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Pitch-Catch Ultrasonic Technique for Evaluating Adhesive Bonding in Sandwich Composite Radome Structures

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Abstract: Sandwich composites with lightweight cores and high-stiffness facesheets are widely used in aerospace and automotive industries. Ensuring the integrity of the adhesive bond between the facesheet and core is critical for structural performance and safety. This review examines the pitch-catch ultrasonic method as a non-destructive evaluation (NDE) technique for assessing adhesive bonding in such structures. The paper summarizes working principles, experimental setups, advantages, limitations, and recent developments in pitch-catch technology, including guided wave and Lamb wave applications. Comparative analysis with other NDE methods and future research directions are also discussed.
Keywords: Composite, Core, Dis-bond, Sandwich composites, Pitch-catch method, Adhesive bonding, Non-destructive evaluation, Ultrasonics.

I. INTRODUCTION

The Radome design is a multidisciplinary activity [1] where electrical and structural requirements are being done parallel. Radomes are typically externally mounted structures on aircraft thus the structural requirements must cater for aerodynamic as well bird impact loads. The Radomes thus are made streamlined for reducing the drag. Bird impact loads are essential for Radomes which are external as well as forward mounted, which makes them susceptible against direct bird impact. The strength of sandwich structures is dependent on facesheet, core and the bonding between facesheet and core. A good bonding provides an efficient load transfer path between facesheet and the core. Further, the bonding can be achieved either by self-adhesive nature of the facesheet or by using a dedicated adhesive layer in between the facesheet and core. A dedicated adhesive layer typically provides better adhesion. The inspection of adhesion between the facesheet and the core is highly challenging activity. Honeycomb core possesses inherent challenges due to low surface area in the form of thin walls for core to facesheet adhesion. Yet honeycomb is widely used for making Radomes due to high specific strength in compression.

Ultrasonic test methods are being used widely for non-destructive inspection of composite structures. Pitch catch method is one of the UT methods available for identification of defects in composite materials.

II. BACKGROUND ON SANDWICH COMPOSITE RADOME STRUCTURES

Radome structures require a delicate balance between structural strength and electromagnetic transparency. Sandwich composites, consisting of a low-dielectric core (such as foam or honeycomb) and high-strength skins (such as glass fiber-reinforced polymers), are commonly used. The adhesive layer bonds these components and ensures load transfer, durability, and performance.

Failure in adhesive bonding can arise from improper curing, surface contamination, or environmental degradation. Hence, reliable inspection methods are vital. The pitch-catch ultrasonic technique provides spatially resolved information on bond integrity, making it suitable for complex composite structures.

III. OVERVIEW OF THE PITCH-CATCH TECHNIQUE

The pitch-catch method involves a transmitter (pitch) and a receiver (catch) placed on the same or opposite surfaces of a test structure. An ultrasonic wave is launched by the transmitter and captured by the receiver after interacting with the material and internal interfaces. Changes in the wave's amplitude, time-of-flight, or frequency content indicate potential disbonds or defects.

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A. *Operating Principles*
- Uses longitudinal, shear, or guided waves depending on material and geometry
- Can be contact-based (with couplant) or air-coupled
- Wave attenuation and phase changes are used to infer bond quality
- Sensitive to disbonds, voids, delaminations, and adhesive degradation

B. *Wave Modes in Sandwich Structures*
- Lamb waves: effective for thin facesheets
- Guided waves: suitable for large-area inspection
- Through-thickness compression: useful for localized bonding evaluation

C. *Pitch-Catch Test Mode*
In pitch-catch mode has three different inspection methods notably the RF method, the impulse method, and the swept method. It does not require any couplant. During testing, if the probe detaches from the surface which is also called lift-off, the effect is distinct from a dis-bond signal. That means a dis-bond and loss of contact between probe and surface would be distinct from each other. This eliminates chances of false positive results.

The probe tips are called elements, and the bond condition elements will affect the characteristics of the sound energy that is transmitted between the tips. A pictorial representation is shown in Fig 1. These characteristics can be displayed in terms of phase and amplitude change. When the structure is in a bonded state, some of the acoustic energy is absorbed by the material beneath the inspection surface, causing a reduction in the signal amplitude shown on the instrument. In a dis-bonded state, the waves move between the transmit (pitch) and receive (catch) elements with minimal attenuation or damping from the bonded structure, leading to a higher displayed signal amplitude. To reduce unwanted noise caused by probe movement, typically a bandpass filter is applied ranging from 0 kHz to 35 kHz for each pitch-catch method.

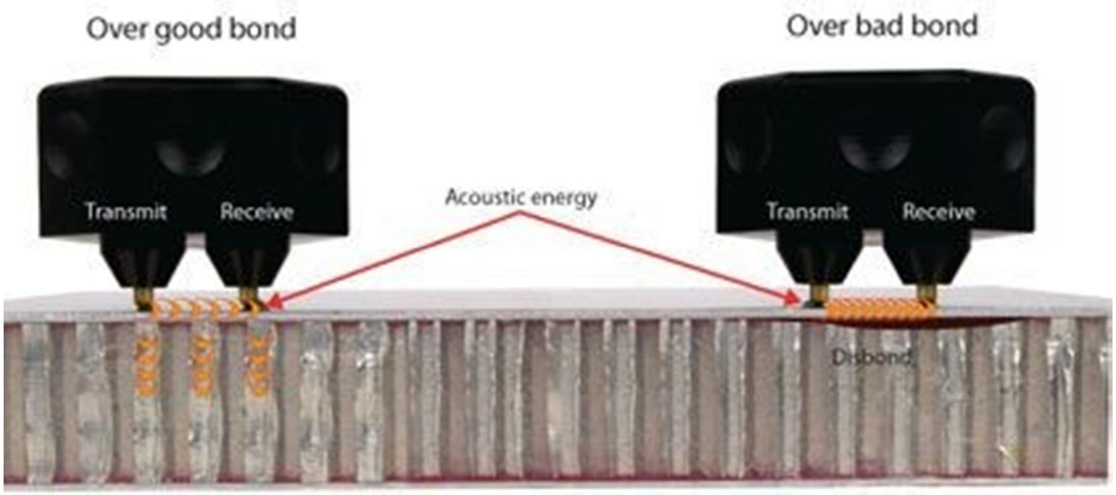

Fig 1: Working principle of Pitch catch method (courtesy : Olympus [3])

D. *Pitch-Catch RF Method*
This method employs a dual-element, point-contact, dry coupled ultrasonic probe. One element emits a burst of acoustic energy into the test material, while a separate element captures the sound as it travels across the test piece between the two probe tips. The bond condition beneath the two tips can be assessed; however, unlike impulse mode, which processes the probe signal through a detector, RF mode presents the raw RF signals directly from the probe's receiving tip. The variation in energy amplitude and/or phase between strong and weak bonds is identified. Gates are defined at the optimal location to track the received signal's response, where the defect has the greatest impact. The placement of the time-gate dictates which part of the signal appears on the flying dot display during RUN modes. The inspection operates at a fixed frequency, established during the setup process.

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E. Pitch-Catch lmpulse Method

In the impulse method, the data received from the tip is processed through a detector before being displayed, unlike the RF method, where the probe signal is shown as raw RF data. This technique identifies differences in amplitude and/or phase between good and defective bond conditions. Similar to the RF method, a gate is defined at the optimal point along the signal to track the response most influenced by the defect. The position of this gate determines which portion of the signal appears on the flying dot display in RUN modes. The inspection is conducted at a fixed frequency, which is established during the setup process.

F. Pitch-Catch Swept Method

The frequency is varied across a range to create a circular display, which appears larger for dis-bonded material. This display represents both phase and amplitude components of the signal throughout the frequency sweep. A key advantage of this method is that lift-off effects are distinguishable from dis-bond signals. Unlike the RF or impulse methods, the swept mode does not operate at a fixed frequency; instead, the inspection is performed using a predefined frequency sweep and repetition rate.

IV. TEST SETTINGS

The Bond master equipment was set to the following settings to find the dis-bond between GFRP skin and aramid honeycomb of the sandwich composite Radome using pitch catch test mode:

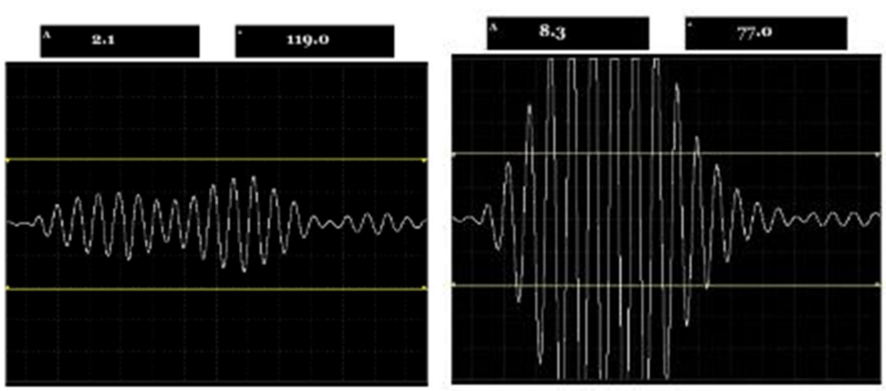
Table 1: Bond Master 600 settings

Equipment settings	
Description	Value
Frequency	10.0kHz
RF GAIN	45.0dB
WIDTH	2000us
GATE	AUTO
RF DISPLAY	RF
CYCLES	10
REP RATE	300

V. ACCEPTANCE CRITERIA

A. Good Bond

The gates were defined as per the setting shown in Table 1. Any variation out of the gates predicts a bad bond, it can be a near dis-bond or a far dis-bond. Fig 2 (a) explains the good bond criteria whereas the Figure 7(b) shows a bad bond area.



(a): Good Bond (d): Dis-bond Near Surface

Fig 2: Acceptance gates for good bond and dis-bond

B. Dis-bond Near-Surface

The Near – Surface dis-bond i.e. the dis-bond is present between the skin and core, where the pitch catch probe is in contact with the skin (top side). The RF wave will touch the screen extreme as shown in **Error! Reference source not found.** explains the dis-bond near – surface criteria

C. Dis-bond Far-surface

Dis-bond far – surface is the dis-bond between the skin and core of the other side (bottom skin and core). The RF wave will cross the gates, but will not go to the screen extremes. Fig 3 shows the dis-bond far – surface criteria.

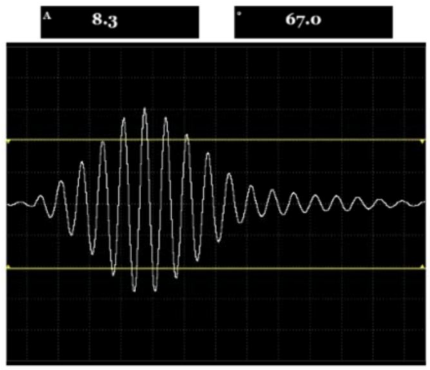


Fig 3: Dis-bond Far surface

VI. TEST RESULTS

A 1m X 1m panel Sandwich Composite Radome panel was taken for testing. The panel had already been evaluated using A-scan UT with no defects present. Additionally, one edge dis-bond was introduced later deliberately in small portion of a good specimen of size 200 mm X 75 mm.

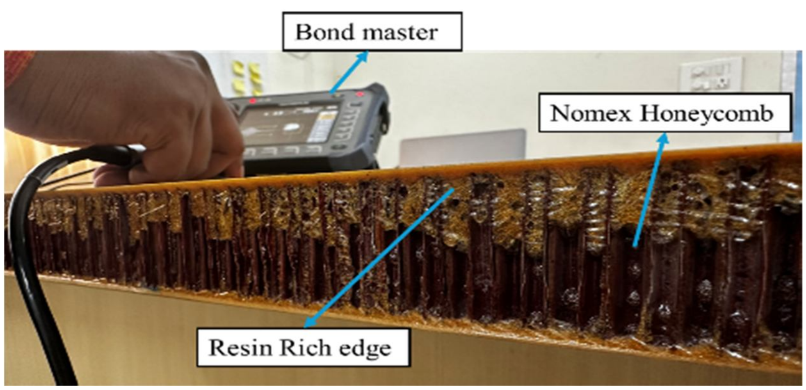


Fig 4: Bond master testing for a Sandwich panel

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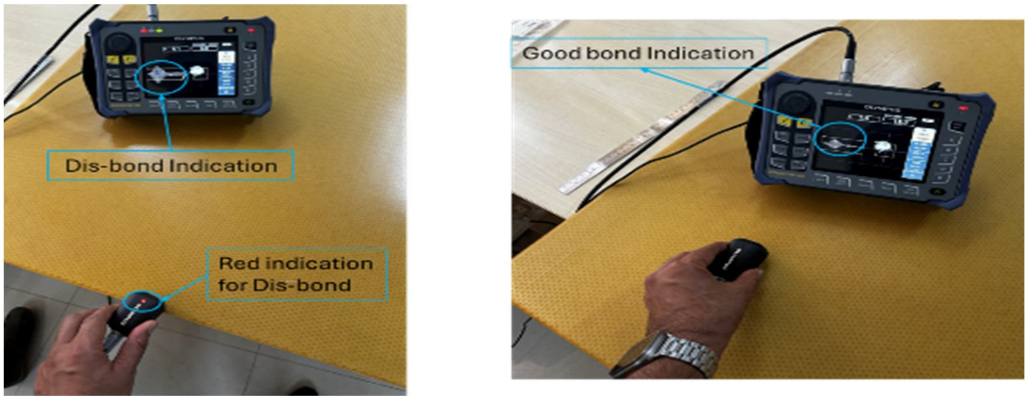

Fig 5: Indication of Good and bad bond locations

The Radome panel was used for high speed soft body impact testing, thus it had dis-bond and good bond regions. The dis-bond regions were near to the impact location, whereas the good bond were away from the impact location as impact is a localised phenomenon.

The above sandwich panel was cut into two pieces, the dis-bond between the skin and core was visually seen. The pitch catch method successfully captured the dis-bonds on the sandwich panel. It behaved accurately at the intentionally introduced dis-bond as well as the dis-bond caused by the high speed soft body impact. The method was much faster and equally effective for identifying impact damages.

The entire panel was tested by sweeping the probe on the surface for marking the good and dis-bonded regions.

A. Challenges and Limitations

- Complex Signal Interpretation: Especially in multi-layered or attenuative materials.
- Access Requirements: Needs adequate access for transducer placement.
- Material Variability: Composite heterogeneity affects signal consistency.
- Coupling Issues: Poor coupling can lead to signal degradation.

VII. CONCLUSION

Composites sustain invisible damages in case of impact incidents, which if not evaluated or inspected may cause catastrophic conditions for the aircraft safety. Out of all the damages facesheet to core/honeycomb dis-bond is difficult to inspect.

It is difficult to inspect sandwich structures for defects due to the shear presence of honeycomb. The empty spaces create multiple reflection thus from a regular A-scan it requires a highly trained operator to carry out such inspections. The same is relatively easy using a pitch catch method.

Despite the challenges and the limitations the pitch-catch ultrasonic technique represents a powerful tool for evaluating adhesive bonding in sandwich composite Radome structures. Its ability to detect internal flaws non-destructively, combined with technological advancements, makes it an indispensable component of modern structural health monitoring and quality control systems. Moreover it provides a accurate methods to inspect large areas in limited time, which otherwise are difficult with conventional pulse-echo methods. Continued research and integration with digital technologies promise to further elevate its effectiveness and adoption in critical applications.

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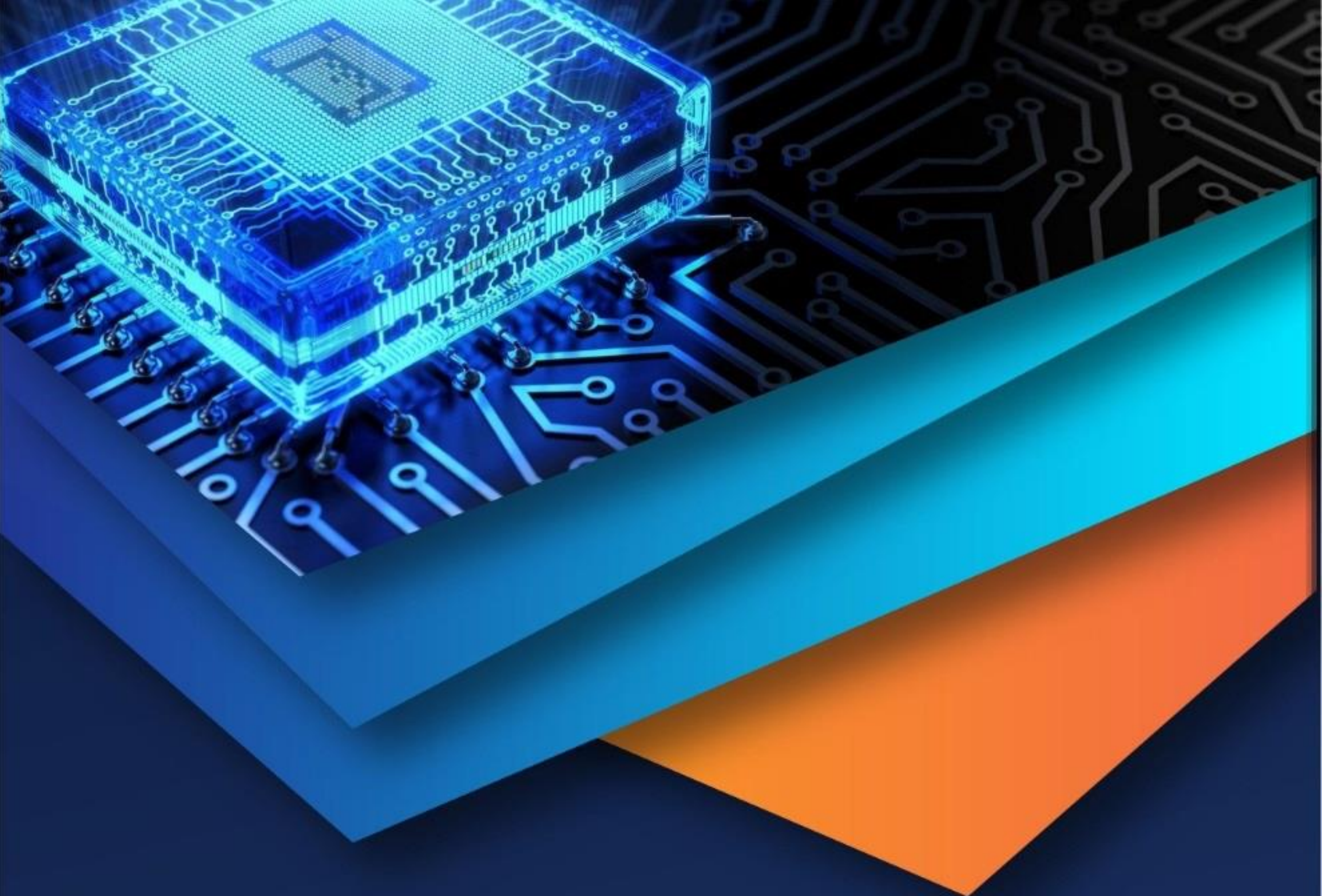

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