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Development of a NDT method using thermography for composite material inspection on aircraft using military thermal imager

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Abstract
This paper describes the methodology used to introduce thermography as new inspection method for composite parts in aircraft maintenance. It is here focused on two main topics : control of leading edge flaps of Belgian F16 (mainly due to ageing aircraft) and inspection of main and tail rotor blades of Belgian A109 Agusta helicopters. The new idea is to use typical military thermal imagers initially bought for surveillance which only give grey level images but with a good thermal sensitivity and spatial resolution and to develop a specific signal processing of digitized images.

Keywords *: thermography, aircraft maintenance, NDT, composite inspection, thermal imager, military imager*

1. Introduction

TNDT (Thermal Non Destructive Testing) is now an emerging method that comes out of laboratory since a few years. It is here proposed to investigate, compare and quantify the different possibilities to use thermography instead of radiography or ultrasonic testing on composite parts in maintenance of military aircrafts. The new idea is to use military thermal imagers also used by the infantry (see figure 1) because the detector is now an infrared focal plane array capable of measuring a very faint difference of temperature (less than 0.07 K)

Figure 1 : military Thermal imager used by Belgian Defense

Thermography is particularly adapted for non destructive testing on composite and can be used on different materials:
- carbon-epoxy
- thin metal skin on honeycomb structure (like aircraft doors)
- epoxy resin with glass fibre reinforcement GFRP
- panel skins with CFRP (Carbon Fibre Reinforced Plastic) like helicopter blades

The control contributes to highlight the most prominent types of discontinuities seen in aerospace composites including [1]

- porosity which reduces the compressive load carrying capability,
- water ingress or moisture which can degrade the mechanical properties of some resins or lead to freeze inside the part causing more and more damage (see picture 2 for honeycomb composite part with central view of hotter area in the centre of the piece viewed in white in picture 2)
- disbond or delamination resulting from low strength in the resin
- impact damage during the taxi or caused by bird strike or by a dropped tool during maintenance
- inclusions which can reduce strength by kinking the fibres around the inserted material

Some defects like water ingress cause high thermal difference on the surface as seen on Fig 2 below. This thermal difference depends on their characteristics, their dimensions and their depth in the piece part. So the camera should have good thermal resolution (NETD or Noise Equivalent Temperature Difference). [2] Recent work made by Italian Air Force showed that 0.1 ml water ingress in one cell of honeycomb flap of AMX aircraft could show a thermal difference of 1°C when surface is heated with a flow of 15000 W/m^2.[3]

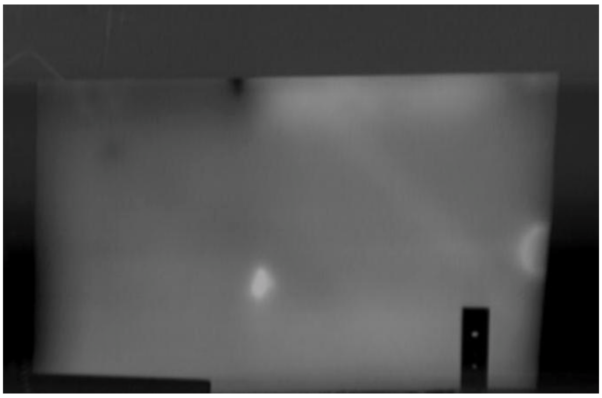

Figure 2 Left : composite part with hole type IQI, Right : thermal image of composite part with water ingress

2. Application to F-16 leading edge and Agusta main and tail rotor blades

The inspection of composite materials is an increasingly important topic due to the expanding number of uses to which such materials are being put. Due to its lightness, composite is used in large quantities in aeronautical applications. For example, F-16 leading edge and Agusta rotor blade are exclusively built in composite.

Composite materials can be affected by manufacturing processes defects (voids due to volatile resin components, foreign bodies, ply cracking, delaminations, bonding defects...) and by in-service defects (fracture of fibres, cracks, delaminations, ingress of moisture, inclusions, impact damage,...).

In case of F-16 leading edge and Agusta rotor blade, it is challenge of outstanding importance to detect defects as precisely as possible. This should avoid unnecessary scraping of expensive material and increase serviceability of parts.

Until now, only tap testing is used to verify integrity of F-16 or Agusta composite parts, mainly because radiography can not detect delamination and because ultrasonic is a point to point technique not practical for parts as long as blades with a length of 5 meters . This test delivers only approximate information on the wellbeing of the material.

It is thus important to develop a more reliable non destructive testing methodology especially adapted to composite materials.

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Thermography is an incoming non destructive testing tool that presents some key advantages in comparison with the other available technologies, namely:

- It is totally non-contacting and non-invasive.
- It can inspect relatively large areas in a single snapshot.
- The data are pictorial format, which is always amenable for the formation of rapid decisions.
- The data are easily stored and retrieved with any classical laptop.
- It allows fast inspection rates (on line information).
- The security of personnel is guaranteed when compared to radiography.

Furthermore, there is no real difficulty to obtain adequate equipment (IR camera, thermal stimulation units, frame grabbers, laptop) as this material is widely used in the Defence. This should reduce drastically the cost of the application and facilitate a large diffusion of this NDT technology amongst all Defence organizations as for example on fig 3 with our military training Alphajet.

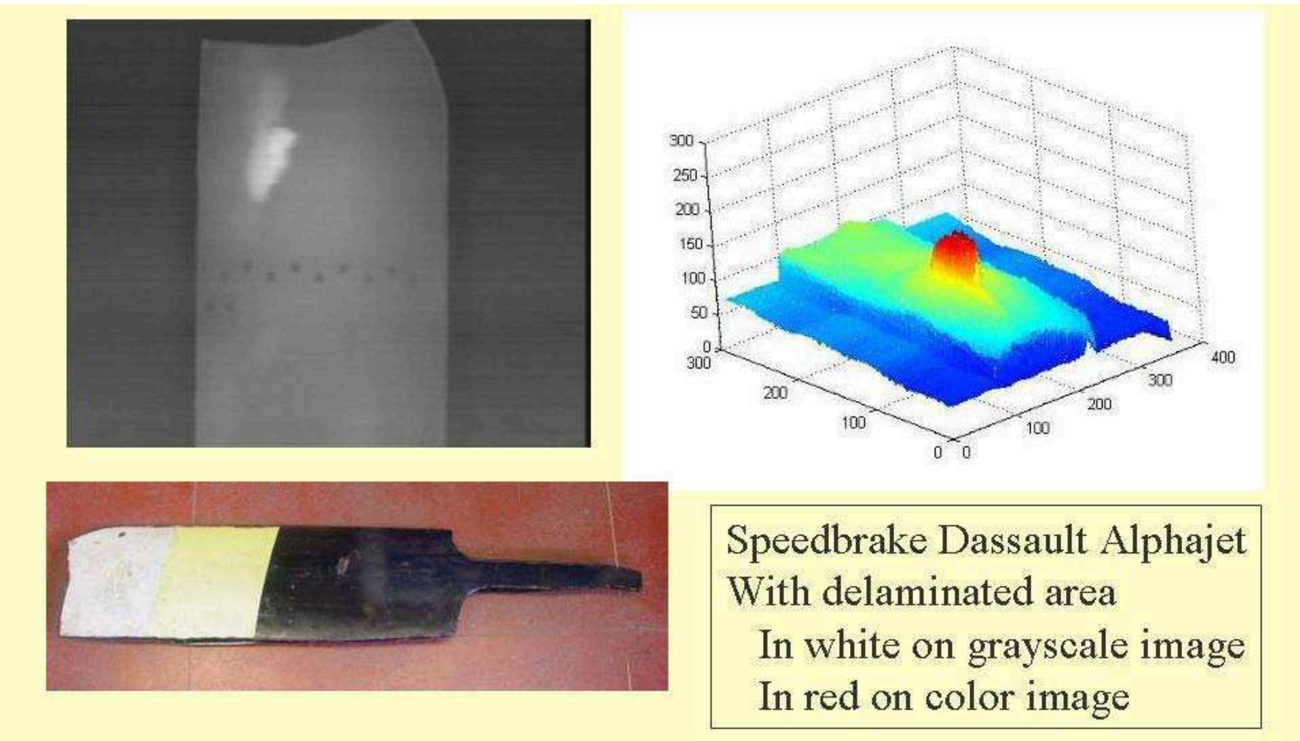

Figure 3 : Example of use of our military thermal imager to detect delamination on Belgian training Aircraft

3. Choice of heating procedures

3.1 A first approach will compare the most popular heating procedures like :

- optical heating (flash tubes, projector, tubular halogen lamps, UV light) ,
- air flux heating (air dryer, thermal paint remover, portable electrical heater 2700 W,…)
- specific heating blankets used also for composite repair

The comparison will take into account main heating properties: repeatability, uniformity, timeliness, duration. The thermal imager can easily be used to retrieve these characteristics but a real laboratory camera can also be used to quantify temperatures directly and more easily.

3.2 A second approach will be an experimental study of raw images obtained using several heaters.

For each method, determination of the more adequate parameters to be used in order to optimise defect detection in a raw image of a known sample:

- final temperature obtained
- duration of the heating (flash or long pulse)
- location and orientation of the heater, start up time to be at constant temperature

4. IR detectors

4.1 A Theoretical comparison between the available detectors will take into account different characteristics of the thermal detector:

We compare our military imager from Thalès with a classical civilian IR camera FLIR SC3000

- Type of IR detector : our military thermal system uses a FPA (Focal Plane Array) HgCdTe hybridized on a silicon CMOS readout circuit
- Type of cooler (our photovoltaic detector is cooled by miniature Stirling-cycle rotary cooler)
- Noise equivalent temperature difference, here less than 0.07 K obtained at the military air conditioned laboratory with calibrated blackbody (with a precise regulation at 0.01°C)

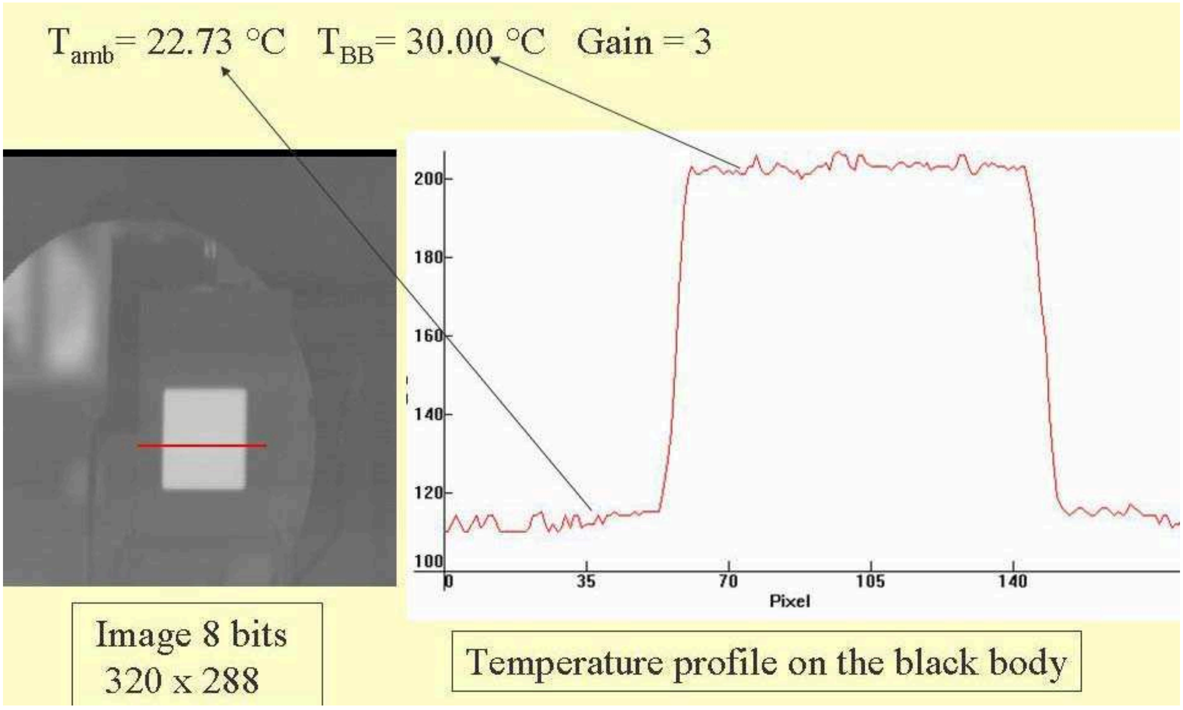

Figure 4. Thermal image made on our calibrated blackbody and temperature profile (graylevel units)

- Detectivity D* (sensitivity figure of merit of an infrared detector) > 2.3 10^{11} Jones for our camera.
- Minimum resolvable temperature difference (the smallest temperature difference that an operator can clearly distinguish out of the noise) checked with calibrated blackbody at the laboratory with different observers following ASTM E 1213 [[4]].
- slit response function (spatial resolution) also compared during other tests with hole type IQI placed on part to have a reference spatial information at lower temperature than the part [[5]]
- Selection of the proper atmospheric band (short wave IR 3-5 µm for FLIR or longer wave 8-12 µm for our military thermal imager)

4.2 An experimental comparison of raw images obtained with different detectors obtained with different cameras will permit to use a calibrated test sample containing different types of defects, of different sizes and at different depths.

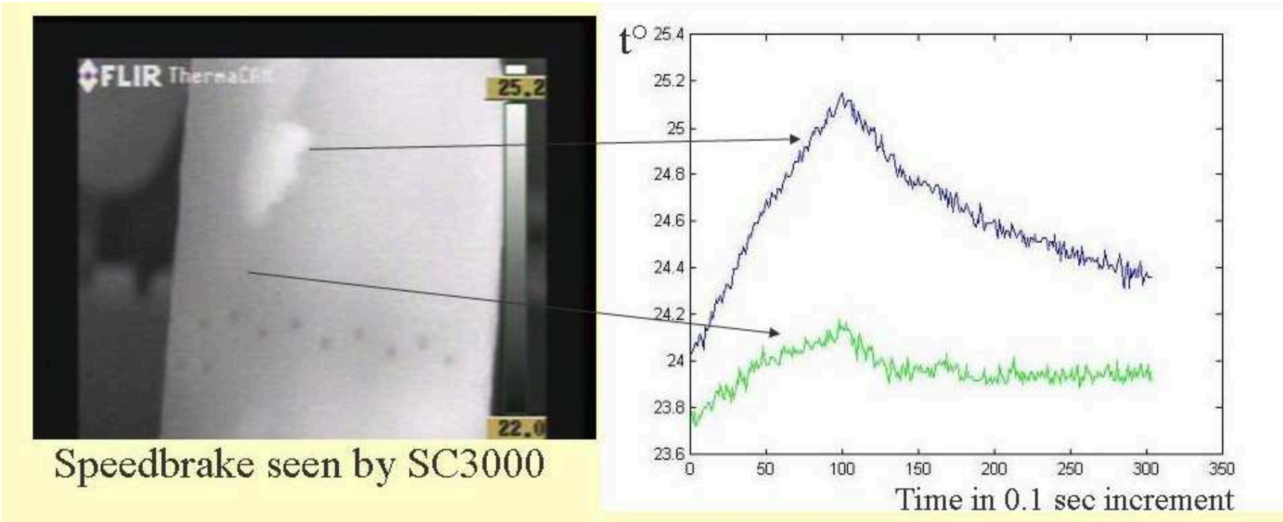

Figure 5 : Alphajet speedbrake tested with FLIR camera with T° evolution during 30 sec on 2 relevant points

5. Choice of a thermography technique

To get a portable inspection method it is here first experienced with pulse thermography. This inspection relies on a short thermal stimulation pulse, with duration of a few seconds for low conductivity specimens (such as graphite epoxy laminates). Such thermal stimulation allows direct deployment with convenient heating sources and prevents damage to the component. The pulse thermography consists of briefly heating the part to inspect and then recording the temperature decay curve. The temperature of the material changes rapidly after the initial thermal pulse because the thermal front propagates by diffusion, under the surface and also because of radiation and convection losses. The presence of defect reduces the diffusion rate so that when observing the surface temperature, defects appear as areas of different temperatures with respect to surrounding sound area once the thermal front has reached them. Consequently, deeper defects will be observed later and with a reduced contrast.

6. Signal processing :

After the choice of the technique and the calibrated sample, it is necessary to realize signal processing of the thermal acquisition, mainly because of :

(1) Noise consideration :
- Experimental determination of noise from the IR detector, electronic noise, noise from external source, noise caused by object inhomogeneity.
- Reduction of noise by adding lots of thermograms.

(2) Camera calibration : vignetting effect, temperature computations (calibration curve).

(3) Choice of best contrast computation : absolute contrast, running contrast, normalized contrast, standard contrast or differential absolute contrast.

(4) Processing and experiment for non-planar surface inspection (like a composite cone with honeycomb of an aircraft like our Belgian C130)

(5) Image processed in false color view to increase seeability by NDT technician

7. Experimental results on known samples

After having processed the acquisition, it must be evaluate some important features of the new technique like :

(1) Reduction in image contrast with defect depth

(2) Effect of host material thermal properties

(3) Temperature decay at the surface over a defect at different depths

(4) Thermal contrast produced at the surface by defects at different depths.

(5) Peak magnitude of the temperature contrast evolution depending of the defect depth

(6) Thermal signature of different defects: delamination, disband and water ingress

8. Validation of the NDT technique

As always in NDT, the new technique must be validated statistically by use of POD (Probability Of Detection) and compare with radiography and ultrasonic C-Scan of the parts. The idea is to characterize the defect detected with 90% of POD following the methodology defined in Working Group AVT051[6].

9. Application of the NDT technique

The whole fleet of Belgian F-16 and Agusta helicopters must be inspected with the technique in order to detect defects and to characterize them.

10. Edition of a NDT technique user guide, course and certification scheme

For the NDT technicians of the industry, it is important to establish a reference training Handbook for level 1, 2 and 3 and to certify people into thermography. The used samples and the rejected flying parts are collected for training and examination at the certification centre of the Belgian National Aerospace NDT Board to be able to certify people following NAS410 or EN4179 which does not for the moment recognize thermography but it has to be done in the near future.

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