LIGHTNING AND COMPOSITE MATERIALS

J.BETEILLE and R.WEBER
AEROSPATIALE FRANCE

A B S T R A C T

Composite materials have been used in aircraft structure for a long time.
Old general aviation aircraft or gliders made of wood and fabrics or glass fibre are very common.
It is also well known that lightning strikes may cause severe damage to composite structure, leading, in some cases to catastrophic results.
This occurrence is very remote in the above aircraft because the flight conditions are limited to VFR or good weather conditions. In the case of commercial aircraft regularly carrying passengers into low atmosphere zones in all weather conditions, the probability of being struck by severe Lightning strikes may be high and reach several times per year in the case of short range aircraft. This state of fact imposes very careful examination of the behaviour of composite parts in Lightning conditions in order to fulfil the safety objectives.

The electrical properties of composite materials depend on the type of composite, but they are all different from those of metallic materials.

These differences may cause worse behaviour of composites in Lightning conditions.

This is mainly due to their poor capability of carrying high intensity currents and poor shielding effectiveness.

The difficulties are emphasised in future aircraft by the increase of electronics and avionic systems using electrical power and the vital role that they fulfil. Nevertheless, careful design and manufacturing precaution may solve the problems encountered.

This paper presents a review of the problems associated with different composite types in Lightning strike conditions :

- Structural degradation (direct effects)
- Electrical system degradation (indirect effects)

A summary of recent investigations undertaken at AEROSPATIALE in this field is given.

PART I-

1- TYPES OF COMPOSITES - ELECTRICAL PROPERTIES

Among the wide range of composite materials most commonly selected in commercial airborne application are listed in Table I.

These materials have been chosen for their strength/weight/cost efficiency ; they are divided into two main categories which have a completely different behaviour.

COMPOSITE MATERIALS
ELECTRICAL PROPERTIES

		MULTIPLY COMPOSITE	PERMEABILITY μ/μ_o	PERMITTIVITY ϵ/ϵ_o	CONDUCTIVITY σ:mhos/m	DIELECTRIC STRENGTH BREAKDOWN VOLTAGE kv/cm
DIELECTRICS		GLASS/EPOXY	1	4 → 7	10^{-9} → 10^{-10}	70 → 90
DIELECTRICS		ARAMID /EPOXY	1	3.5 → 6	$2\ 10^{-8}$ → $5\ 10^{-9}$	70 → 90
DIELECTRICS						
DIELECTRICS	AIR		1	1	$< 10^{-15}$	5 → 30
CONDUCTORS		GRAPHITE/EPOXY	1		10^3 → 10^5	
CONDUCTORS						
CONDUCTORS	ALUMINIUM ALLOY		1		$2\ 10^7$ → $4\ 10^7$	
CONDUCTORS						

TABLE 1

LIGHTNING PATH ON AIRCRAFT STRUCTURES

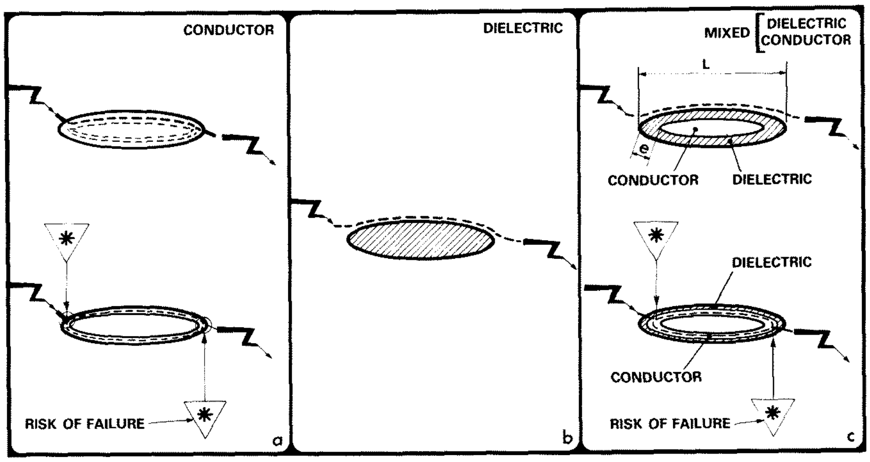


FIGURE 1

1. 1- Conductors (carbon fibre composite)

The conductivity of Carbon fibre composites is two or three orders lower than aluminium alloy conductivity but they offer a better path for lightning current than the surrounding air and this current will penetrate into the structure (Fig. 1).

Compared with metal, C.F.C exhibits :

- A higher arc burning voltage (10 times)
- An increased ohmic heating (100 or 1000 times)
- A lower thermal conductivity which concentrates heating and raises temperature
- A temperature limitation lower than metal (65°C)

1. 2- Insulators (Glass Fibre/Epoxy or Aramid/Epoxy)

These materials are dielectrics which are better insulators than the surrounding air (ionised) and the lightning path will follow the surface (Fig.1) unless the breakdown voltage between their two sides is exceeded ; in this case the electric arc goes through the materials which is punctured.

2. LIGHTNING STRIKE EFFECTS

A summary of Lightning strike effects on structure incorporating composite parts is given in Table II.

These effects are comparatively worse than those observed on metallic structures.

2. 1- Direct Effects

Direct effects are the physical consequences of arc attachment and current transfer.

2.1. 1-Carbon epoxy (not protected)

a- In the arc attachment zone
Local damage can be expected in the case of severe Lightning strike and some protective means have to be provided in the exposed zones.

This protection has to be matched to the safety objectives and the overall economics.

Some limited damage can be tolerated when the probability of occurrence is low, if safety is not impaired and if repairs can be made in cost-effective conditions.

b- In swept stroke zones
The effects are similar but they are less extended.

c- In transfer zones
The principal risks are heating and sparking. These problems occur mainly at joints between two structural parts, because a good electrical low impedance continuity is difficult to obtain in carbon fibre composite joints, when the thickness of parts is small.

Carbon fibre/epoxy laminates behave roughly like an homogeneous conductive material for current

LIGTHNING STRIKE EFFECTS

COMPOSITE MATERIALS

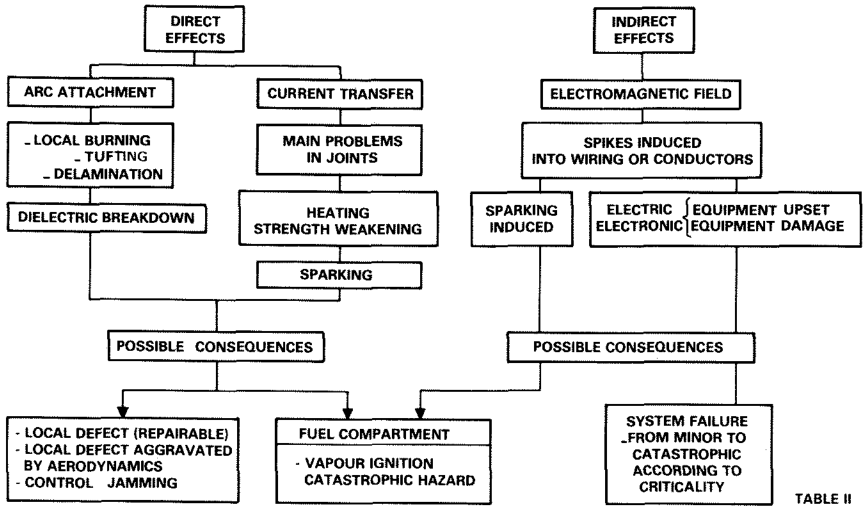


TABLE II

transfer inside the bulk but in the case of adhesive bonding of two parts the electrical continuity is broken.

This also happens at the surface of laminates due to epoxy migration during the cure phase. Furthermore when assembling parts made of carbon epoxy and aluminium alloy parts, protection against corrosion due to electrolytic effects introduces an insulating layer between the two parts.

In these joints the current path generally goes through the assembling bolts or rivets and not through the laminate surfaces.

To avoid local overheating it is necessary to have a current density in constriction points which is low enough to be accepted by the physical characteristics of the composite.

Sparking can occur for the same reasons as heating and also, even if heating is limited, when the inductance of the path is high enough to create a voltage step between the two parts (high rise time of Lightning currents). For this reason assemblies and joints in fuel vapour compartments have to be carefully designed.

2.1. 2- Glass/Epoxy Aramid/Epoxy

Parts entirely made of non-conductive materials may remain unaffected by Lightning currents but as they are transparent to electric and magnetic fields the conductive parts installed adjacent to, or inside the composite skin may become the Lightning attachment point, and the arc penetration inside may lead to large damage.

2. 2- Indirect Effects

Indirect effects are characterised by transient voltage spikes developped into conductors which are not directly struck by lightning.

This phenomenon is induced by the electromagnetic fields associated with Lightning Strikes and in particular the magnetic fields created by lightning currents running into adjacent conductive structures.

Inside a closed highly conductive structure electromagnetic fields are negligible and indirect effects do not occur.

This condition is quite well fulfilled in all metallic structures.

When the aircraft skin is entirely metallic the threat on wiring installed inside is minimized and generally do no harm to wiring and equipment.

This is not the case when electromagnetic apertures due to non conductive or low conductivity skins exist.

In this condition the indirect effects may reach high voltage values and it is necessary to take appropriate protective measures to avoid :
- sparking (in fuel compartment)
- insulation breakdown
- equipment damage

3. LIGHTNING PROTECTION FOR COMPOSITES MATERIALS

The summary of protective measures generally used with composite materials is given in Figure 2-.

The type of protection must be adapted to each particular case taking account of the risk associated with the aircraft zone in which the part is mounted.

3. 1- Direct Effects

The general principle for obtaining an effective protection is to try to spread the lightning currents out as broadly as possible in order to have low current densities and to try to maintain them on the external side of the structure.

Good electrical continuity must be maintained all along the current path to avoid voltage steps and sparking.

An efficient protection can be afforded by adding a thin layer of conductive material such as Aluminium or Bronze mesh to the external side of the skin, aluminium foil or Aluminium flame spray coating (20 to 50 microns). These thin layers considerably reduce arc penetration but they have the following disadvantages :
- added cost
- damaged by severe lightning strikes
- prone to maintenance or erosion degradation

In high probability Lightning hang-on zones metal plates of sufficient thickness will provide a more durable protection.

The surface protection is necessary when the composite thickness is very thin to avoid strong delamination and aggravation by Aerodynamic loads.

In the case of unprotected thick monolithic carbon fibre laminates the effects will be limited to burning 2 to 4 external plies and repair may be possible.

3. 2- Indirect Effects (See fig. 2-)

3.2. 1- Structural protection

Protection against indirect effects is somewhat more difficult when we have in conjunction a large quantity of electrical wiring installed in all parts of the aircraft and a large quantity of electromagnetic apertures.

In effect, we have to consider the coupling of lightning current spikes all along the different possible paths.

If no precautions are taken, induced spikes in wiring could reach extremely high values (several thousands of volts).

For this reason it is necessary to provide structural shielding by means of conductive layers around wiring installed along lightning current paths.

In zones having a low probability of direct attachment these layers can be installed on the internal side of the skin, in order to have a better in-service endurance and easy bonding to adjacent structures.

3.2. 2- Equipment protection

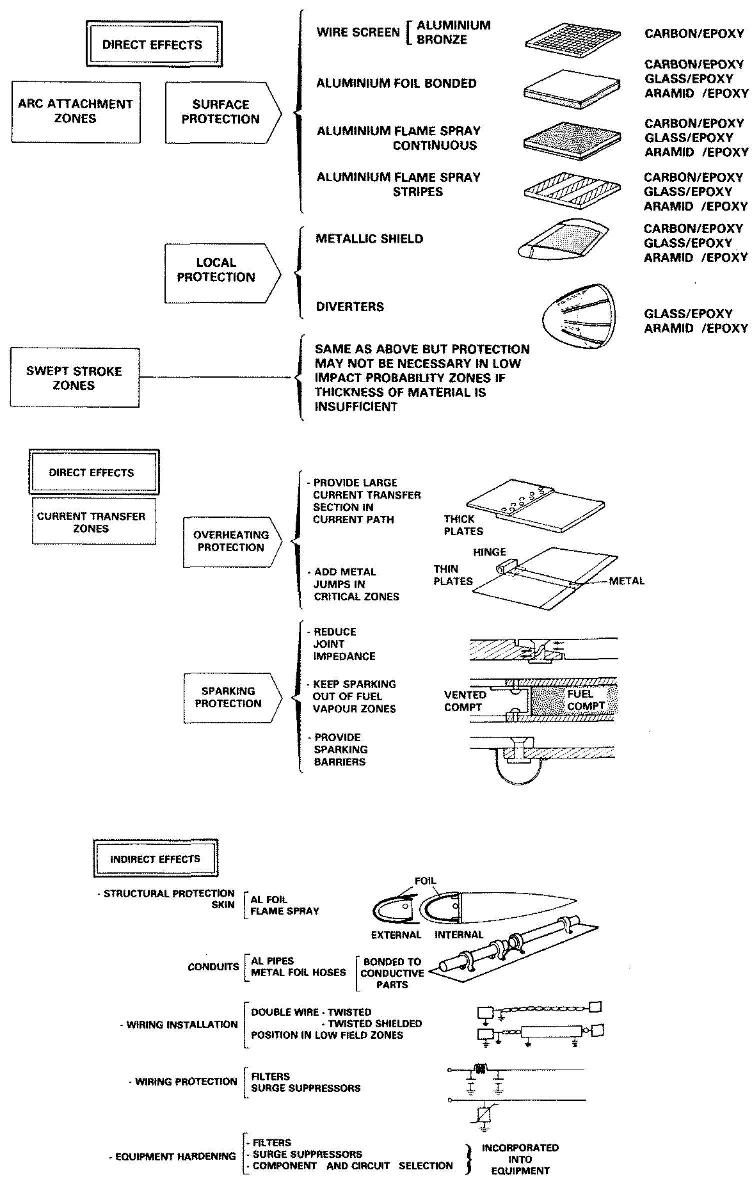
The present structures of modern and future aircraft become more and more complex and the mixing of different types of composite and metal parts will give rise to difficult problems in obtaining effective shielding. In order to obtain precautions as good as those of an all metallic structure, the penalties in cost and weight may be very high and jeopardize a part of the advantages afforded by the use of composite. In consequence a better way of progressing is to improve the capability of equipment and components to withstand high level spikes. At a first view it seems unreasonable to require the systems working at low voltages to accept spikes reaching several thousands of volts, but it should be noted that duration and the overall energy is generally low. The recent development of light weight reliable surge suppressors (varistors-transorbs-diodes) provide an efficient means of improving tremendously the equipment tolerance level to spikes, even when the circuits incorporate such sensitive devices as CMOS.

3. 3- Conclusion

Complete protection against lightning strikes effects for an aircraft built with large composite parts without suffering excessive penalties on weight and cost will be achieved by a judicious combination of structural protection and equipment hardening. The tools to reach this goal exist but it will necessitate careful examination of each part and system and the efficiency of protective means must be demonstrated by analysis and tests.

LIGHTNING PROTECTION

COMPOSITE MATERIALS



PART II

LIGHTNING TESTS ON COMPOSITE STRUCTURES

1- TEST PROCEDURE

On new types of structures it is not possible to predict their behaviour in lightning strike conditions and laboratory tests have to be performed.

The first step of the method is to determine by high voltage tests the impact point in the complex structure.

The second step consists of applying simulated hight intensity lightning currents on test specimens or structural parts in order to observe the extent of damage. It is this second type of tests which is specifically performed in "Aerospatiale Laboratoire Central".

2- TEST FACILITIES

Test apparatus include a high voltage DC generator, a bank of capacitors and switching devices, capable of producing current pulses up to 200 kA and a set of batteries capable of producing continuous currents.

The test parameters are defined in accordance with the Airworthiness Authorities' requirements.

3- DIRECT EFFECT TESTS

Different types of tests are performed according to zoning.

3. 1- Arc Attachment zones

This zone is subjected to the most severe lightning conditions and damage may be important.

Examples :
Photo 1- Light alloy specimen
Photo 2- Carbon composite specimen
Photo 3- Composite protected by flame spray

3. 2- Swept stroke zone

This zone is less severe because the levels are lower and the duration of attachment is reduced by the arc blow-out due to aerodynamic forces.

3. 3- Transfer zones

These zones are far away from the arc attachment but heating and sparking caused by high current transfer may occur when a lack of electrical continuity exists.

Examples :
Photo 4- Sparking on structural joint
Photo 5- Electromagnetic forces on structural joint

4. INDIRECT EFFECTS

The voltages induced by lightning strikes into wiring running inside the structures are very sensitive to their location and the electrical properties of surrounding structures.

Tests have been undertaken to compare different types of laminates with respect to their shielding properties in the lightning frequency range.

These experimental tests are performed on a box whith removable walls which can be fitted with different composite specimens.

The voltage induced in wiring installed in the box is measured through fibre optics.

CONCLUSION

Lightning simulation tests on composite structures are necessary to define suitable protection and optimise the solution envisaged. They also enable us to demonstrate that the safety objectives required by the Airworthiness Authority are achieved.

The test conditions should be periodically updated as knowledge on the natural lightning parameters improves.

"LIGHTNING TESTS"

LIGHT ALLOY SPECIMEN

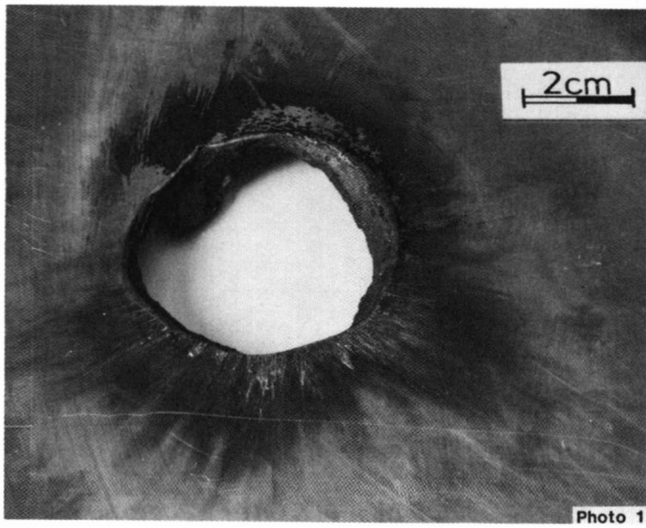


Photo 1

SPARKING ON STRUCTURAL JOINT

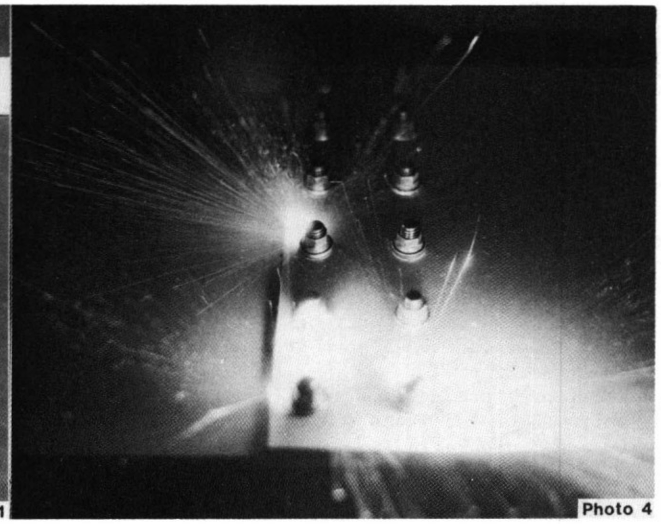


Photo 4

CARBON COMPOSITE SPECIMEN

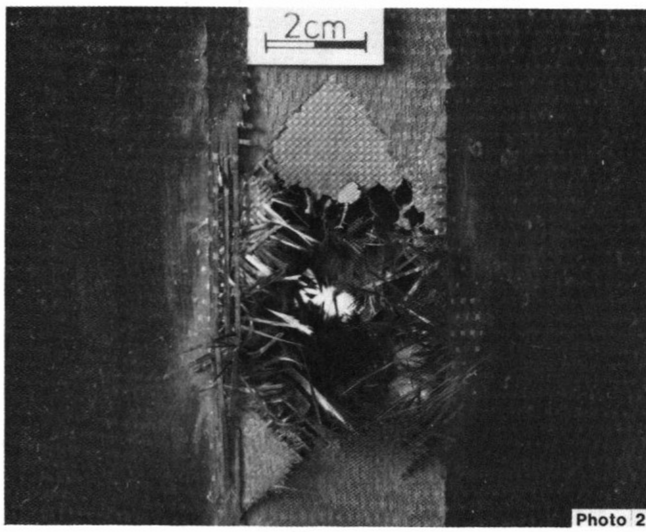


Photo 2

ELECTROMAGNETIC FORCES ON STRUCTURAL JOINT

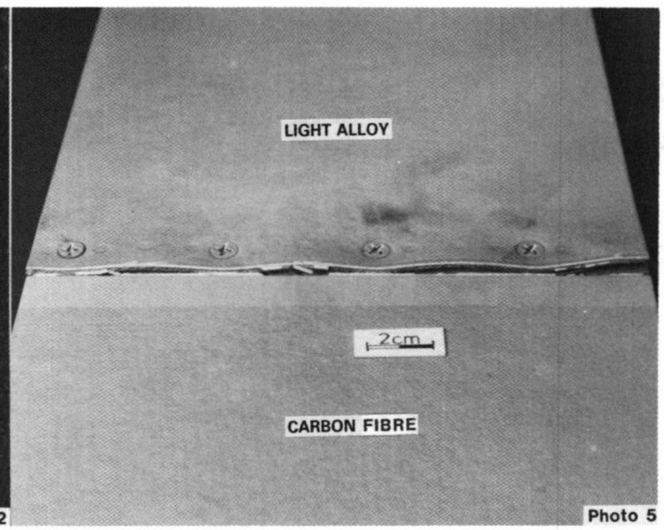


Photo 5

COMPOSITE PROTECTED BY FLAME SPRAY

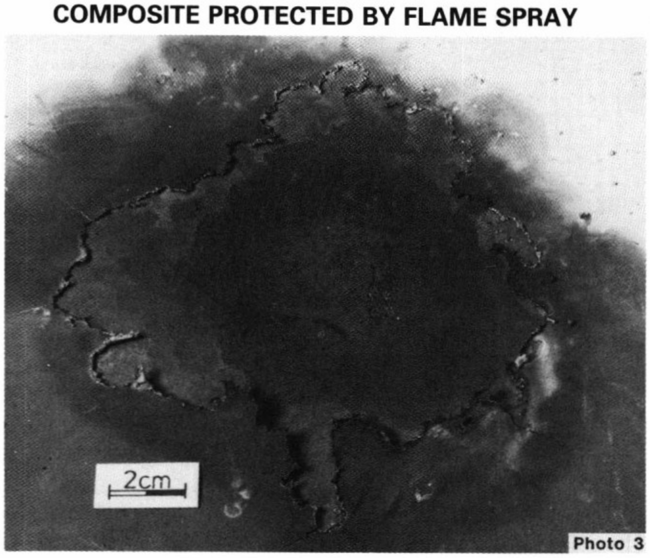


Photo 3