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INTRODUCTION

The research on every weather flight conditions induces to protect closely aircraft from atmospheric constraints, especially lightning effects which become more and more important nowadays because of the substitution of aluminum by composites : indeed, the composite skin does not shield sufficiently vital electronic equipments inside the aircraft. As a matter of fact, new aeronautical technologies increase the vulnerability of the aircraft against lightning.

In reality various cases are considered :

-when there is strike attachment on the structure, one talks of direct effects (mechanical destruction, sparks ...) ;

-when there is a proximate strike, then indirect effects occur (electromagnetic phenomena on wiring, equipments ...).

The AS355 "Ecureuil" helicopter, with its composite structure which represents about 25% of its empty weight, is an example of the new technology and thereby particularly sensitive to indirect effects. Within the framework of the certification of the digitally-controlled TM319 engine, which equips this rotorcraft, the Service Technique des Programmes Aeronautiques (S.T.P.A.) asked the C.E.A.T. for implementing the lightning simulation (indirect effects) and carrying out the whole measurements.

This paper describes only the first part which consists in a general study, with a low level generator, of coupling process in a composite airframe . The two next parts will consist in the evaluation of disturbance appearing in the computer connections during a real lightning strike, and in the assessment of its failure probability against the disturbance with a more powerful generator.

TESTING SETTING UP

The main routes of lightning current between two attachment points (input and output) are in general : nose-tail and main rotor-skids.

A damped sinusoidal current is injected through an arc on the structure at the input attachment location. The output point is linked to a quasi-coaxial return which is connected to the generator. The latter and the quasi-coaxial return are connected to the building earth.

Some test cables, twisted shielded pairs, have been fixed in realistic places of the airframe. The disturbances and the currents in these cables are measured in order to know the coupling agression for each cable.

A cartography of magnetic fields measured on accessible metallic portions has been set up in order to obtain correlative results.

Generator

The lightning agression simulation is achieved with the help of a capacitive discharge generator whose main caracteristics are the following :
the generator capacitance is 2 µF and can be charged to voltages of 10 to 50 kV ;
the total inductance (for whole arrangement) is about 7.5 µH, giving an oscillating current waveform of 43 kHz on the discharge capacitor ;
the maximum current and rate of rise are 17 kA and 5 kA/µs ;
the total resistance of the circuit is about 160 mΩ.

Coaxial-return circuits

The main goals of the quasi-coaxial return in which the rotorcraft is placed are :

- to obtain a real like distribution of electromagnetic fields, all around the aircraft
- to reduce the self induction coefficient of the complete set-up, in order to obtain the shortest rise time. This arrangement is insulated from the ground and made of wire netting with $13 \times 13 mm^2$ mesh ; it is connected to the generator and to the tail or the skids. It is placed at a distance corresponding roughly to the airframe radius at the considered place (fig.1).

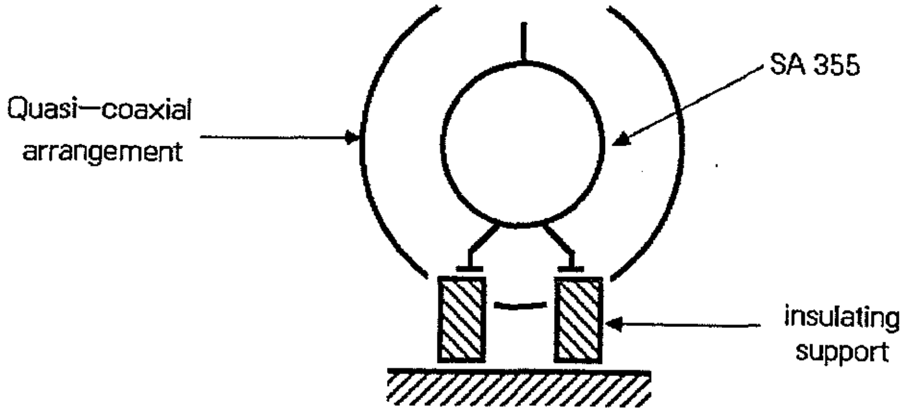


Fig. 1 Test set—up

Test circuits

Twisted shielded pairs running from the cabin and the tail to the equipment case are installed in the helicopter (fig.2). These paths are representative of the wiring places in the actual aircraft. The disturbances, the maximum currents and the equivalent generator for each cable, brought back to the full threat strikes (100 kA/µs, 200 kA max.), are deduced by

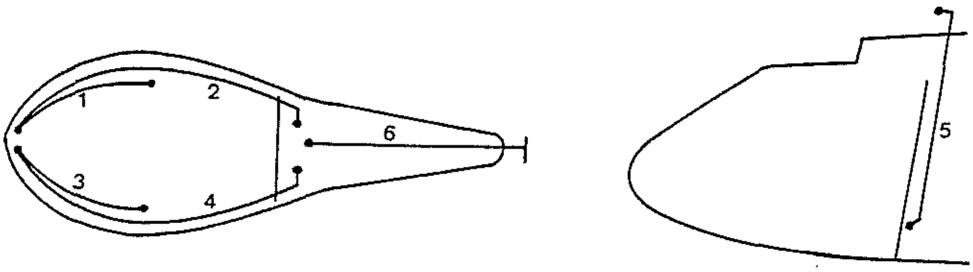


Fig.2 Position of test cables

extrapolation from the open circuit voltage (Voc) and the short circuit current (Isc) during the injection. These data allow the characterization of protections.

MEASUREMENT MEANS

All parameters are transmitted from the sensor to the control room by Thomson TSN245 M100 optic link with a frequency range of 300 Hz to 120 MHz (fig.3).

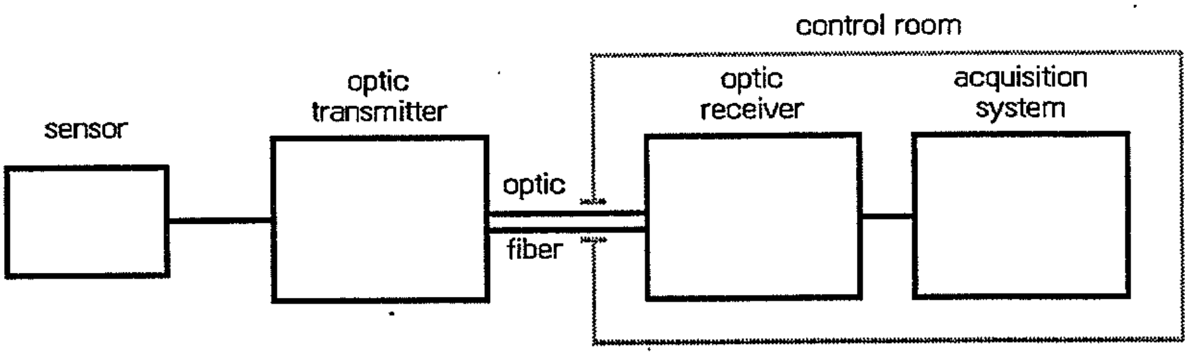


Fig.3 Measure arrangement

Injected current

The injected current is measured by means of a Pearson model 3025 pulse current transformer.

Surface magnetic field

These measures are carried out with the help of a Thomson TSN245 H10 ground plane sensor with a 6 kHz to 130 MHz frequency range.

Voc and Isc

The disturbance measurements in open circuit are achieved by means of a high impedance (2x1MΩ, 15pF) differential voltage sensor with a 300 Hz to 120 MHz frequency range (Thomson TSN245 V10). The short-circuit currents have been measured with the help of a current probe (Solar model 6471).

Acquisition system

These signals are converted at a 200 MHz sampling rate with a depth of 2048 samples (Tecktronix 7612).

EXPERIMENT

Skin current density measurements

The sensor placed on the metallic surface gives a value directly proportional to the current which circulates in the skin. In the same configuration of arrangement and injected current, we can estimate thanks to several measurements the diffusion in the structure of the aircraft. In the case of the "Ecureuil" ten points were chosen (taking the symetry into account) on the principal part of the rotorcraft (except for the tail because its cylindric form does not allow sensor positioning). The measurements were carried out into two directions at each point, in the vertical and horizontal planes. The results are given in fig.4. H field in one direction gives an information on the current in the perpendicular direction. We can see that the current runs essentially through the B,D,F, and H points. Then it is possible to imagine roughly the distribution of the current lines in this lightning configuration.

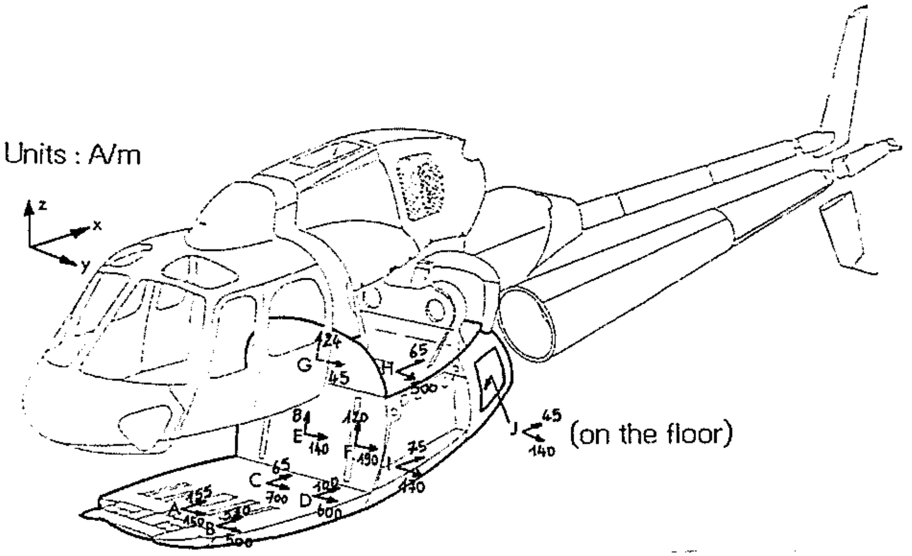


Fig.4 Current distribution in metallic part (in stressed lines)

Cable induced transients measurements

The main parameters for cables were :
- their length (3.5 to 6.5 m)
- their position in the aircraft
- their type of connections

Four wiring modes were tested ; voltage and current were measured as seen in fig.5. From the signal obtained, we determine the type of coupling :
- if the signal shape is similar to that of the injected current, the coupling mode is a resistive one ;
- if the signal shape is similar to that of the derivative of the injected signal, the coupling is an inductive one.

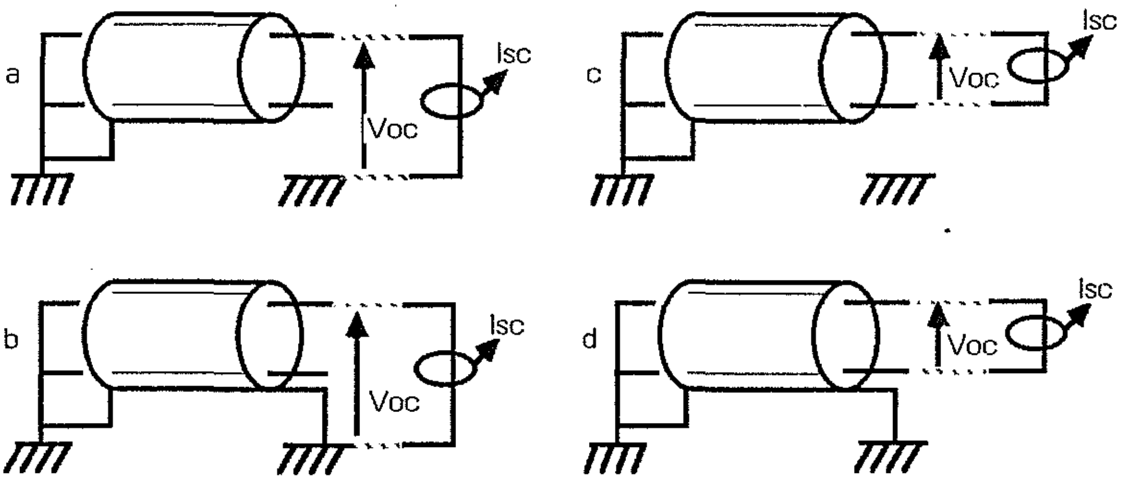
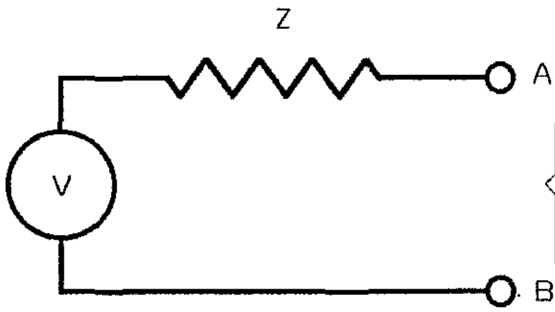


Fig.5 Different wiring configurations

This interpretation allows to extrapolate measured values to those which would be obtained with the full threat current. Such a current defined for this test ($di/dt = 100$ kA/µs, $I_{max} = 200$ kA), could not be simulated with our generators at the date of this test. The caracteristics of the injected waveform are : $di/dt = 5$ kA/µs and $I_{max} = 17$ kA. It requires factors of approximately $K_1 = 12$ and $K_2 = 20$ to extrapolate to full threat values of I_{max} (resistive case) and di/dt (inductive case) respectively. Then it is possible to calculate the equivalent generator to the agression (fig.6) for a typical cable inside this type of helicopter when struck by a current as it is defined in the standard.



V : measured Voc x K1 or K2
Z = V / I
I : measured Isc x K1 or K2

Fig.6 Equivalent generator to the agression

This method is used to determine the characteristics of protections which are connected to A and B points, especially the energy they have to put up with.

Remark : this extrapolation does not exactly reproduce the reality but this operating process is commonly admitted for it leads to overestimated conditions in comparison with reality.

The values obtained for 3, 4, 5 and 6 (fig.2) cables are presented fig.7. In several cases, differential measures (configuration c and d, fig.5) appeared too low for the sensor sensitivity, then all of these results do not appear in the table.

Cable #	Measure	fig.7a	fig.7b	fig.7c	fig.7d
4	Voc	420	30	80	14
	Isc	100	24	/	/
	V	8400	360	1600	280
	I	1200	288	/	/
	Z	7	1	/	/
3	Voc	420	20	15	5
	Isc	160	70	/	/
	V	8400	240	300	100
	I	1920	840	/	/
	Z	4	3	/	/
6	Voc	45	26	/	/
	Isc	15	7	/	/
	V	900	520	/	/
	I	180	84	/	/
	Z	5	6	/	/
5	Voc	60	18	/	/
	Isc	20	5	/	/
	V	1200	216	/	/
	I	240	60	/	/
	Z	5	4	/	/

Units : Voc, V in Volts
Isc, I in A

V, I : extrapolated values
Voc, Isc : measured values

Fig. 7 Table of results

The maximum measured value for induced transient levels was 440 V open circuit voltage and 150 A short circuit current. At the beginning of the signal, superimposed on the general trend, we found two frequencies equal to 1 and 5 MHz. These HF oscillations were found again on electric field measurement : first, on the floor in the front of the cabine -5 MHz-, secondly on the floor in the equipment case -1 and 5 MHz-. If the quasi-coaxial current return and the airframe under test are considered as a /4 resonant coaxial link (closed at one end), it is possible to calculate, theoretically, the resonant frequency which is 5 MHz for a 15 m long set-up.

Fig.8 and 9 show the injected current in the airframe, as well as the Voc and the Isc current collected for a typical cable, first when the shield is not connected to the helicopter skin on the measurement side, and then in the contrary case. On both cases the shield is connected on the opposite side. The higher tension is measured in the first case ; the coupling is then an inductive one. In the same configuration, a connected shield brings an important attenuation which is about 25 dB and the coupling is a resistive one. These results show clearly the shield efficiency.

CONCLUSION

This test shows that it is possible to measure disturbances on wirings and has given some informations about the attenuation brought by the shield, (25 dB) ; this value is consistent with those established by the cable constructors. We can imagine the degradations that a shield rupture could bring to a sensitive system.

The different measurements of the electromagnetic field are correct as we find naturally the injected waveform and the structure oscillations.

The coefficients of the full threat lightning extrapolation seem to be important (12 and 20 respectively for I_{max} and di/dt) to obtain a precise value of the real disturbance in the case defined by the standard. But the extrapolated values are known to be more severe than those we will obtain in reality. However, a current injection at higher level and faster rise time would give a better accuracy of the disturbance values. This is the purpose of the two next stages of this campaign, which will be done with a more powerful generator (50 kA, 25 kA/µs).

Furthermore, the measurements done on the test cables allow us to understand and evaluate quite easily the coupling process in this rotorcraft airframe ; this experiment will be useful to interpret the measures on real cable strands which will constitute the last steps of the test campaign.

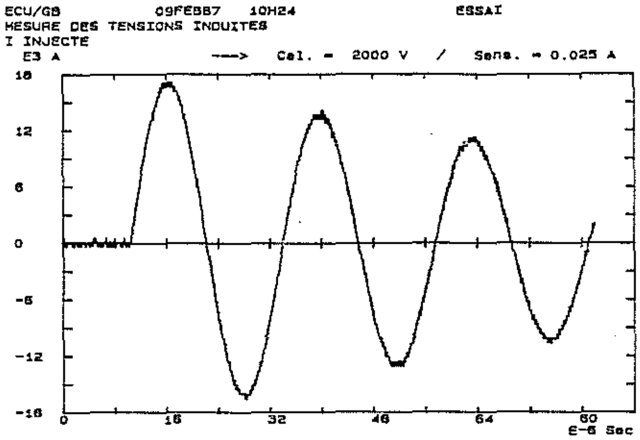


Fig.8 Injected current

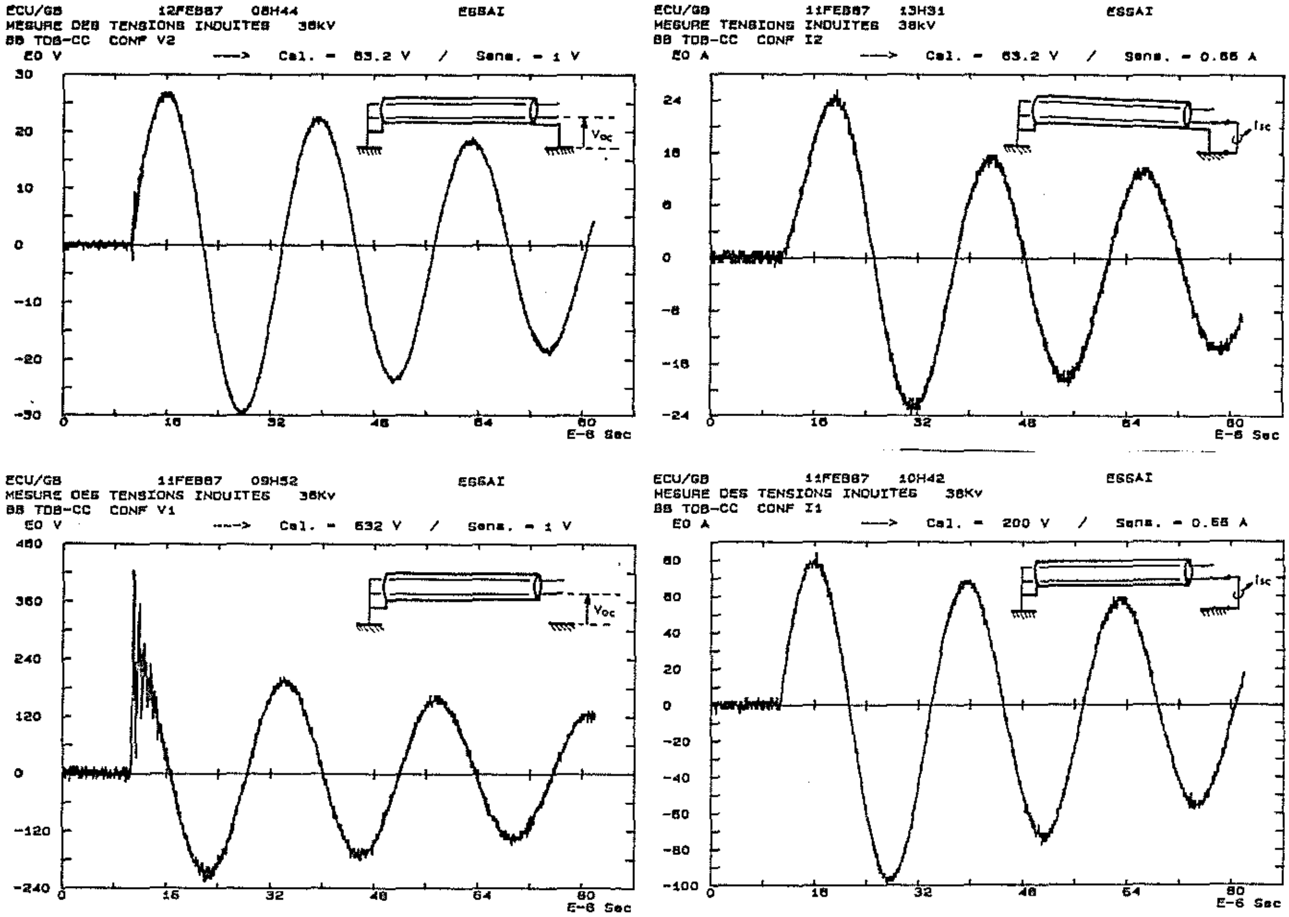


Fig.9 V_{OC} and I_{SC} measurements for cable n°2 (fig.2)