

AIRWORTHINESS ADVISORY

Airworthiness Impacts of Lightning Protection

ATTACHMENTS:

- (1) Glossary of Terms and Supporting Information
- (2) News Letter, ASD/EN, 23 Jul 1976

PURPOSE

This Airworthiness Advisory (AA) provides Delegated Technical Authorities (DTAs), System Program Managers, Directors of Engineering (DoE), Chief Engineers (CE), and MAJCOMs with criteria and guidance to support formulation of the Lightning Protection Airworthiness (AW) certification basis and associated compliance methodology. These criteria and methodology are provided to ensure that new and modified air systems have undergone appropriate review to understand airworthiness requirements, impacts to safety, methods of compliance and risks associated with non-compliances.

SCOPE

This AA applies to all United States Air Force (USAF) air systems, including those operated by the Air National Guard and USAF Reserve.

REFERENCED DOCUMENTS

- [1] MIL-HDBK-516C, *Department of Defense Handbook Airworthiness Certification Criteria*, 12 December 2014
- [2] The Horizontal Extent of Lightning Based on Altitude and Atmospheric Temperature, AFIT/GM/ENP/02M-10, 26 March 2002
- [3] A Comparison of Horizontal Cloud-to-Cloud Lightning Flash Distance Using Weather Surveillance Radar and the Distance Between Successive Flashes Method, AFIT/GM/ENP/99M-03, March 1999
- [4] NOAA Technical Memorandum ERL NSSL-105, "The Distance Between Successive Lightning Flashes", Raul E. Lopez, Roland L. Holle, September 1999
- [5] Monthly Weather Review, "Lightning in the Anvils of Supercell Thunderstorms", Stephanie A. Weiss, Donald R. MacGorman, Kristin M. Calhoun, 2 February 2012

[6] MIL-STD-461, Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment

[7] MIL-STD-464, Electromagnetic Environmental Effects Requirements for Systems

BACKGROUND

“At 9:38 a.m. April 29th 1996, lightning struck an AC-130H aircraft on Hurlburt Airfield, killing an airman, and injuring ten others on a maintenance crew. This mishap occurred despite adherence to AFOSH Standard 127-100 (Department of the Air Force, 1992), which was the standard at the time of the incident states "The weather officer will advise when thunderstorms and lightning are within a radius of 5 miles of the installation. All maintenance activities will cease when an electrical storm is within a three-mile radius of the installation, and will not resume until the storm passes beyond the three-mile limit."” [3].

Lightning strikes occur to aircraft and are hazardous to their safety of flight and safety to others around the aircraft on the ground; therefore, the aircraft and associated subsystems must include provisions for lightning protection. There is no known technology to prevent lightning strikes from occurring; however, lightning effects can be minimized with appropriate design techniques.

Lightning occurs at all levels in a thunderstorm. The majority of lightning discharges never strike the ground (cloud-to-ground), but occur between clouds (cloud-to-cloud), within a cloud (intra-cloud), or terminate in clear air (cloud-to-air). It should be noted that in many cases an aircraft flying near or within a thunderstorm, in cumulus clouds around a thunderstorm’s periphery, or in cirrus clouds downwind of recent thunderstorm activity, can actually trigger the lightning strike to occur. This makes the aircraft an integral part of the equation and not just an innocent victim of circumstances.

USAF historical records, as shown in Attachment 1, revealed that prior to 1976, at least six aircraft and ten lives had been lost from lightning strikes upon aircraft, which were not designed to modern lightning standards.

The Air Force Safety Center records from the Air Force Safety Automated System (AFSAS) over the period of 2006 – 2015, reported 241 lightning strikes that led to a formal mishap report:

Mishap Class	Number of Mishaps
A	5*
B	8
C	139
D	25
E	64

(* Note that all 5 of the Class A mishaps were Remotely Piloted Aircraft (RPA) with no lightning protection design.)

The lack of Class A events for manned aircraft in recent years can be attributed to the application of modern standards for lightning protection design and certification requirements, which were developed during the late 1980's and the early 1990's. These standards are the same ones utilized in the [1]. Note that the above data is based on lightning strikes that were reported, but there are a number of strikes that do not get reported.

POLICY

[1, Sec.13.1.1, 13.1.3 and 13.2.4] provide the lightning standards and methods of compliance for air systems and associated subsystems. In addition, [1, Sec. 8] has related criteria for fuel system lightning protection (Sections 8.3.12, 8.4.10, 8.7.2.1 and 8.7.2.10). These criteria are based on [6], [7] and a number of Federal Aviation Administration (FAA) standards and recommended practices, which are supported by decades of commercial and military aircraft flight experience.

GUIDANCE ON REQUIREMENTS

Due to the complicated nature of lightning and how it interacts with aircraft, the definition of lightning requirements has been broken down into two primary categories. The first category is identified as Lightning Direct Effects, which constitute the characteristics of lightning that drive physical damage to the aircraft. The physical damage effects of lightning are the burning and eroding, blasting, and structural deformation, high pressure shock waves and magnetic forces produced by the associated high currents. In addition, there is a sub-category of Direct Effects associated with the fuel system and other flammable liquid systems, which may result in a hazardous condition, i.e. unintentional ignition as a result of the high currents and voltages from the lightning strike. Direct Effects requirements are captured in [1, Sec. 13.2.4] and address both system and component level requirement definition. Also, as stated earlier, the fuel system certification requirements have additional related criteria in Section 8.

The second category is defined as Indirect Effects. Indirect Effects are electrical transients being injected into air system electrical circuitry as a result of the interaction from the electromagnetic fields associated with lightning currents present in the aircraft and the equipment wiring routed within the aircraft. In addition, Indirect Effects can cause currents or voltages that are hazardous to personnel. For example, serious electrical shock may be caused by currents and voltages conducted via mechanical control cables or wiring leading to the cockpit or weapons station of an aircraft from control surfaces or other hardware struck by lightning. Indirect Effects are sub-divided into Transient Control Levels (TCL) and Equipment Transient Design Levels (ETDL). TCL's represent the transients expected to impinge the electrical interface of an aircraft electrical circuit and are typically measured or determined at the air system level. The ETDL represents the design capability of the equipment interface to safely withstand the transient when

applied to interface and are typically applied to the components and sub-system electrical interfaces as part of the equipment qualification testing. Design practices typically want to see a 2:1 ratio (6 dB) margin between ETDL vs. TCL. Indirect Effects requirements for component/sub-systems are captured in [1, Sec. 13.1.1 and 13.1.3]. The Indirect Effects requirements at the air system level are captured in 13.2.4.

DESIGN AND VERIFICATION METHODOLOGY

Techniques such as shielding, electrical grounding and bonding, diverter strips, terminal protection devices such as diodes, filters and spark gaps are used as part of the lightning protection design. The following steps describe the recommended methodology for satisfying the certification requirements for aircraft lightning protection:

1. Identify the systems to be assessed
2. Determine the lightning strike zones for the aircraft
3. Establish the airframe lightning current paths for the zones
4. Determine the aircraft lightning transient threats for components/subsystems, including avionics, fuel system, structure, and OML components
5. Design components, systems, and structure to handle the threats defined in Step 4 with a minimum of 6 dB margin
6. Verify compliance
7. Take corrective measures, if needed

Verification of the lightning requirements is essential to demonstrate that the design protects the system from the lightning threat. There is no single approach for verification of the lightning protection design. A well-structured test program supported by analysis is necessary.

For example, Direct Effects requirements on external structures can be verified by coupon testing of representative skin or structure. It may also include full scale testing of an entire radome. Fuel tank protection is typically achieved by eliminating the potential for ignition of fuel vapors when the aircraft is struck by lightning (i.e. domed nut-plates, fillet seals, copper mesh around fasteners). Protection of fuel tanks is verified by coupon testing of representative fuel tank walls demonstrating spark free conditions inside the tank and/or supplemented by an inerting system designed to eliminate possible ignition by reducing flammability of the fuel-air mixture within the tank. However, an on-aircraft inerting system such as the Onboard Inert Gas Generating System (OBIGGS) cannot be relied upon as a sole source of fuel system lightning protection because there is no verifiable aircraft lightning protection when the aircraft engines are not running. At the time this AA is written, ambient air temperature cannot be used to predict the flammability of the fuel-air mixture because many factors affect the temperature of the fuel-air mixture within each fuel tank (i.e. bulk fuel temperature, solar heating, convection, thermal heating from structure and components, fuel flammability properties, fuel delivery temperature during refuel, etc.).

Indirect Effects are verified by injection of lightning type electrical transients on subsystems and equipment cables to demonstrate the equipment capability to withstand such current and voltage transients. In addition, aircraft low level Continuous Wave (CW) excitation is used to demonstrate Indirect Effects compliance and to show required design margins for safety/flight critical equipment.

As previously indicated, the naturally occurring lightning event is a complex phenomenon. The engineering models that are defined in the referenced design standards are a combined definition using a family of waveforms, which represents the technical community's best effort at defining a comprehensive simulated environment for design and verification purposes. Following these standards do not guarantee that the design will be invulnerable to lightning strikes, but it does provide a high level of confidence in the air system's capability to safely survive and operate through a strike event. It should be noted that the focus of [1] criteria is primarily to address flight critical and safety critical aspects, and there are significant facets related the damage tolerance of an air system and the associated economic impacts. These economic aspects are beyond the scope of this AA, but nevertheless should be considered in the design.

ASSESSING RISK AND MITIGATIONS

For assessing the flight critical and safety critical aspects of lightning protection, design-based AW assessments are the only acceptable path for AW compliance. This is due to the unpredictability and randomness of lightning coupled with the catastrophic consequences of a strike on an unprotected aircraft. As a result, probability calculations are neither a valid path to compliance nor should they be used to mitigate flight critical and safety critical risks. Therefore, it is imperative that an up-front lightning protection design substantiated by applicable verification methods be the only path to achieve compliance.

In some cases, flight testing of aircraft occurs prior to verification of the lightning protection design. Under these circumstances, the flight test program must include restrictions to prohibit flying within 25 Nautical Miles (NM) from thunderstorms. This flight mitigation is also used when the aircraft lightning protection design is not present or when the protection design has been degraded.

The 25 NM separation mitigation is common across all three services and is also used by FAA and the National Aeronautics and Space Administration (NASA). It is based upon an extensive history/experience base. It should be noted that the 25 NM separation distance from thunderstorms reduces but does not eliminate the possibility of an aircraft being struck by lightning since flashes can occur at larger distances from the thunderstorms clouds and can occur up to an hour after the storm appears to have left the area. In addition, large pockets of charge can occur in developing thunderstorms that have not yet exhibited lightning and decaying thunderstorms that have not produced lightning for some time that can be discharged by an aircraft flying between opposite charge pockets.

A study conducted at the Air Force Institute of Technology (AFIT) in 2002 [2] examined over 40 million lightning flashes and associated branches occurring at Kennedy Space Center over a 4-year time period. This study found that the 99th percentile of occurrence for lightning strike distance between the surface and 83,000 feet is 22 NM in the summer and 27 NM in winter, which supports other sources that identify 25 NM as a safe separation distance for nearly all lightning strike events. Though strikes were observed well beyond this distance (up to 89 NM), the infrequency of these events, when combined with proven operationally validated data and a need to define a reasonable safe distance that still allows for flight operations, suggest 25 NM as the standard to maintain. These conditions are also cited in climatology reports and industry lightning research studies [5].

The graphic below [3] illustrates typical lightning strike pathways and polarity in cloud-to-ground lightning in and around a thunderstorm cell. This graphic schematically represents some of the various locations within and around a thunderstorm a strike may occur.

Note: This graphic does not depict cloud-to-cloud and cloud-to-air strikes that account for ~60% of all lightning strike activity.

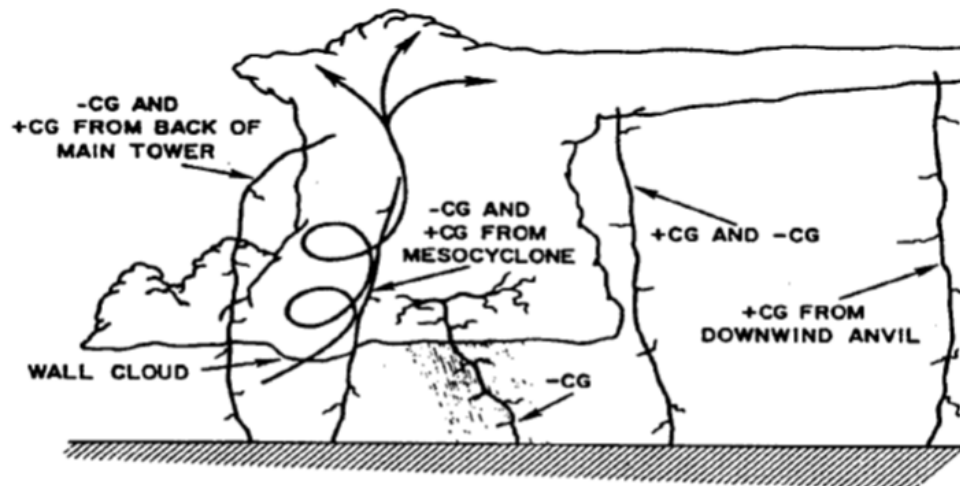


Figure 4 Adapted from Rust and MacGorman (1981) showing most flashes to ground from anvil regions are positive, and flashes to ground from precipitation regions are negative

Significant variation in strike distance from the thunderstorm center exists over time within a single storm and also when comparing two different thunderstorms. A National Oceanic and Atmospheric Administration (NOAA) technical memorandum issued in 1999 [4] identified that a single thunderstorm may create lightning strikes up to 35 miles apart over a 10 minute period. This horizontal variation is important because lightning can occur in any portion of clouds associated with the thunderstorm, not just near the center of a thunderstorm. Because of the

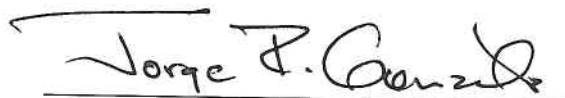
dynamic changes that occur in the lifecycle of a thunderstorm as it matures, moves, and eventually dissipates, all clouds associated with the thunderstorms should be assumed to be able to generate lightning. This information further suggests that a standard 25 NM standoff distance from thunderstorms be maintained for aircraft with missing, degraded, or inactive lightning protection systems.

ADDITIONAL SUPPORT

There is no “one size fits all” lightning protection approach for AW. Technical evaluations are executed on a case-by-case basis taking into consideration the extent of the design modification or new design and the aircraft type. Even though there is a substantial amount of information and supporting guidance contained within the Society of Automotive Engineers (SAE) documents referenced in [6] and [7], in most cases, the Program Office will require an AW Subject Matter Expert for determining AW impacts of lightning. Technical expertise is available from AFLCMC/EZAC to assist as required.

POINTS OF CONTACT

USAF Airworthiness Office (AFLCMC/EN-EZ) is the OPR. Comments, suggestions, or questions on this bulletin should be emailed to the USAF Airworthiness Office Mailbox (USAF.Airworthiness.Office@us.af.mil).



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Attachment 1**GLOSSARY OF TERMS AND SUPPORTING INFORMATION*****Abbreviations and Acronyms***

AA – Airworthiness Advisory

AF – Air Force

AFIT – Air Force Institute of Technology

AFLCMC/EN-EZ – Air Force Life Cycle Management Center, Engineering Directorate

ASD – Aeronautical Systems Division

AW - Airworthiness

CE – Chief Engineer

CW- Continuous Wave

dB – Decibels

DoE – Director of Engineering

DTA – Delegated Technical Authority

ETDL – Equipment Transient Design Levels

FAA – Federal Aviation Administration

NASA – National Aeronautics and Space Administration

NM – Nautical Miles

NOAA – National Oceanic and Atmospheric Administration

OBIGGS – Onboard Inert Gas Generating System

OML – Outside Mold Line

RPA – Remotely Piloted Aircraft

SAE – Society of Automotive Engineers

TCL – Transient Control Level

USAF – United States Air Force

Attachment 2

Internal Air Force Working Paper, News Letter, ASD/EN, dated 23 Jul 1976

ENUN18053

INTERNAL AIR FORCE WORKING PAPER
 DEPARTMENT OF THE AIR FORCE
 HEADQUARTERS AERONAUTICAL SYSTEMS DIVISION (AFSC)
 WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433



REPLY TO
 ATTN OF: EN

JUL 23 1976

SUBJECT: Newsletter

TO: Chief Engineers

Aircraft Lightning Strike

During the ten year period from 1965, the Air Force has reported 766 lightning strikes. Official losses from these strikes include six aircraft and ten lives. Avionics losses, which occurred in approximately half the reported cases, totaled over \$13 million.

Since official avionics losses are declared only when structural lightning damage is evident and because aircraft operating regulations require pilots to stay twenty miles away from lightning activity except in extreme emergencies, it appears that all lightning strikes and damage are not reported. As an indication of the probable frequency of aircraft lightning strikes, U.S. airline representatives report an average of one strike per aircraft per year on commercial aircraft.

The effect of most lightning strikes is minimal because of the shielding effects of the aircraft's metal surface structure. When lightning does penetrate the super structure, the damage is often severe, especially to electronics. A favorite point of entry is the Pitot nose boom where the lightning jumps the insulation and follows the boom heater wiring into the aircraft electrical system. Less frequent, but common points of entry are through the radome and through wing tip lights.

Damage is caused by direct current conduction and/or by electric or magnetic fields. It ranges from thermal melting/exploding of structure and electrical devices to inadvertent electrical reactions such as computer data dumps, activation of armament, and erroneous measurements. The estimated average current pulse is about 30,000 amps with maximum values about 200,000 amps. Insufficient measurements have been made to obtain reasonable estimates of the pulse duration.

The deleterious effects of lightning can be minimized by using the techniques of shielding, bonding, diverting and electrical protection.

Shielding is provided by the aircraft's surface structure, metal plating or wire mesh placed around critical equipment, coax cabling of wires, and by special conductive coatings. Good bonding of structural and electrical joints will provide better flow of current and minimize the possibility of thermal rupture.

Diverting techniques, as the name implies, are used to conduct the electric impulse away from critical areas. For example, metal strips or

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buttons are placed on radome surfaces so as to conduct lightning away from the radar. They are designed to minimize interference with radar performance. (The buttons are spaced close enough so current jumps from one to the other rather than to the radar.)

Electrical suppressors and filters, such as spark gaps, choke coils, thyristor and zener diodes can also be used as electrical protection for circuits. Many lightning hardened circuits and components are available thanks to the work done to protect against electro-magnetic pulses (EMP).

Technology is not currently available to predict lightning effects without actual hardware testing. To determine the impact of direct current, one-tenth scale vehicle models are systematically struck in lightning chambers to determine points of contact of the lightning bolt. Full scale vehicle sections are then put in the chamber to measure the amounts of direct current which penetrate the surface (such as through the Pitot boom). Induced currents are found by attaching electrical wires to two points on the actual vehicle. The reaction at critical equipment locations is measured when the system is pulsed. The in-service shocks expected by the critical equipment are found by using the ratio of the estimated lightning strike current to the test pulse current. The equipment is then shocked in the laboratory in increasing steps up to this expected value to determine vulnerability and to establish fixes.

With the expanding use of composite structure (non-shielding) and "fly-by-wire" flight control systems, additional emphasis has been placed on aircraft lightning protection. A recently completed DAG report has highlighted two general areas that require additional emphasis and understanding. One is the need for better understanding of the flow of direct/induced current in the interior of the aircraft and its effect on avionic equipment. The other is the need for better reporting methods from the services and airlines on the extent of lightning strikes and damage. An EN/XR/AFWAL ad-hoc committee has been formed to prepare a comprehensive "road-map" for lightning to implement the findings of the DAG report.



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