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# AIRCRAFT LEADING EDGES MINOR DAMAGES DETECTION BASED ON THERMOGRAPHIC SURVEY OF ELECTRICAL ANTI-ICING SYSTEM

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**Keywords:** airplane, leading edge, accidental damage, ant-icing, NDT, thermography.

**Abstract:** Aircraft leading edge is one of the most important subjects of aircraft scheduled maintenance. Leading edge as part of the slot on transport aircraft is not critical to fatigue stress in most of the cases. However, leading edge is extremely vulnerable to the accidental damage in combination with environmental damage. Maintenance is usually provided by visual inspection before every flight. Nevertheless, development of anti-icing system based on contact electrical heating opens possibility to thermographic Nondestructive Testing (NDT) methods usage. These methods could detect minor damages, which are visually undetectable especially in the case of composite materials. This paper describes possibility of thermographic methods (using anti-icing system) application as mean of leading edge minor damage detection.

## 1 INTRODUCTION

Anti-icing system is one of the most important system of modern airplane. It protects essential parts of aircraft structures (leading edges of wing, tail, elevator, etc.) from ice (Figure 1). Anti-icing system failure in icing condition could lead to the catastrophic consequences [1]. Scheduled maintenance is a key element of preventing of these potentially dangerous situations.

Nowadays anti-icing protection is mostly based on pneumatic systems or hot air conducted from engines. However, electrical heating systems (EHS) are starting to appear. These systems are already used on huge airliners (B787) in order to achieve higher effectivity [2]. These systems are also applied on smaller airplanes (for instance DA-62). EHS application brings new means of maintenance and diagnostics. The main objective of our research was to verify the usage of thermography as a means of leading edge minor damage identification. Research is focused on electrical heating system based on Positive Temperature Coefficient (PTC) applied on leading edge anti-icing system.

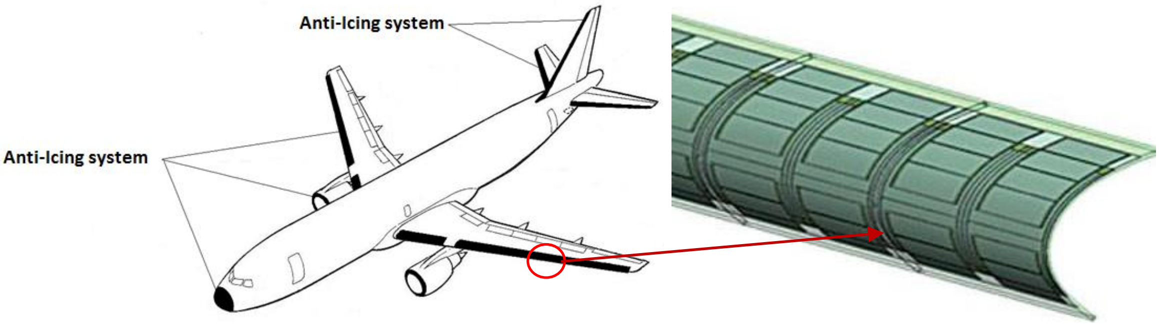



**Figure 1: Leading edge anti-icing system example (left). In detail the B787 leading edge heating system (right, Source: www.compositesworld.com)**

## 2 PTC HEATING SYSTEM

PTC (Positive Temperature Coefficient) heating systems [3, 4, 5] are self-regulating heaters that run open-loop without external regulations and controls. PTC heaters use conductive grids printed on thin and flexible polymer substrates. Regulation characteristics are based on applied materials (for instance polydimethylsiloxane loaded with carbon particles). This is great advantage in comparison with traditional heating systems based on wires or coils which generates heat which have to be externally regulated.

Basically, PCT heating systems work as the thermistor. The resistance increases together with temperature. The Figure 2 shows resistance- temperature characteristic (R-T) of a PCT thermistor. Temperature $T_C$ is called switch temperature. The switch temperature is the temperature at which the resistance starts to rapidly rise. The switch temperature depends on type of PCT thermistor. Switching PTC thermistors have a slightly negative temperature coefficient up to the point of minimum resistance $R_{min}$.

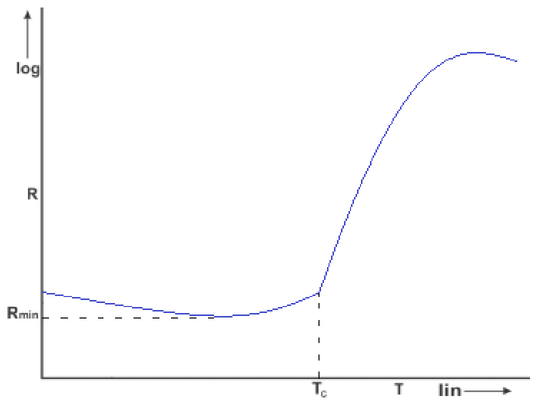



**Figure 2: R-T characteristic PCT thermistor**

Another advantage of PTC heating system is rapid temperature increase to the operating temperature. Laboratory testing showed that surface temperature could increase from initial -55°C to the 40°C in 24 seconds (and from -55°C to the 0°C in 4 seconds). System was tested in climatic chamber ESPEC AR680. Temperature was measured by thermocouple Omega SA1-T2 paste on test sample surface (see Figure 3 and 4). These attributes are quite favourable for modern anti-icing systems.

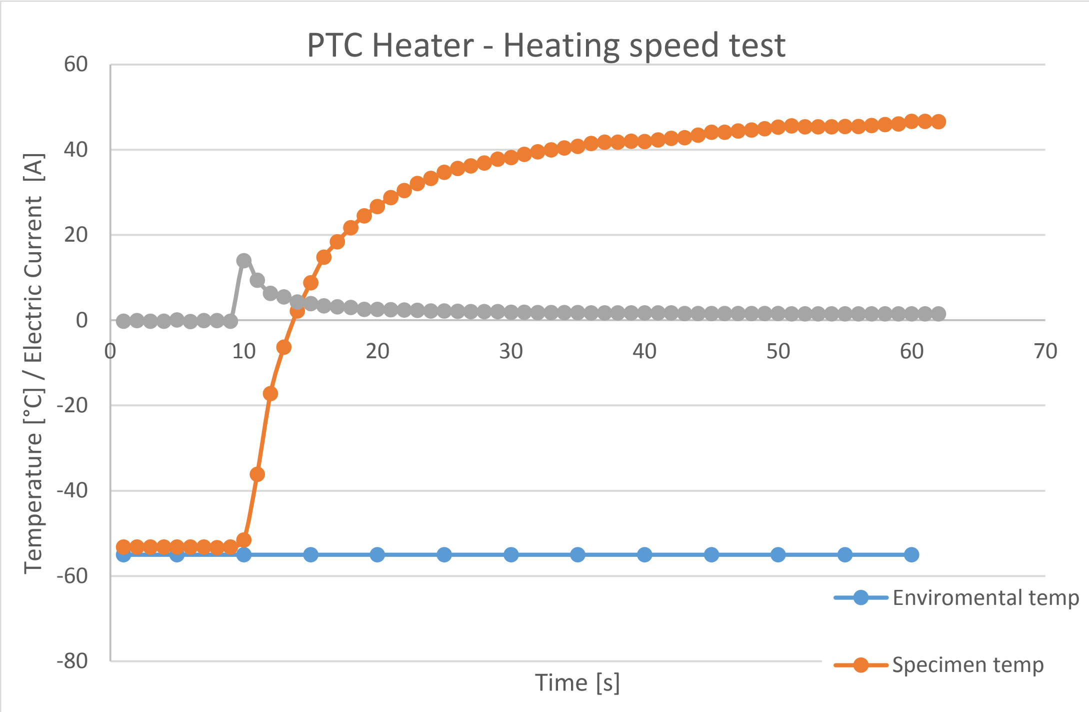



**Figure 3: PTC heater heating rate and electric current for environmental temperature -55°C**

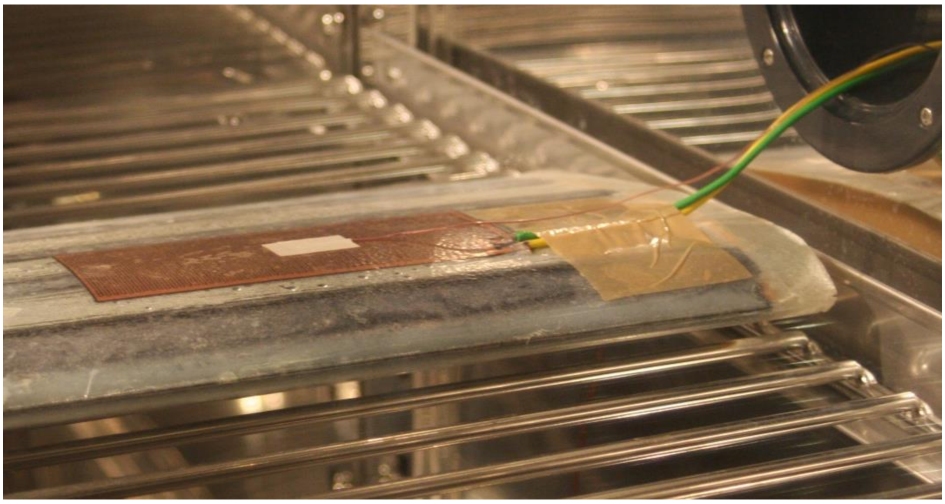


**Figure 4: Testing specimen in climatic chamber (PTC heating foil by Conflux)**

## 2.1 PTC in Anti-Icing systems

PTC elements are primarily intended as anti-icing system capable of automatic or manual activation after icing detection. System activates heating elements. These elements start to heat up to the "switch" temperature (for composite materials it is set to 60°C). When the threshold temperature is met, power consumption decreases to level, where the temperature holds still. Increased temperature prevents icing occurrence. These state is maintained until system deactivation.

System could be used as anti-icing as well as de-icing. In the case of de-icing application system is activated until ice is defrosted (heating duration is based on thickness and structure of ice cover). It is favourable to uses PTC heating system to the relatively thick ice cover.

PTC EHS are installed on external layers of surface. Therefore, they are sensitive to the accidental damage. It is essential to detect minor accidental damages before these damages are expanded as result of fatigue stress and environmental influences. Minor damage detection could lead to collateral damages detection of primary structure damages (for instance delamination). So far primary mean of leading edge examination is direct visual inspection. EHS usage brings new possibilities of NDT thermographic methods application as mean of fast and effective leading-edge inspection.

## 3 THERMOGRAPHY

Thermography is one of many infrared imaging science´s example. It detects radiation in long infrared range of electromagnetic spectrum. Infrared radiation is emitted by objects with temperature above absolute zero. Therefore, it is possible visualize temperature distribution in the form of thermogram. Infrared thermography is widely used NDT method. In aviation industry it is used for detection of structural defects [6, 7].

**Thermographic method categories:**

- Passive infrared thermography- Inspected object has different temperature to the ambient environment

- Active infrared thermography- Active energetic stimulation is required to achieve temperature contrast of inspected object

For common aviation structures it is beneficial to use active thermography (structure active stimulation). Active methods main disadvantage is necessity of expensive equipment and external source of thermal radiation. It could be overcome by using anti-icing system itself as source of emitted thermal radiation. Than it is possible to use passive thermography.

### 3.1 Thermal Anti-icing System and their Application in NDT methods

Thermal anti-icing based on electrothermal principle are more and more applied on modern aircrafts, especially in the case of full composite structures. The electrothermal elements (more precisely foils) are mostly installed on external layers of leading edge surfaces. Elements are separated into particular segments to ensure system functionality in the case of partial failure. Also, it is not required to start the engines during anti-ice system pre-flight test. System could be connected to the external power source. Thermographic testing is quite fast (heating to the operating temperature +60°C takes around 5 seconds in the case of environmental temperature around 25°C). In this case, it is possible to apply thermographic testing in Level A check or even during pre-flight check.

Advanced PTC (positive temperature coefficient) elements are cell designed. Therefore, heating element failure is isolated to cells in the proximity of structure damage. The main idea of thermography application is the possibility to easily detect system failure or more precisely failure block of elements. This failure indicates location of accidental damage (external impact).

This ability could be used to test the structure itself. Local system failure indicates potential structure damages. Than these spots will be subject of higher level of maintenance. This type of inspection is especially useful for composite material in the case of accidental damage without structure penetration. Visual inspections are not capable to detect hidden defect in the form of internal delamination. These defects could slowly grow until they reach critical damage length and possible structure failure.

Local defect detectability depends on several attributes, like damage size, material heating rate, etc. PTC foils has been already tested during experimental testing.

### 3.2 Experimental testing

Experimental testing has been divided into two phases.

First phase is focused on heating element behaviour during extreme operational conditions (impacts, high stress load, etc.). In this phase hidden defects like delamination are not considered. It means that occurring damage is also detectable by visual inspections. Experiment subject was PTC foil-electrothermal Cunflux (140x70 mm) laminated on composited “demonstrator 1” (Interglass 3x160 g, heating foil, 1x160 g) see Figure 5. As a thermographic camera was used FLIR T420 [8] (Temp. range: -20°C to 650°C; Spectral range: 7,5 - 13 µm; Temp. sensitivity: 0,045°C; Resolution: 320x240).

Defect was simulated single bore through external layers of demonstrator and crack with length 25 mm. Bore diameter was increased from 4 to 10 mm. Time duration of experiment was 120 seconds for each diameter. This procedure showed influence of structure heating on thermography results and demonstrated local failure of heating elements. Experiment duration was in correlation with standard pre-flight check duration for wing leading edge inspection.

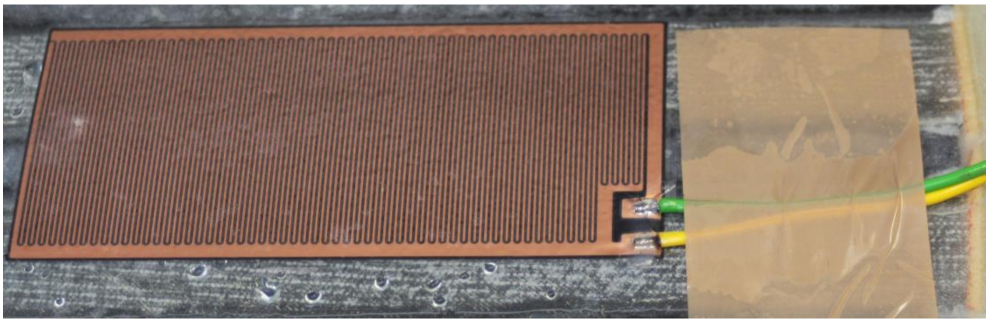


**Figure 5: Testing specimen (PTC heating foil by Conflux)**

Experiment process (bore diameter 10 mm, crack size a = 25 mm) is illustrated in the Figure 6. Thermograms in Figure 7 shows collection of temperature change in the defect’s proximity. It is evident, that defect larger than 10 mm size are clearly detectable in the case of combination with heating element penetration. Results also show that it is beneficial to locate heating elements across the suspected defect growth.

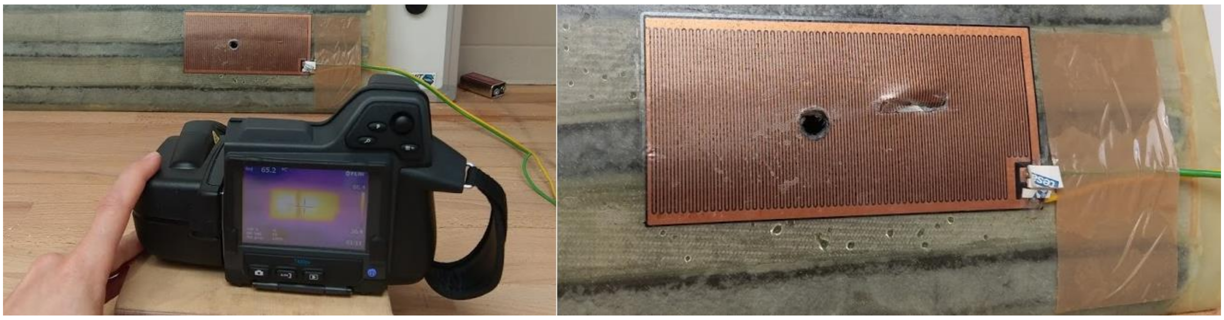
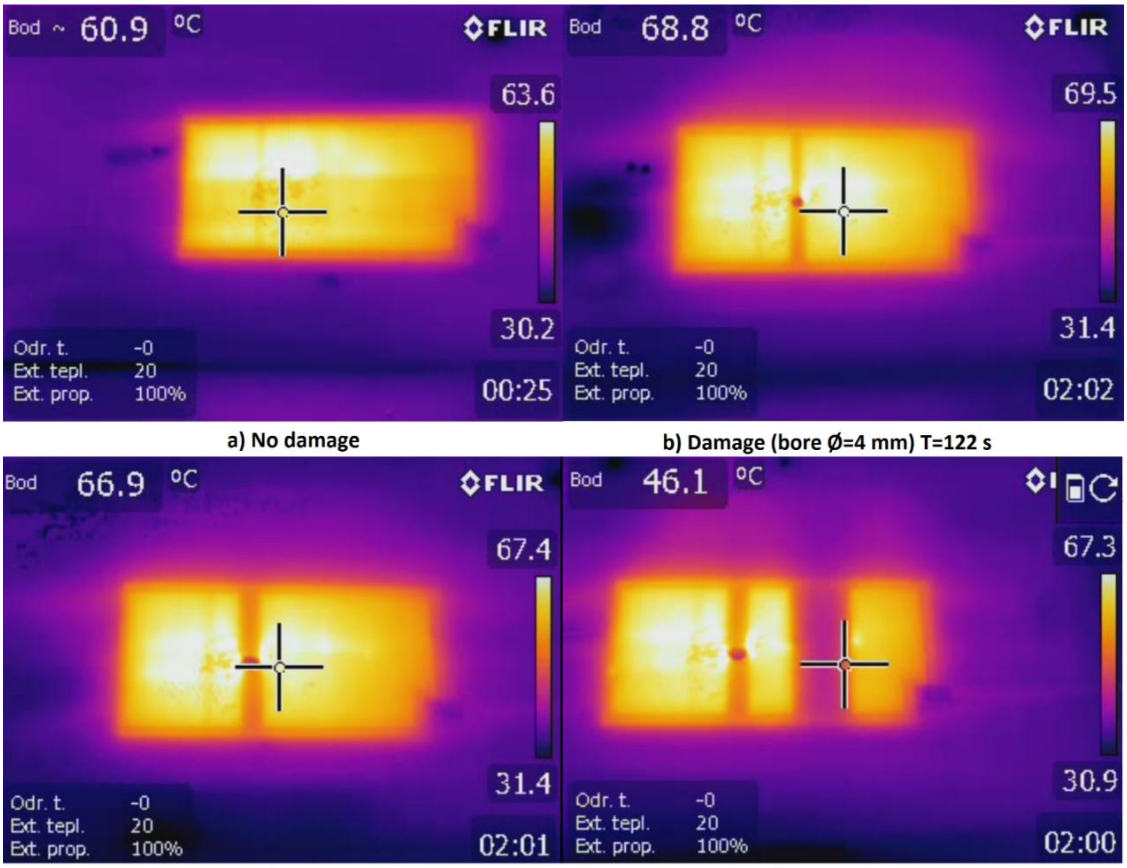


**Figure 6: Thermography application on damaged specimen (bore diameter 10 mm, crack size a = 25 mm)**




**a) No damage** **b) Damage (bore Ø=4 mm) T=122 s**

**c) Damage (bore Ø=10 mm) T=121 s** **d) Damage (bore Ø=10 mm + crack a=25mm) T=120 s**

**Figure 7: Thermograms of a testing specimen a) without damage; b) bore diameter 4 mm; c) bore diameter 10 mm; d) bore diameter 10 mm, crack size a = 25 mm**

The second phase of testing is in development. It will be primarily focused on testing of ability to detect damage without penetrating the main structure. The secondary goal is to find the delamination without damage of the heating element. For these purposes the demonstrator no.2 is prepared (Figure 8). The demonstrator no.2 is equipped by 3 independent heating elements.

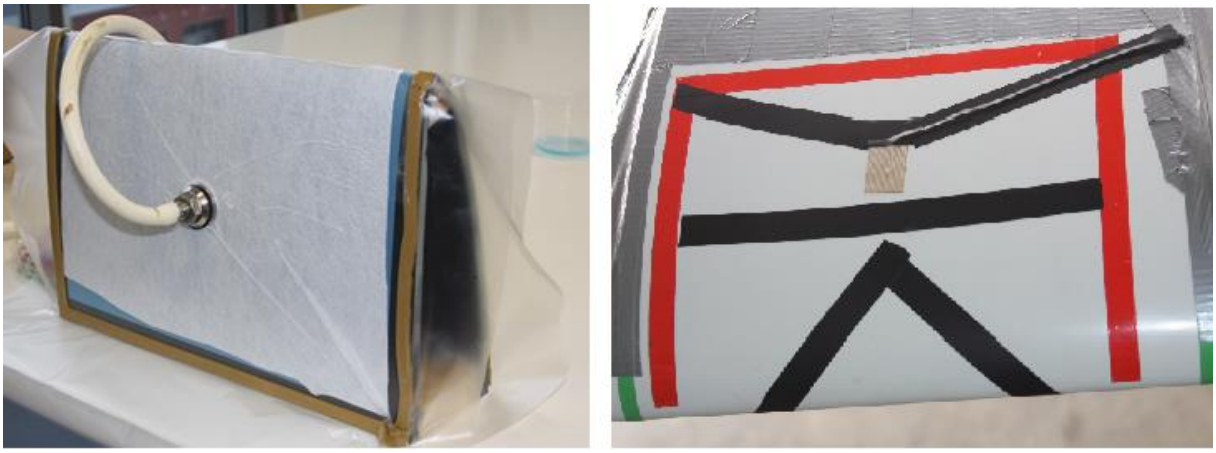


**Figure 8: Demonstrator no.2**

The surface of the demonstrator no.2 is painted. Damage to the demonstrator will be applied by a calibrated impactor (see Figure 9) with a ball impact point 25 Ø and Ø50 mm. Impact energy of the impactor is scalable in range 2 J to 60 J.

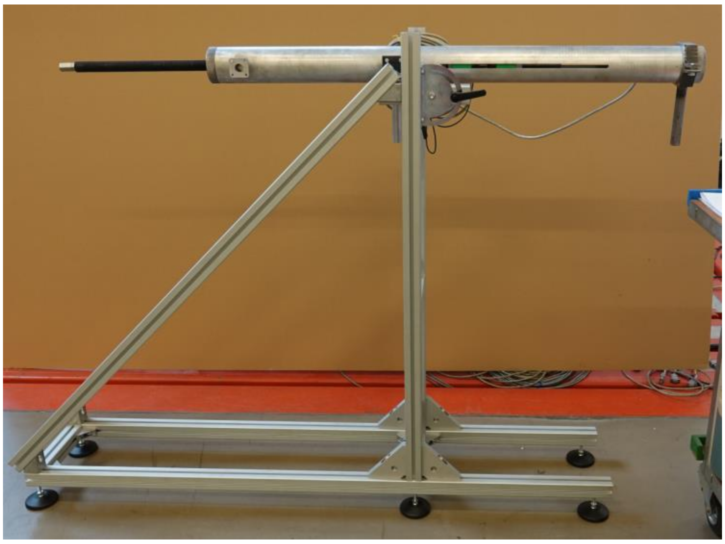


**Figure 9: Calibrated impactor with impact energy from 2 J to 60 J**

## 4 CONCLUSION

Aircraft leading edges inspection based on thermographic survey of electrical anti-icing system is discussed in this paper. Thermography is nowadays one of the expanding NDT practices used in aviation industry, especially on composite structures.

Proposed passive thermography inspection applies anti-acing system as an energy (heat) emitter. Where, primary target of inspection is state of the heating element. In the case of damage detection, the location is labeled as a target for detailed inspection, especially if there is no visible penetration of structure.

First phase of research was focused only on damages with penetrated the structure. Next phase will evaluate other types of damages for instance delamination of main composite structure.

However, conducted experiment indicates, that thermography could be effective mean of **Level A** leading edge with electrical anti-icing system inspection.

## ACKNOWLEDGEMENTS

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