LIGHTNING PROTECTION OF LOW DENSITY AIRCRAFT STRUCTURES

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Abstract

Low density aircraft structures are characterized by wing and empennage surfaces employing thin metal semi-monocoque construction and extensive metal to metal adhesive bonding. The lightning strike damage potential of these features necessitates a high level of protection.

This paper reviews the lightning protection techniques which may be incorporated to protect low density aircraft structures from the hazards of a lightning strike. These techniques have arisen from testing carried out on the de Havilland Lightning Surge Simulator in association with government funded programs as well as an analysis and simulation of actual in-flight lightning strikes to low density aircraft.

Introduction

There is an increasing amount of time and effort being spent on aircraft safety from a lightning standpoint. This is reflected in the large body of literature which has appeared on the subject over the past few years. A recent document has been published by the SAE Committee AE4, and is entitled "Aerospace Recommended Practice: Lightning Effects Tests on Aerospace Vehicles and Hardware" (1), which summarizes the test waveforms and techniques recommended for lightning simulation testing in the United States.

The inherent design of low density aircraft structure warrants a careful examination of the lightning strike susceptibility of such an aircraft.

The low speed characteristics of a S.T.O.L. aircraft are enhanced by wing and empennage surface areas constructed of thin gauge aluminum with extensive metal to metal adhesive bonding. One also finds an increase in the number of aircraft parts fabricated from high strength metallic and non-metallic composites. When such a design philosophy is applied to fuel tank structure which is exposed to a lightning strike, lightning protective schemes must be instituted to prevent possible fuel ignition due to sparking across joints or penetration of the skin structure.

In the interests of weight reduction the nose structure of some aircraft may be fabricated of a non-metallic composite and may contain avionics packages. Damaging voltages and currents may be coupled into these units unless some form of shielding is placed around the nose bay.

Furthermore, in the interests of low speed lift augmentation, low noise and low fuel consumption, turboprops still find widespread use for this class of aircraft. In the case of the de Havilland Dash 7, the propeller blades are constructed of a glass fibre surrounding and bonded to an aluminum spar. Such a construction necessitates some form of lightning protection. In addition, propeller blades provide an attachment point for the lightning strike which is then swept back over the wing and the fuel tank region.

Despite the large fund of information available in the literature, as mentioned above, the principles which can be directly applied to the class of aircraft structures manufactured by de Havilland do not cover all aspects of lightning protection. As a result a research program with joint funding by de Havilland and the Canadian Defence Research Board was initiated. This contributed to an understanding of the behaviour of certain structural configurations, and many of the concepts explored have since been incorporated in the design of the Dash 7.

The Lightning Strike Phenomenon

It must be accepted that the aircraft will be struck by lightning. Perry (2) has compiled statistics indicating that aircraft are struck by lightning once per 780 flying hours for jet aircraft operating in the Berlin Corridor (low altitude), to one strike per 19,000 hours for four engine turboprops on long range flights.

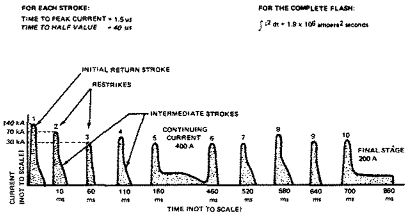
The lightning flash is a phenomenon in which the atmosphere is attempting to achieve a lower energy state. The buildup of charge in a thundercloud is generally pictured as a separation of positive and negative charge centers. The concentration of charge continues to increase until electrical breakdown occurs and the air in the vicinity of the charge centers becomes ionized.

Generally there are three accepted forms of lightning: cloud to ground flashes, inter cloud flashes and intra cloud flashes. Aircraft are susceptible to all three forms of lightning. However, empirical analysis has generally only been focused on cloud to ground strikes.

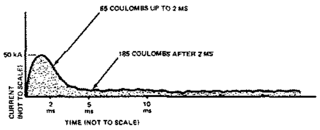
Also the lightning discharge may result from either a positive or negative cloud charge. The latter occurs approximately 80% of the time. Therefore, emphasis is placed on the negative cloud to ground strikes.

The lightning discharge actually consists of several intermittent discharges. The complete discharge is termed a flash. Upon electrical breakdown of the charge center, charge (negative in this instance), is lowered, on a column known as the "stepped leader" in rapid discontinuous steps. When the leader nears the ground, the intense electrical field existing between leader tip and the ground induces an upward moving streamer. The marriage of the two initiates the "return stroke". The return stroke discharges the leader channel at about 10^7 m/sec and may possess a peak current of 200 ka rising to peak value in a few microseconds. Following this, currents of a few hundred to a few thousand amperes may flow for several milliseconds (Intermediate and Continuing Currents).

Subsequent strokes may occur discharging other areas in the charge center. If these strokes occur in a reasonably short period of time (100 ms) to the previous strokes, what is termed a "dart leader" will traverse the existing ionized channel at a speed of 10^6 m/sec. Longer time periods would result in dissipation of the ionized channel and necessitate a new stepped leader. The current waveform of a typical positive and negative flash is shown in Fig. 1 (1).



(A) SEVERE NEGATIVE LIGHTNING FLASH CURRENT WAVEFORM



(B) SEVERE POSITIVE LIGHTNING FLASH CURRENT WAVEFORM

FIGURE 1
SEVERE LIGHTNING FLASH CURRENT WAVEFORMS

Aircraft are generally struck at lower altitudes (under 7 km) at temperatures of approximately 0^oC (temperature associated with the formation of negative charge). These values are very much dependent upon geographical location and season (3).

The incidents of recorded lightning strikes to aircraft have prompted a study to divide the aircraft into zones possessing different lightning attachment and transfer characteristics. For example, zone 1A is an area prone to initial attachment by a lightning stroke, such as a leading edge or a propeller blade tip, but possessing a low probability of flash hang-on.

Zone 2A would be a swept stroke zone with a low probability of flash hang-on (wing mid-span). The B zones would possess the same attachment characteristics, however, the probability of flash hang-on would be high, such as the outboard or inboard trailing edges.

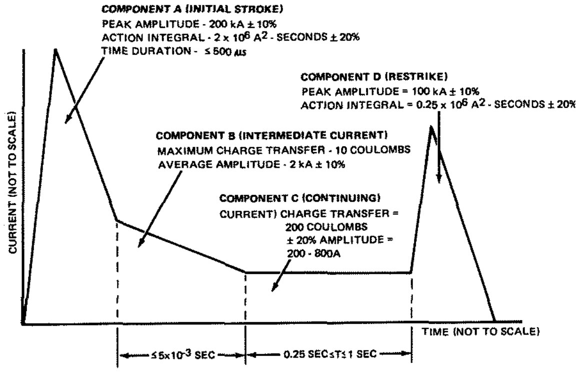


FIGURE 2A
CURRENT TEST WAVEFORM COMPONENTS FOR EVALUATION OF DIRECT EFFECTS

A number of laboratory waveforms have been established in an attempt to simulate the voltage and current characteristics of a lightning discharge Figures 2A, 2B and 2C (1).

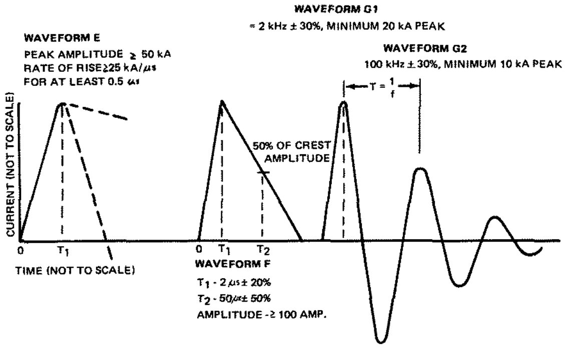
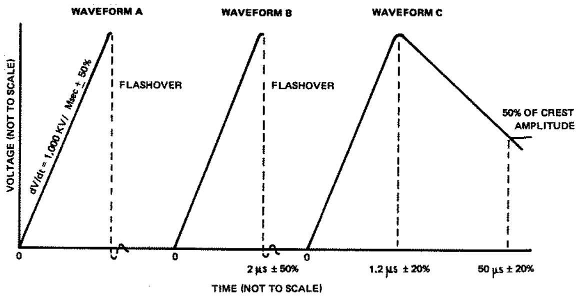


FIGURE 2B
FAST RATE OF CHANGE CURRENT WAVEFORMS FOR EVALUATION OF INDIRECT EFFECTS
NOTE: Peak amplitudes are not the same

Current waveforms A-D are used to evaluate the "direct effects" of a lightning strike such as sparking, burning, eroding, magnetic forces and blast pressures. Current waveforms E, F and G are employed for an anlysis of the "indirect effects" such as induced voltages in aircraft electrical circuitry.

Voltage waveforms A, B and C are used to determine the initial lightning stroke attachment points to the aircraft or a section of aircraft geometry.



NOTE: Peak amplitudes are not necessarily the same

FIGURE 2C
HIGH-VOLTAGE TEST WAVEFORMS

INDIRECT EFFECTS TEST	CURRENT WAVEFORM			TEST TECHNIQUE PARA. NO.
	E	F	G	
External Electrical Hardware	X			4.8
Complete Vehicle		X *	X *	4.9

* Note: Either Waveform F or G may be used for Complete Vehicle Test.

TABLE 3
APPLICATION OF LIGHTNING CURRENT WAVEFORMS FOR INDIRECT EFFECTS TESTS

It has been established that each of the zones are affected by specific waveforms which enable a test engineer to empirically assess the lightning protection of aircraft components (Tables 1 - 3), (1).

LIGHTNING TEST	HIGH VOLTAGE WAVEFORM			TEST TECHNIQUE PARA. NO.
	A	B	C	
Model A/C Attachment Point Test		X		4.1
Full Size Hardware Attachment Point Test	X			4.2
Aperture Streamer Test			X	4.6

TABLE 1
APPLICATION OF LIGHTNING HIGH-VOLTAGE TEST WAVEFORMS

TEST ZONE	CURRENT COMPONENT				TEST TECHNIQUE
	A	B	C	D	PARA. NO.
1A	X	X			4.4.2.1, 4.5, 4.7
1B	X	X	X	X	4.4.2.1, 4.5, 4.7
2A		X *	X **	X	4.4.2.3, 4.5, 4.7
2B		X	X	X	4.4.2.4, 4.5, 4.7
3	X		X		4.4.2.5, 4.5, 4.7

* Use average current of 2 kA = 10% for dwell time measured in Test 4.3.

** Use average current of 400 amp for dwell time in excess of 5 msec as determined in Paragraph 4.4.2.3.

TABLE 2
APPLICATION OF LIGHTNING CURRENT COMPONENTS FOR DIRECT EFFECTS TESTS

Lightning Strike Protection of Wing Fuel Tanks

From a lightning standpoint the use of thin metal skins and metal to metal adhesive bonding is primarily a concern when used as fuel tank structure, adjacent to a fuel vapour - air combustible mixture. A lightning discharge sweeping across the surface of the tank skinning could dwell at a single attachment point for a time period long enough to result in penetration of the skin and possible fuel ignition.

The other concern is the effect of the flow of lightning currents across joints located in a fuel tank environment. This problem will be examined first.

Aircraft structural joints may be classified as permanent or removable joints both of which fasten one aircraft component to another. From the lightning standpoint, the goal is a common one - to safely conduct the lightning current from component A to component B. Such a goal is a critical one if the joint constitutes a member of an aircraft fuel tank. In such a case, the phrase "safe joint" would define a joint which conducts lightning current from component A to component B without sparking inside the fuel region (exposed to fuel vapours). This is rendered difficult by environmental considerations. Bare metal corrodes, and corrosion in joint areas could result in sparking (as well as cracking) problems. These joints can be protected against corrosion, but treatments which are good corrosion inhibitors (e.g. anodize, paint, etc.) are usually poor electrical conductors, resulting in sparking.

Therefore, from the lightning standpoint, the choice of materials and protective treatments is very important in aircraft joints especially those that carry lightning currents in fuel tank regions.

A representative edge member configuration would be an access panel - wing skin joint typical of an aircraft wing fuel tank (Fig. 3).

The path of the lightning current from a strike on a fuel access panel passes through a number of joints on its way to the main aircraft structure. This main structure due to its multitude of good electrical paths can conduct the lightning current without any further concern for

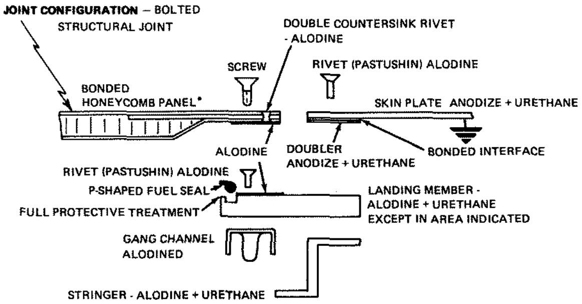
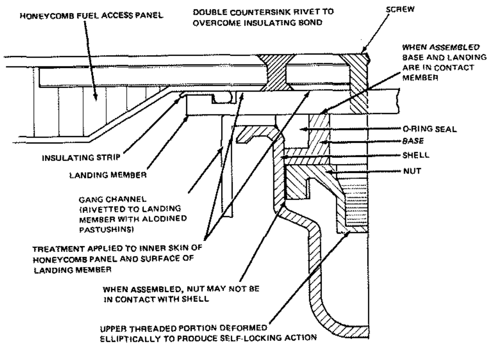


FIGURE 3 TYPICAL FUEL TANK JOINT



PART	MATERIAL	FINISH
NUT	STEEL	CADMIUM PLATE
SHELL	STEEL	CADMIUM PLATE
BASE	AL. ALLOY	ALODINED
GANG CHANNEL	AL. ALLOY	ALODINED
SEAL	RUBBER	—

FIGURE 4 SECTIONAL VIEW OF BOLTED STRUCTURAL JOINT

flight safety.

The joint comprising the access panel and wing skin has been designated the bolted structural joint and actually consists of two joints.

The first joint is removable consisting of a bolted attachment fastening the access panel to the landing member and is termed the bolted lap joint. The second joint which connects the landing member to the wing skin by means of rivets and adhesive, is termed a permanent joint. A similar permanent joint is found at the skin to spar location.

If internal arcing were to occur at any of these fuel exposed joints, fuel ignition is almost certain to occur.

During the testing of the permanent and bolted joints, numerous treatments, rivet specifications and gasket designs were evaluated. It was desirable to obtain the most lightning and corrosion resistant joint possible. Generally it has been observed that alodine is a good conductor while anodize, although more corrosion resistant, is a poor conductor and usually results in severe sparking when applied to current carrying components. Similarly regions which are bonded or contain sealant for corrosion and sealing protection create a high dielectric barrier which requires the current to take an alternate path.

An examination of the joint indicated in Fig. 3, which incorporates acceptable lightning and corrosive protective technique of bolted and permanent joints will provide a good summary of the development in this area. Figure 4 shows a sectional view of the fuel access panel edge member assembly.

The bolted structural joint specimen was approximately twenty-four inches in dimension. The current from a lightning strike originating on the fuel access panel must pass into the main wing structure. The access panel consists of an .032 inch outer skin and an .016 inch inner skin bonded to an aluminum honeycomb core.

In view of these insulating interfaces, the current has two reasonably attractive paths to follow. First of all, the current could travel down the screw shank and arc across to the landing member. This is a result of the clearance fit, an inherent manufacturing design. Although such arcing is inboard of the fuel seal and not directly exposed to fuel vapours, it should be avoided, since the arcing could force a shower of sparks past the seal, into the tank area.

Secondly, the current could continue down the screw shank into the nut, anchor nut housing, gang channel, rivet (securing the gang channel) and into the landing member. Sparking at any of these components, directly exposed to fuel vapours, could result in fuel ignition. Several instances of severe sparking from the anchor nut, gang channel assembly were evident in early testing. In many of these cases the anchor nut and gang channel were anodized, and a close examination of these parts revealed sharp edges and areas where metal to metal contact is questionable.

Current carried by the screw will pass into the nut. From the nut, the current may pass into the anchor nut shell or the base, although metal to metal contact is not ensured in the former case. The current in the base cannot pass directly into the landing member since the latter component is treated with urethane for corrosion protection. The current, therefore, transfers into the shell, to the gang channel and into the landing member by way of the rivets fastening the gang channel to the landing member. The nut and shell are constructed of cadmium plated steel which is conductive, however, the multitude of current transfer points and the presence of an anodized gang channel could result in serious sparking. Therefore, it was desirable not to rely on the screws to carry the bulk of the lightning current.

To create an alternate, more attractive current path, it was decided to install double countersink rivets in the access panel at six-inch intervals to provide electrical continuity between the outer and inner panel skins normally insulated from each other. With the inner skin of the access panel now at the same electrical potential as the outer skin, there existed a possibility whereby arcing could occur from the inner skin of the access panel to the lip of the landing member. As a result, a "P" - shaped fuel seal was designed in which the "0" ring section of the seal inhibits fuel leakage and the flat section provides good insulation between the access panel and landing member lip. Additional protection was implemented by placing the full protective treatment on the lip of the landing member (urethane).

The passage of the current from the landing member to the main wing structure requires the analysis of a permanent structural joint. Rivets are used to carry the current from the landing member to the wing skin, as the doubler skin interface is bonded (Figures 5A and 5B). The rivets are treated with alodine which offers corrosion protection and is a good conductor.

FIGURE 5A SEVERE SPARKING FROM ANODIZED RIVETS, FASTENING STRINGER, LANDING MEMBER, SKIN PLATE

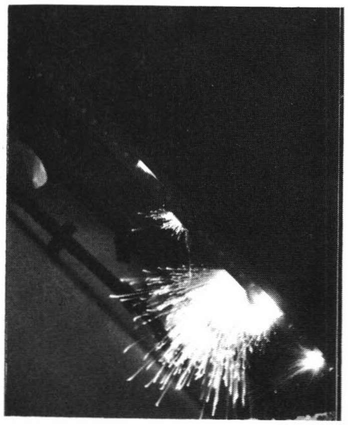


FIGURE 5B SEVERE SPARKING FROM ANODIZED RIVETS, FASTENING STRINGER, LANDING MEMBER, SKIN PLATE

Extensive tests have shown that these design features permit a safe current transfer through the various joint components.

The same general design philosophy may be applied to other fuel tank components such as filler caps, (Fig. 6) fuel level indicators (dip sticks) pressure relief and dump valves, boost pumps, and other components which penetrate the skin of the wing fuel tank. As before, the objective is to create, between the unit and the main aircraft structure, a low resistance path which is isolated from fuel vapours. The concern is not as great for components attached to lower tank skins since they are usually covered with fuel. However, conditions may arise in which these units are exposed to a combustible fuel vapour - air mixture under thunderstorm conditions and hence the same protection should be supplied whenever possible.

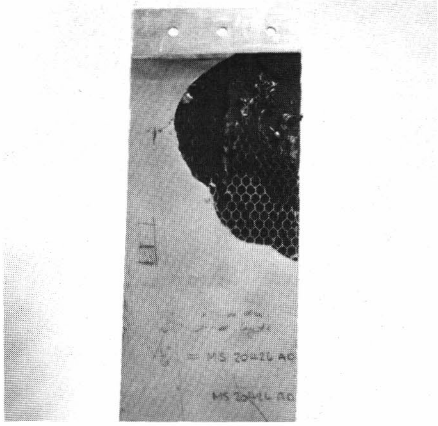


FIGURE 6 DAMAGE SUFFERED BY ALUMINUM HONEYCOMB PANEL LOWER SKIN WAS ACTUALLY SEVERED DURING TEST

The problem of penetration of the fuel tank structure by a lightning discharge is another problem which must be examined.

FAA Advisory Circular 20-53 outlines recommendations for fuel tank skinning of .080" minimum thickness for lightning penetration resistance (based on the Continuing Component) (4). With the introduction of sandwich panels and thin metal skins to the industry and with the previously mentioned recommended modification in the lightning waveforms (1), it becomes necessary to carry out research into the effects of lightning strike on fuel tank skinning.

With the introduction of the lightning swept stroke as recommended in (1), the test program adopted the Intermediate Component (Component B). This component is characterized by a current surge of 2000 amperes flowing for a duration of 5 milliseconds with a maximum charge transfer of 10 coulombs.

Although the continuing component transfers a greater charge into the specimen, the Intermediate Component has a much higher I^2dt content which is a measure of the energy dissipated in a fixed resistance (termed the Action Integral I^2dt). It is this feature which makes the Intermediate Component the more severe of the two from a penetration standpoint. With a sweeping Intermediate component of fixed time and current amplitude the probability of panel penetration for a given panel thickness is a strong function of surface treatment. As the arc sweeps over the panel surface, it attaches itself at different locations and dwells at each location for a given time period.

Surfaces with insulative coatings increase the dwell time of the arc by necessitating a higher arc voltage to breakdown the dielectric coatings at a new attachment point. Brick (5), for example, cites a minimum dwell time of 2 milliseconds for anodized aluminum. Furthermore, it has been recommended (1) for penetration testing, that the Intermediate component be combined with Component D into a single test discharge. It is felt that the current characteristics of this latter component might affect the reattachment point and puncture capability of a swept stroke (6).

A lightning swept stroke can be regarded as a series of static burns on the aircraft surface. Each attachment point is a static condition with respect to the arc and aircraft surface. The dwell time of the arc at each attachment point is determined by the dielectric strength of the surface treatment for a given aircraft speed and lightning waveform. Therefore the surface treatment directly affects the energy and coulomb transfer into each attachment point.

A typical polyurethane paint caused the arc to dwell in one location long enough to result in penetration of .032" aluminum skin.

Tests carried out on an .050" skin coated with the regular paint (polyurethane) scheme saw the arc dwell in one location for the duration of the test, resulting in severe burns, although the panel was not penetrated by the arc. (Fig. 7A)

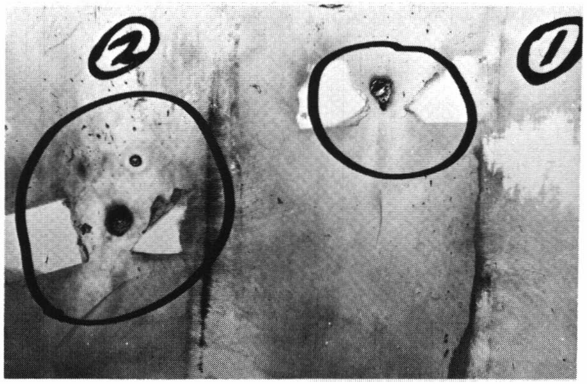


FIGURE 7A SWEPT STROKE DAMAGE TO .050" ALUMINUM COATED WITH A REGULAR PRIMER AND PAINT.

A number of surface treatments were examined in an attempt to decrease the dwell time of a lightning swept stroke on aluminum honeycomb panels, and hence decrease the probability of penetration.

An acceptable treatment, in addition to promoting surface flashover of the stroke, must also have good anti-corrosion characteristics. Furthermore, it is desirable to have a treatment which is aesthetically pleasing and which can be readily applied.

A treatment which has shown good results is an aluminum loaded primer and enamel applied to the DHC-7, .050" skin specimens and tested under conditions of a swept stroke. Generally the lower dielectric strength of the treatment has promoted surface flashover of the arc and reduced damage to the specimen (Fig. 7B).

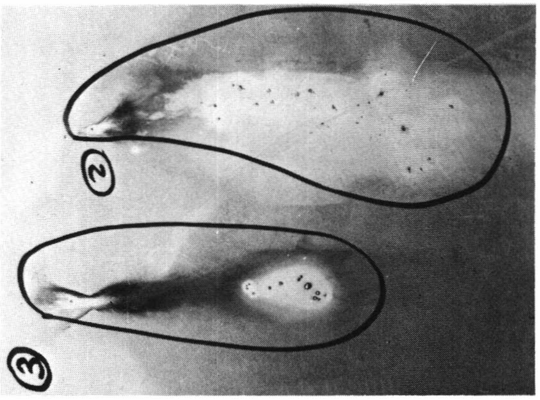


FIGURE 7B SWEPT STROKE DAMAGE TO .050" ALUMINUM COATED WITH ALUMINUM LOADED PRIMER AND PAINT.

SIMULATED LIGHTNING DISCHARGE - COMPONENT D (100 ka); INTERMEDIATE COMPONENT B (5 ka) INTEGRATED INTO A SINGLE DISCHARGE. WIND SPEED - 80 MPH.

A problem related to, but slightly different from that of skin penetration is fuel ignition due to localized heating, without penetration (often referred to as hot spot ignition). This is not generally of great concern with aluminum skins because the melting point is low enough that exposure times of some 30 seconds (7) are required to cause ignition and lightning activity of sufficient duration to maintain a molten pool of material for that length of time will result in actual penetration. For other materials such as titanium and stainless steel however, the problem does exist and it becomes necessary to determine temperatures under a strike. A practical method of measurement was devised during the development program and reported in (8). Since it is not generally a consideration with aluminum alloys, normally used in low density aircraft structures, however, it will not be here described in detail.

Other materials finding growing popularity in the aircraft industry are the non metallics being used in composite structures. The problem of lightning strike to non-metallic structures is much more pronounced than with metallic structures.

In the use of a large non-metallic surface, the dielectric strength may be insufficient to cause the arc to flashover the non-metallic structure and reattach itself to a nearby metallic component. The result may be penetration of the composite in which thermal effects could vaporize the resin and the shock pressures mechanically deform the structure.

Penetration testing of the non-metallic sandwhich panels provided two protection schemes which were acceptable from a lightning standpoint-aluminum mesh and aluminum spray. It was decided, in light of the weight factor, that aluminum mesh would be the more acceptable system.

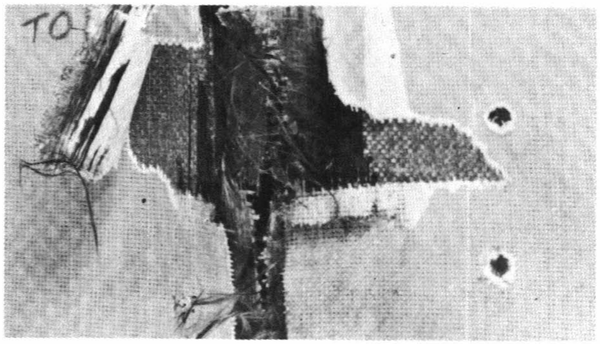


FIGURE 8A EFFECTS OF LIGHTNING DISCHARGE ON KEVLAR NOMEX PANEL (GRAPHITE SUB-LAYER) WITH NO LIGHTNING PROTECTIVE SCHEME.

Subsequent swept stroke tests on non-metallic panels possessing the mesh produced good results (Figures 8A, 8B and 8C).

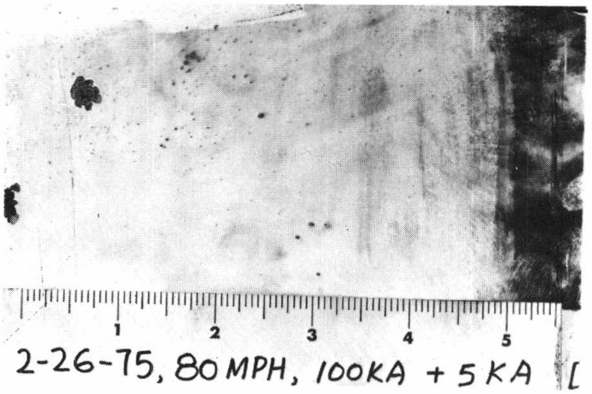


FIGURE 8B SWEPT STROKE DAMAGE TO KEVLAR NOMEX PANEL (GRAPHITE SUBLAYER) PROTECTED WITH ALUMINUM MESH (.004" DIA.; 120 x 120 DENSITY) AND COATED WITH A TYPICAL AIRCRAFT PRIMER AND ENAMEL.

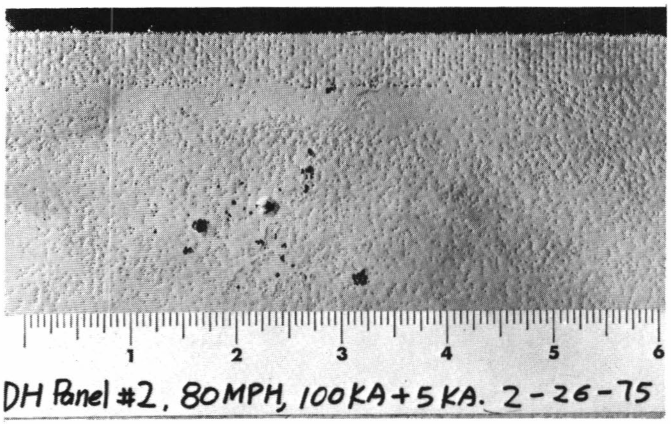


FIGURE 8C SWEPT STROKE DAMAGE TO KEVLAR NOMEX PANEL (GRAPHITE SUB-LAYER PROTECTED WITH ALUMINUM MESH AND COATED WITH AN ALUMINUM LOADED PRIMER AND ENAMEL. (7.2 OZ ALUMINUM PASTE PER IMPERIAL GALLON)

Two types of panels were evaluated. These were constructed of Kevlar-Nomex and Graphite-Nomex honeycomb. Both types of construction are finding widespread use in the aircraft industry. Graphite fibres have moderate electrical conductivity and when combined with a resin could create serious problems from a lightning standpoint. Current from a lightning strike entering the graphite fibres, heat the fibres to a sufficiently high temperature to cause pyrolosis (decomposition, vaporization) of the resin, resulting in structural disintegration of the composite. It is therefore very important to protect these materials from a lightning strike.

Indirect Effects of Lightning Discharge

There are a number of areas on the aircraft which might require protection from the indirect effects of a lightning strike. For example an avionics package might be placed inside a non-metallic nose compartment. Changing magnetic fields resulting from a lightning strike could penetrate an unprotected compartment and induce damaging voltages into the electrical system.

It is important to examine the means by which a magnetic field enters the interior of an aircraft. For lightning current pulses in the micro second region, flowing in the aircraft skin, rapidly changing external magnetic fields are created. These fields may appear inside the aircraft structure by two means - diffusion and aperture penetration. Diffusion flux involves the diffusion of the charge density through the metallic structure. The other method of flux penetration into aircraft interiors is through existing apertures in the structure. The aperture flux appears much sooner, has a faster rise time and is more localized than diffusion flux.

The internal magnetic flux may then induce dangerous voltages into electrical circuitry.

Electromagnetic shielding afforded by a structure generally may be subdivided into two types; shielding by countercurrents and shielding by symmetry. The latter type is exemplified by a metal cylinder with uniform current distribution. Inside the H field is zero. In the former case, countercurrents are established in a shield which carries lightning currents. These countercurrents oppose the in-coming field, which results in a cancellation of that field.

Tests were carried out on a full scale nose compartment to determine the degree of electromagnetic shielding afforded by the lightning protection system.

The nose structure test specimen consisted of the avionics nose bay and the radome, which was constructed of glass fibre skins and a nomex honeycomb core. The avionics bay was constructed of kevlar skins/nomex core. The avionics bay door was constructed of fiberglass skins and a foam core. The lightning protection of the nose consists of four .025" x 0.75" aluminum straps on the bay. In addition the bay contains an aluminum mesh (.004" dia. 120 x 120 density) impregnated in the outer skin. The avionics bay door is also protected by an aluminum mesh.

The radome and avionics nose were fastened to a large metal cabinet as seen in the accompanying Figure 9. The majority of lightning discharges were directed at one of the four aluminum radome straps.

Testing may be subdivided into two categories. The first consisted of internal magnetic field plotting which incorporated a loop consisting of 4 turns of wire placed inside the avionics bay to measure the internal H field at different locations in the bay. From this internal H field plot an approximate induced voltage value could be calculated corresponding to a given loop area formed by the avionics wiring and the ground plane.

The second series of tests consisted of placing a wire harness inside the avionics bay. The wire was routed in the same manner as in an aircraft and connected to an oscilloscope from which direct induced voltage readings could be obtained. Also included were a number of avionics shelves (aluminum construction) in the avionics bay.

The tests showed that it is important that a complete Faraday cage exist to provide proper countercurrent shielding for the internal avionics equipment. For example with the forward web electrically isolated from the aluminum mesh, the front end of the nose, essentially become an aperture to the penetrating flux resulting in an internal H field approximatley 8 times higher than when the web formed part of the Faraday cage.

Furthermore, to enhance the symmetry shielding of the mesh, it is necessary that the lightning discharge transfer from the radome strap and distribute evenly into the aluminum mesh.

Another important factor is the placement of wires. It became apparent that all internal wiring routed from an electronic package on a shelf to the terminal junction panel should be run along the inside surface of the bay up to the panel and returned along the inside of the bay as close as possible and parallel to the original wire. As a result all loop areas formed by the wiring will be minimized and all loops will be in a plane parallel to the inside surface of the bay and not perpendicular to the surface. All wiring running aft into the cockpit area from electronic boxes or the terminal junction panel should be run along a shelf and as close as possible to that shelf.

When all of these features were incorporated into the test specimen the internal fields were reduced to levels which are judged to be acceptable.

Concluding Remarks

There are other areas and components on typical aircraft structure which require a detailed examination to afford lightning protection to the complete vehicle. The above considerations, however, indicate the approach taken to solve some of the problems encountered in the process of producing low density aircraft structure which is safe in a lightning environment.

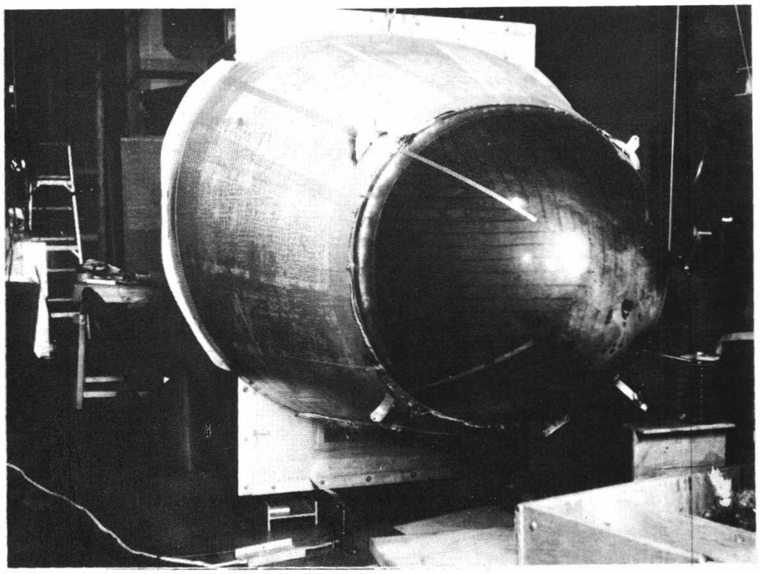


FIGURE 9 TEST CONFIGURATION TO DETERMINE DEGREE OF EM SHIELDING AFFORDED BY ALUMINUM MESH OF NOSE AVIONICS BAY.

References

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