
# Composite Inspection Benefits and Challenges Using Ultrasonic NDT Solutions

## 1 Introduction

Ultrasonic Non-Destructive Testing (NDT) is widely utilized by engineers to inspect a range of composite materials, including aluminum laminates and carbon fiber-based composites. This technology enables the generation of comprehensive inspection maps and volumetric integrity reports, offering interpretation ease comparable to traditional X-ray imaging. While significant advancements have been made to enhance the efficiency, resolution, and performance of UT, there remain specific challenges when inspecting composite structures. These challenges encompass considerations such as part dimensions and geometry, the demand for increased productivity, variations in acquisition conditions, and the requirement for complete coverage of large surfaces.

To address these challenges, Sonatest offers comprehensive composite inspection solutions. Our phased array RSflite and VEO3 product line, combined with large probe and wheel arrays, serve as efficient workhorses for mapping c-scans. When evaluating smaller areas, the D-70 or our unparalleled Sonatest Wave provide exceptional options. We always prioritize portability and speed, ensuring our instrument line is the ideal companion for both manufacturing and long-term maintenance NDT support.

# 2 A Perfect Match between Ultrasonic NDT and Composite Inspection

## 2.1 Composite and the Industry

Composite materials offer significant advantages as they are composed of multiple components that collectively enhance the material's overall performance. By combining different constituents, engineers can construct structures with specific mechanical properties while simultaneously reducing weight and improving corrosion resistance. The aerospace industry, known for its pioneering spirit, has embraced composites and extensively incorporated them into aircraft construction. In fact, the latest aircraft models now feature composite materials comprising up to 50% of their overall structure. Ensuring the quality of each component and material composition necessitates comprehensive inspection procedures. Fortunately, modern inspection techniques, such as phased array ultrasound evaluation, allow for efficient and reliable assessment using a single and multi-task instrument. This streamlines the inspection process and enables accurate control of the composite material's quality and performance.

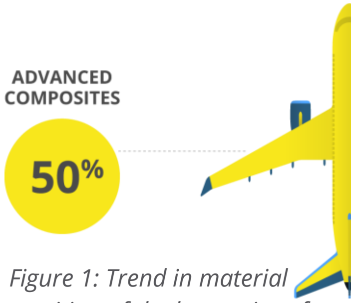



*Figure 1: Trend in material composition of the latest aircrafts*

*Figure 2 High-Level Performance Racing*

For similar reasons, the trend of using composite materials is also observed in other industries like automotive, marines, drone and rail for instance. Composites play a significant role in modern motorsport, comprising up to **85% of materials in cars** used across various disciplines such as Formula racing (including F1), Rally car racing, Moto GP, karting, and more. Conducting inspections both on and off the track proves invaluable in identifying damaged components requiring repair or replacement. Moreover, these inspections aid in the detection of manufacturing defects, such as lamination issues, poor bonding, porosity, and other critical factors. By equipping teams with this vital information, inspections enable them to make swift and informed decisions in the pit lane, contributing to **improved performance, budget restrictions** and **safety.** Furthermore, thorough inspections support the design and verification process of each vehicle component, ensuring optimal performance and reliability which undeniably the key to all racing strategies.

## 2.2 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 3: Sonatest UT equipment used for composite assessment on the Concorde program

For more than 65 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. 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.

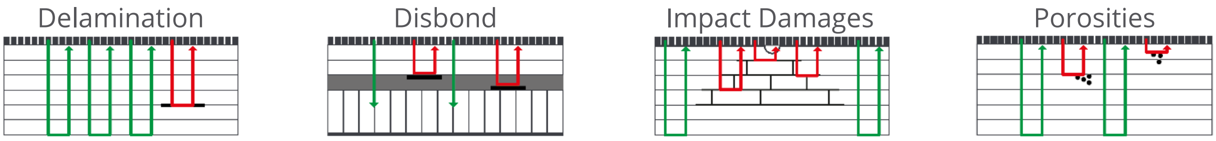



*Figure 4: Typical composite defects captured with ultrasonic NDT solution.*

## 2.3 Ultrasonic NDT Evolution for Composite Inspection

Empowered by the latest software and electronic 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 and the C-scan. 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.

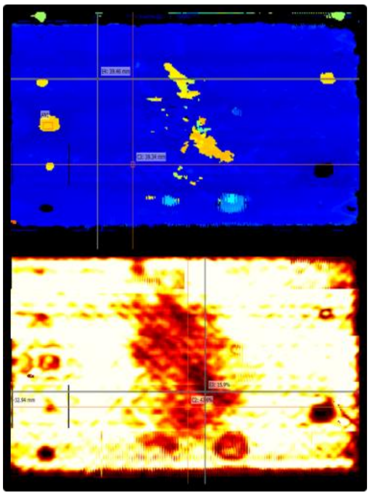


*Figure 5: The top image shows a C-scan time of flight and bottom image a C-scan amplitude.*

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

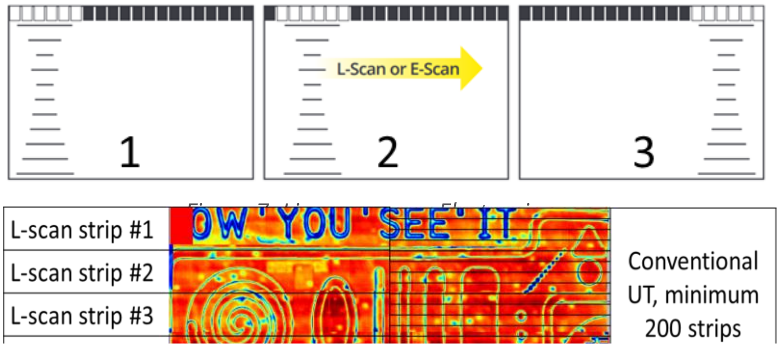



*Figure 6: L-scan needs to encode less strips to cover the same area*

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. The example on Figure 6 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 8 shows examples of the type of images that can be generated using linear array devices.

Delaminations | Back surface wrinkling | Impact damages | Porosities and voids

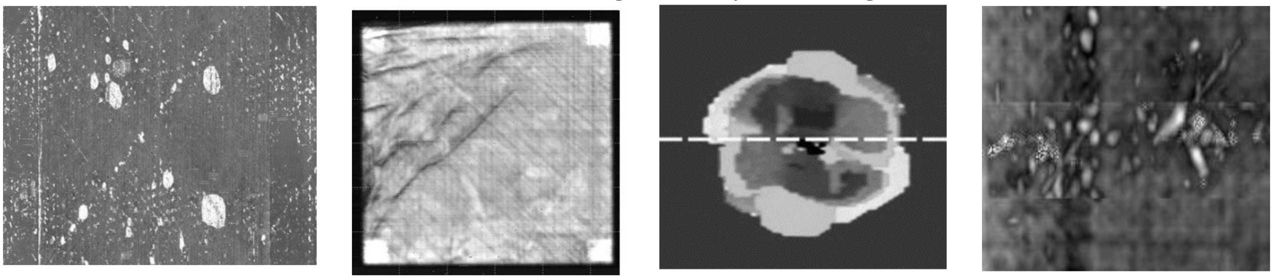


*Figure 8 Ultrasonic C-scan imaging made with a Linear Array system over typical composite defects*

### 2.3.1 TFM meets Composite Inspections

In the recent years, we have been able to use large, phased array 1D probe to glass fibre reinforced polymer (GFRP). The recent imaging technologies that Sonatest developed allows the instrument to create high focused pixel without depth of field distortion unlike the typical aggressive aperture L-scan[1] when focus is out its depth of field. The 0.5 and 1 MHz large frequency probe may unlock challenging, thick and exotic composite material testing.

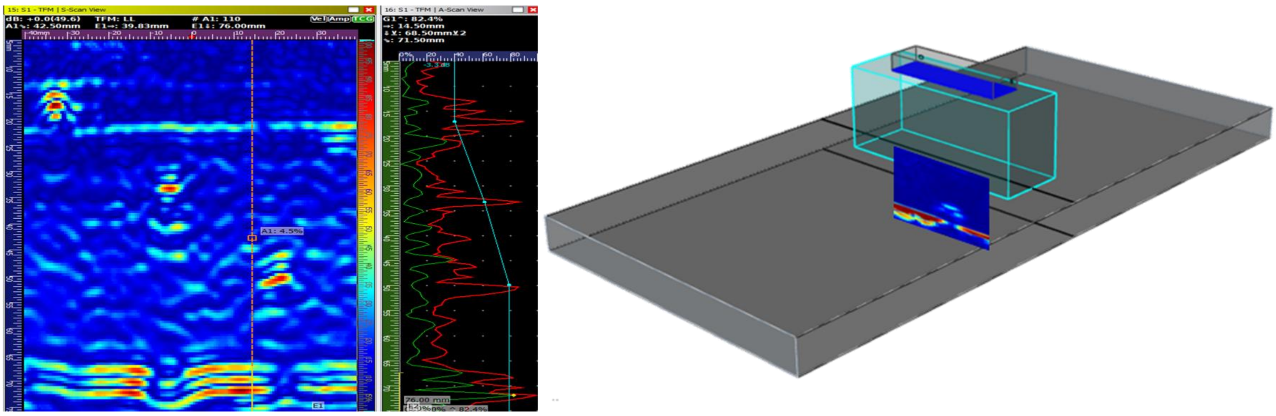


*Figure 9 TFM Side View On a 80 mm GFRP Sample*

[1] *"Low Frequency GFRP Imaging with Variable Aperture TFM", by Rioux and presented at the ASNT 2022. Contact Sonatest at marketing@sonatest.com for more information.*

# 3 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 **RSflite** and **VEO3** 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. For a 3D analysis, complex part and advanced tools as TFM profiler, we recommend **UTstudio+** and/or CIVA Analysis.


*Figure 10 WP2, Rsflite and UTmap kit*

# 4 Overcoming Some Challenges of Using Ultrasonic NDT

## 4.1 Dimensions and Geometry of the Part

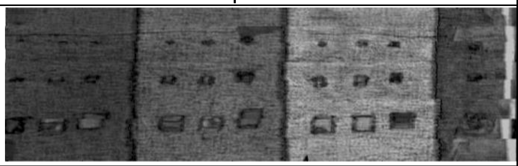
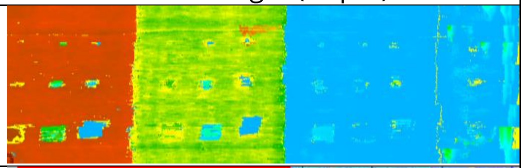
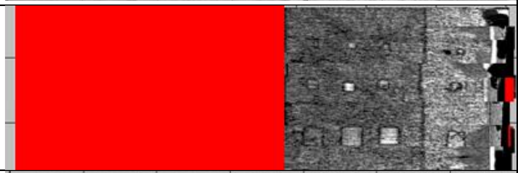
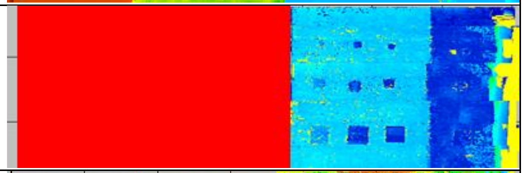
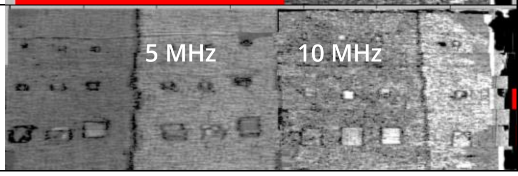
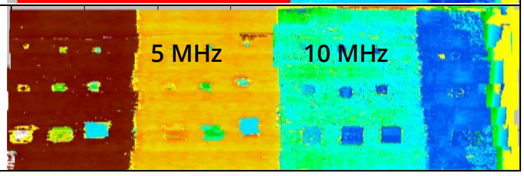
Composite inspection poses a major challenge due to the size and geometry variation of parts, which is further compounded by the demand for innovative projects that require strict adherence to dimensions, shapes, strength-to-weight ratios, fatigue, corrosion, and heat resistance requirements. To ensure the longevity and durability of these components, mechanical designers now seek 100% volumetric inspection to guarantee the integrity of the entire geometry.

### 4.1.1 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.

#### 4.1.2 Part Size, Shape and Geometry

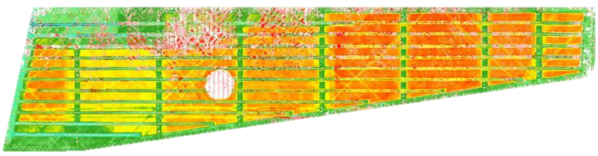


*Figure 11: 7 m long rear stabiliser high res. C-scan*

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 11 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.

## 4.2 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-the-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 tier 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.

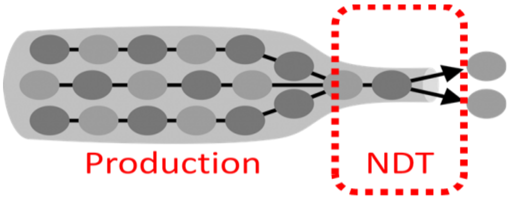


*Figure 12: NDT, often at the end of production*

### 4.2.1 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/VEO3 | Prisma |
|---|---|---|
| Max speed | 230 mm/s | 65 mm/s |
| Max Pulse Rate Frequency (PRF) | 17 600 Hz | 5000 Hz |
| Comparison | | RSflite is 254% faster |

Boosted by impressive recording capabilities, the Sonatest PA instrument 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.

### 4.2.2 TFM Imaging as an alternative to L-scan

TFM imaging has been shown to effectively solve large glass or carbon fiber matrix structures. A new receiving aperture strategy has been developed to improve the depth of field focus compared to L-scan imaging. Traditional L-scan imaging only provides satisfactory resolution within the focusing distance, which can be inadequate for large probes and thick composite components. In contrast, TFM imaging is capable of focusing at all points and provides high pixel response, resulting in improved image quality over materials with high attenuation or poor quality material granular structure.

## 4.3 Save Time with High Value Post-Acquisition Features

UTmap is a powerful tool that streamlines post-acquisition data management. It is common for acoustic parameters to change during data acquisition due to various factors such as variations in coupling, different surface conditions, or changes in thickness. However, Sonatest recognized these limiting factors that can impact data quality and developed innovative solutions to address them.

When performing weld analysis and volumetric evaluation, we highly recommend using UTstudio+. This software offers advanced features that allow for detailed analysis and precise measurements. For even more in-depth 3D modeling, CIVA Analysis is also an interesting option.

### 4.3.1 Optimise Mapping Rendering

Compared to other software solutions, UTmap allows individual and Merged 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.

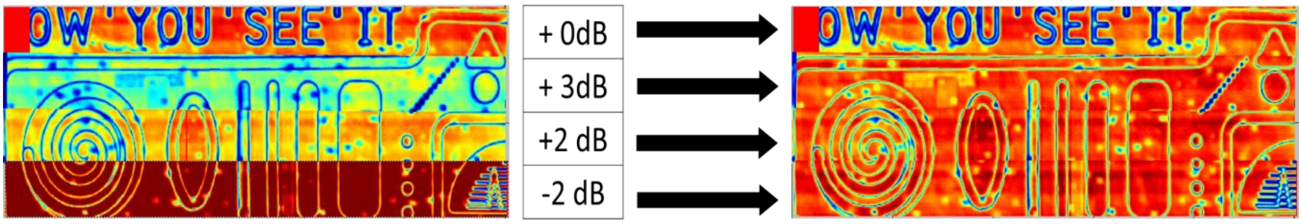



*Figure 13: Left image, the strips in original data set do not all have the same sensitivity level. Right image, the sensitivity of each strip has been manually adjusted creating a homogenous C-scan image.*

It is worth noting that starting from version 4.4, UTmap software batch of C-scan (AKA Merged-C-scan) imports obtained from a 2D encoded scan plan. Additionally, the software provides the option to crop individual lines to remove unwanted data. When used in conjunction with snapping cursors tooling, this feature ensures that the area evaluation precision matches the resolution of the pixel data.

### 4.3.2 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 the front” of the mapping.

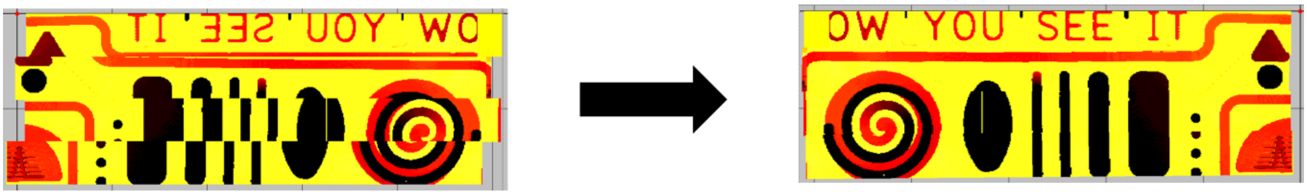



*Figure 15: The position and overlap of the strips can be manually adjusted within UTmap*

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.

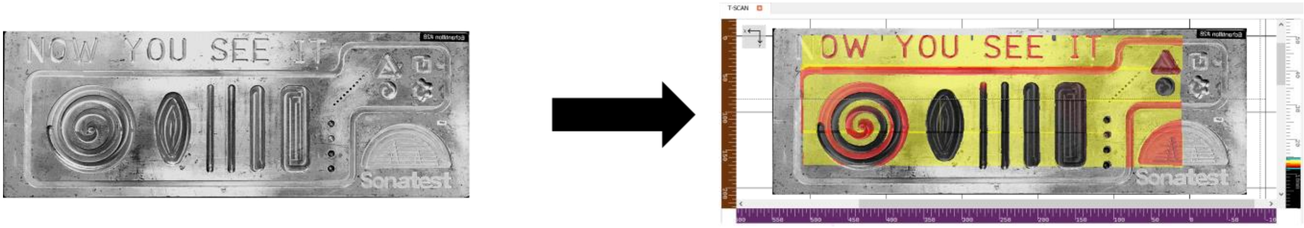



*Figure 16: The part CAD or image can be imported as an overlay guideline within UTmap for precise data alignment*

## 4.4 For Composites, Signal Quality Can Make a Huge Difference

Due to the vast range of manufacturing processes used for composite parts, their dimensions, attenuation and geometry can differ significantly. Consequently, manufacturers need to ensure that the chosen inspection equipment can handle a wide range of composite material configurations. There are three essential ultrasonic specifications that must be checked and verified in order to select the best equipment: bandwidth, signal-to-noise ratio (SNR), and near-surface resolution.

Bandwidth refers to an instrument's capability to handle and perform well using different probe frequencies. For ultrasonic linear array technology for composite material, a 5-MHz probe is a safe compromise between signal resolution and material penetration. However, thicker or more attenuative material may require the use of lower frequencies such as 2 MHz or even as low as 500 KHz, at the expense of signal resolution. On the other hand, thinner material requires a shorter wavelength to discriminate the top and bottom surfaces, so probes with a frequency of up to 10 MHz may be selected.

The SNR is a critical metric that ensures the ability to distinguish a defect in a highly attenuative and noisy material. The higher the SNR, the greater the difference between the indication and the noise level. When inspecting attenuative material, the user needs to increase the instrument gain to raise the amplitude of the defects at different depths. However, boosting the gain with poorly designed instruments amplifies the noise as well, resulting in poor image quality. The better the equipment, the lower the self-produced noise will be, helping to keep the overall noise floor as low as possible, providing much improved imaging.

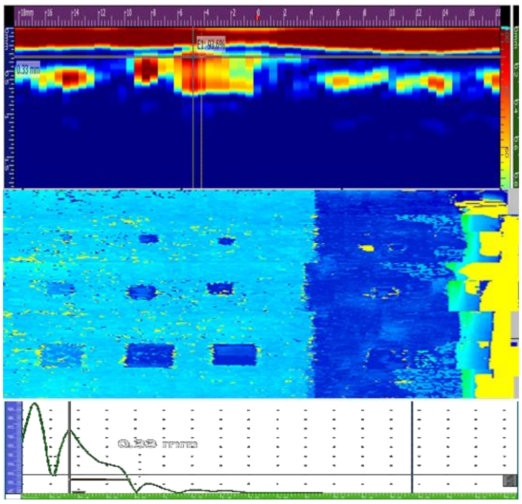


*Figure 17: The RSflite - 10 MHz outstanding near surface resolution is able to discriminate a defect at 0.3mm depth*

Near-surface resolution is the last crucial specification that should be considered, especially when detecting anomalies within the first plies of a laminate or for thin materials. This characteristic determines the smallest distance from the surface where an indication could be detected, localized and precisely sized. It has been tested down to 0.3 mm using a 10 MHz probe, as shown in Figure 18 and the results of section 3.1.1.

With over six decades of experience, our large bandwidth Sonatest PA instrument with high SNR and exceptional near-surface resolution offers unprecedented performance. A case study presented at the 2018 ASNT Annual Conference[2] showed that the Sonatest RSflite and VEO3 gave a distinct advantage in sizing small porosities that were previously undetectable with other instruments. Furthermore, our electronics provides an incredibly sharp near-surface resolution. This equipment combines both speed and signal quality, making it an optimal package designed for composite inspection.

## 4.5 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 order to optimise the amount of adhesive required to reach specific mechanical properties.

At the first step, the window has been scanned using 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

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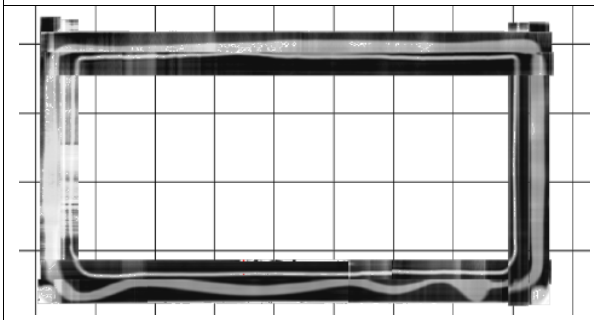
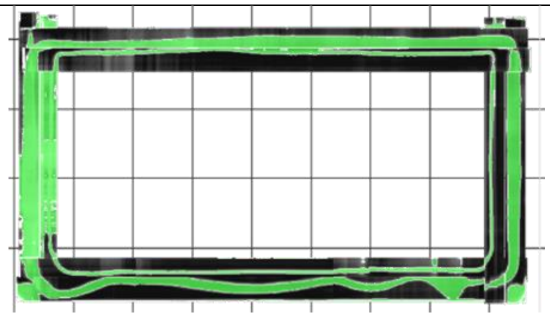
[2] *Refer to the "PA Techniques and Defect Evaluation for Composites", by Rioux and presented at the ASNT 2018. Contact Sonatest at* marketing@sonatest.com *for more information.*

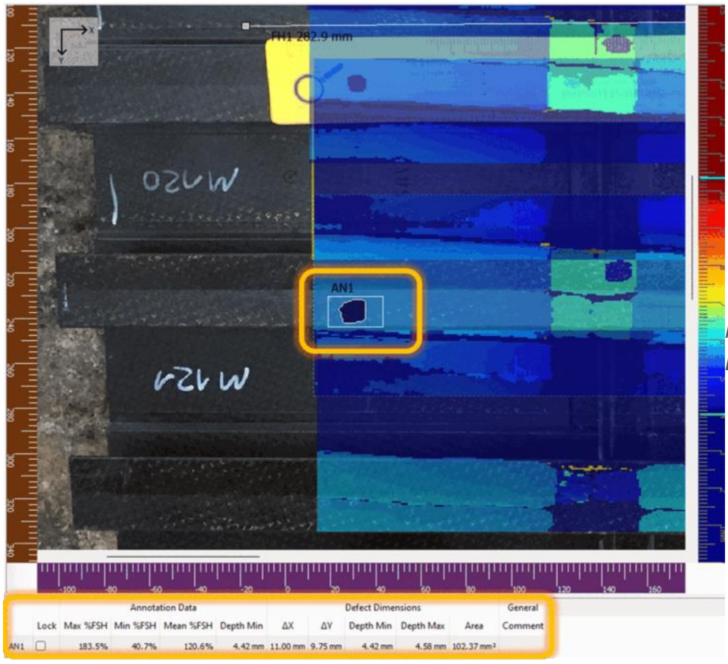
coherent mapping of the component. After simple post-processing adjustments (re-gating and software gain sensitivity), it has been possible to quickly create an amplitude based C-scan map. As displayed in Table 3, The map clearly shows the bonding area in the left image, in the right the overall surface area of bonding has automatically been calculated precisely.

*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 the user to **quickly locate and size indications of any 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 all pre-defined defect analysis, 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.**

*Figure 18 Teflon Highlighted: Size, Dimensions and Area Fast Evaluation*

## 5 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 and mapping X-Series probe,** our PA instrument have 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.