Applications of NDT Methods on Composite Structures in Aerospace Industry

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Abstract

This paper reviews present NDT methods used for composite inspection in aircraft industry. Manual and automatic ultrasonic testing with single element transducers and linear phased array probes in pulse echo and through transmission mode is applied mainly. But also resonance methods, shearography, thermography and special methods are used. Laser ultrasound is a candidate for future contactless automatic inspection.

1. Introduction

Composite materials are used more and more in aircraft production. Main composite types are Carbon Fibre Reinforced Plastics (CFRP), Glass Fibre Reinforced Plastics (GFRP) and metal-aluminium laminates (e. g. Glass Fibre Reinforced Aluminium GLARE©). Typical parts made of CFRP are flaps, vertical and horizontal tail planes, center wing boxes, rear pressure bulkheads, ribs and stringers. For the Airbus A380 GLARE is used even for some shells of the upper fuselage. The weight percentage of composites in modern civil aircrafts like the A380 is in the order of 25%. It may be expected that this percentage will further increase for the next generation of civil aircrafts and that main structure parts like fuselage and wings will be composed of composites, too.

These composite parts require adequate Non-Destructive Testing (NDT) methods. NDT is applied in production as well as during maintenance (in-service). Flaws to be detected are delaminations and debondings, porosity and foreign body inclusion. The most applied NDT method is ultrasonic testing (manual as well as automatic, in pulse echo and through transmission, with single element transducers and linear phased array probes). But also resonance methods, shearography and thermography and special methods are used. This papers reviews the present NDT methods for composite inspection in aircraft industry and reports about future demands.

2. Manual and Automatic Ultrasonic Testing

Manual ultrasonic testing with single element transducers is still the most applied method for composite parts with small and medium size. The inspectors are evaluating the A-scans for flaw detection. Flaw sizes are measured by manual scanning of the probe around the maximum echo, e. g. using the 6dB method.

In the last years the first linear ultrasonic phased array (PA) inspection systems were applied for aircraft inspection. With PA's any desired wavefront can be generated by pure electronic means. The individual transducers are triggered with a certain delay. The superposition of individual wavefronts results to a new wavefront with the desired properties. The PA techniques can be used to tilt and focus a sound beam by electronic means and for electronic scanning of a sound beam. Another advantage with respect to single element transducers is the availability of images (B-scan, C-scan, S-scan) instead of only A-scans, which allows better interpretation of signals inside complex structures. An example of PA inspection of a bonded stringer is shown in figure 1. The signals of various reflecting surfaces and interfaces can be clearly identified in the B-scan (right part of the figure).

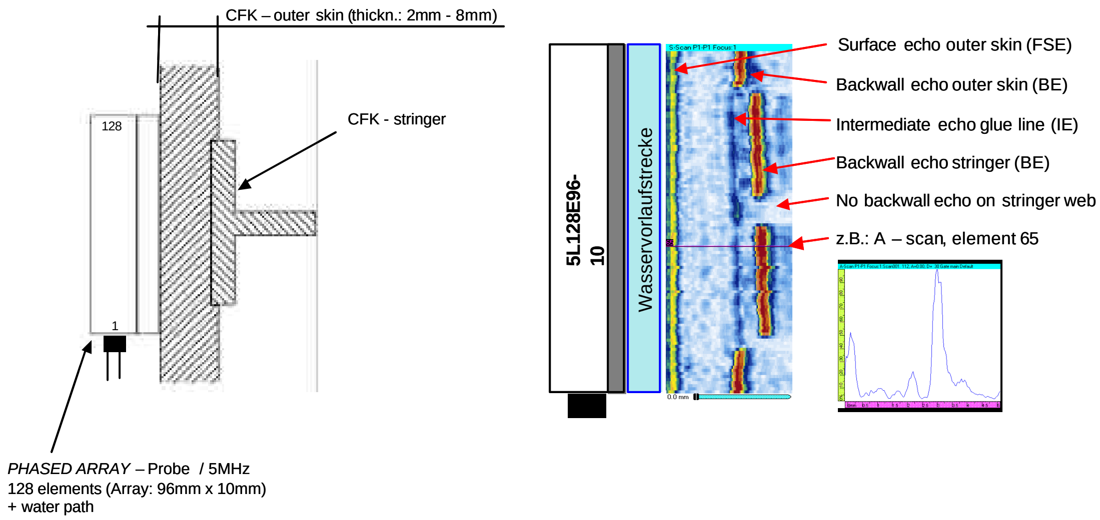

Figure 1: Phased Array Inspection of Stringer Skin Bonding

Big CFRP parts are inspected automatically or semi-automatically with multi-channel facilities. Such machines consist of a portal, which moves the inspection probe over the surface of the part. An example from an Airbus multi-channel facility working in pulse-echo mode is shown in figure 2. The probe consists of 96 individual transducers (channels). The maximum testing area is 13m $\times$ 7m, with a speed of 100mm/s. The part in the figure is a rear pressure bulkhead. At Airbus multi-channel facilities are used to inspect vertical and horizontal tail planes (shells, up to 10 meter long), rear pressure bulkheads, flaps and other long or big CFRP parts. Evaluation of data is assisted by special software tools.

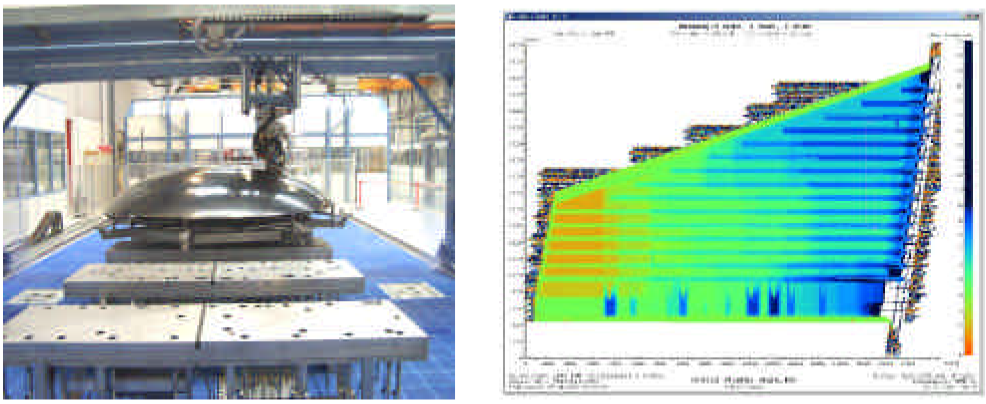

Figure 2: left: Airbus Stade Multi-channel Facility No. 2; right: D-scan

3. Air-Coupled Ultrasound

In ultrasonic testing a coupling medium (usually water) is used to couple the sound field in the component with minimum losses. Losses due to reflection occur at interfaces, where the sound impedance changes drastically. This is the case e. g. at the interface between air and part. This impedance change is much lower between water and part. The coupling medium reduces therefore the losses.

However, there are components which should have no contact with water or any other coupling medium. This is the case e. g. for honeycomb components and sandwich parts or parts with a foam core. For such components the air-coupled method can be applied. This technique uses a high sound pressure to compensate losses and low frequencies (50kHz to some 100 kHz). The scheme of air-coupled ultrasonic testing in transmission is shown in figure 3, an example is shown in figure 4. A double shell structure with foam core inside is investigated by impact tests. The stringer debonding is clearly visible in the C-scan.

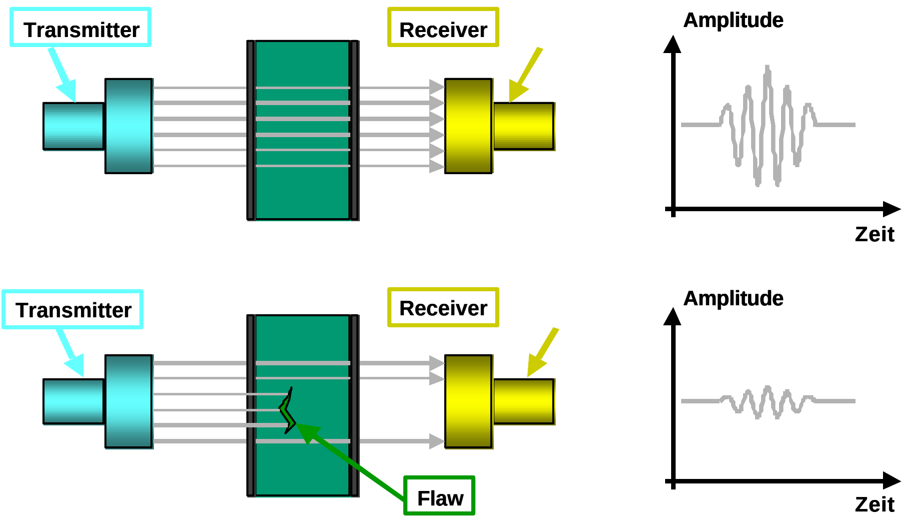

Figure 3: Air-Coupled Ultrasonic Testing

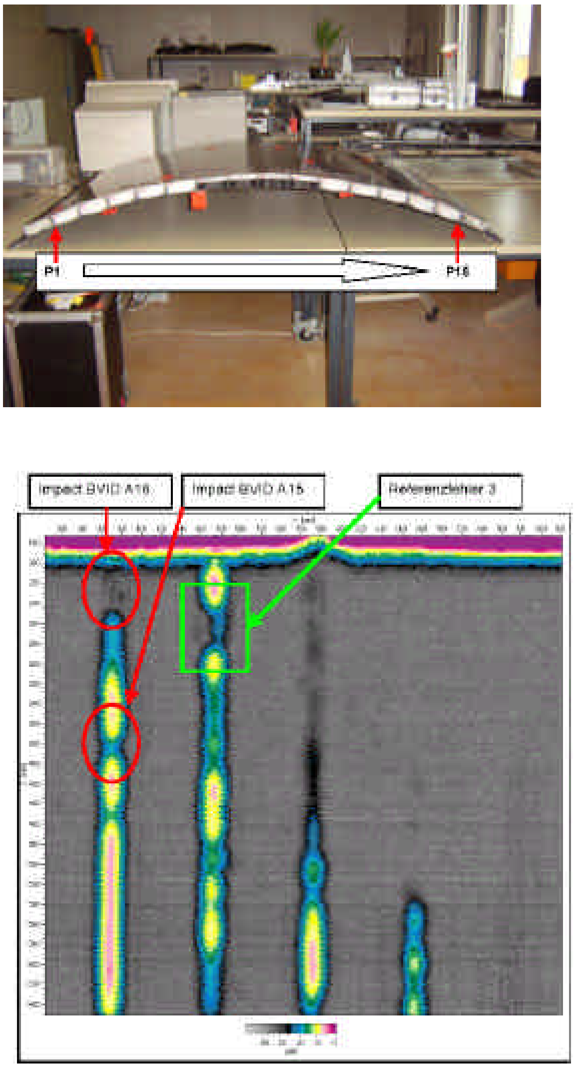

Figure 4: Air-coupled UT Example: Double Shell Structure (top), C-scan (lower bottom)

5. Porosity Measurement

Prorosity in composites may degrade the stiffness of the structure. Porosity has to be detected therefore in production. At Airbus Germany the requirement is that at most 2.5% volume porosity is allowed. An ultrasonic testing method has been developed and qualified to detect porous areas in CFRP components.

In porous areas often no intermediate echo occurs, because pores may scatter the incident sound in all directions. The method is therefore based on measurement of backwall echo reduction due to pores. The backwall echo amplitude decreases, if the sound wave is attenuated by porosity. It could be shown, that there is a good correlation between backwall echo reduction and volume porosity determined by micrographic analysis, see figure 5. Such correlation diagrams are recorded for all different material type and thickness combinations used in production. The similarity of ultrasonic behaviour regarding porosity was shown by approved statistical tests performed on a large data basis. Because of this similarity, different material types may be merged. As a result a unique ultrasonic backwall echo reduction threshold value for classifying porosity as greater than 2.5% by volume has been elaborated. These threshold values depend **on thickness only** and are decisive for all epoxy resins reinforced by carbon fibres in unidirectional built-up, fabric built-up and mixed built-up (based upon statistical security by an adequate confidence level). Similar threshold values will be available soon also for GFRP.

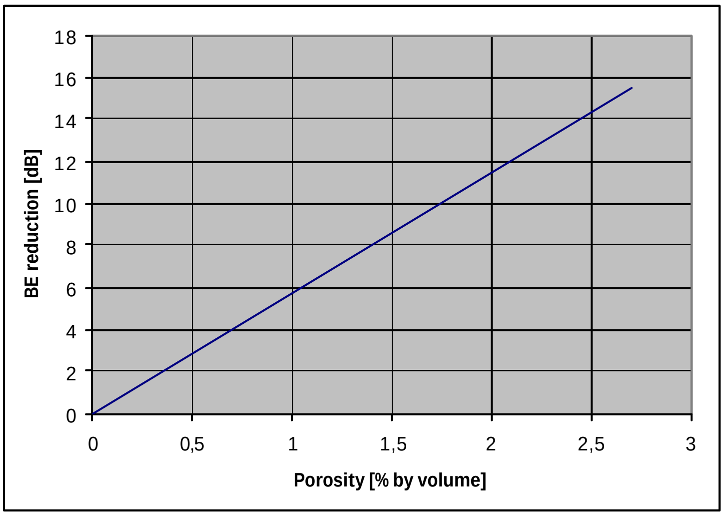

Figure 5: Ultrasonic Backwall Echo Reduction versus Volume Porosity

4. Laser Ultrasonic Testing

Laser ultrasonic testing combines features of optical inspection (contactless, two-dimensional) with those of ultrasonic testing (looking inside the part), see scheme in figure 6. A pulse laser is directed onto the surface of the component under test. It generates an ultrasonic wave, propagating in the material. As for conventional ultrasonic testing the signal is reflected at flaws and interfaces (backwall). The reflected signal is detected optically, e. g. using a second (long pulse) laser and an interferometer. After filtering the detected signal is similar to a conventional A-scan. Scanning of the focussed laser pulse over the surface generates a C-scan.

The main advantage of laser UT is that the sound waves propagate always normally to the part surface, independently from the incidence angle of the laser light. The method is therefore predestinated to inspect parts with complex geometry, where conventional multi-channel systems cannot follow the surface shape and manual testing is not economical. On the other hand laser UT facilities are (presently) very expensive and complex and have a low scanning speed, because only one channel (laser spout) scans the components. Some development work is still necessary to make this technique mature for NDT in civil aircraft production.

An example is shown in figure 7. The inspected surface is at the corner. The Laser UT A-scan is comparable to A-scans of conventional ultrasonic testing. Normally this part is inspected manually. An automatic inspection by conventional ultrasonic testing with transducers is difficult due to the complex geometry.

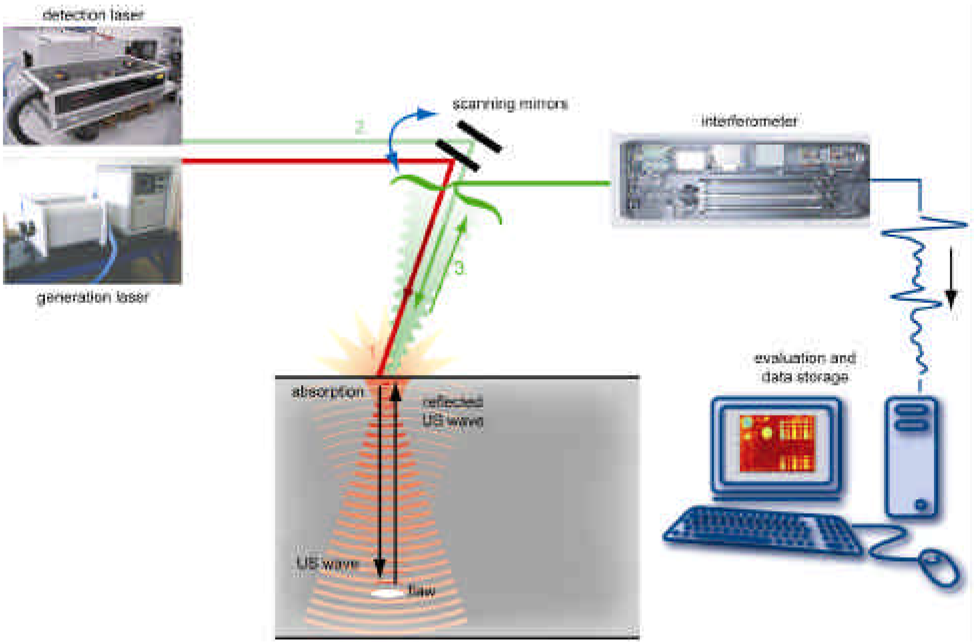

Figure 6: Laser UT

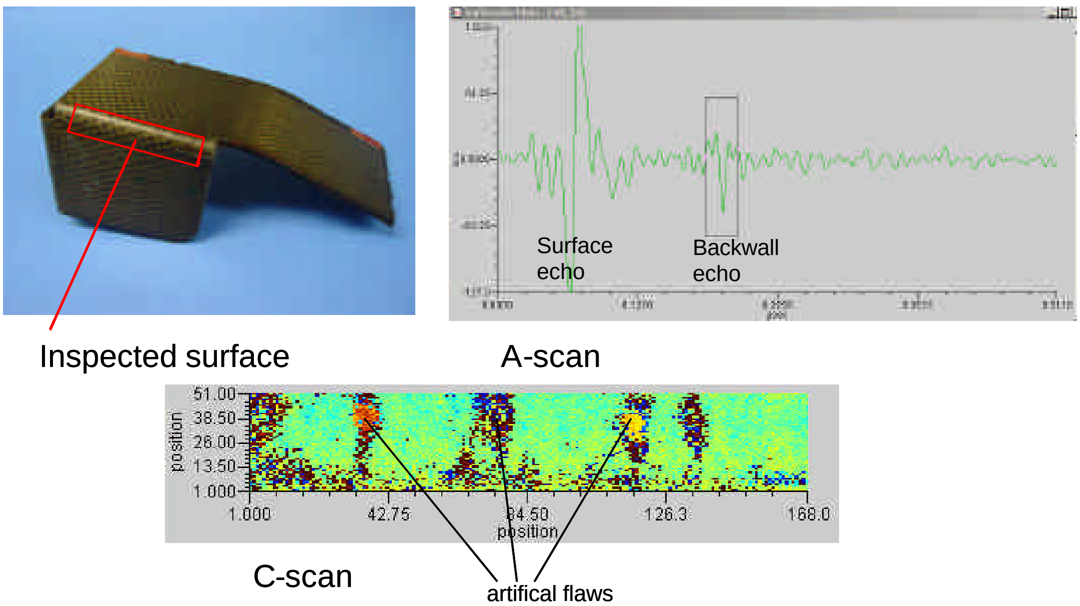

Figure 7: Laser UT Inspection of a Component with Curved Geometry

7. Shearography

20 years ago the NDT community was very enthusiastic concerning the capability of the new method Holographic Interferometry (HI). Hi is an optical two-dimensional method with very high sensitivity. With this method even smallest defects could be found. However, after a short period Hi was discarded for NDT purposes (not for quantitative deformation measurement), mainly due to two disadvantages. On the one hand the complicated chemical development process of holographic media was not acceptable for measurements in production environment (even the thermoplastic film with semi-automatic development could not solve this problem). Secondly, the price for the high measurement sensitivity was the sensitivity of the measurement apparatus to vibrations.

The next step in interferometric measurement was Electronic Speckle Pattern Interferometry (ESPI), which replaced the holographic film by an electronic target, but led the vibration problem still unsolved. So ESPI was also an intermediate step.

Finally Shearography also solved the vibration problem, because both interfering beams are guided via the possibly vibrating component. Meanwhile complete shearography systems with laser, optical head and computer controlled data recording and evaluation are commercially available.

Airbus applied shearography to several CFRP inspection problems. One example is shown in figure 8. Flaws due to incorrect repair of the spoiler are clearly visible in the unwrapped phase map. Shearography is mature for aircraft applications, but it competes with existing solutions, mainly with ultrasonic testing. A big advantage of shearography is that it is contactless and delivers directly two-dimensional information. Debondings and delaminations are easily detectable. On the other hand porosity is difficult to detect, because there is no direct correlation between the measured surface deformation and the pores inside. Shearography is therefore a candidate for in-service application, where porosity detection is not required. Possible applications are detection of stringer debondings or other flaws caused by damage, e. g. impact damages.

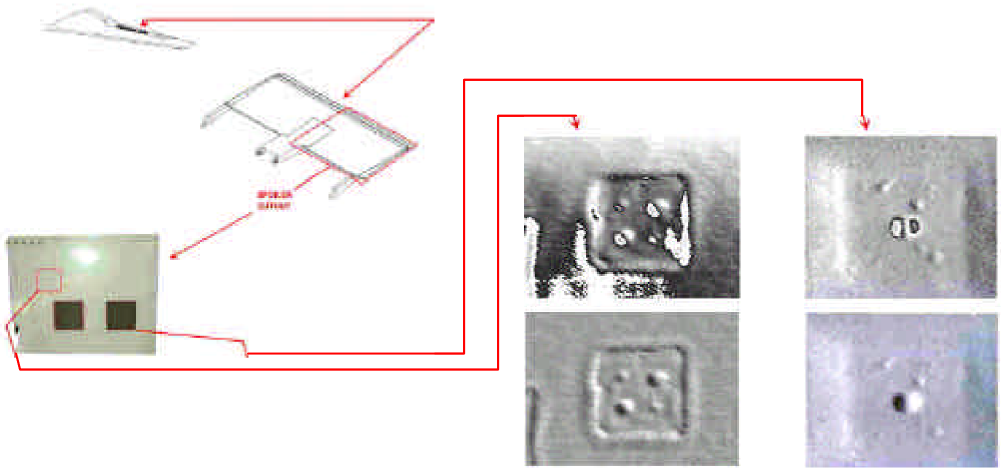

Figure 8: Shearography Measurement

8. Conclusions and Outlook

Ultrasonic testing is a standard method for CFRP inspection. Manual testing with single element transducers is applied for small parts, big parts are tested with multi-channel facilities. The phased array technology (with linear arrays) is entering more and more in production and in-service. Laser ultrasonic testing still in the laboratory phase, but has potential for inspection of parts with small and medium size and complex geometry. Shearography is meanwhile an established method, but until now only a few real applications in production or in-service exist.

Future challenges in NDT for CFRP are driven by a potentially higher percentage of composite in aircraft structure. This requires more in-line inspection tools, i. e. an integration of NDT in the manufacturing process chain. Today "parts meets the NDT system", in future this should be vice versa - "the NDT system should meet the part". In some cases manufacturing processes could be supervised by pure on-line system, replacing classical NDT.

Furthermore production needs NDT methods, which are sensitive only to defects. It is not economic for an inspector to spend 99% of the evaluation time to look on faultless areas. It is much better to have a system, which guides him directly to suspicious areas. A further step is then to develop intelligent defect identification tools, which can decide between genuine defects and spurious indications.

For preparation of NDT procedures it is often necessary to perform extensive laboratory investigations, in which all potential combinations of part geometry, flaw size and position, probe configurations etc. are tested. In future NDT modeling tools may help to reduce such investigations by replacing them partially by numerical simulations.