Certification of Radome Lightning Direct Effects Protection

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Abstract. Composite material is used more and more in airplanes year after year. The electrical conductivity of composite material structure is poorer than metal structure, so appropriate lightning protection measures should be adopted to shunt lightning current when composite structure suffering lightning strike, and the harmful consequence will be minimized. The paper takes radome as an example, which is located at nose area liable to suffer lightning strike, introduces radome lightning protection measures, and according to lightning direct effect verification process, discusses on means of compliance, plans high voltage strike attachment test and high current physical damage test of radome. It provides reference for airworthiness verification for radome.

1. Introduction
The aircraft radome is located at the front of the aircraft, and has a high probability of being struck by lightning. In order to improve the survival ability of the aircraft in adverse weather environment, lightning protection measures should be taken for the radome. When the radome is struck by lightning, the lightning leader is attached to the lightning protection system, and the current is transmitted to the airframe through the lightning protection system to release the radome and its interior The avionics equipment plays a protective role. Taking radome as an example, this paper discusses the airworthiness compliance verification method.

2. Background
In 1940, for the first time in the world, military aircraft radomes were made of glass fiber reinforced unsaturated polyester resin. From 1960s to 1970s, glass fiber reinforced plastic (GFRP) products have been widely used in aviation industry. In this kind of composite, the amount of glass fiber is 30% ~ 60%, and the matrix materials are mainly unsaturated polyester resin, epoxy resin and phenolic resin. The specific strength (tensile strength / density) of GFRP is higher than that of steel, and its corrosion resistance is better. Since then, lightweight carbon fiber and carbon fiber composites with high specific strength and high specific modulus have also been developed. After carbon fiber, aromatic polyamide fiber (aramid fiber) and other high-performance fibers have been developed. Such composites represented by carbon fiber composites are called advanced composites materials (ACM).

The aircraft may suffer from lightning stroke during flight. Table 1 lists the statistical data of lightning accidents of various types of civil aircraft. From these data, it can be seen that on average, the aircraft will suffer a lightning stroke every 3000 flight hours, that is, once a year\textsuperscript{[1]}. Therefore, in order to ensure flight safety, lightning protection must be considered in civil aircraft design. With the
increase of composite materials used in modern civil aircraft, lightning protection design for non-conductive composite structures is particularly important. Take the radome as an example, its structural integrity can effectively protect the radar antenna from the impact of the external environment of the aircraft, such as aerodynamic load, rain, static electricity, lightning, hail, bird strike or other impacts. Figure 1 shows the glass fiber honeycomb radome broken down by lightning. Reasonable lightning protection design can avoid such phenomenon. For civil aircraft, it is necessary to verify the airworthiness of lightning protection design to ensure flight safety. In this paper, taking radome as an example, the certification method of structural lightning protection design is discussed.

![Table.1 Statistics of civil aircraft lightning accidents](image)

| Aircraft Type   | Number of Lightning Strokes | Flight Hours | Flight Hours per Lightning Stroke |
|-----------------|----------------------------|--------------|----------------------------------|
| Piston Type     | 808                        | 2000000      | 2475                             |
| Propeller Type  | 389                        | 1291000      | 3320                             |
| Jet Type        | 521                        | 1741000      | 3340                             |
| **Total**       | **1718**                   | **5032000**  | **2930**                         |

Figure.1  Radome Damaged by Lightning

3. Airworthiness Requirements

CCAR 25.581 provides relevant requirements for lightning protection of aircraft structure.

*CCAR 25.581 Lightning Protection*

(a) The airplane must be protected against catastrophic effects from lightning.

(b) For metallic components, compliance with paragraph (a) of this section may be shown by-
   (1) Bonding the components properly to the airframe; or
   (2) Designing the components so that a strike will not endanger the airplane.

(c) For nonmetallic components, compliance with paragraph (a) of this section may be shown by -
   (1) Designing the components to minimize the effect of a strike; or
   (2) Incorporating acceptable means of diverting the resulting electrical current so as not to endanger the airplane.

For lightning protection, 25.581 (a) provides the general requirements, that is, in order to prevent catastrophic consequences caused by lightning, relevant protection measures must be considered in aircraft design; for metal components, its conductivity is relatively good, generally intact electrical bonding can ensure good lightning protection effect, and the value of lap resistance should be less than 50m Ω; for non-metallic components, 25.581 (c) mentions to minimize the consequences of flashover, there is no quantitative concept, but it should at least ensure that no catastrophic consequences will occur. At the same time, acceptable diversion measures should also ensure the safety of the aircraft.
4. Radome Compliance Verification

The direct effect of lightning is the physical effect caused by the direct attachment of lightning channel to aircraft and/or lightning current conduction on aircraft and/or equipment. This includes perforation, bursting, bending, melting, burning and vaporization of insulators on aircraft and equipment surfaces/structures. It also includes direct injection of voltage and current by lightning on corresponding lines, pipelines and other conductive parts. Possible injuries to personnel include shock effect and glare/blindness caused by strong flash.

Generally speaking, in order to show the aircraft's compliance with the direct effects of lightning, the applicant will generally carry out six compliance activities. These compliance activities are an iterative process, as shown in Figure 2. The six activities are as follows:

1. Determine the lightning strike zones for aircraft;
2. Establish the lightning environment associated with the zones;
3. Perform Lightning Hazard Assessment. Determine aircraft structure, systems and components safety classifications and make a Lightning Hazard Assessment to review the design of the aircraft and its systems and components to identify lightning direct effects and their potential hazards;
4. Design protection in accordance with acceptance criteria;
5. Verify Compliance;
6. Determine and implement corrective measures\(^2\).

![Figure.2 Compliance Route of Direct Lightning Effect](image)

4.1. Determine the Lightning Strike Zones for Aircraft

Not all voltage waveforms and current components of the external lightning environment are applicable to every part of the aircraft. The lightning zoning is convenient to match the aircraft position with the external lightning environment. The location of these areas depends on the geometry
and operational parameters of the aircraft and varies with aircraft model. Therefore, a set of lightning zones must be established for each aircraft model. Generally speaking, there are 1A, 1B, 1C, 2A, 2B and 3. SAE ARP5414 gives the definition of each lightning zone and the determination method of lightning zoning. The applicant can determine the lightning zoning by comparing with the existing similar design, or through service experience or test method. The typical lightning stroke zoning of civil aircraft is shown in Figure 3. It can be seen from the figure that the radome is located in zone 1A, which is the area with high initial lightning attachment probability.

Figure 3: Typical Lightning Stroke Zoning of Civil Aircraft

4.2. Establish The Lightning Environment Associated with The Zones

There are two ways to express the external lightning environment, one is the composite waveform of lightning current component on the aircraft surface, and the other is the voltage waveform which can represent the relevant electric field effect before lightning attachment. According to SAE ARP5412, the voltage waveform of radome in area 1A adopts D waveform (as shown in Fig. 4). The leading edge time of voltage waveform D is 50 ~ 250 μS, the actual output voltage amplitude is at least 1500kV. The current waveform adopts current components A and B (as shown in Fig. 5) and is injected in the form of composite components. The current component A waveform can be oscillatory or unidirectional. The current amplitude is 200kA ± 10%, the maximum rise time (between the peak value of 10% and 90%) is 50 μs, the action integral is \(2 \times 10^6 \text{A}^2 \text{s} \pm 20\%\) and the action time (to the peak value 1%) are not more than 500 μS. The waveform of current component B must be unidirectional, with an average amplitude of 2kA ± 20%, pulse width of 5ms ± 10%, and coulomb of 10C ± 10% [3].
Voltage waveform and current waveform are used for lightning attachment point test and lightning current test respectively.

4.3. Perform Lightning Hazard Assessment
All aircraft structures must be evaluated for the effects of lightning to determine any hazardous consequences that may be caused by lightning. Through the assessment, it should be determined whether the structural failure or failure caused by lightning is likely to cause catastrophic
consequences immediately (or after a certain delay). According to the safety assessment, all aircraft structures identified as lightning related must show compliance with the requirements of lightning protection regulation 25.581.

The lightning safety classification of aircraft structures can refer to the classification of aircraft structures in damage tolerance and fatigue assessment, focusing on the main structural parts (PSE). According to AC25.571-1C, the main structural member (PSE) plays a major role in carrying flight load, ground load or pressurization load. The radome is located at the front of the aircraft. Although it is a non-PSE part, its structural integrity can effectively protect the radar antenna from the impact of the external environment of the aircraft, such as aerodynamic load, rain, static electricity, lightning, hail, bird strike or other impacts. The failure of radome may lead to disastrous consequences. It is recognized that the radome needs to meet the lightning protection requirements. In order to ensure the integrity of the radar antenna in the radome, the design criteria of the radome are that the structure is intact and no parts fall off after lightning.

4.4. Design Protection in Accordance with Acceptance Criteria

Acceptable design schemes can be derived from existing design practices, design guidance or previously verified manual data. For radome, measures should be taken to ensure that the non-conductive surface can effectively shunt the lightning current. The typical lightning protection design of radome achieves the purpose of shunting by setting lightning protection shunt bar on the outer surface of radome, supplemented by appropriate lap joint.

The radome is composed of composite material cover, reinforcing frame, rainproof and antistatic coating system, lightning protection system, metal joint and connector, anti-corrosion cover, quick release lock, sealing ring, etc. Figure 6 shows the structure of radome.

![Figure 6: Radome Structure](image)

There are mainly two kinds of shunt bars on the surface of radome, one is solid aluminum strip, the other is button type shunt strip. Solid aluminum strip is often used in civil aircraft, and the splitter bar is fixed on the outer surface of radome with countersunk screw. The lightning protection system consists of lightning protection shunt bar, reinforcement ring assembly and lap screw. After the radome is equipped with lightning protection shunt bar, when the aircraft head is struck by lightning, the lightning current can be released through the lightning protection shunt bar. The lightning current conduction route is shown in Fig. 7.
The main factors that affect the protection effect of radome lightning protection system are the material of shunt bar, the size of cross-section of splitter strip, the arrangement of splitter bar interval, etc. The selection of these main factors is usually preliminarily determined based on experience, and then the rationality is verified by test, and the design parameters are adjusted as required until the protection requirements are met.

4.5. Verify Compliance

The compliance verification needs to show that the structure can withstand the corresponding Lightning Environment safely. It can be verified by similarity analysis, experiment, calculation analysis or combination of several methods. Generally, new materials and new designs need to be tested to verify compliance.

According to SAE ARP 5416, for radome located in zone 1A, it is necessary to implement the radome lightning attachment point test and lightning current test[4], and use the voltage and current waveform mentioned above. The lightning attachment point test is used to determine the lightning attachment point and breakdown path of insulation material. The lightning current test is used to determine the effect caused by lightning current flowing into the attachment point. The test can refer to the following criteria,

1) During lightning attachment point test, radome composite sandwich structure shall not be perforated or layered.

2) During the lightning current test, the lightning protection shunt bar or its connecting bolt on the radome shall not fall off, but the shunt bar is allowed to deform locally; the hinge, quick release lock and guide pin of the radome shall not be disconnected.

4.6. Determine and Implement Corrective Measures

According to the compliance verification results, if the acceptance criteria approved by authorities are not met, the connection scheme between radome and fuselage, the connection form of metal parts and the number and distribution of shunt bars shall be optimized and verified again until the requirements are met.

5. Conclusion

According to the airworthiness requirements of direct lightning protection, the circumferential layout and length of lightning protection shunt strip of radome should be reasonably designed. The lightning leader should be attached to the lightning protection system first, and the current can be discharged through the lightning protection system to ensure the safety of radome and its internal avionics equipment. This paper discusses the verification method of lightning protection for radome, and verifies the effectiveness of radome lightning protection design by planning lightning attachment point test and lightning current test.
Acknowledgments
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