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To cite this version:

Victor Munoz Cuartas, Marianne Perrin, Marie-Laetitia Pastor, Hélène Welemane, Arthur Cantarel, et al.. Application of non destructive testing to the detection of aeronautical defects in composite structures. International Conference of Nonconventional Technologies, Jun 2013, Sibiu, Romania. hal-02285220

HAL Id: hal-02285220

https://hal.science/hal-02285220v1

Submitted on 11 Feb 2021

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APPLICATION OF NON DESTRUCTIVE TESTING TO THE DEETCTIONS OF AERONAUTICAL DEFECTS IN COMPOSITE STRUCTURES

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ABSTRACT: A study of two Non-destructive Testing methods (NDT) was carried out in specimens with different kinds of simulated defects. Ultrasonics test (US) and Infrared Thermography (IRT) were applied with the aim of evaluate the detectability and the accuracy of each method. These techniques acquired great importance in the aeronautics industry because they control the aerostructure without intervening in their physical and mechanical integrity. In the second part of the study, a comparison of both techniques was done with the purpose of analysing their limits and advantages. It appeared that detectability of defects was much better in a sample with flat-bottomed holes defects in the case of Ultrasonic Test. However it was found that Infrared Thermography is far more limited to the thickness of the specimen than the ultrasonic waves. On the other hand, defects were all revealed with IRT in a sandwich composite including Teflon inserts, which was not the case for US.
KEY WORDS: Non-destructive testing; Ultrasonics; Infrared thermography; Composites; Simulated defects

1. INTRODUCTION

The use of composites in the aerospace industry has increased dramatically since the 1970s. The primary benefits that composite components can offer are reduced weight and assembly simplification. It happens that different types of mechanical and thermal loads are applied to these structures when they are in service, generating internal stresses. It is in this way that delamination or disbonding may result in the aerostructure. Defects such as random inclusions or undesirable material have also been found during the manufacture process of composite materials [1]. These flaws may create stress concentration with serious consequences. It is therefore important to test the composite structure to ensure their integrity. These defects have to be revealed in order to make the correct maintenance or replacement. The faster the damage or defect is detected, the safer the aerostructure is.

Many techniques have been used with the purpose of detect such defects and in the operational configuration. Liquid penetrant inspection, magnetic control inspection, eddy currents control, radiographic testing and shearography are some of the methods used for evaluating the health of the material, without altering its properties [2]. These kinds of controls are called the Non-Destructive Testing (NDT). The most widespread technique is the ultrasonic testing. It is the only technique certified by the aeronautics industry [3]. Ultrasonic Test (US) uses high frequency waves to conduct examinations and make measurements. Ultrasonic inspection is used for flaw detection/evaluation, dimensional measurements and material characterization [4]. Some studies have already shown the detectability and the accuracy of a flaw in size, shape and deepness for different kinds of composite structures used in the aeronautic industry [1,5].

A full-field measurement technique based on Infrared Thermography (IRT) is also used in the NDT field. Infrared thermography is a non-destructive, non-intrusive, non-contact mapping of thermal patterns or thermograms, on the surface of objects. IRT is more widely used in recent years for structural investigation [5]. The mean difference about IRT with regard to US is that IRT does not give the information about the depth of defects. Some works aimed to compare different infrared thermography configurations, have detailed the accuracy of defects detection [5,6].

The aim of this work is to evaluate two different specimens by ultrasonics test and infrared thermography. A carbon-epoxy laminated composite and a carbon-epoxy-glass sandwich composite were tested to verify the accuracy and detectability of their simulated defects by using both NDT methods. Specimens have different kinds of defects and were made in different materials used in the aeronautic industry. Defects have various diameters and locations on the material so that the limit of size and detection in deep can be determined. The second

objective is to compare the information obtained by each technique. Finally, a conclusion about the intention of capitalize the information obtained by NDT methods is presented.

2. SPECIMENS AND EXPERIMENTAL PROCEDURE

2.1 Specimens

The specimen used to compare the detectability and accuracy between the IRT and the US is a carbon/epoxy laminated composite with flat bottomed holes defects and variable thickness. It is called specimen A (figure 1). This sample is divided in 2 sections. The first one is 4 mm width in 50 mm length. The second section is 130 mm length with 8 mm width. This sample contains 15 holes with diameters ranging from 2 mm to 10 mm. These holes have different deepness (from 0.52 mm until 7.5 mm). The aim of these holes is to simulate discontinuity on the specimen that is considered as a continuous medium.

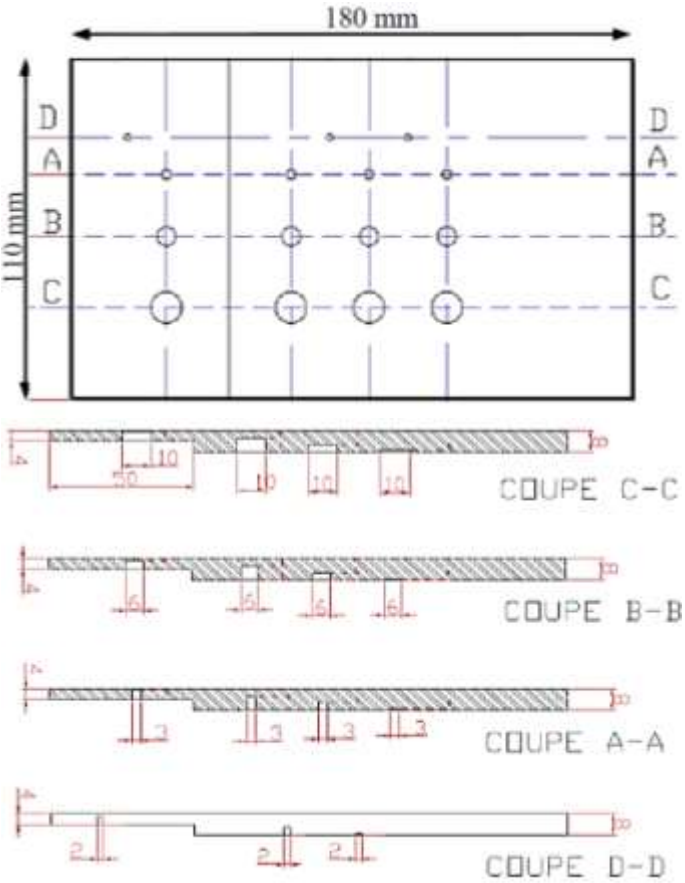


Figure 1. Manufacturing drawing of the specimen A

A second sample, called specimen B was also used. It was tested only in infrared thermography because of its materials properties. This specimen is a carbon-glass-epoxy skin with foam-core sandwich composite including Teflon inserts. The thickness of its skin is 0.66 mm. It has been demonstrated that the foam-core is a sound insulation, whereby, the ultrasonic waves can not penetrate this specimen to be detected by the receiving transducer [5]. This specimen contains 18 defects. These simulated flaws are Teflon inserts ranging from 3 mm to 6 mm. They are located at the skin section. These inserts were placed during the stacking of the tissues so that they simulate as best as possible a delamination in the sample. The manufacturing drawing of this specimen is showed in figure 2.

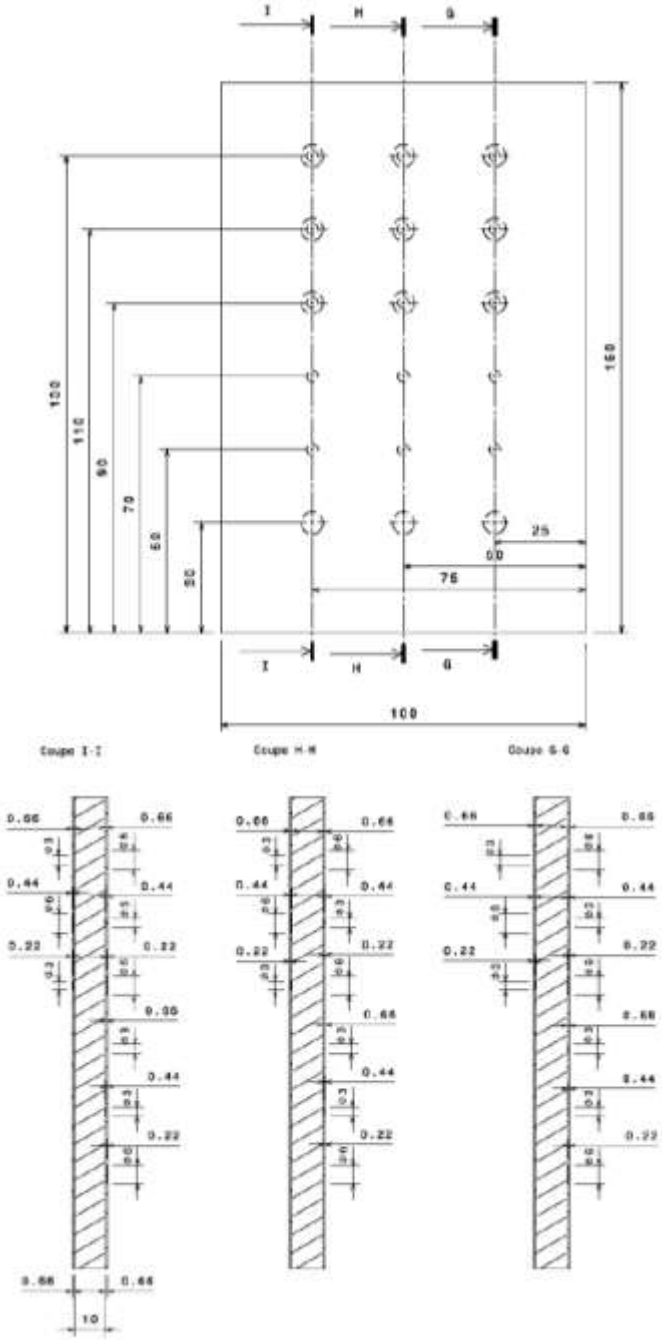


Figure 2. Manufacturing drawing of the specimen B

2.2 Experimental protocol

2.2.1 Ultrasonics

In ultrasonics, the sound energy is introduced and propagates through the material in the form of waves. When there is a discontinuity (such as inclusion, delamination or disbonding) in the wave path, part of the energy will be reflected back from the flaw surface. The reflected wave signal is

transformed into an electrical signal by the transducer and is displayed on a screen. There are two configurations that can be used in an US testing: reflection and transmission. In this study, only reflection configuration is used in specimen A.

This technique allows to get information about the modulus of elasticity by measuring the wave velocity [7]. Deepness, size and shape of a detected defect, can also be obtained by this technique.

In this study, a Omniscan 32: 128 PR is used with a 5L64-NW1 multi-elements transducer. The Omniscan is both, ultrasonic source and receiver at the same time. The frequency of the transducer is 5 MHz, which is the common frequency in aeronautics NDT [5]. For specimen A, the wave velocity is 2983 m s^{-1}. This experiment was carried out by contact; therefore it is necessary to use a gel coating between the sample and the transducer. Ultrasonics testing enables two-dimensional mapping, accordingly, a freescan was also used as a coding system to detect the position of the transducer in regard to the specimen. Specimen A was placed in a support to hold it while the experiment was being carrying out. Figure 3 shows the ultrasonics device.

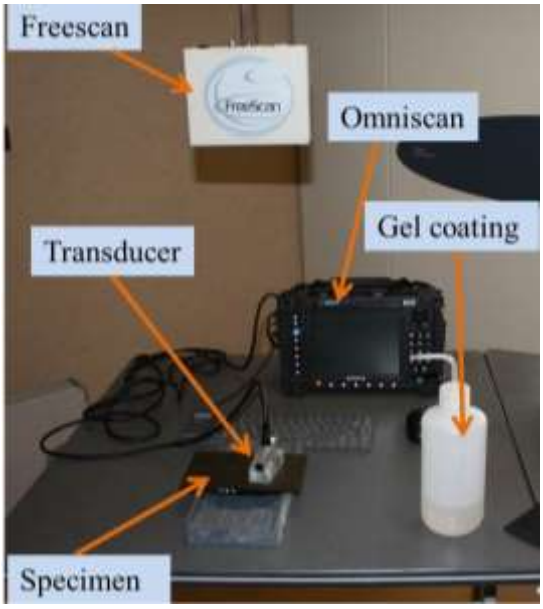


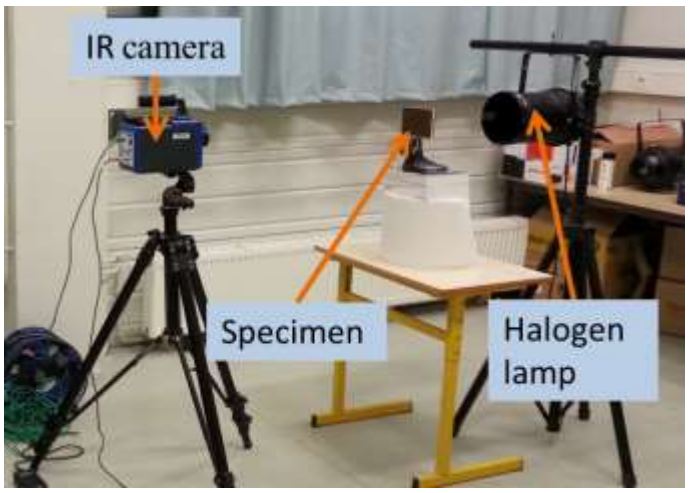
Figure 3. Ultrasonic measurement

2.2.2 Infrared Thermography

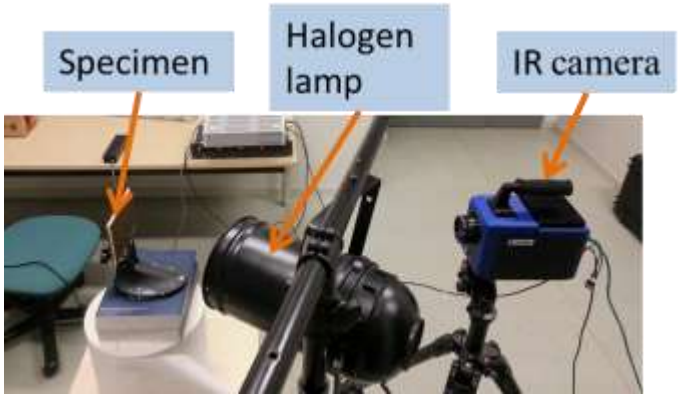
Infrared thermography (IRT) provides colourful images and movies of specimens where local changes in surface temperature indicate subsurface defects. Thermal waves are propagated through the material. When they pass by a different medium, a thermal gradient is generated in the specimen. Indeed, the two mediums have different emissivity coefficients. These differences are captured by an infrared camera enabling the emissivity coefficient to be converted to temperature. It is measured on the front of the specimen. Thermal two-dimensional mapping is created and inhomogeneities can be detected [1,5,6].

This technique allows to get information about the position, size and shape of the flaw. In this line of thought, delamination, disbonding or crack networks can be detected [1]. Contrary from the US, information about the deepness can not be obtained.

To heat the sample, a 1000 W halogen lamp is used in two configurations: transmission and reflection. Specimen A was tested only in transmission mode (figure 4a) and specimen was tested in both configurations (figure 4a and 4b). The infrared sensor was an IR camera whose thermal resolution was 20 mK. A 30 s and 50 Hz movie was recorded in which 15 s corresponds to the heating of the sample and the 15 last seconds to its cooling. The treatment of the movie was done with the ALTAIR software. The analysis of the movie is done in relative mode with the purpose of removing the ambient temperature.



a) Transmission mode



b) Reflection mode

Figure 4. Infrared measurement

Lock-in IRT was also used on both specimens. The idea behind lock-in IRT is that temperature modulation induced at the surface of the inspected component from the outside propagates as a harmonic thermal wave. Lock-in IRT allows better

defect inspection than common IRT and it is less sensitive to environmental conditions [8]. The connection of the lock-in IRT is detailed on figure 5. A signal generator is also needed in addition to the classical IRT.

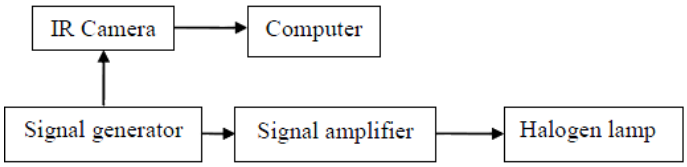


Figure 5. Lock-in thermography connection

3. RESULTS

3.1 Ultrasonics

As it was said on section 2, only specimen A was tested with ultrasonics, because material properties of specimen B do not let waves to propagate through the foam-core.

Analyses of results are made taking into account two parameters: detectability and accuracy. 14 of the 15 holes were detected by this method. This is the 93% of them. The only defect that was not detected, is the one located at 1 mm deep and 2 mm of diameter. However, it is noticed that defects located near the contact surface (less than 1 mm) are difficultly distinguish from the signal input peak. On the other hand, the detected defects were measured on average, 1 mm larger or smaller than they really are. Defects located at 7.5 mm deep (3 and 6 mm diameter) were measured 1 mm smaller than their real size, and those located at 5,2 mm deep (2, 3 and 6 mm diameter) were measured at the correct dimension. 10 mm diameter defects were all measured 1 mm larger than their real size. Table 1 shows the measured dimension for each range of defects.

Table 1. Defect measurement on specimen A using US

	Depth (mm)				
	0,52	1	2,8	5,2	7,5
Real diameter (mm)	Measured diameter (mm)				
10	11	NaN	11	11	11
6	7	NaN	6	6	5
3	4	NaN	4	3	2
2	NaN	Non detected	NaN	2	2

Figure 6 shows the C-Scan mapping for this specimen in which measurements were done.

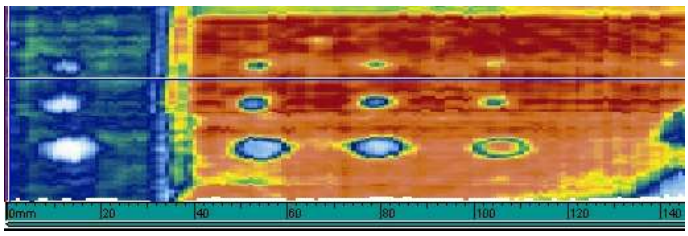


Figure 6. Lock-in thermography connection

Other works [5] have obtained similar detectability with better accuracy for the same specimen. The gap between the real size and the measured size is 0.5 mm. Those measurements were done by using the –6 dB method. It consists of measuring the defect where the backwall echo, decreases 50%.

3.2 Infrared thermography

3.2.1 Specimen A

As in US testing, two parameters were taken into account to analyse the results: detectability and accuracy. A single picture must be selected from the recorded film. That selection depends on the quality of the image for each defect. In this study, for specimen A, 2 different images (figure 7) were selected to measure 2 ranges of defects located in two different sections of the specimen. These ranges of defects are located at 0.52 mm and 2.8 mm deep respectively and they are in the 4 mm section and 8 mm section of the sample. Figure 7 shows that only 6 from the 15 defects, were detected using classical IRT in transmission mode.

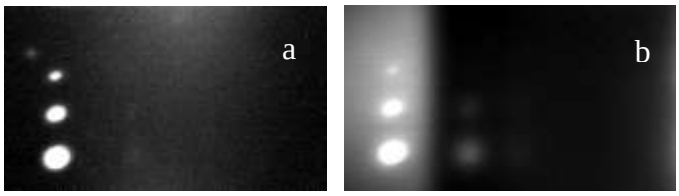


Figure 7. IRT mapping of specimen A

Defects at 0.52 mm deep were measured using image 7a and those at 2.8 mm deep using image 7b. It is noticed that heat saturation is generated after a short period of time. The 4 mm width section is rapidly saturated and in the 8 mm width section, no other defect is revealed with the increasing temperature.

The size of the measures defects has the same gap than in US testing. They were measured 1 mm larger than they really are. Table 2 shows the detailed size of the defects.

Table 2. Defect measurement on specimen A using IRT

	Depth (mm)				
	0,52	1	2,8	5,2	7,5
Real diameter (mm)	Measured diameter (mm)				
10	11	NaN	11	Non detected	Non detected
6	7	NaN	Non measurable	Non detected	Non detected
3	4	NaN	Non detected	Non detected	Non detected
2	NaN	2	NaN	Non detected	Non detected

6 mm diameter defect at 2.8 mm deep was detected but no measurements could be done because the temperature difference between defective and healthy parts was not enough to be measured. It is also remarkable that the number of detected defect decreases with deepness. While the defect is deeper, more difficult is the detection.

In lock-in IRT, the number of detected defects in specimen A increased. However, no measurement of their size was done because of the temperature difference. In addition to classical IRT, 3 mm diameter defect at 2.8 mm deep and 5.2 mm deep defects (6 and 10 mm diameter) were visible as shown in figure 8.

Figure 8. Lock-in IRT in specimen A

3.2.2 Specimen B

In the case of specimen B, lock-in IRT has similar results as in classical IRT. All defects were detected and they could be measured in diameter.

Best results were obtained at 0.1 Hz for both specimens tested in lock-in IRT. It was founded that the textured surface of specimen B was confounded with the defects in IRT mapping. Measurements were therefore less accurate than classical IRT in specimen A.

Defects located at the camera side, were easily distinguished; on the other hand, defects located on the opposite side of the camera, were difficultly detected. In addition, the dimension of the measurements was 2 or 3 mm larger that the real size of the defect. Table 3 shows the founded size for each range of defects.

Table 3. Defect measurement on specimen B using lock-in IRT

Real diameter (mm)	Measured diameter (mm)
6	8
3	5

Figure 9 shows the result on specimen B tested by lock-in thermography.

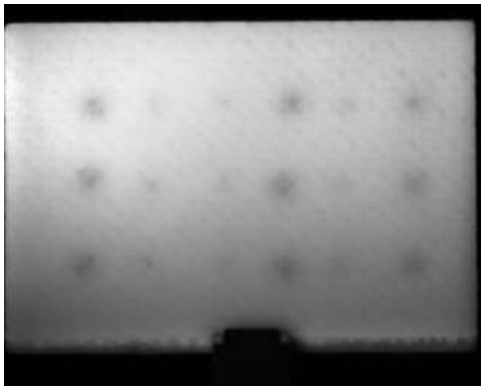


Figure 9. Lock-in IRT in specimen B

Péronnet E. [5] tested the same sample and found a gap between real size and measured size ranging from 1.5 mm to 3.5 mm. This information is in accordance regarding the experiments on the present study.

Nowadays there are not specific methods for measuring the real size of a defect from an IRT mapping. The criterion depends on who does the measure. In some works, the size of defects has been calculated using a system of grey image measurement [5].

4. ANALYSIS

A comparative analysis was done aimed to explain the reach of each technique. Table 4 summarizes the reach for each technique regarding different parameters.

Table 4. Characteristics of US and IRT

Parameter	US	IRT
Accuracy in size	1 mm (larger)	1 to 2 mm (larger)
Minimal diameter	2 mm from 1 mm deep	2 mm from 0 mm deep
Detection in deepness	More than 8 mm in laminated composites	2,8 mm for a 6 mm diameter defect in laminated composites
Detectability in the laminated composite	14/15. Non detected a 2 mm defect at 1 mm deep	6/15. Non detected defects beyond 5,2 mm deep and 3 mm diameter
Detectability in foam-core sandwich composites	NaN	18/18 by analysing both sides of the sample
Time for getting results	About 10 min	Instantly
General limitation	Detection of defects close to the inspection surface	Important specimen thickness

The C-Scan mapping in US shows that detectability is more affected by the diameter of defects rather than thickness. This detection becomes more difficult when the defect is close to the detecting surface (less than 1 mm). In this case the defect echo is confused with the echo of the detection surface.

By the other hand, it is clearly noticed that IRT is very limited to large thicknesses. Defects are not

visible beyond 2.8 mm in a carbon-epoxy laminated composite. However, by the use of lock-in IRT, the reach on thickness became to 5.2 mm. At any rate, diameter of defects also affects the detectability in IRT. Figure 7b and 8 shows that flaws located in the same range of deepness with different diameter are not all detected. The heat diffusivity inside the material does not let to see temperature difference in the surface of the sample.

In the case of lock-in thermography, low frequencies are more convenient for detecting the flaws in both specimens. The use of a sinusoidal signal with low frequency (0.1 Hz) allows to optimize the wave spread in the specimen thickness. Other works [6] with the same sample found that the best frequency for detectability of defects is 0.05 Hz.

For the carbon-glass-epoxy skin with foam-core sandwich composite, the use of infrared thermography is quite difficult since the foam is a thermal insulator. It is recommended to control the 2 skins of the sandwich separately and in reflection mode (figure 4b). Otherwise, the heat flux may not arrive to the detection surface.

5. CONCLUSION

The subject of this study was to compare the ultrasonics test and the infrared thermography as NDT techniques. By using 2 different samples it was shown that both methods have the same accuracy regarding the diameter of the flaws, which is not case for detectability parameter. 93% of defects in a carbon/epoxy laminated composite were detected by the US while only 60 % of them were detected by the IRT.

In the case of a carbon-glass-epoxy skin with foam-core sandwich composite, all defects were detected by IRT. Results were similar using both, classical IRT and lock-in IRT for this specimen, but the measured size was less accurate than the laminated composite. The textured surface was confused with the defects.

In future works, mechanical characterisation on carbon-epoxy laminated composites will be study by calculating the elastic constants from the velocity of the ultrasonic wave. Then NDT techniques will be used for monitoring the evolution of damage. Static and dynamic test (tensile, fatigue) will be carried out and at the same time, NDT techniques (Ultrasonics, Infrared Thermography and Acoustic Emissions) will monitor the evolution of the damage.

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