GLASS FIBER AIRPLANE INSPECTED WITH

INFRARED LOCKIN THERMOGRAPHY

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INTRODUCTION

Lockin thermography is a remote nondestructive testing method, suited for the inspection of large surfaces. As the method is based on heat conduction inside the material it can reveal any variation of the material thermal properties: the heating source is modulated at the desired frequency and the surface temperature is analyzed in order to obtain the amplitude signal and the phase signal in relation to the heating source. The feasibility of phase angle images eliminates the need for homogeneous surface heating which would be difficult for large areas. Inspection and quality control of the big structures of an airplane are essential to assure integrity and safety. To demonstrate the applicability of lockin thermography for on field inspections, we present the results obtained on an airplane consisting mainly of GFRP (Grob 115). Though no special treatment of the surface has been performed, we could detect hidden structures and repairs.

THEORY

The modulated heating of a sample surface produces a temperature modulation inside the material, whose propagation behavior can be described as a thermal wave [1,2,3]. The variation of temperature due to the heating of a sample is determined by the diffusion equation:

$$\nabla \cdot (k\nabla T) + Q = \rho c \frac{\partial T}{\partial t} \qquad (1)$$

where T is temperature, k the thermal conductivity, ρ the mass density, c the specific heat, and Q the heating power per unit volume. The general a.c. solution of equation (1) in case of modulated surface heating, mono-dimensional problem, and two-layered semi-infinite sample is [4]:

$$T_i(x,t) = (A_i \cdot e^{\sigma_i x} + B_i \cdot e^{-\sigma_i x}) \cdot e^{j\omega t} \tag{2}$$

where i=1,2 indicates the layer, $\sigma_i = (1+i)\sqrt{\omega \rho_i c_i / 2k_i}$, ω is the modulation frequency, and A_i and B_i can be derived from boundary conditions. Equ. (2) can be seen as the superposition of two waves moving in opposite directions. The propagation of a thermal wave inside the material is influenced by the presence of voids, flaws and any other change in the thermal properties of the material. The surface temperature, T(0,t) resulting from a modulated surface heating has an amplitude and a phase shift (with respect to the heating source) that depends on the internal thermal characteristics of the material. A thermal wave is highly damped and the decay rate depends on modulation frequency, so that high frequency waves reveal material features close to the surface, while low frequency waves can reach larger depths. Thermal wave interferometry performed with a laser beam and an infrared detector is a well known and extremely sensitive NDE technique allowing for the measurement of only one single point at a time. Lockin thermography is the multiplex version of this slow point by point technique [5, 6]. Hence it allows inspection of large areas at low thermal wave frequencies within only a few modulation cycles. A modulated lamp or a hot air gun is typically used as a heating source, while the detection system consists of an infrared camera (Agema 900) which is sensitive in the 8-12 μm range (fig.1). The temporal behavior of every pixel of the infrared image is analyzed in order to obtain the local modulation amplitude and phase shift with respect to the heating source. A compensation is required due to the scanning process, which generates an additional phase shift. While the amplitude image is affected by inhomogeneities of heating and variations of surface emissivity, the phase image as a propagation time effect is independent of such influences. Images taken at different modulation frequencies show features located at different depths.

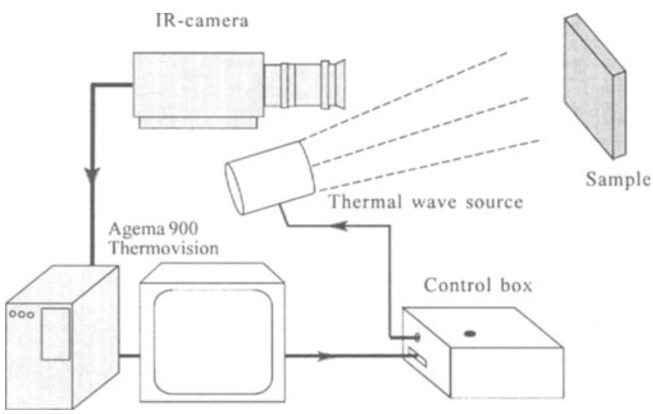

Figure 1. Lockin thermography system.

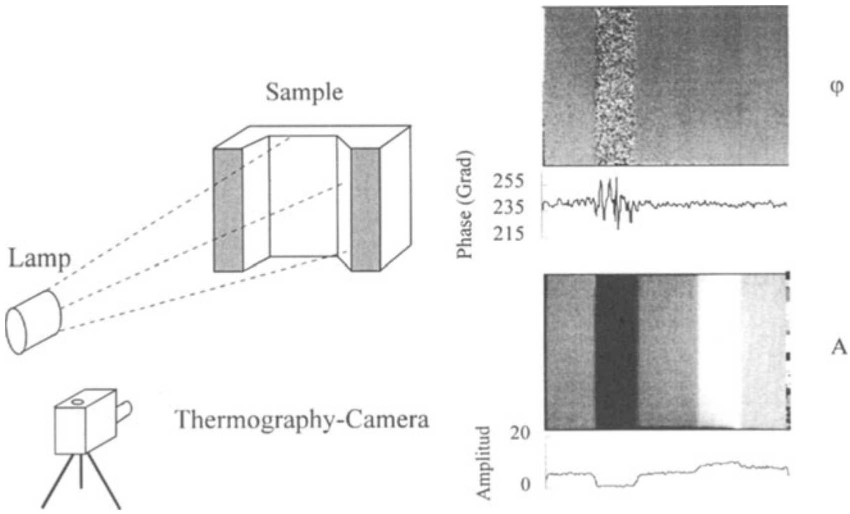

Figure 2. The phase image is independent from surface orientation and variations of surface emissivity.

Figure 2 shows the difference between phase and amplitude image obtained with a sample that has differently oriented surfaces. It is interesting to see how even the surface orientation does not affect the measurement.

MEASUREMENT

The airplane used for the inspection is a Grob G115 (fig. 3), mainly made of glass fiber reinforced polymer (GFRP). The lockin system has been brought to an airfield in order to

Figure 3. Picture of the airplane Grob G115

test the possibility of inspecting a real airplane outside the laboratory, in its real environment. The surface of the plane was silver and bright white; no surface treatment was used in order to improve the surface emissivity or homogeneity. Depending on the size of the area, up to three modulated lamps (1000 watt each) were used. The kind of material (GFRP), characterized by a low thermal conductivity and thermal diffusivity, required the use of very low frequencies. The time for an inspection at a typical frequency of 0.015 Hz is about two minutes. A mirror was used to inspect many parts located underneath. Fig. 4 shows the plane and the lockin system during the inspection of the nose gear.

RESULTS

Fig. 5 shows the cowling of the plane: many stripes are visible due to the overlapping parts of the GFRP material used in the construction of the shell. The three round structures, not visible on the other side, indicate the points where the cables for the landing lights are attached underneath the cowling. The dark spots are fasteners. During a hard landing the front and the main gear were damaged. No damage was visible at the attachment of the two gears, but the structure had to be opened for an inspection and delaminations were found and subsequently repaired. Fig. 6 shows a repair at the attachment of the front gear.

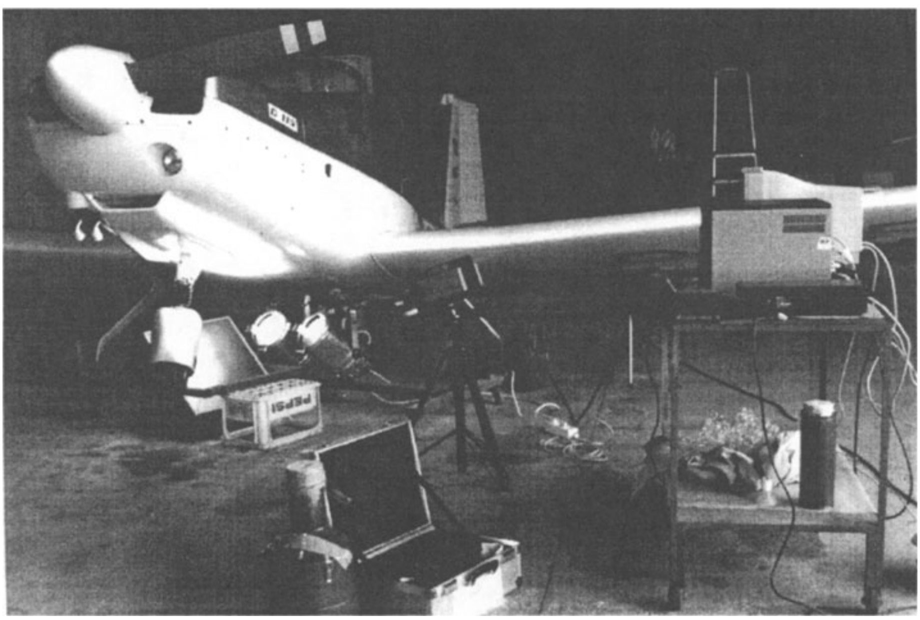

Figure 4. Plane during the inspection of the nose gear

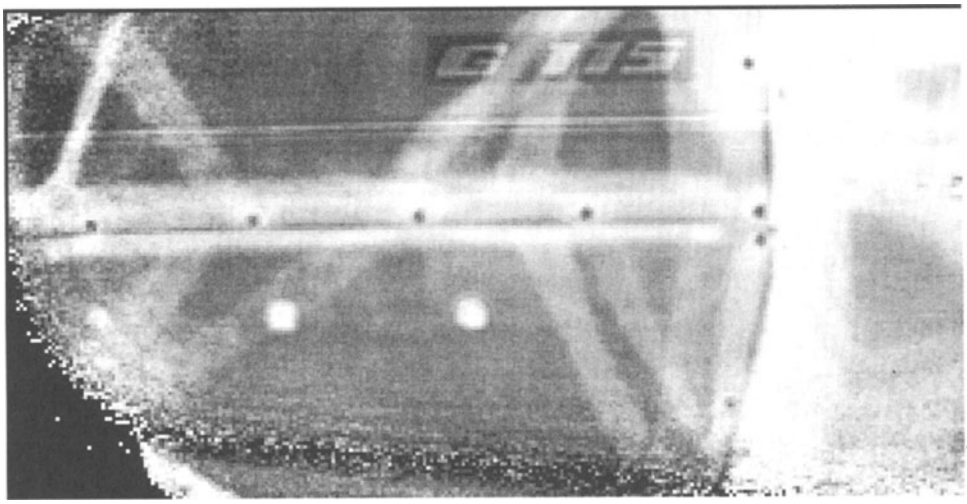

Figure 5. Part of the upper and lower cowling of the plane (0.015 Hz).

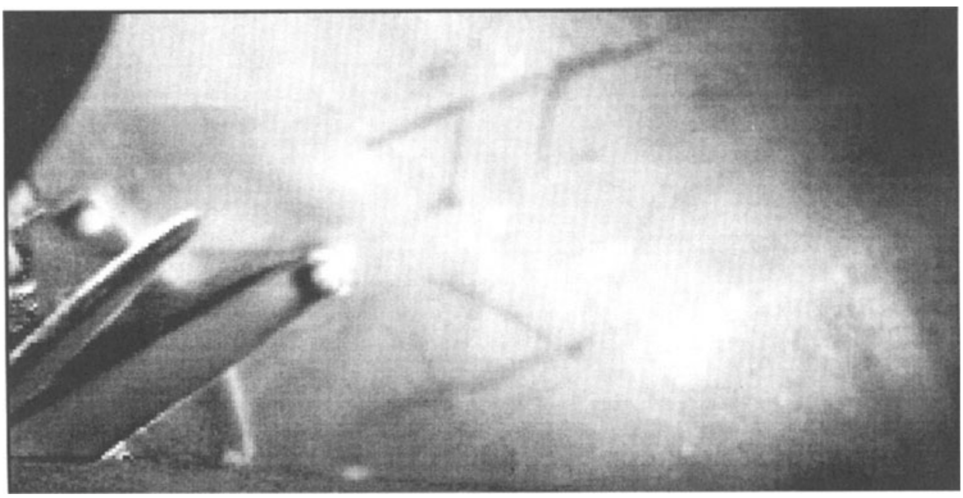

Figure 6. Repair of a delamination at the attachment of the front gear at the bottom of the fuselage (0.02 Hz)

Fig. 7 is the same area imaged at a lower frequency: in this case deeper details are visible, like the attachments of the pedals for the pilot. The torque bars of the elevators were substituted due to corrosion problems; fig. 8 shows the inner structure of the left elevator: a plate used to repair this part is clearly visible; also visible is that the new tube is shorter than the original, so that a void is left.

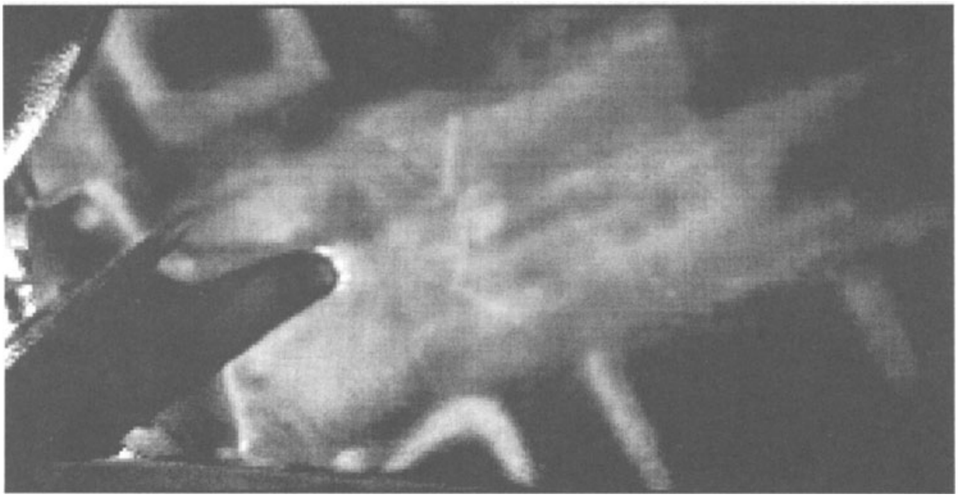

Figure 7. The same area as in fig. 6 has been imaged, but at a much lower frequency (0.0037 Hz): deeper structures like the attachment for the pilot pedals are visible.

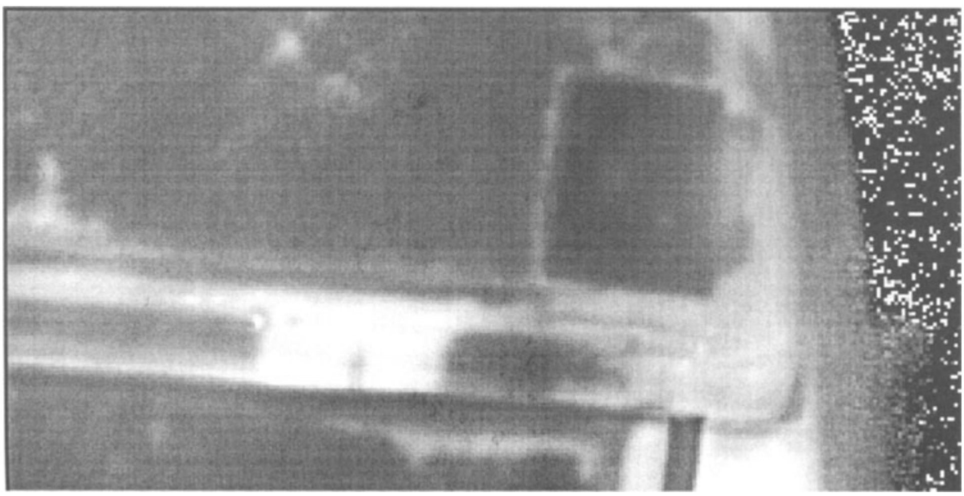

Figure 8. Elevator (0.02 Hz): the plate used for repair and the void left between the two tubes are visible

Fig 9 shows a repair at the left main gear attachment. The repair is at the right of the hole. The hole was made in order to access the internal part of the wing, inspect and repair the attachment of the gear; no delamination was optically visible from the outside after the accident. The fuselage of the plane was inspected using three lamps. Fig. 10, taken at 0.004 Hz, shows the vertical bulkheads of the fuselage.

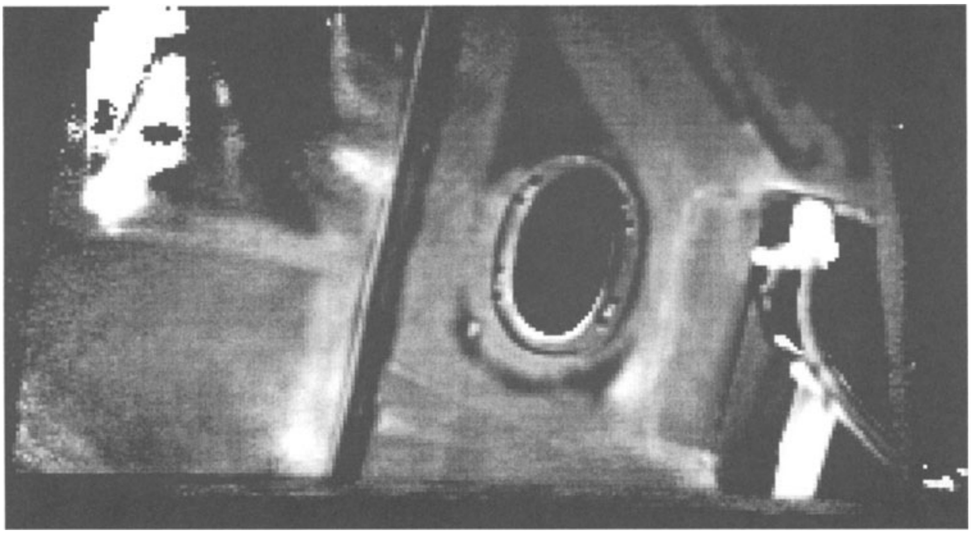

Figure 9. Repair at the main gear (0.015 Hz).

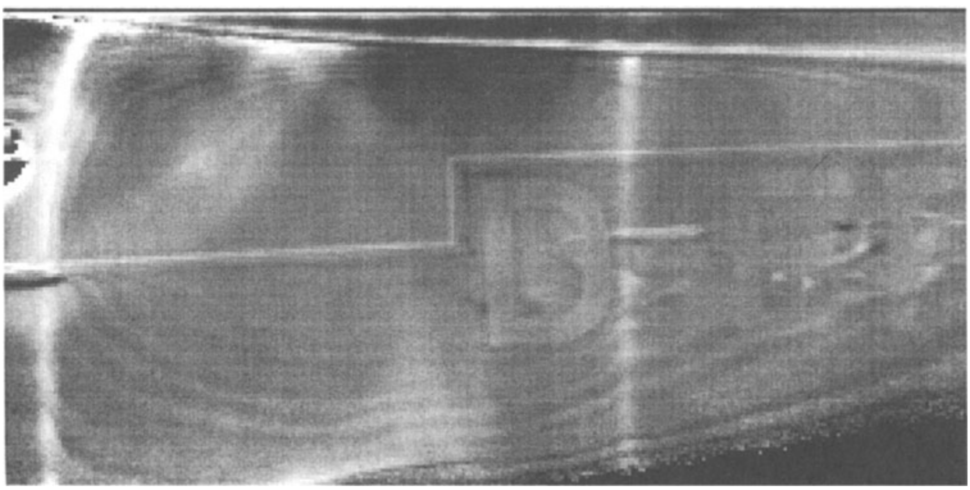

Figure 10. Fuselage of the plane.

CONCLUSIONS

Lockin thermography has proved to be a good and versatile inspection method for airplane structures: there has been no need of any surface treatment, and every interesting section of the plane was inspected revealing internal hidden structures. Reflections from constant heat sources did not disturb the measurement: only the reflection of the modulated lamps had to be avoided. The results obtained on structures exceeding by far the size of the samples used in photothermal laboratories indicate the applicability of the method to monitor in a remote way the integrity of aerospace structures. This is an essential contribution to monitor the safety e.g. of aging aircrafts.

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