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IR thermography for lightning-strike damage monitoring in composite materials

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Abstract

The increasing tendency to substitute metallic parts of aircrafts by lighter composite structures comes with other issues. One of them is the resistance of composite materials to lightning strike. The present paper illustrates how the use of infrared thermography can improve the understanding of lightning-strike induced damage and assess its severity. It is based on an experimental campaign carried out in ONERA: several carbon/epoxy composite samples, with or without specific protection, were impacted by lightning arcs of various current levels. An infrared camera was used during and after those tests to monitor and analyze the resulting damage inside the samples.

1. Introduction

The introduction of composite parts in aircrafts, especially for the fuselages, makes it inevitable to take into account their resistance to lightning strike in the design and certification processes. In that context, ONERA has been developing an experimental test bench (the GRIFON bench, see Fig. 1) which can deliver lightning D-waveforms of various current levels [1].

In order to identify the damage induced by lightning strike and to assess its severity, non-destructive inspections of the tested composite coupons are needed. Moreover, just like what is commonly done for composites under mechanical loading, non-destructive techniques are also required to set the damage scenario of those coupons during the lightning test. The present paper illustrates the relevance of IR thermography to address both challenges:

- pulse thermography is used *after* the tests as a quantitative diagnosis tool to identify the lateral extents and depths of the detected delaminated interfaces;
- passive thermography is used *during* the tests as a real-time damage monitoring tool to set the order of appearance of delamination.

Thermal maps provided by both acquisition modes are compared to each other. A discussion, already initiated by a few authors [2], is finally proposed on the apparent analogy between lightning-strike damage and mechanical impact damage.

2. Experimental setup

All lightning-strike tests are performed on the GRIFON bench of ONERA (Fig. 1). The impacted coupons are unidirectional carbon/epoxy composite composites which are commonly used for fuselage parts in commercial aircrafts. The real-time thermal monitoring of the rear-face, e.g. the face opposite to the lightning arc, is carried out with a mid-wave infrared camera (X6580sc series) with a frame rate of 200 images per second.

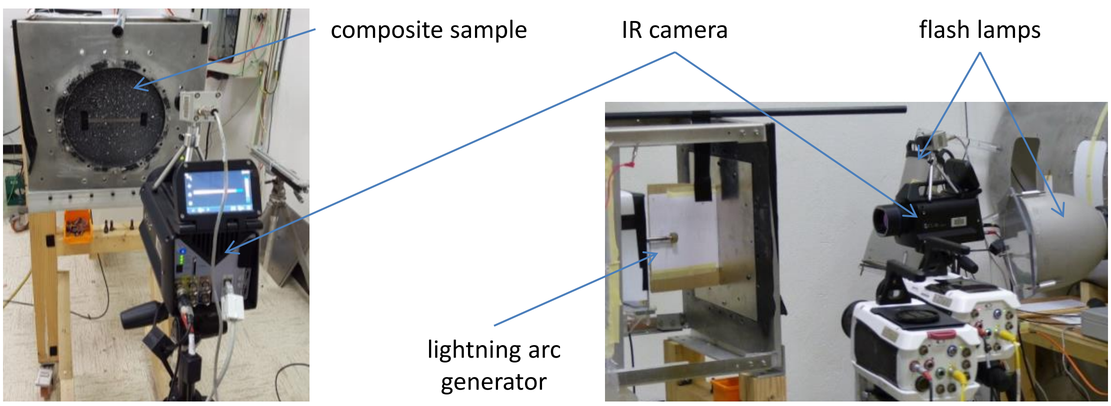


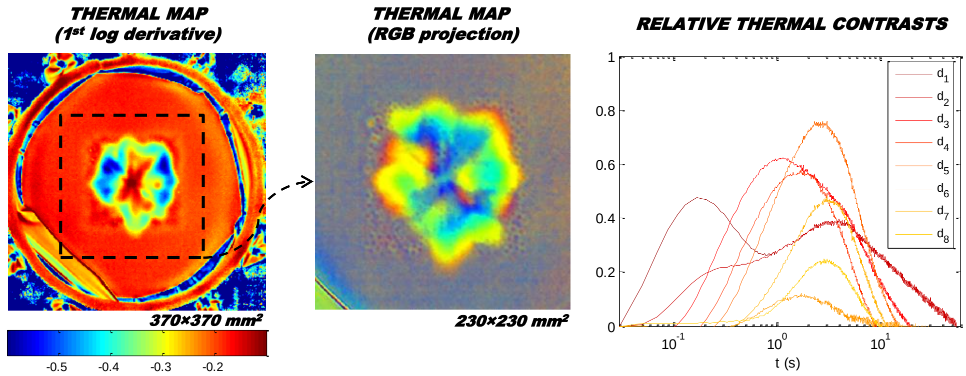
***Fig. 1**: Instrumentation of a lightning-strike test applied to a composite sample, carried out in the ONERA GRIFON bench.*

Flash lamps, generating an energy of 6 kJ over 4 ms, are used for the pulse thermography inspection performed right after the test in order to properly assess the damage generated inside the composite coupons by the lightning arc.

3. Pulse thermography: non-destructive assessment of lightning-strike induced damage

The non-destructive inspection of the coupons is carried out by pulse thermography. A frame rate of 100 images per second is chosen and the recording duration is set to 60 s, which are standard parameters for carbon/epoxy composites. Raw data is processed through a logarithmic polynomial fitting operation, accordingly to the TSR procedure [3] and to the recent additional developments proposed by ONERA [4].

The resulting thermal maps make it possible to assess the global extent of the delaminated areas, the depths of which can be deduced from the occurrence times of their emerging contrasts. An example is given in Fig. 2 for a 2.05 mm thick coupon for which the lightning-strike damage has generated delamination up to the interface between the 9^{th} and 10^{th} plies (counting from the rear-face).



DEPTHS IDENTIFICATION

	t_{emer} (s)	z (mm)	plies interface
rear-face	2.20	2.05	-
d_1	0.01	0.14	1/2
d_2	0.03	0.24	2/3
d_3	0.07	0.37	3/4
d_4	0.14	0.52	4/5
d_5	0.20	0.62	5/6
d_6	0.39	0.86	7/8
d_7	0.49	0.97	8/9
d_8	0.62	1.09	9/10

***Fig. 2**: Pulse thermography inspection of lightning-strike induced damage. 1st logarithmic derivative (left), RGB projection (middle) centered around the impact zone, time-evolution of the relative thermal contrasts (middle) and identification of the depths of the delaminated areas based on the occurrence times of the emerging contrasts (right).*

The helical-like damage patterns induced by lightning-strike (Fig. 2) are quite similar to those generated by low-velocity mechanical impacts on unidirectional carbon/epoxy composite materials [5].

4. Passive thermography: non-destructive *in situ* monitoring of the propagation of lightning-strike damage

The real-time thermal damage monitoring of the lightning-strike test is carried out with a frame rate of 200 images per second. The successive inter-plies delamination is checked over the first 300 ms following the arc generation (Fig. 3).

The global damage pattern observed from such this real-time monitoring turns out to be in excellent agreement with the non-destructive inspection carried out after the test. This tends to validate the relevance of passive thermography as a tool for lightning-strike damage monitoring.

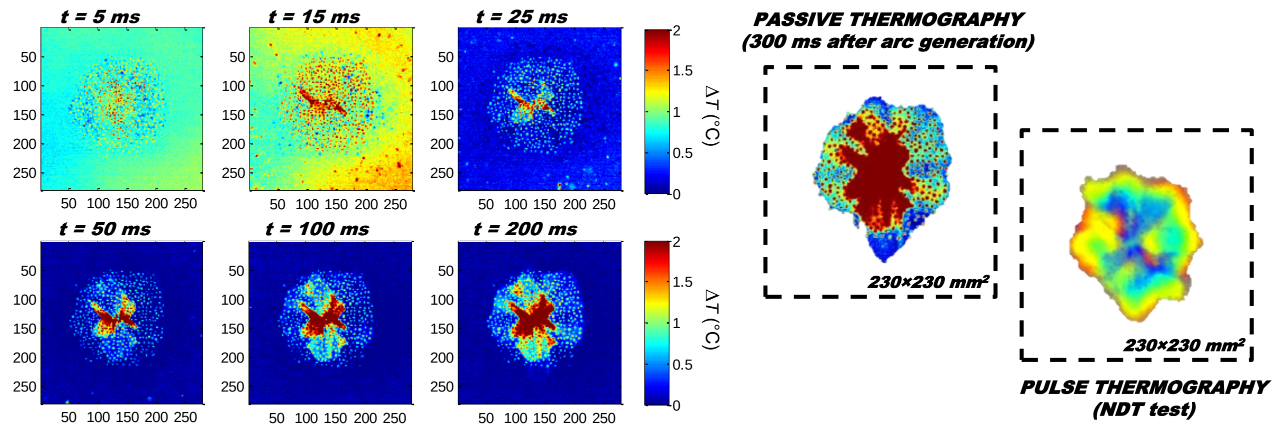


***Fig. 3**: Passive thermography for in situ damage monitoring of the lightning-strike induced damage. Time-evolution of the heating maps over the first 200 ms after the arc generation (left). Comparison of the thermal map at t=300 ms and the pulse thermography map from the inspection after the test (right).*

Acknowledgments

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