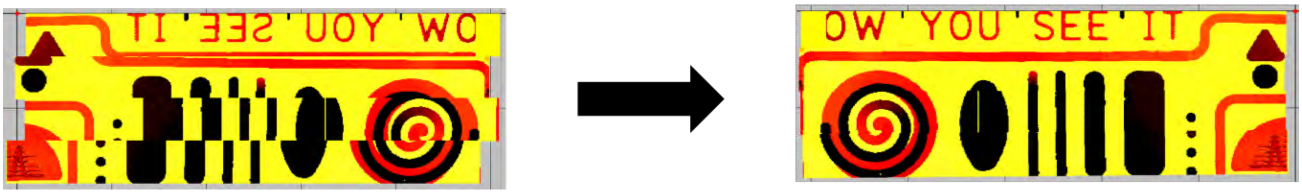


Figure 15: The position and overlap of the strips can be manually adjusted within UTmap

To improve data alignment precision, UTmap offers the unique possibility to import 2D CAD drawings of the part (or a simple picture) in the T-scan workspace. The C-scan strips can then be precisely applied with opacity option on the CAD overlay to create even more comprehensive inspection reports.

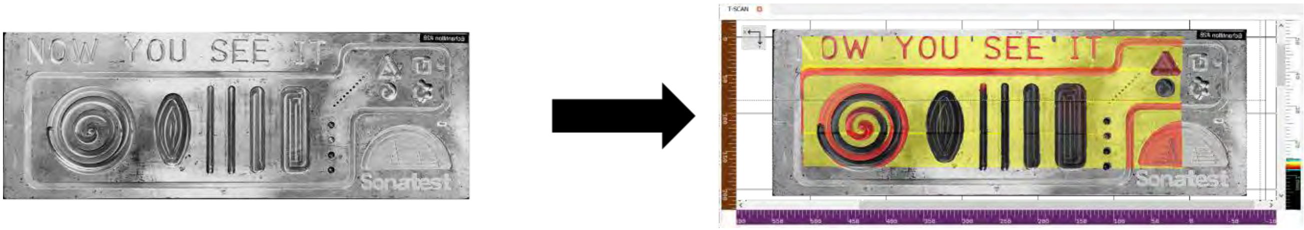


Figure 16: The part CAD or image can be imported as an overlay guideline within UTmap for precise data alignment

3.4 For Composites, Signal Quality Can Make a Huge Difference

Because of the variety of manufacturing processes, the dimensions, the attenuation and the geometry of composite parts differ enormously. Thus, manufactures have to ensure the selected inspection equipment will be capable to cope with the widest range of composite material configurations. Among many, three ultrasonic essential specifications shall be checked and verified in order to select the best piece of gear: the bandwidth, the Signal-to-Noise Ratio (SNR) and the near-surface resolution.

An instrument bandwidth indicates its capability to handle and perform well using different probe frequencies. In the case of ultrasonic linear array technology for composite material, a 5-MHz probe is a safe compromise between signal resolution and material penetration. However, some thicker or attenuative material can require the use of lower frequencies like 2 MHz to as low as 500 KHz. The compromise is that the signal resolution is greatly reduced with the probe frequency. At the other end of the spectrum, a thinner material requires a shorter wavelength to discriminate the top and bottom surfaces. In this case, probes with a frequency of up to 10 MHz will be selected.

The SNR is a metric that will guarantee the ability to distinguish a defect in a highly attenuative, noisy material. The highest the SNR is, the highest is the difference between the indication and the noise level. When inspecting attenuative material, the user needs increasing the instrument gain in order to raise the amplitude of the defects at different depths. With poorly designed instruments, as the noise level is high, boosting the gain to better see defects will, of course, amplify the noise as well, resulting in very weak image quality. Remember that part of the noise comes from the type of material inspected, the other portion being created by the electronics itself. The better the equipment, the lower this self produced noise will be, helping to keep the overall noise floor as low as possible, providing much improved imaging.

The near surface resolution is the last critical specification we listed. This is a key requirement for thin material or when the challenge is to detect anomalies within the very first plies of a laminate. This characteristic determines the smallest distance from the surface where an indication could be detected, localised and sized precisely. It has been tested down to 0.3 mm (10Mhz Probe), refer to the Figure 17 and the results of section 3.1.1.

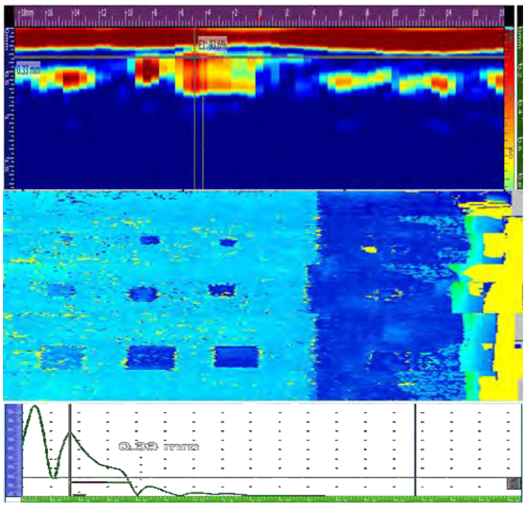


Figure 17: The RSflite - 10 MHz outstanding near surface resolution is able to discriminate a defect at 0.3mm depth

Backed by more than 60s years of passion and know-how, Sonatest's RSflite large bandwidth instrument, great SNR and exceptional near surface resolution offers performances never attained in the past. An interesting composite case study[1] has been presented at the 2018 ASNT Annual conference to support this claim. The presentation has shown that the Sonatest RSflite gave a distinct advantage at being able to size special small porosities, solving an important customer issue that was so far undetectable with other instruments. As well, the RSflite delivers an incredibly sharp near surface resolution. This optimal package designed for composite inspection simply – and successfully – combines both speed and signal quality.

3.5 Fast, Lean, Precise and… Hassle-Free Reporting

No matter the industry, report writing can be tedious. According to the complexity of the inspection, it may require summarising a huge amount of information. The end user's challenge is to make the report as simple as possible without compromising the quality of the information. Sonatest's UTmap software integrates useful tools and features that have been specifically designed to cover that need. Following is a brief customer case highlighting this statement.

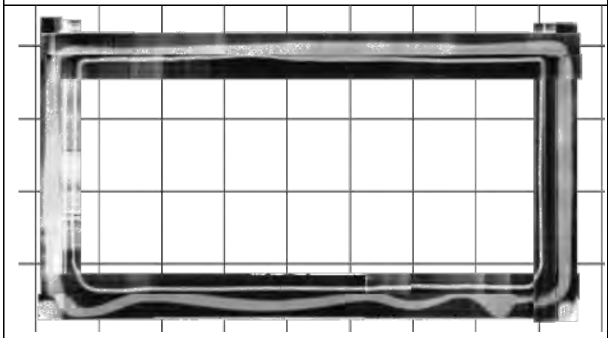
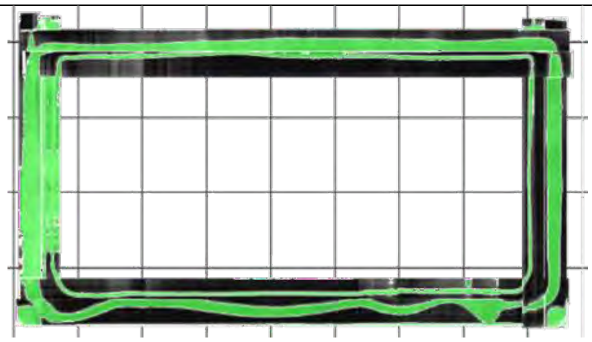
The data found in Table 3 has been produced when scanning a glass window prototype designed for the transport industry where the glass layer is bonded to a metallic frame with an adhesive. For this case, the customer was looking for the following information:

1) Evaluate the bonding quality between the glass and metallic structure;
2) Measure precisely the bonding area of the assembly in other to optimise the amount of adhesive required to reach specific mechanical properties.

At the first step, the window has been scanned using the RSflite instrument with the 5 MHz WheelProbe2. Then, all strips have been imported in the UTmap software. Very quickly, the user has been able to stitch the bands and create a coherent mapping of the component. After simple post-processing adjustments (re-gating and software gain sensitivity), it has been possible to quickly create an amplitude-based C-scan mapping. As displayed in Table 3, the mapping clearly shows the bonding area and calculate precisely, and automatically, the total surface of this area.

[1] Refer to the "PA Techniques and Defect Evaluation for Composites", by Rioux and presented at the ASNT 2018. Contact Sonatest at marketing@sonatest.com for more information.

Table 3: Fast and simple reporting using the Sonatest UTmap stitching and automatic contouring features

Amplitude C-scan mapping (grayscale colour palette)	Bonding automatic contouring and area calculation using the annotation (green area = 11799 mm²)
	 Example of other automatic calculations:

Max %FSH	Depth Max	Depth Min	ΔX	ΔY	Δ Depth
83.3%	3.68 mm	1.67 mm	239.60 mm	338.33 mm	2.01 mm

Sonatest took much care when it developed this automated indication sizing tool in its UTmap software. The feature allows to quickly find and size unforeseeable indication shape. As shown above, the green area was automatically detected and highlighted the UTmap defective zone algorithms based on amplitude or time-of-flight fully editable criteria. In this example, the area without adhesive was reflecting more energy; hence, the gain sensitivity was set to bring the back-wall echo at 80% FSH. The bonded area criteria started to be considered acceptable when the back-wall echo level drops to 65% FSH. Once set, the software updates the T-scan zone by contouring the targeted zone in real time which makes the user feel comfortable to play around and try different rejection criteria. Statistical information like dimension of the contoured zone is available in the annotation table for extended report information.

For this case, the Sonatest UTmap stitching capability, the individual stripe post-processing adjustments and the automatic contouring tool made the reporting activity very simple, yet precise and informative.

4 Conclusion

Among different NDT technologies, UT remains one of the most accurate solutions to inspect composite materials. As well, it is a fast technique to deploy on site. This paper presented and described the benefits of using ultrasonic linear array technology and some of the challenges a technician could expect when inspecting composite materials with it. With the latest developments, innovative manufacturers like Sonatest now offer solutions to overcome these difficulties. Indeed, paired with the WheelProbe2, the RSflite has the fastest recording capability and its optimised workflow interface improves productivity. Driving a large range of probe frequencies, delivering an outstanding SNR quality signal and a sharp near-surface resolution performance makes this new Sonatest's solution the perfect choice for a wide range of composite materials applications. Moreover, UTmap software offers features that levels uneven acquisition conditions, lowering constraints at the scanning stage of the inspection.

Backed with 60 years of experience delivering ease of use and performance, Sonatest once again came up with innovations to overcome today's challenges of a demanding industry.