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LIGHTNING PROTECTION ACTIVITY IN THE DEVELOPMENT OF A NEW HELICOPTER

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ABSTRACT

An overall lightning protection policy has been implemented in the development of the EH101 helicopter. Starting from the implementation of a distributed single point grounding philosophy at equipment level the engineering studies has been addressed to cover the various aspects of lightning protection at subsystem and system levels.

Particularly severe tests have been devised to verify the performance of the equipments.

In addition to this lightning tests (voltage and current injections) will be carried out on different parts of the structure where lightning hazards are deemed to be more probable. A complete tailcone section where the joints and the structural connections are built in accordance with the best knowledge and complete rotor hub with representative blades will be tested.

Different types of protective techniques on the various structural parts of the helicopter have been partially tested trying to match the electrical requirement with the structural and mechanical constraints.

INTRODUCTION

For a long time lightning damages have been mainly related to direct effects which correspond to actual holes burned in the skin with the possibility of conduction of lightning currents inside the structure to vital parts of the aircraft. Indirect effects which are related to electromagnetic coupling to wiring and avionic equipments have recently become of concern because the increased susceptibility and sophistication of new electronic circuits.

The direct effects rarely caused severe problems to aircraft structures because they provided excellent protection; unfortunately the increasing use of composite materials in the aircraft industry is rendering the aircraft more vulnerable to lightning strike direct and indirect effects. In this paper we review the lightning problems and the proposed protective techniques. The testing activity is also studied trying to propose meaningful and representative test methods.
To assess the lightning effects on an aircraft it is common practice to characterize the structure in zones and the lightning current in components. According to MIL-STD-1757 the aerospace vehicle surface is divided in the following zones:

Zone 1 : Surfaces of the vehicle for which there is a high probability of initial lightning flash attachment (entry or exit).

Zone 1a: Initial attachment point with low probability of flash hang on.

Zone 1b: Initial attachment point with high probability of flash hang on.

Zone 2 : Surfaces of the aircaft across which there is a high probability of a lightning flash being swept from a zone 1 point of initial flash attachments.

Zone 2a: A swept stroke zone with low probability of flash hang on.

Zone 2b: A swept stroke zone with high probability of flash hang on.

Zone 3 : Zone 3 includes all of the aircraft surfaces areas other than those covered by Zone 1 and 2. In Zone 3 there is a low probability of an attachment of the direct lightning flash. However, Zone 3 areas may carry substantial lightning currents by direct conduction between two attachment points.

The following lightning design parameters (current components), related the qualification test procedures are defined in Table A.

LIGHTNING DESIGN PARAMETERS			
	PARAMETER	VALUE	TOLERANCE
HIGH CURRENT COMPONENT 'A'	PEAK CURRENT	200 kA	10%
	ACTION INTEGRAL	2×10^{6} A s	10%
	PULSE LENGHT	$< 500\,\mu s$	
	RISE TIME	$< 25\,\mu s$	
INTERMEDIATE CURRENT COMPONENT 'B'	AVERAGE AMPLITUDE	2 kA	10%
	CHARGE TRANSFER	10 C	10%
CONTINUING CURRENT COMPONENT 'C'	AMPLITUDE	200 - 800 A	
	CHARGE TRANSFER	200 C	20%
RESTRIKE COMPONENT 'D'	PEAK AMPLITUDE	100 kA	10%
	ACTION INTEGRAL	0.25×10^{6} A s	10%
	PULSE LENGHT	$< 500\,\mu s$	
	MAX RATE OF RISE	> 10" A/s	

T A B L E A: LIGHTNING DESIGN PARAMETERS DEFINITION

The current components A, B, C, D, are used to determine dirrect effects.

The current waveform E, that is intended to determine indirect effects, has the following characteristics:

FAST RATE OF RISE STROKE	PEAK AMPLITUDE	$\geq$ 50 kA
	RATE OF RISE	$\geq$ 25 kA/μs
CURRENT WAVEFORM 'E'	MINIMUM TIME	0.5 μs

The normal correlation of the current components application with attachment zones is indicated in the Table B.

ATTACHMENT ZONE	CURRENT COMPONENETS
1A	A, B
1B	A, B, C, D
2A	B, C, D
2B	B, C, D
3	A, C

T A B L E B: CORRELATION OF CURRENT COMPONENTS WITH ATTACHMENT ZONES

This correlation is better put in evidence in the relevant test plan.

PROTECTIVE TECHNIQUES

In case of metal structures the aircraft skin is sufficient to provide an adequate protective to direct effects. Indirect effects occur because of apertures (windows, bays etc.), antennas, exposed cables, seams, points and penetration through the skin.

Direct effects. Direct effects are more severe for nonmetallic structure. Three types of nonmetallic materials can be taken into consideration: glass or polymer fiber reinforced epoxies (fiberglass or kevlar) boron or graphite reinforced plastics, and polycarbonates.

Fiber glass and kevlar, which are mainly used to achieve light weight in wing kips, fin caps and access doors, have no electrical conductivity.
Protection against puncture can be obtained by using suitable diverters on the outside skin in case the structure must remain non conductive as in radomes. If this is not the case a conductive coating is often applied as a protection. The conductive coating may be flame-sprayed metal, woven mesh, aluminized fiber glass.
Carbon fibers are resistive conductors and have an electrical resistivity of about $0.1 \cdot 10^{-3}$ ohm cm. which becomes 6×10^{-3} ohm cm. in a resin matrix. This resistivity is 2000 less than aluminium resistivity which is tipically $28 \cdot 10^{-6}$ ohm cm.
Protection against direct effects can be achieved by using a suitable metallic coating or by increasing the thickness of the material. The latter technique is obviously unacceptable. The coating may be:

- Wire meshes knitted from fine aluminium or copper wires. The meshes permit hot gases to escape without damaging the composite material.

- Flame spray metal which is applied as a coating 4 or 6 mils thick.

- Aluminized fiberglass thorstrand (trademark by Excell) is a fabric of fiber glass on which aluminium has been deposited. The fabric is cocured as the outermost ply of a laminate.

<u>The indirect effects.</u> The indirect effects can be divided into three different phases:

- The lightning strikes causes electrical currents to flow on the skin of the aircraft resulting in a surface current density $\bar{J}$ corresponding to a tangential magnetic field H_t and a charge density corresponding to normal electric fields En.

- The penetration of energy into the aircraft occurs because of apertures, seams, joints, antennas, cables and diffusion.

- The internal propagation of electromagnetic energy occurs along all metal conduits and cables to which electronic boxes are connected. The energy may temporarily upset or permanently damage the internal circuits.

The problem of calculating surface current density and charge density requires the solution of Maxwell's equations. Because of the complex geometries involved the solution is not always easily achieved. It can be obtained by means of numerical methods. Similar difficulties exist in the case of internal penetration and propagation of electromagnetic energy. The coupling through an aperture represents the most difficult one. Some canonical problems have been addressed and studied:

- apertures in a perfectly conducting plane;
- apertures in two dimensional perfectly conducting bodies;
- apertures with wires behind the opening.

The theoretical approaches shall be used to size the coupling problems in broad terms in order to establish boundary values. The applicable protective techniques are the following:

A) Shielding

It is important to characterize the airframe (faraday cage) inherent shielding effectiveness as a function of the lightning frequency spectrum in order to determine the e.m. energy coupling transfer functions and therefore, according to the interior field predicted levels, to define in detail the relevant coupling reduction techniques referred to the equipments and in particular the wiring system.
Careful consideration shall be given to the routing of wires through the airframe so the interference coupling is kept to a minimum.
Where it is possible, the wires suitably classified and protected shall be routed to obtain the maximum screening effect from the aircraft skin.

Connector and screen termination requirement shall be applied correctly.
In particular with the exception of audio circuits all screens shall be terminated and connected to every connector backshell in their path.

B) <u>Terminal protecting devices</u>

They includes filters and suppressors.
The filters operate in frequency domain and the suppressors operate in time domain. The suppressors application is generally more frequently. There are three common type of lightning arresters: varistors, gas discharge devices, and semiconductors. Each has advantages and limitations in the areas of current capability, voltage limiting ability and their effects on the normal operation of the circuits being protected. No one type is suitable for all applications, and often one device must be combined with another into a hybrid type device. Two combinations type are generally used:

1) arc-discharge devices and varistors as shown in Fig. B.
2) arc-discharge devices and diodes as shown in Fig. C.

The ability of limiting the voltage and the capability of standing high surge currents are important characteristics of bidirectional varistors. The zinc oxide type is characterized by the former feature and the silicon-carbide type excels in the latter feature.

Arc discharge devices or spark gaps are unique in their ability to pass transient currents many times beyond the capability of solid-state devices and varistors. The spark gap is used primarily in applications where overvoltages can be tolerated for a short time, and where the expected transient can contain energy beyond the capabilities of the solid-state diode or varistor.

Semiconductor devices are generally used in shunt applications to provide a low impedance path to ground for the transient generated by lightning. These devices are characterized by a more rapid response to transients having fast rising voltages than do the other protection devices. However their ability to absorb high energy surges is less than other protection devices.
In addition they also limit voltages to a far lower magnitude than other protector types and consequently find many applications where protection of other semiconductor devices is required.

C) Grounding

In the development of a new aircraft the selection of the grounding philosophy represent a matter of remarkable importance.
The Distributed Single Point Grounding (DSPG), as shown in Fig. D, represents the best grounding method.
The advantages of this solution are the following:

a) Weight saving because it is no longer necessary to use external signal ground modules to collect signal reference grounds.

b) Less design complexity of RF equipment because it is no longer necessary to separate RF circuitry from audio frequency stages.

c) Improved shielding effectiveness because of reduced RF pick up of extraneous signals from the signal reference line. This represents an advantage also for EMP and lightning protection.

TESTING ACTIVITY

The present state of lightning simulation testing for direct effects is relatively well defined. The state of art for indirect effect is still under development.

A) <u>Direct Effects</u>

1) High Voltage Tests

This tests are performed to determine the likely discharge attachment points on specific structural parts such as tailcone section, rotor hub with representative blades.
The two voltage waveforms used for these voltage tests are:

1.2/50 - 1.2 μsec. Rise Time/50 μsec. Pulse Width (at half amplitude)

250/2500- 250 μsec. Rise Time/2500 μsec. Pulse Width (at half amplitude)

The amplitude of the applied voltage is such that it produces the discharge corresponding to the voltage peak. Sequences of the pulses will be applied with the following rate.

-- 25 pulses 1.2/50 sec. positive polarity
-- 25 pulses 1.2/50 sec. negative polarity
-- 25 pulses 250/2500 sec. positive polarity
-- 25 pulses 250/2500 sec. negative polarity

The minimum current associated with the voltage discharge is 10 kA. During the tests there shall be no mechanical damage of the structure.

The test conditions and procedures are to be compliant with the relevant rules described in MIL-STD-1757A.

2) Current Tests

The tests have the purpose of verifying the performance of the specific structural part's or components's protective system against mechanical and thermal stress determined by the lightning current flow.
It is important to carry out in advance this testing activity on the particular flat specimens that are representative of specific <u>jointing</u> techniques and bonding methods in order to evaluate their design validity.

These specimens are to be used to test RF performance and shielding effectiveness.
The current discharge will be applied directly to the specimen under test with the all relevant design parameters defined in Table A except the current waveform E.
During these tests there shall be no mechanical damage or overheating of the structure and the protection system.
The test conditions and procedures are to be compliant with the relevant rules described in the MIL-STD-1757A.

B) <u>Indirect Effects</u>

1) External Electrical Hardware

The test method T05, described in MIL-STD-1757A, is applicable to this type of hardware such as antennas, navigation lights etc.
This test foresees the current waveform E application in order to evaluated in particular the magnetically induced effects.

2) Sub-system Testing

The sub-systems considered critical will undergo qualification testing to a particular method of conducted susceptibility to simulated spikes that represente the reduced coupling, due to the specific airframe shielding effectiveness, from the lightning flash.
The purpose of this test is to demonstrate that a test pulse, to be define on the basis of the interior field predicted levels, does not produce dangerous values of voltage and current of any component in the under test equipment and establish a base line lightning tolerance level.
Where the results analysis reveals an insufficient safety margin to a full threat strike, these subsystem will be subject to on-aicraft testing.

3) System Testing

This will be undertaken on a completed aircraft and will take the form of a 4kA/usec pulse, or faster, from a mobile capacitor bank into the airframe at points selected to simulate the likely lightning current path. The transients induced on the cableforms associated with the critical equipments will be recorded in both frequency and amplitude, and the results extrapolated to the full threat 200 kA/µsec. Any sub-system failing to demonstrate an adequate safety margin, and sub-systems which have not been satisfactorily tested by qualification, will be subject to on-aircraft bulk current injection techniques, at full threat and at same frequencies found during low level strike, using a tuneable pulse generator. Unless any reworking/modification to the system is required the system will be put forward for certification.

CONCLUSION

The lightning protection requirement becomes more and more stringent due principally to the large use of composite materials that reduce the airframe shielding effectiveness.
Therefore it is essential to optimize the joint effort that is to be spent by all engineers, involved in different technical branches of the firm, in development activity of the overall lightning protection policy in order to achieve the aim of providing an aircraft with a high degree of safety.
In my opinion the jointing techniques studies, test procedures and methods definition are generally the most critical aspects of this important activity.

REFERENCES

MIL-STD-1757 A	Lightning qualification test techniques for aerospace vehicle and hardware.
EA98Q153J	EH101 - Lightning protection policy.
EM98P060A	EH101 - EMC requirement - Electrical interfaces and grounding philosophy.

ZONE DEFINITION

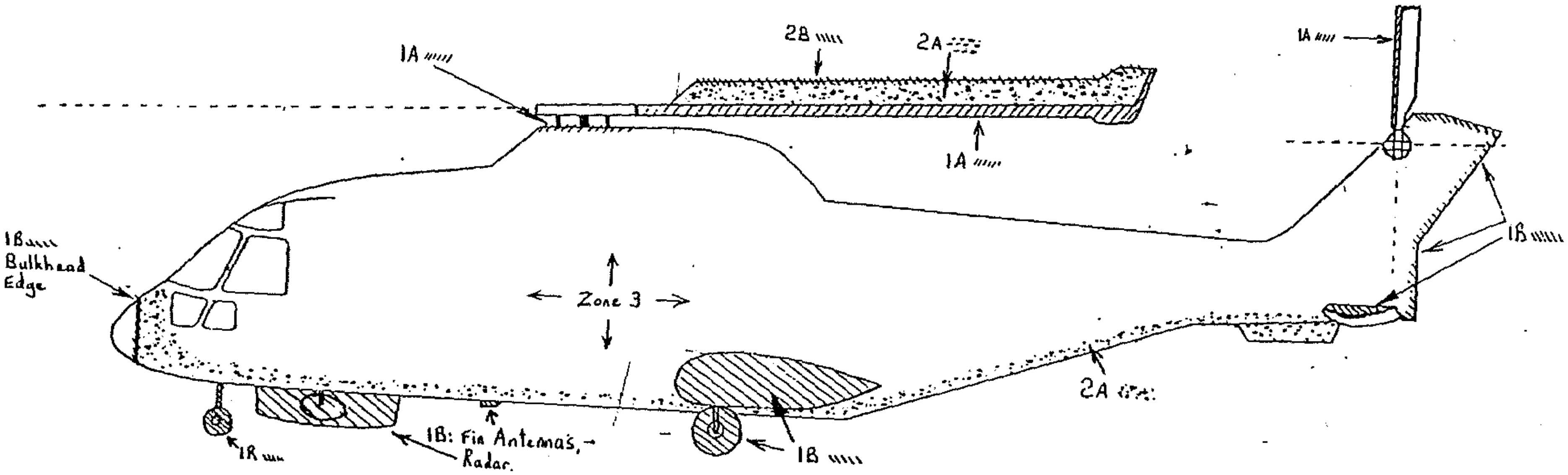

FIGURE A - -ZONE DEFINITION

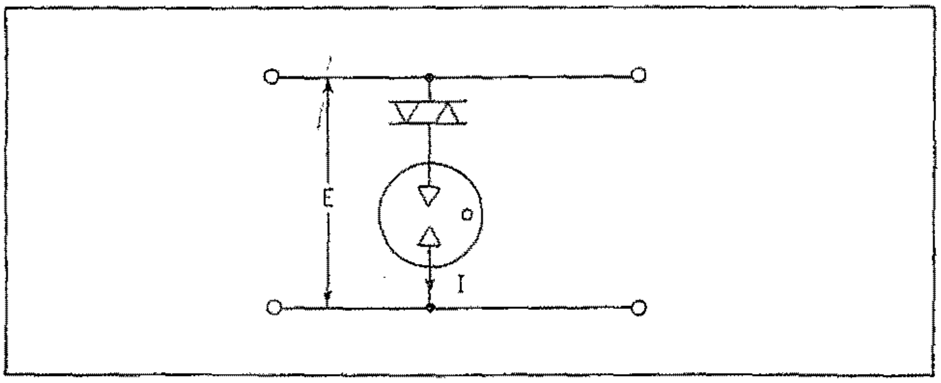

FIG. B - Hybrid Protective Device Made of Varistor and Spark Gap Combination

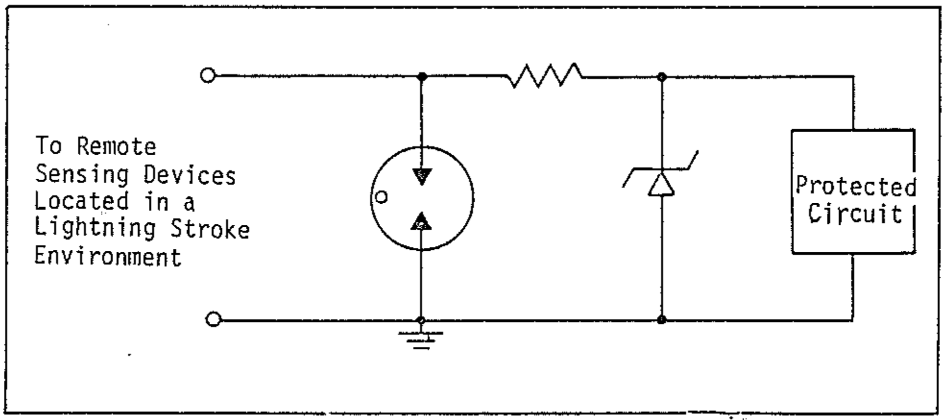

FIG. C. – Spark Gap-Zener Diode Hybrid

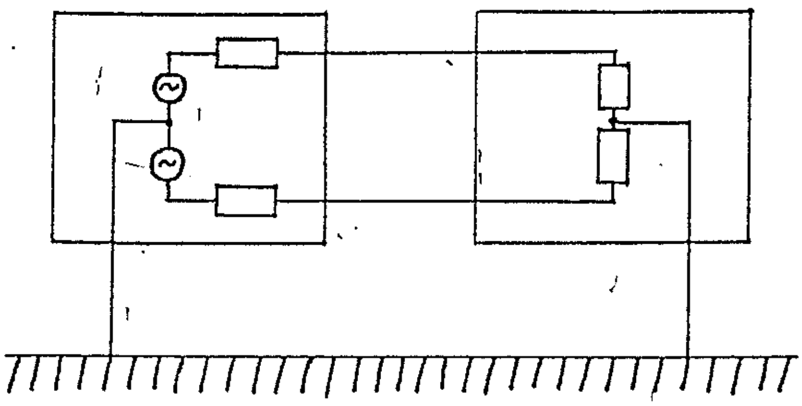

FIG. D - Distributed Single Point Grounding (DSPG)