THERMAL NDT & E OF COMPOSITE AIRCRAFT REPAIRS

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Abstract: The objective of this study was to investigate different defects and material systems (notch or delamination under carbon and boron composite patching bonded with FM73 adhesive film to the surface of Al 2024-T3) using several thermal non-destructive testing and evaluation techniques. Active thermographic approaches, using, firstly, a simple heat excitation source with an infrared camera, secondly, an integrated pulsed thermographic system, thirdly, pulsed phase thermography and lastly, thermal modelling, were used in the inspection of the composite aircraft repaired panels. In all situations the subsurface defects, were positioned intentionally. After the detection of the defects, representative images obtained from the thermographic investigation underwent quantitative analysis with the intention of obtaining information about the defects in space and in time.

Introduction: The purpose of a repair on a damaged area is to transfer through the patch the applied load(s) from one side to the other, by-passing the defected area. Such defects in the past were repaired by the use of metal patches, joined mechanically by the use of pins or screws. Since these repairs implied the formation of stress and strain concentrated areas around the fasteners, leading to additional structural problems, the alternative technique of using composite patches by employing adhesive films in order to attach the repair to the metallic structure is an important maintenance approach. In this technology, the patch is commonly formed from carbon or boron composite, applied onto a wider area of the defect on the metallic structure, with the direction of the fibres in parallel to the direction of the load(s) [1].

Composites offer a large number of advantages over the conventional aircraft material of aluminium; higher specific strength and stiffness, superior corrosion resistance, improved fatigue performance, etc. A considerable amount of work has been conducted using various non-destructive testing techniques in the detection and identification of defects in aircraft structures [2-4]. Thermography is one of the latest non-contact and non-destructive techniques that can be used effectively for the assessment of aircraft materials.

Active thermographic approaches, using, firstly, a simple heat excitation source with an infrared camera [5], secondly, pulsed thermography (PT), thirdly, pulsed phase thermography (PPT) and lastly, thermal modelling, were used in the inspection of the composite aircraft repaired panels. PT is a popular thermal stimulation technique where the surface under investigation is pulse heated (time period of heating varying from a few milliseconds for high conductive materials such as metals to a few seconds for low conductive materials such as composites) using one or more pulse heating sources and the resulting thermal transient at the surface is monitored using a thermal camera [6]. PPT combines the pulsed acquisition procedure of PT with the phase/frequency concepts of lock-in thermography for which specimens are submitted to a periodical excitation [7].

Finally, as far as the mathematical - thermal modeling is concerned, a specific software (ThermoCalc 3D) was used [8], in order to obtain information about specific defects (notches and delamination) in space and in time.

Experimental: Three different experimental set-ups were used for the inspection of multi-ply carbon or boron composite patches.
Firstly, a simple heat excitation source (hot air gun) with an infrared camera (Avio TVS 2300 Mk II ST, 3-5.4 μm) was employed.
Secondly, PT, using an integrated pulsed thermographic system (Thermoscope) employing a medium wave (3–5 μm) infrared camera (Merlin by Indigo) was used. The system has an attached integrated flash heating system (power output from lamp is 2KJ in 2 to 5 ms). A sampling frequency of 7.5 Hz was used on a 320x256 pixel array.
Thirdly, PPT using a focal plane array infrared camera (Santa Barbara Focal Plane SBF125, 3 to 5 μm) working at a sampling frequency of 22.55 Hz on a 320x256 pixel array was utilised. Two high power flashes (Balcar FX 60), giving 6.4 KJ for 15 ms each, were used as heating sources.
The thickness of each ply of the composite patches was 125 μm. Description of the investigated samples are shown in table 1, whilst the actual dimensions of the samples and their defects are presented in table 2.

Sample	Description of Sample
A	Simulation of delamination (Teflon 25 mm x 25 mm between 3rd & 4th ply) on boron composite patch on Al 2024-T3 panel
P1	Carbon composite patch on notch on Al 2024-T3 panel

Table 1: Description of investigated panels

Sample	X-axis (mm)	Y-axis (mm)	No. of Plies	Defect Dimensions (mm)	Total Area (mm2)	Defect Area (mm^2)	Defect (%)
A	70	150	6	25 x 25	10500	625	5.95
P1	65	160	6	10 x 1	10400	10	0.09

Table 2: Dimensions of samples and their defects

Furthermore, mathematical - thermal modelling, using specific software, was also attempted in order to obtain information about the defects (delamination and notch) in space and in time. The ThermoCalc-3D software, which has been developed for simulating thermal non-destructive testing problems where transient temperature signals over subsurface features are of a primary interest, was used. The thermo-physical properties [9] and heating time parameters shown in tables 3 and 4 respectively were used for the modelled composite panels.

Material	Thermal Conductivity ($Wm^{-1}K^{-1}$)		Heat Capacity ($JKg^{-1}K^{-1}$)	Density (Kgm^{-3})
	X axis	Y & Z axes		
Carbon Composite	7	0.8	1200	1600
Boron Composite	22.5	9.35	1000	2000
Adhesive Film	0.197	0.197	1922	0.89
Al 2024-T3	126	126	961	2768
Air	0.026	0.026	1007	1.16
Teflon	0.252	0.252	1043	2150

Table 3: Thermo-physical properties of materials used during modelling

Sample	Heat Time (s)	End Time (s)	Time Step (s)
A	0.05	5	0.05
P1	0.05	10	0.1

Table 4: Heating time parameters for samples used during modelling

Results & Discussion: Since composites have relatively low thermal conductivity values, it is acknowledged that when examining a composite material, the clearest images (high thermal contrast between defect and sound area of sample) are acquired at relatively long periods during the cooling down transient process. However, since the best possible calculated size of a detected defect could be attained at shorter transient times, the obtained thermal images that actually underwent the image processing analysis were obtained at fairly short transient times.
The results after investigating sample A using the first experimental approach (simple heat excitation source) are presented in the following figure (figure 1). The situation in this sample was that a defect – delamination (Teflon) was formed deliberately on the boron composite patch. The Teflon part (dimensions of 25 X 25 mm) was positioned between the 3rd and 4th ply of the composite patch. The approach was able to detect the artificially created delamination on the boron composite patch.

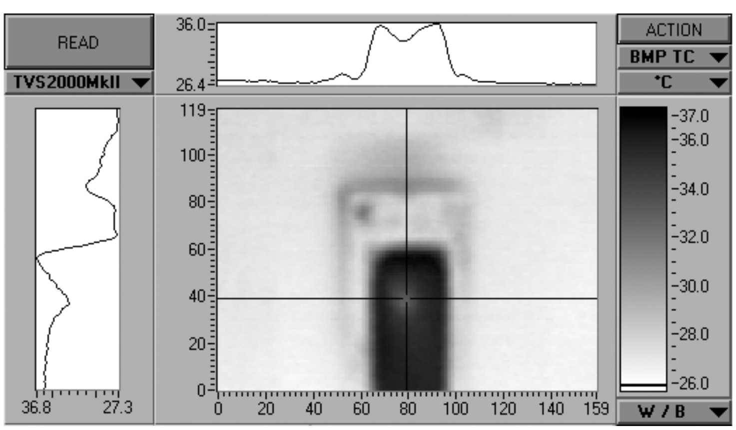

Figure 1: Thermal image & line profiles of sample A using a simple heat excitation source

Similarly, using the second experimental approach (PT) the following thermal image (representative image) and line profiles were obtained (figure 2).

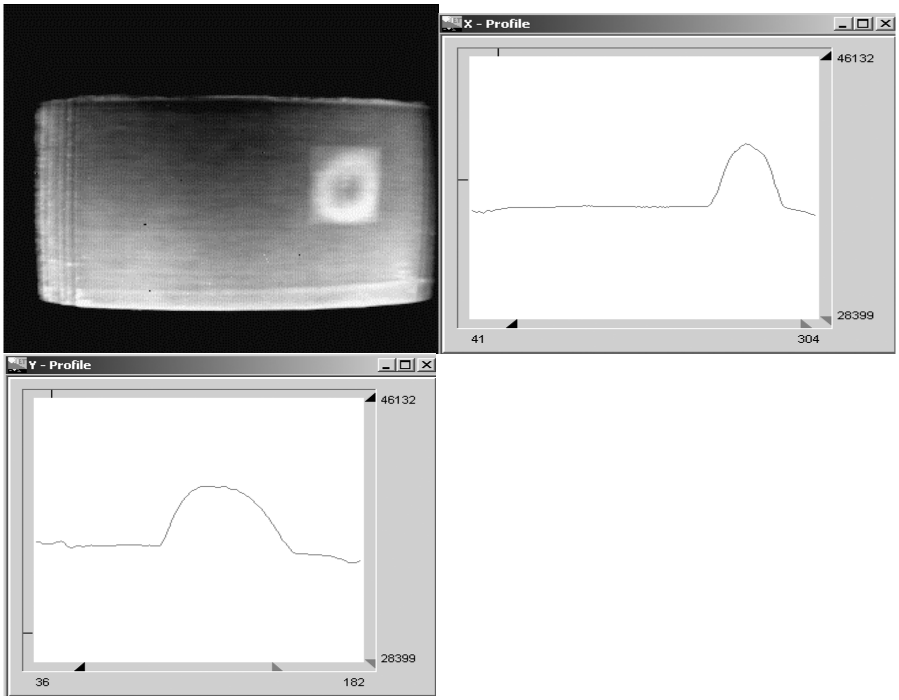

Figure 2: Thermal image & line profiles of sample A using pulsed thermography

Furthermore, from the line profiles it was possible to calculate the size of the defect in the examined sample employing the Full Width Half Maximum (FWHM) approach (in both cases). In the first case, the result was 5.37% and in the second case it was 5.68%. This could be compared with the 5.95%, which is the real surface patch percent area.
Figure 3 shows the obtained result after investigating again sample A by the use of the experimental set-up 3 (PPT). An early recorded thermogram (top-left) is used to segment the plate from the image (bottom-left) and to count the total number of pixels. The maximum contrast thermogram (top-right) and the maximum contrast phasegram (bottom-right) are then used to segment the defect by thresholding. In the first case, the defect was calculated to occupy 5.86%, whilst in the second case 5.93% of the patch area. Again, this is to be measured up to with the real surface patch percent area of 5.95%.

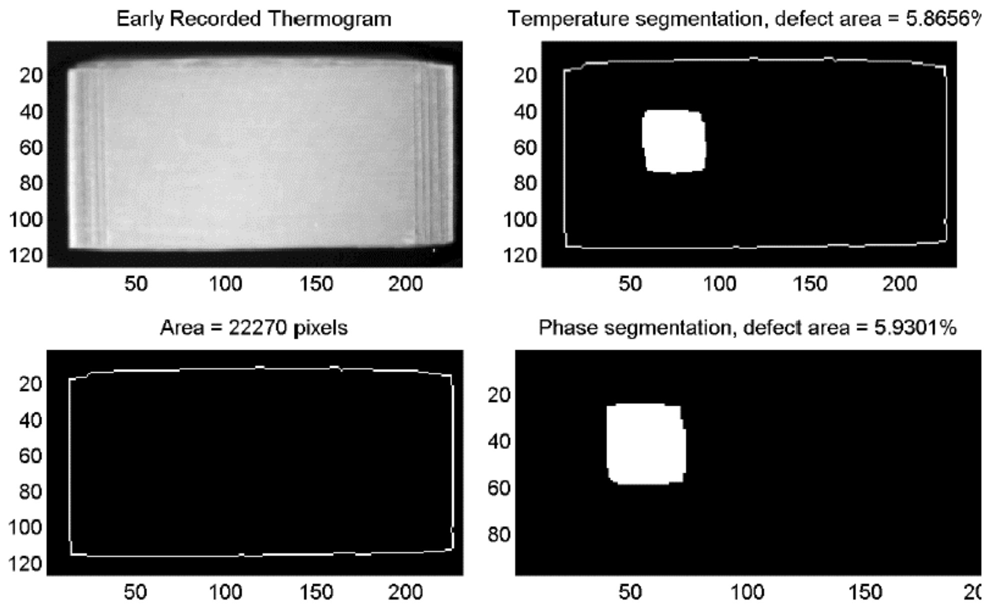

Figure 3: Thermographic investigation of sample A using PPT

A representative thermal image, spatial profiles and the thermal contrast curve of sample A from the thermal modelling run are presented in figure 4. The results give a good indication of how the boron composite material responds to thermal excitation. It shows the behaviour of a delaminated composite material after it was heated with a thermal heating source uniformly in order to detect a sub-surface defect by means of transient thermography.

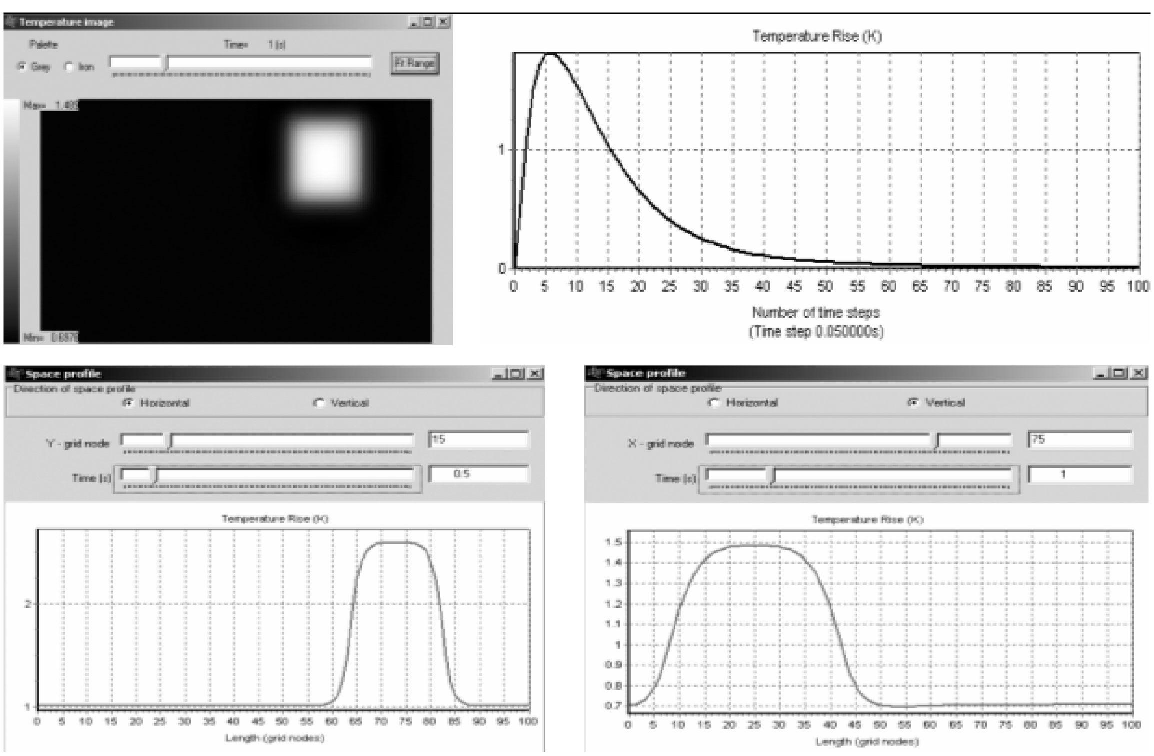

Figure 4: Representative thermal image, spatial profiles and the thermal contrast curve of sample A from the thermal modelling run

The following figure, figure 5, presents the obtained results after investigating sample P1, using the simple heat excitation source (experimental approach 1). The dimensions of the notch on the surface of the aluminium panel were 10 mm (length) and 1 mm (width).

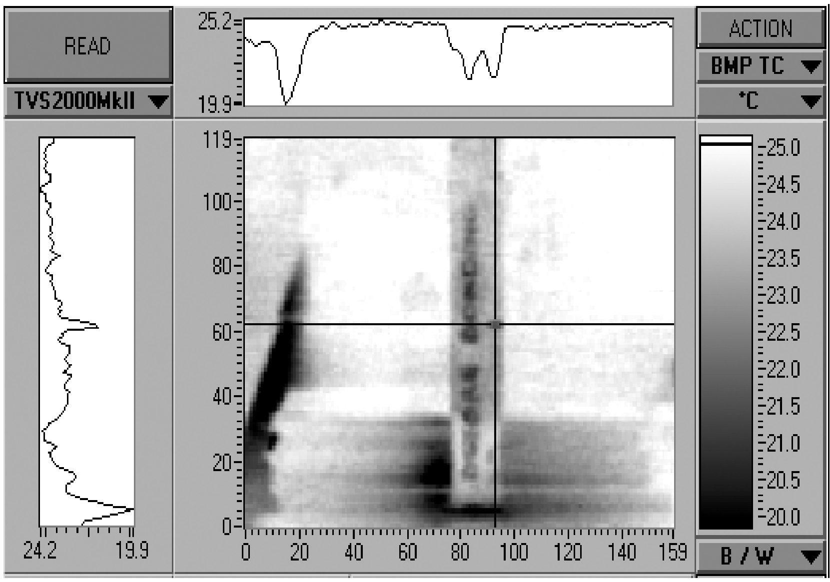

Figure 5: Thermal image & line profiles of sample P1 using a simple heat excitation source

Similarly, using the second experimental approach (PT) the following thermal image (representative image) and line profiles were obtained (figure 6).

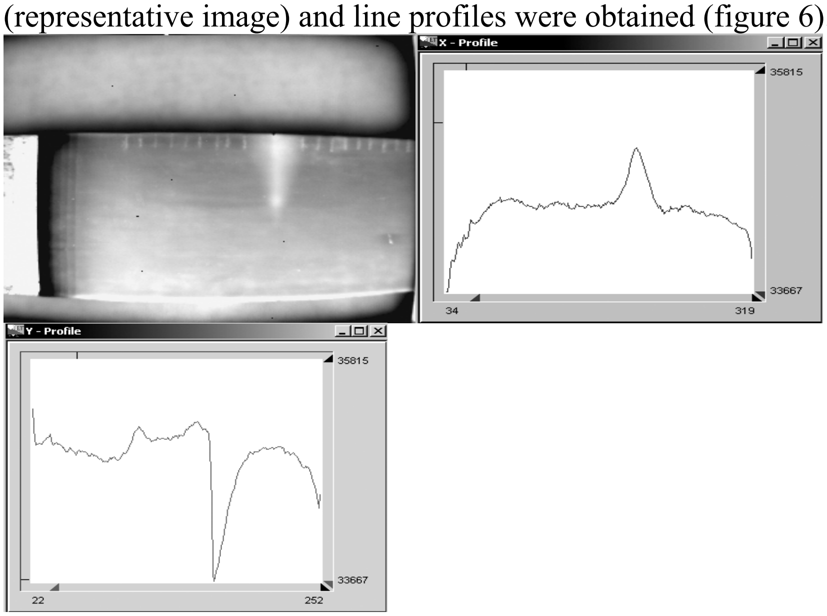

Figure 6: Thermal image & line profiles of sample P1 using PT

Then, from the line profiles it was possible to calculate the size of the defect – notch in the examined sample employing the Full Width Half Maximum (FWHM) approach (in both cases). In both situations, the result was 0.18% instead of 0.09% (actual defect percentage).
Figure 7 presents the defect segmentation for sample P1. Both thermogram and phasegram thresholding oversize the defect dimensions (~1.8% instead of 0.09%) according to the sample specifications.

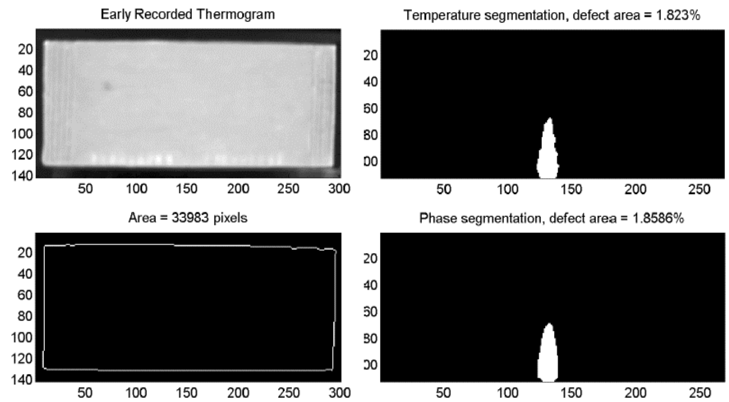

Figure 7: Thermographic investigation of sample P1 using PPT

Results (thermal image, spatial profiles and the thermal contrast curve) from the thermal modelling run (sample P1) are also presented in Figure 8. The results give a good indication of how the carbon composite material responds to thermal excitation and how easily a relatively near surface defect can be detected.

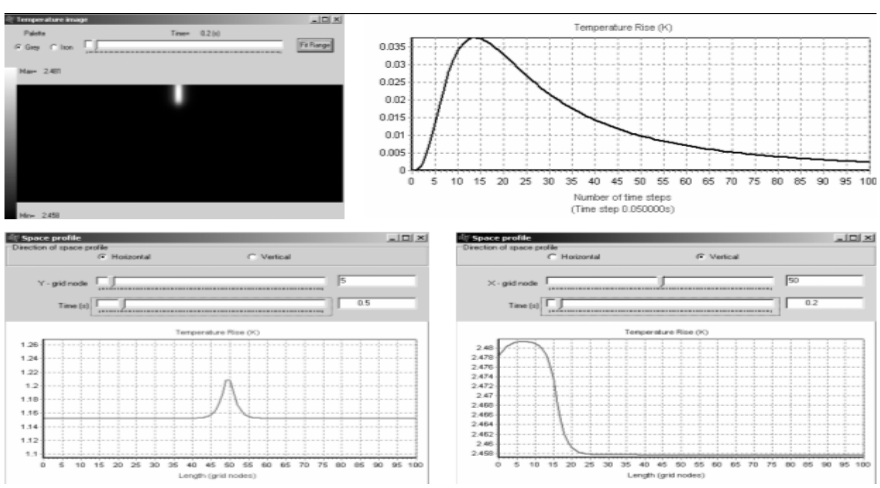

Figure 8: Representative thermal image, spatial profiles and the thermal contrast curve of sample P1 from the thermal modelling run.

The quantitative measurements of the defects of both investigated panels are shown in table 5.

Sample	Actual Defect Area (% Patch)	Defect Area % (using simple heat excitation source)	Defect Area % (using PT)	Defect Area % (using PPT)
A	5.95	5.37	5.68	5.93
P1	0.09	0.18	0.18	1.82

Table 5: Quantitative measurements of defects: actual and using image analysis techniques

So, from the obtained results it is realised that using all experimental approaches it was possible to assess the investigated panels and so detect their sub-surface defects. Furthermore, the use of thermal modelling proved to be an optimistic approach in the evaluation of defects on aircraft composite repairs.

Conclusions: The main objective of this work was to study the efficiency of different thermal NDT & E techniques to detect a couple of defects on boron and/or carbon aircraft composite patches. The simulated delamination and the notch beneath the six plies of boron and carbon epoxy composite patches respectively, were clearly identified by the use of the experimental and the thermal modelling approaches.

The good agreement between measured percent area of defects and real defective areas, with respect to the approaches presented in this work, show that Thermal NDT approaches can be considered as a quantitative non-destructive assessment tool. It is therefore concluded that such approaches can be used in the rapid investigation of sub-surface defects, producing interpretable results. Nonetheless, its success is highly dependent on defect depth and size, which restricts its application to near surface defect imaging.

References:

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