THE EFFECT OF ELECTRIC PROPERTIES OF ADVANCED COMPOSITES ON THE DESIGN OF MODERN AIRCRAFT

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Abstract

Advanced composites have been widely used in the structures of modern aircraft, which has resulted in the revolution of design thoughts and for aircraft structures. Among many excellent performances of the advanced composites, the electric property is one of the important characteristics which must be considered by the composite structures designers.

The electric properties of advanced composites have been studied in the paper as well as their effect on the design of modern aircraft structures and the stealth capability of aircraft. The application of composites has provided much improvements on the stealth capability of aircraft, however, it may bring other problems such as the static-electrisity depositing, electric-magnetic shielding and lightning protection for composite structures, which have been discussed in the paper too. Further more, recent advances in the study on electric properties of cimposites in China were reviewed and some suggestions on above problems were provided by the author. It can be believed that the study on the electric properties of composites would be of important effect on the wider application of advanced composites on the modern aircraft structures.

I. Introduction

Advanced composites have been considered as an excellent structural material for the aircraft constructions. Among their many excellent properties, the electric property is an important factor to which designer for modern aircraft must pay the special consideration, since the electric properties of composites and metals are significantly different.

The application of advanced composites not only lightened the weight of structures and improved the properties, but also provided the aircraft with higher stealth capability. Due to this fact, advanced composites played a very important role in the recently developed stealth aeroplanes such as B-2 bomber, F-19A, F-25, ATA and ATF fighters [Ref 1].

It has been noted that as the composite parts of aircraft increased, it brought with a new problem: the existence of large area composite parts in constructions will make the aircraft be affected easily by external electric-magnetic interfere (EMI), and harmful electrostatic depositing (ESD) may occur on the surface of these non-metal parts. And also the composites aircraft is more easily damaged by lightning strikes than metal ones when exposures to thunderstorm activity [Ref 2].

It seems that stealth of aircraft is contrary to shielding of external EMI, and some methods for discharging harmful ESD and providing protection to avoid the lightning strike may result in the increase of weight of structure. The purpose of this paper is to deal with above problems and provide some helpful suggestions.

II. Structural Composites and Their Electric Properties

Common structural composites of aircraft are boron fibre, carbon / graphite fibre, fibreglass, Kevlar-49 fibre composites and their hybrids as well as the honeycomb sandwich structures. These materials are of different electric properties because of different component material of them, which have been shown with that of aluminum in Table 1 [Ref 3].

Electric property of material includes its electric conductivity in the low-frequence electric field such as the direct current, and its dielectric characteristics in the high-frequence electric field such as the electric-magnetic wave.And these two are usually contrary to each other, which means that the material is of opposite electric behaviours when it is in different frequence electric fields.

The electric property of CFRP is between the conductor and semi -conductor, which means that CFRP is of certain electric conductivty. And the electric resistance of CFRP is not constant, which depends on the modulus of fibre and stress loaded. CFRP is also of certain electric shielding ability which was compared to aluminum in Fig.1.

GFRP and KFRP are typical dielectric materials which have been used to make up covers of radar antennae in the aircraft.

The electric property of hybrid fibre composites obeys to the mixture rule, which means in most conditions, hybrids are also the dielectric materials. The composite honeycomb sandwich structures are of combined electric property of their component materials, sometimes maybe of special absorption to E-M waves.

III Stealth and Composites

Modern military aircraft, such as fighter and bomber plane, will be asked to be of higher stealth capability to avoid research of radar. In order to obtain the higher stealth capability, engineers have carried out the research on the figure, structure and materials of aicraft. Among them, with no doubt, the greatest progress has been made on the material, especially on the structural composite material and coating materials.

There are two methods to escape the research of radar, the first is to provide the structure with the transparent ability to radar waves, the second is to give the structure with the capability of absorbing radar waves. Both of them can be achieved by application of composites, especially the honeycomb sandwiches with special coating and fillers (refer to Figure 2).

GFRP, KFRP and their hybrids as well as sandwiches are of transparent property to radar waves and less radiant heat. In some structures where are not asked to be of high modulus and stress, such as cover of antannae, tip of wing, back edge of wing and so forth, application of these materials has improved the stealth ability of aircraft [Ref 4].

As shown in Figure 2, graphite fibre composite skin / both Nomex and Aluminum honeycomb core with some fillers sandwich structures are of high capability for aborbing radar waves, and can be used as the structural material, especially in places where maybe meet to radar waves. The sandwich structure consists of surface coating, surface panel, honeycomb core with the filler and bottom panel, and the density of filler increases from surface to the bottom. As the radar waves catch the plane, a part of them will be absorbed by the surface coating, the rest pass through the surface panel,and be reflected repeatedly by honeycomb core and bottom panel, and absorbed by the special filler. By choosing proper figure and structural materials, reflection of radar waves from the front and back edges of wing could be almost eliminated completely.

It also be noted that hybrids are of abroptive capability to the radar waves in wide frequence range, and can be used as the structural materials.

It could be predicted that the stealth capability of aircaft would be enhanced in recent future by following progress made on the structural composites:

a. The hybrid layup methods which are of higher absorbing property and mechanical properties;

b. Application of new thermoplastic matrix composites;

c. By improving the surface treatment technologies of carbon and graphite fibre so that the fibre woule be transparent or abroptive to radar waves;

d. Products of new graphite fibre which is of higher absorbing capability to radar waves.

IV ESD Discharging and EMI Shielding

The static electrisity may appear in all the parts of aircraft, among which ESD in the metal parts will not occur because the static electrisity could be discharged by the dischargers at proper positions, and so do the CFRP because of which is also of a certain conductive capability.

GFRP and KFRP, which are widely used in covers of antennae and panels as well as the windows of instrument cabinet, can not pass the static electrisity by themself. When the voltage of ESD in these non-metal surfaces is so high that it may discharge to surrounding metal part (refer to Fig.3), EMI resulted from the discharging will result in the formation of electric noises. This electric noise concentrates on high frequence and low frequence ranges. The effect of later on the electronic equipment attached to aircraft is more apparent.

There are some methods to pass the ESD in composite parts. For CFRP, it was asked to be provided with a good electric connection between the CFRP parts and metal ones, due to existence of dielectric layer between them to avoid the electrochemic corossion. For GFRP, KFRP and their hybrids, It is better to be coated with a conductive layer on the surface of composites. However, the coating for covers of antennae was required not to reduce the performance of equipment, which means that the coating is asked to be of both lower electric resistance (1-15 MΩ) and higher wave-transparent capability (95-97%). The both requirements are contrary to each other. It was fortunate that this special coating has been obtained and used widely in aircraft [Ref 5]. It also will be noted that there is necessary to be of good electric connection between the coat ing and metal parts,and the coating must be used with waterproof coating together in order to avoid the more serious formation of ESD.

Methods to pass the ESD in the parts such as windows of instrument cabinet, panels of body, fairing covers and driving rudders where are not asked to be wave-transparent, are always considered together with the methods to shield the external EMI and protect the dangerous lightning strikes.

Modern aircraft is of advanced electronic equipments such as the main control computer, radar, telex-driving systems and control system of weapons. Traditional metal plane provided the aircraft with a natural shielding cover. But the composite parts, due to their lower condutivity, can not provide with such a shielding cover. And therefore, when aircraft with large area composite parts exposures in the space with strong EMI, it is easily affected by the external EMI. Sometimes EMI result in the confusion of electric informations of aircraft.

Common EM waves, the lightning EM pulses (LEMP) and the nuclear EM pulsès (NEMP) resulted from the nuclear explosion, all could become the resoures of EMI. The strong EMI not only affects the transport of electric information, but also damages the sensitive electronic equipments of aircraft.

There are several methods to shield the external EMI, and these methods are proper to different positions where required:

1. To form a conductive layer on the surface of composite parts, especially in the place where is easily damaged by lightning strikes.

2. The important cables be packed with metal tubes and Tedlar tubes coated with aluminum.

3. To design the connection area betwee composite parts and metal ones specially, and arrange the cables which pass through composite parts in proper position to avoid EMI.

4. Some important electronic equipments be provided with special shielding measures.

It's necessary to point out that above methods for shielding are appropriate only to medium strength EMI. And to super-high strength EMI (up to 50,000 v), resulted from nuclear explosion, we haven't known related shielding measures very well, and these methods are very important to living of aircraft under the nuclear war, though the nuclear war will not occur in recent future.

V Protection of Lightning Strike

It is the basic requirement for modern aircraft that it will be able to fly in various weather conditions. Sometimes, it may fly in the storm and meet strike of lightning. As shown in Figure 4, natural lightning strike could be divided into two sections, the first is the high current section which will result in the damages of aircraft by both heating and electroheating and the second is the high Coulomb section which may cause the composite parts burnt by electric arc with high temperature resulted from the long-time electric pulse. Lightning strikes with huge energy discharging are usually very dangerous to aircraft, especially to those which are of fuel box wings.

Strikes of lightning to aircraft can be divided into three areas by the type of strike and protection requirements, and these areas will vary with the fly rate, plane shape and structural materials:

Area 1 -- surface of places where are easily striked directly by lightning.

Area 2 -- surface of places where are striked by the scanning lightning from Area 1.

Area 3 -- other surface of aircraft.

Division of areas of lightning strikes for a fighter plane is shown in Figure 5. It can be seen that Area 1 where is easilly striked directly covers the parts which have been widely made up of composites. It's necessary to provide these composite parts with effective protection methods to ensure the safety of flight of aircraft.

There are two methods to avoid the strike of lightning. One is to provide the composite parts with a path of current, and the other is to make these parts insulated to the lightning strikes. And the first is generally used in Area 1, the later in Area 2. It's not necessary to provide Area 3 with special protetion to lightning strikes when it is of good electric connection with other areas.

It has been considered in Ref 2 that it's not better to provide Area 1 with a current path because it may cause the weight of structure inceased and its effect on reducing the damage of lightning strike is very limited, although this method has been used widely in modern aircrafts. And this current path, especially the conductive surface layer, will reduce the stealth capability of aircraft.

It is suggested by the author that it's best to make the composite parts insulated to the lightning strikes, which can be obtained by coating the surface with an insulation material or bonding with an insulation plastic film. It will be noted that this insulation layer has no capability to pass the ESD in the surface and provide the internal electronic equipments with shielding for external EMI by itself. And the research on related materials will be carried out continuaslly.

The current considerations on above problems was reviewed and concluded in Table 2.

VI Conclusions

Recent progress in the some problems which were resulted from the application of advanced composites on aircraft were reviewed in the paper. Some methods for passing the ESD in composite parts and shielding the external EMI were analyzed. Some suggestions for the protection of lightning strikes were made by the author. And the research on these problems is of very important effect on modern composite aircraft.

REFERENCES:

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Table 1 Comparision of electric properties of composites with aluminum

Material	Electric Resistence	Dielectric Constant	Damping Tanδ
CF/Epoxy			
0°	4.0×10^{-3} Ω.cm	----	----
90°	6.6 Ω.cm	----	----
KF/Epoxy	5.0×10^{15} Ω.cm	4.12	0.024
GF/Epoxy	2.0×10^{15} Ω.cm	4.3 - 4.5	0.042 - .045
Aluminum	2.8×10^{-6} Ω.cm	----	----

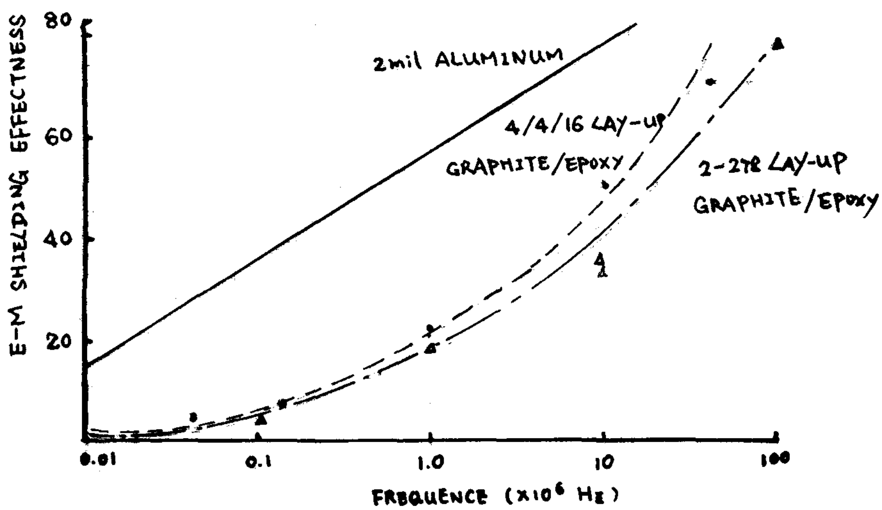

Fig. 1 Comparision of E-M shielding Effectness between CFRP and aluminum

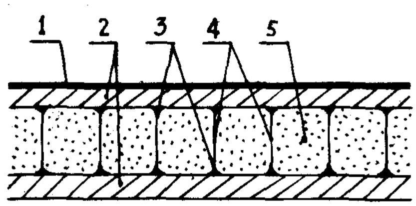

Fig. 2 Typical structural composite honeycomb sandwich

1 -- surface coating   2 -- surface skin
3 -- adhesives   4 -- honeycomb core
5 -- special fillers

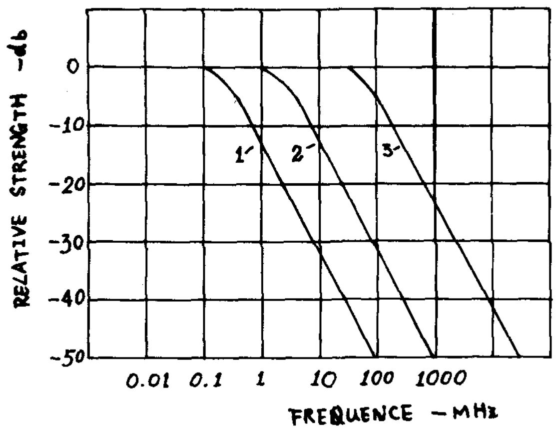

Fig. 3 The frequence spectrums of electric noises caused from discharging of ESD

1 -- flowing discharge 2 -- corona discharge
3 -- arc discharge

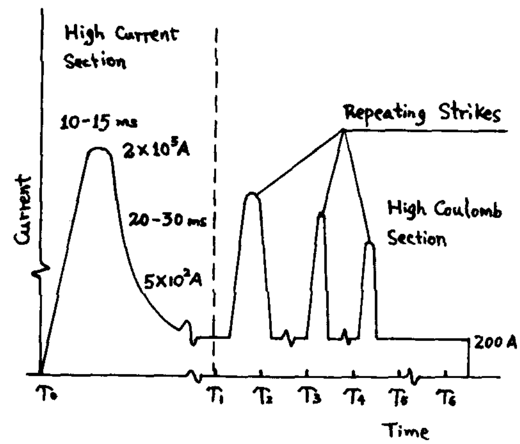

Fig. 4 The main wave shapes of lightning strike current

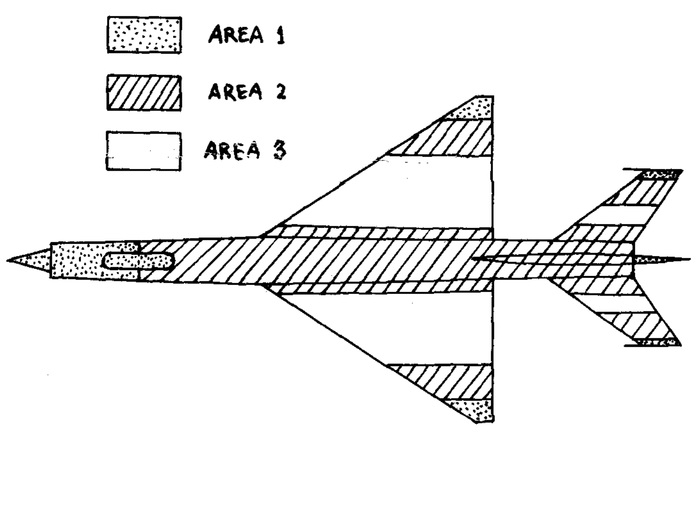

Fig. 5 The typical divisions of lightning strike area of a fighter plane

Table 2 The characteristics and applicable range of current methods on the structures of aircraft

Type	Method	Applicable Area 1	Applicable Area 2	Applicable Area 3	Characteristic: Stealth	Characteristic: LS Prot	Characteristic: EMI Shie	Characteristic: ESD Disc
Insulation layer	coating	X	A	A	A	A	X	X
	film	X	A	A	A	A	X	X
Current path	metal strip	A	B	X	A	B	C	B
	metal film strip	B	B	X	B	B	B	A
Conductive surface layer	metal film	B	B	X	X	B	A	A
	porous metal strip	C	C	X	X	B	B	A
	metal coating	B	B	X	X	A	A	A
	metal wire net	B	B	X	X	B	B	A
	metal film strip	B	B	X	X	B	C	B

A -- best B -- better C -- common X -- not applicable