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# NONDESTRUCTIVE EVALUATION OF METAL-COMPOSITE BONDED JOINTS

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## 1. INTRODUCTION

Adhesive-bonded joints are extensively used in aircraft components and assemblies where structural integrity is critical.

In particular, the use of composite materials in structural and dynamic parts together with the requirements to transfer concentrated loads in particular zones makes the metal-composite bonded joints important from the point of view of nondestructive (ND) quality control.

Defects such as voids in glue line, lacks of bonding or cracks will affect joint strength.

So it is necessary to research and develop nondestructive techniques and methods both to locate position and dimensions of the flaws in the inspected part and to evaluate the kind of defect.

The subject of this paper is the presentation of nondestructive ultrasonic techniques and methods of inspections of metal-composite bonded joints developed by the author on structural elements and real components of AGUSTA-WESTLAND EH101 helicopter within the ND inspections during civil certification tests, the development of the ND evaluation procedures and the ND controls of experimental parts.

The joints between metallic materials as aluminum alloys, titanium alloys, steel and composite materials as glass/epoxy, graphite/epoxy (and hybrid of them) are the object of these ND activities.

## 2. ULTRASONIC TECHNIQUES OF INSPECTION

As the common aim of these activities is the solution of NDE problems on the real parts, the difficulties to be solved are of two kind.

The first step is the research of adequate techniques to detect the reference defects, on every representative specimen of the different joints, building an ultrasonic image that defines the real boundaries of the defected area with a good resolution.

The second step is the development of methods and procedures to apply the different techniques on real components solving problems of accessibility, ultrasonic coupling, automatic scanning or manual contact between probes and part.

Best results can be obtained by automatically scanning the specimens with an ultrasonic beam and either acquiring the attenuation through the total thickness (Through Transmission mode, FIG.1A) or recording the time of flight and the amplitude of the pulse reflected by the adhesive interface between metal and composite (Pulse Echo mode, FIG.1B)

A detailed analysis of pulse shape (FIG.2A) and its spectrum (FIG.2B) can give many information on the kind of defect [1].

When it is not possible to inspect a part in Through Transmission mode and only the metallic side is accessible, the analysis of distribution of multiple reflection echoes (FIG.3) in the metal allows to detect defects in the glue line and to distinguish if the lack of bonding is in contact with the metal or with the composite.

When only the composite side is accessible, multiple-echoes technique is very difficult to apply due to high ultrasonic attenuation of composite so, if the thickness of metal and flatness of its back side are sufficient, it is possible to inspect that joint with a particular application of the Double Through Transmission technique.

## 3. REFERENCE STANDARDS

An important role is given to the inspection reference standards and the description of the ways to simulate and build the reference flaws [2].

Reference flaws and specimens must be developed for each inspection configuration. These standards must be made available to and used by NDE operators to standardize their inspection procedures and to permit them to detect anomalies that will indicate a flaw.

Except for built-in defects, the test standard for adhesive-bonded structures should be fabricated in the same manner as the production assembly. The defects should be introduced in the same bond line as that to be inspected in the structure. The standard can be a series of simple test specimens composed of details identical to the several areas of the assembly to be inspected and having a bond of good quality but with controlled or known defect location and size.

Two are the typical flaws that must be reproduced in reference standards representative of a real configuration:

1) lack of bonding between adhesive and adherents

2) porosity in the adhesive line

Figure 4 shows two methods for producing standards for simulating unbonds. These methods are useful for all ultrasonic application methods provided that between Teflon inserts and adherents will remain an effective separation (some microns of void are sufficient).

Figure 5 shows a way to fabricate a variable-quality standard for porosity in the adhesive line by inserting tapered shims between composite and metal sheet before bonding. Tapered shims cause increasing porosity from the thin end (good quality) to the thick end (poor quality).

## 4. APPLICATIONS

### 4.1 BONDED JOINT ACCESSIBLE FROM BOTH SIDES

This is the simplest configuration to inspect.
In fact it is possible to use the Through Transmission technique (Fig.1a) and the presence of defects is revealed by the increasing of the ultrasonic beam attenuation when the two probes cross over an unbonded zone during scanning.

The inspection of the EH101 Outboard Tension Link (FIG.6) shows a particular application of this technique. Every bond line between composite plates (upper and lower) and metallic frame is accessible from both sides except in correspondence with the vertical wall frame where the metal hinds the probes to complete the scanning.

A solution is given by the use of metallic wall as a wave guide for ultrasonic beam, setting the probes as shown in FIG.6 . The result of a scanning on a real part containing reference flaws just over the vertical wall frame bonding is shown in figure 7.

### 4.2 BONDED JOINT ACCESSIBLE ONLY FROM METAL SIDE

In this case Pulse Echo technique must be used (FIG.1b) and it is important to maintain the transducer perpendicular to the bond line during scanning.

With the transducer pulsing from the metal side, the echo of the adhesive interface between metal and composite is received and represented by the ultrasonic analyzer.

Increasing the gain it is possible to represent also the following echoes of the same interface (multiple reflection echoes, FIG.3). These echoes correspond to the multiple reflections of the ultrasonic beam into the metal thickness. The amplitude of every echo and their total number are due to the quality of interface and these factors increase in presence of a lack of bonding.

In fact adhesive bonding gives a good ultrasonic coupling so that a great part of ultrasonic beam is transmitted from the metal to the composite through the interface, while a part is reflected. Lack of bonding decreases transmission (also till complete disappearance) and increases reflection at the interface.

Figure 8 shows the signal profiles acquired on a reference standard for aluminum to glass/epoxy bonding using a 5 MHz transmitter/receiver transducer. Good bond and flaws (lack of bonding between metal and adhesive and between adhesive and composite) are so recognizable.

### 4.3 BONDED JOINT ACCESSIBLE ONLY FROM COMPOSITE SIDE

Also this configuration must be inspected in Pulse Echo mode and it is possible, although very critical, to use the technique described in par. 4.2, but with the probe from the composite side. Main problem is the high ultrasonic attenuation of composite together with its microstructure. In this case, to obtain multiple echoes, gain must be increased so much that noise (internal structure echoes) will cover the interface echoes. If the thickness of composite allows the use of low frequency transducer, it is possible to obtain a sufficient number of multiple reflections to distinguish a lack of bonding from a good bonding. In figure 9 signal profiles of a good and bad bond are shown for a joint between glass/epoxy (20 mm thick) and titanium using a 0.5 MHz transducer.

A particular application of the Double Through Transmission (DTT) technique can detect flaws in this kind of joint using as reflector the back side of metal. In this case, using a transmitter/receiver transducer from the composite side the following echoes are observed:

1) front surface of composite (entering echo)
2) adhesive interface
3) back side of metal (DTT echo)

The echo (3) is recorded after the ultrasonic beam has passed through the interface twice and so the amplitude of this echo is due to the quality of the bonding.
Figure 10 shows the signal profiles, for this kind of inspection, using a 2.25 MHz transducer.
When the transducer is on the flaw the DTT echo completely disappears.

## 5. CONCLUSIONS

With these techniques of ultrasonic analysis it is possible to locate position and evaluate dimensions of lack of bonding in many bonded joint configurations between metal and composite. Automatic systems for scanning and signal acquisition are used to carry out these inspections particularly for Through Transmission mode while it is more critical for other techniques that need contour following multi-axes systems to maintain the transducer perfectly perpendicular to the adhesive interface, or the reflector, during automatic scanning

## REFERENCES

1. J.L. Rose, Elements of a feature based ultrasonic inspection system, Materials Evaluation, Vol.42, N. 2, February 1984
2. ASM International, Metals Handbook IX Edition, Vol.17, Nondestructive Evaluation and Quality Control.

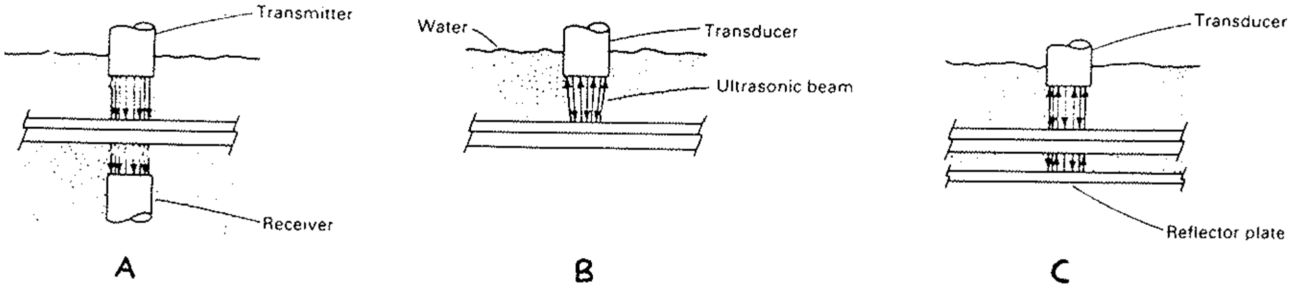


FIG. 1: Ultrasonic inspection techniques. A) Immersion Through Transmission. B) Immersion Pulse Echo. C) Immersion Double Through Transmission.

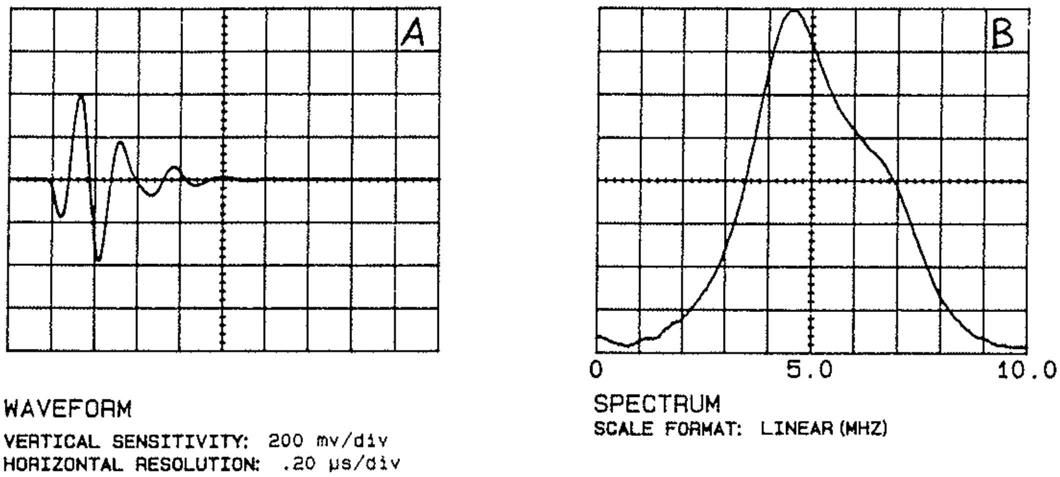


FIG. 2: A) Pulse shape (signal profile) in time domain and (B) spectrum in frequency domain of a 5 MHz transducer.

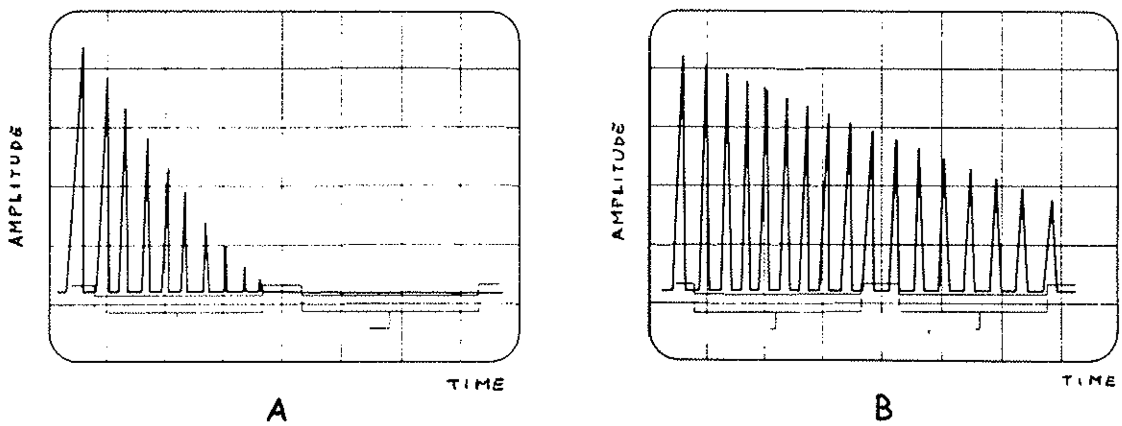


FIG. 3: Multiple Reflection Echoes technique. Monitor response for (A) good bond (B) unbond

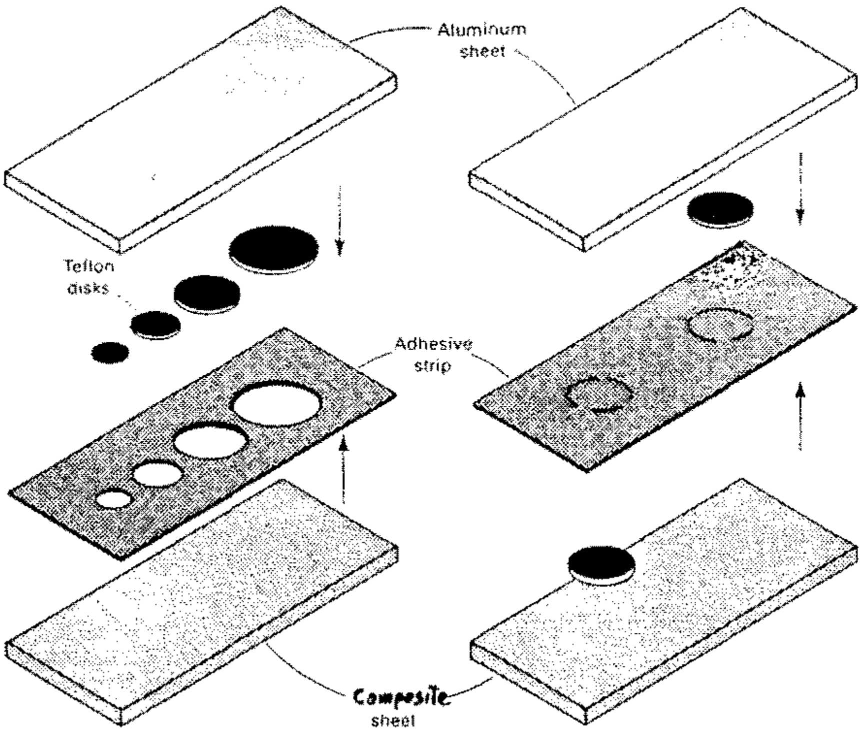


FIG. 4: Two methods of fabricating unbond reference standards

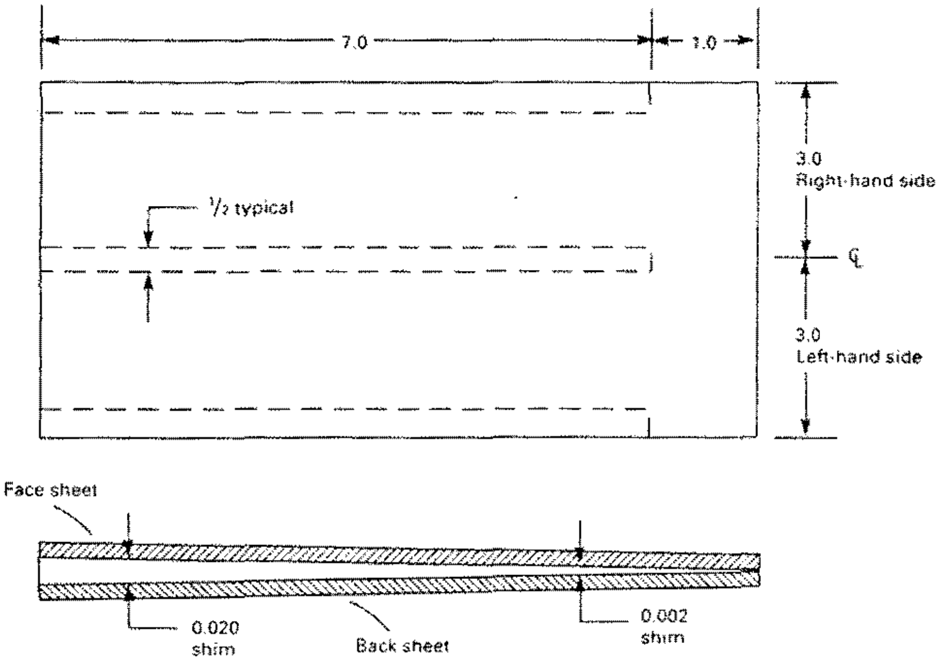


FIG. 5: Method for fabricating a variable-quality standard for porosity. Dimension given in inches

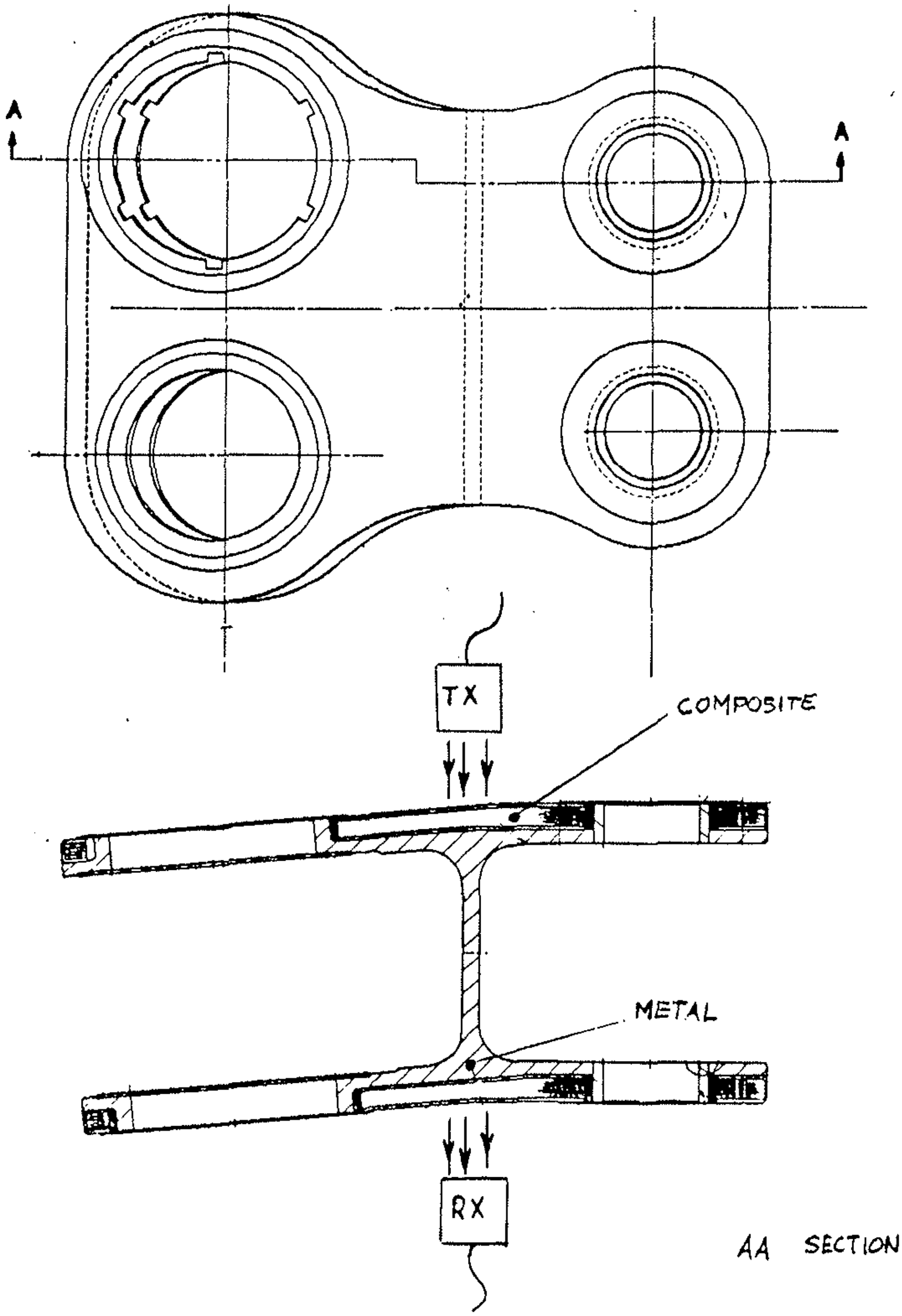


FIG. 6: EH101 Outboard Tension Link. Transducer setting (TX= transmitter, RX= receiver). The part and the transducers must be immersed into water during inspection.

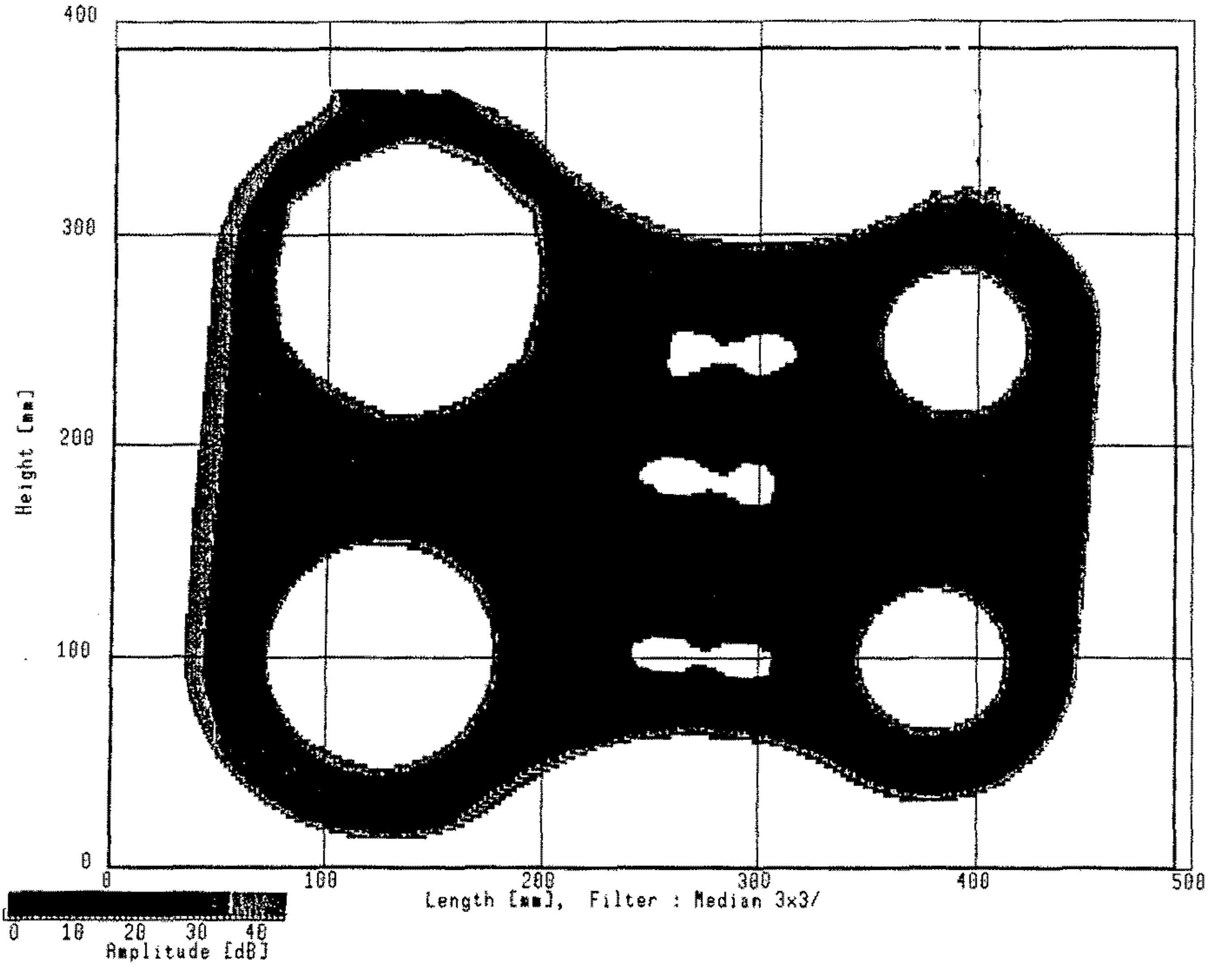


FIG. 7: Ultrasonic map (C-SCAN) of an Outboard Tension Link with 3 reference defect on adhesive interface.

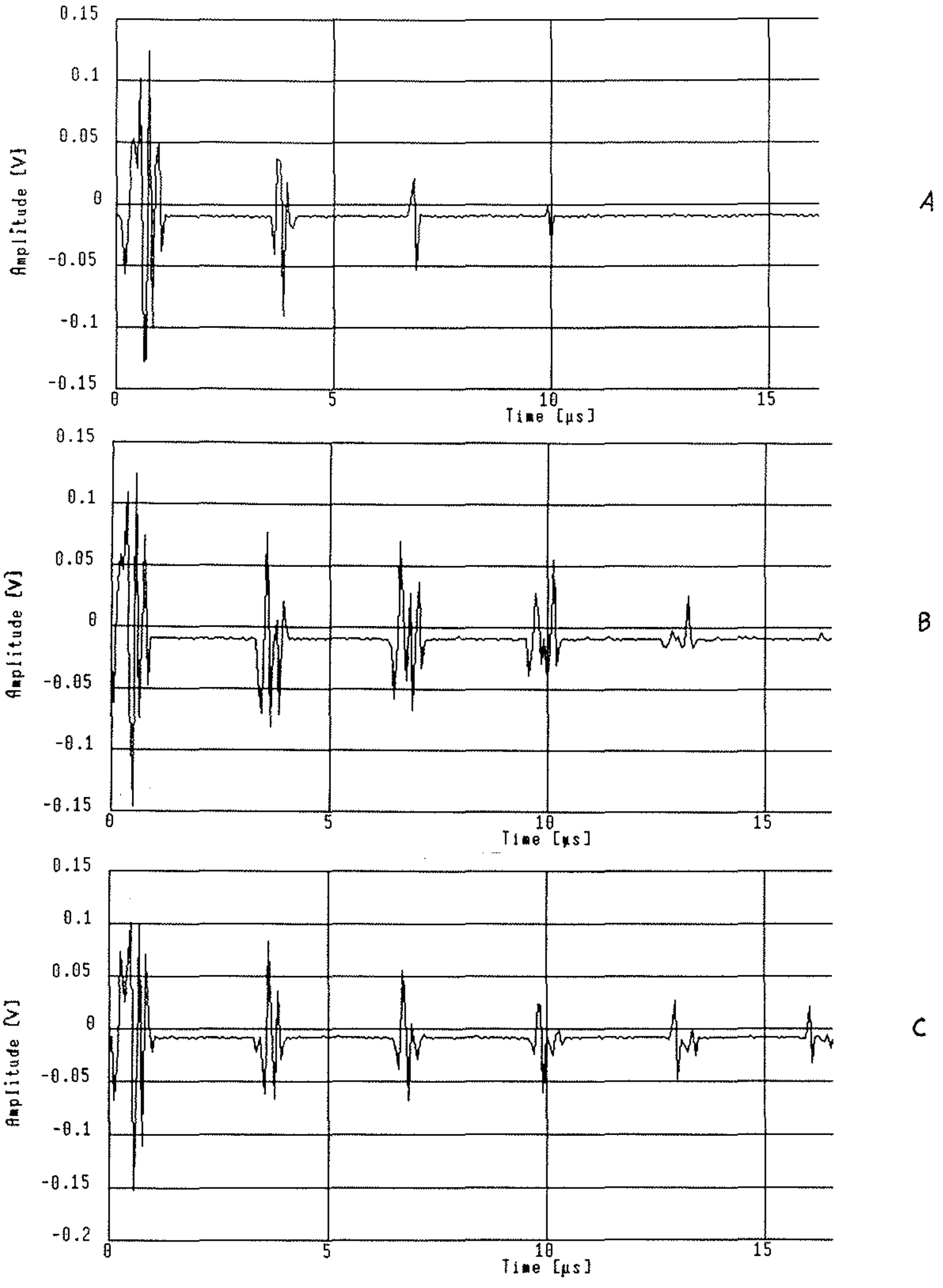


FIG. 8: Multiple Reflection Echoes (MRE) - signal profiles (from metal side) for (A) good bond (B) lack of bonding between adhesive and composite, (C) lack of bonding between metal and adhesive

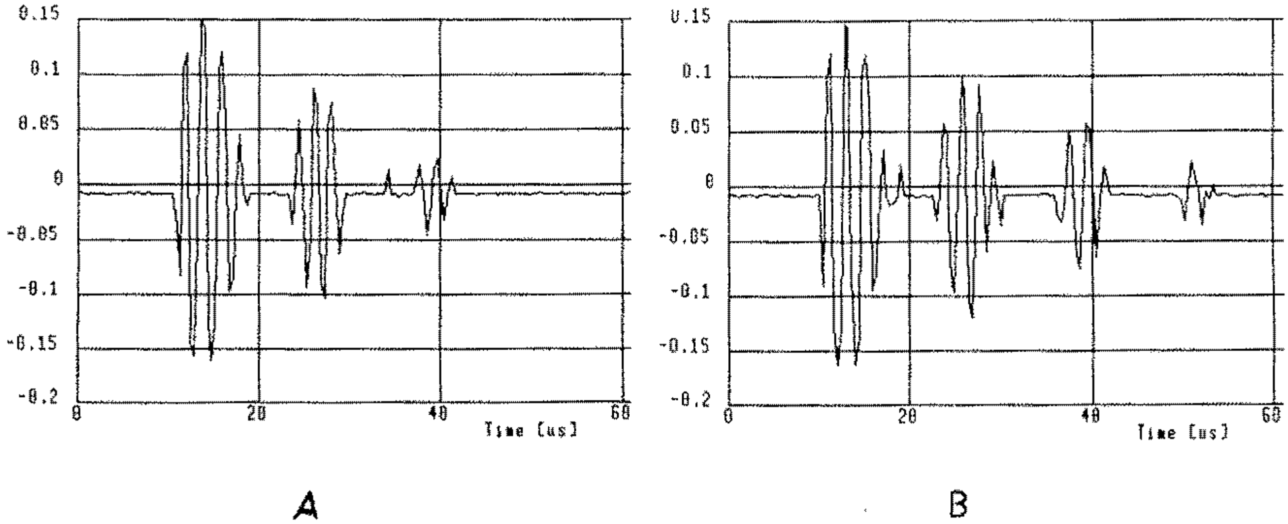


FIG. 9: MRE - signal profiles (from composite side) for (A) good bond, (B) unbond

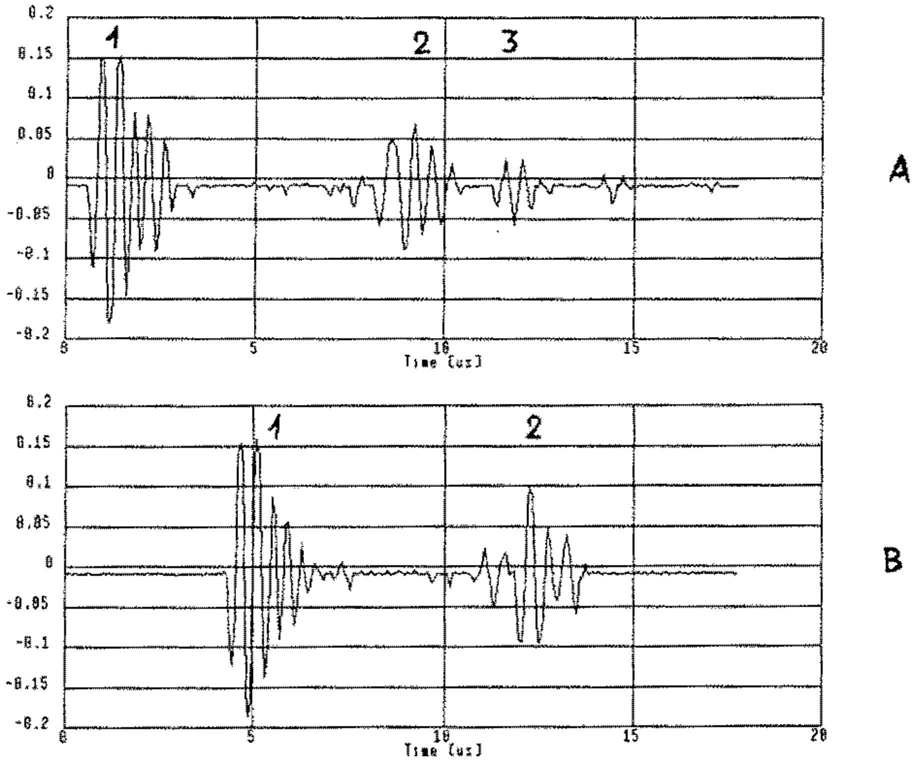


FIG. 10: DTT- signal profiles (from composite side) for (A) good bond, (B) unbond