Electromagnetic Effects Harmonization Working Group (EEHWG)—Lightning Task Group: Report on Aircraft Lightning Strike Data

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16. Abstract

In 1995, in response to the lightning community's desire to revise the zoning criteria on aircraft, the Electromagnetic Effects Harmonization Working Group (EEHWG) decided that lightning attachments to aircraft causing damage should be studied and compared to the then valid zoning classification per Federal Aviation Administration Advisory Circular AC 20-53A. The primary function of the EEHWG is to harmonize the environments that aircraft are being subjected in both the North American and European environments. A Lightning Task Group was formed in EEHWG, and strike data were solicited from almost all major airframe manufacturers in North America and Europe. After these responses were received, this report was prepared for the general EEHWG committee.

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EXECUTIVE SUMMARY

The goal of this report was to obtain information on aircraft lightning attachments to an aircraft structure. Several manufacturers participated in this study providing a total of 2402 lightning strike encounters. After reviewing the lightning data, the lightning task group for the general EEHWG Committee made the following observations.

1. The zoning guidelines currently in place as outlined in Federal Aviation Administration (FAA) Advisory Circular 20-53A are valid.

2. In certain aircraft models, there are a significant number of lightning attachments resulting in damage in Zone 2.

3. There is not enough data to sufficiently warrant the need for a Zone 1 extension.

4. As a result of this data, it has been shown that no zone is completely immune to damage from lightning attachments.

The findings of this study are summarized in this data report. Additional data gathering from other manufacturers is ongoing and will be used to evaluate the current FAA zoning classification.

INTRODUCTION

The Federal Aviation Administration (FAA) established the Electromagnetic Effects Harmonization Working Group (EEHWG) under the Aviation Rulemaking Advisory Committee on Transport Airplane and Engine Issues and tasked it to update, in coordination with the Joint Airworthiness Authority (JAA), lightning protection certification requirements for aircraft. As part of this task, the EEHWG was asked to update the aircraft lightning attachment zone definitions in the existing FAA lightning advisory circulars.

In 1995, the EEHWG initiated a study on lightning attachments to aircraft causing damage to compare with the lightning attachment zone definitions in the FAA Advisory Circular (AC) 20-53A [1]. A lightning task group was formed within the EEHWG, and lightning attachment data were solicited from major aircraft manufacturers in the U.S. and Europe. Responses were received by a significant number of those contacted. The aircraft covered in the responses were of widely different sizes, geometric profiles, external skin composition (i.e., metal, carbon-fiber composite, etc.), and had various flight profiles. In 1998, the Lightning Task Group solicited updated lightning attachment data from a number of aircraft manufacturers to compare these data with the updated zoning definitions.

After these responses were received, a report was prepared by the Lightning Task Group for the general EEHWG committee. The initial report was prepared by Tapas Mukutmoni of McDonnell-Douglas in 1996. The updated report was prepared by Olaf Spiller, Airbus Industries, the lightning task group chairman.

Following on the work of Mukutmoni and Spiller, the EEHWG prepared a draft report, "Aircraft Lightning Zoning," to replace the lightning attachment zone information in FAA AC 20-53A [1]. This EEHWG report was adopted by the Society of Automotive Engineers (SAE) Lightning Committee and published as SAE ARP5414, "Aircraft Lightning Zoning" [2]. EUROCAE Working Group 31 published an equivalent document as EUROCAE ED-91, "Aircraft Lightning Zoning" [3].

1996 DATA (MUKUTMONI)

The intent of this exercise was to obtain information of the aircraft locations where lightning tend to attach most frequently and cause damage to the structure. The fact that such damage may, in some cases, compromise the safety of the aircraft in flight provided impetus for the EEHWG to look into this matter.

The list below shows the aircraft manufacturers that responded, in alphabetical order. (Aircraft models covered are in parentheses.)

- Airbus Industries (A310 and A320)
- Boeing (B747, B757, and B767)
- Cessna (Citation 500 and 650)
- Dassault (T-A through J, MD)
- Fokker (Jets - F28, F70, and F100; Turboprops - F27 and F50)
- McDonnell-Douglas (MD-80)

The total number of lightning strikes that caused damage to aircraft, reported by the aircraft manufacturers, are shown in table 1. The reporting period was roughly between 1955 and early 1994. Figures A-1 and A-2 in appendix A summarize all reported data. Figures A-3 to A-9 show the data from individual manufacturers.

TABLE 1. NUMBER OF LIGHTNING STRIKE ENCOUNTERS REPORTED BY THE AIRCRAFT MANUFACTURERS (1996 DATA)

Manufacturer	Number of Lightning Strikes
Airbus	169
Boeing	1812
Cessna	16
Dassault	278
Fokker	44
McDonnell Douglas	83
Total	2402

LIMITATIONS OF 1996 DATA

The draft 1996 data report by Mukutmoni identified the following issues that should be considered when assessing the 1996 aircraft lightning attachment data.

- The phenomenon of lightning attachment to aircraft is not fully understood. Lightning attachment to an aircraft can easily be confused with strong electrostatic discharges in a thunderstorm environment when lightning activity is frequent in neighboring areas of airspace.

- Aircraft with adequate instrumentation to distinguish between the mentioned phenomena are not available in commercial aviation.

- Catastrophic or hazardous (severe-major) damage to aircraft due to lightning strike is extremely rare.

- Detailed information in aircraft manufacturers databases necessary for an in-depth evaluation of every facet of lightning attachment is, in most cases, not available.

- Airline pilots do not report all incidents.

- This is the first attempt (1996 status) by an industry committee to collect lightning attachment/damage data where a large number of aircraft manufacturers responded.

- Though there are a relative significant number of strikes reported in the Zone 3 areas, it should be recognized that strikes in these areas are normally of much lower amplitude or severity due to the fact that these strikes are typically of intercloud activity (i.e., typically the striking distance is small). It has to be recognized that the sample of statistical data presented in this report does not answer all outstanding questions on the phenomenon of lightning attachment to aircraft. More work in this direction is necessary.

CONCLUSIONS FROM 1996 DATA

The draft 1996 data report by Mukutmoni identified the following conclusions after assessing the 1996 aircraft lightning attachment data.

a. The zoning guidelines, as prescribed in FAA AC 20-53A, are essentially valid. Any drastic extension of Zone 1, similar to what one would get using the simplified rolling sphere technique, cannot be justified.

b. In some aircraft models there are a significant number of lightning attachments resulting in damage in Zone 2 (up to 41% reported by Fokker jets). The term damage in this report has been used to denote a distinctly identifiable change from the original state of the aircraft structure which required some kind of repair. None of the damage noted in this report resulted in safety-related problems.

c. Reported data did not include sufficiently detailed information to support any definitive conclusions regarding the need for a Zone 1 extension. However, given the number of lightning attachments within Zone 2, some extension may be justified. The Task Group proposes to request the additional information needed to make an informed decision on this issue.

d. No lightning attachment zone is completely immune to damage from lightning attachments. According to available reports, the damage in Zone 3 due to lightning attachments were minor in all cases. It may be prudent to introduce some protection from lightning attachment at a reduced level.

These conclusions were provided to the EEHWG Lightning Task Group for members review and comment.

LIGHTNING TASK GROUP COMMENTS ON 1996 DATA

The 1996 data reported by Mukutmoni were reviewed by the EEHWG Lightning Task Group. The written comments on the 1996 data assessment received from members of Lightning Task Group are listed below.

a. M. McRae (FAA) Comments

   1. For aircraft in this study zoned per the guidelines prescribed in FAA AC 20-53A, the percentage of strikes reported within Zone 1 ranged from 87% to 53%; the percentage of strikes reported within Zone 2 ranged from 41% to 12 %; and the strikes reported within Zone 3 ranged from 23% to 0%. Also, the number of lightning strike attachments which caused reportable damage on a given aircraft always decreased from Zone 1 to Zone 2 and again (with one notable exception) from Zone 2 to Zone 3. Consequently, the zoning guidelines prescribed in FAA AC 20-53A would appear to be a valid means of predicting the relative probability of encountering a lightning strike on a given surface of most fixed wing aircraft.

2. Reportable damage from lightning strike attachments occurred in all three lightning strike zones of fixed wing predominantly metallic aircraft in this study. These aircraft were zoned per the guidelines prescribed in FAA AC 20-53A, which prescribes limited direct effects protection for Zones 1 and 2 but does not prescribe any direct effect protection for Zone 3. Consequently, while the reference zoning guidance itself appears to be adequate for assessing the relative probability of attachment, some additional lightning protection guidance should be developed to assure that the probability of encountering an aspect of the lightning environment for which the aircraft is not protected, is acceptable, given the anticipated consequences of that encounter.

b. J. Howells (UK CAA) Comments

The raw data was composed from maintenance reports on aircraft/structure damage attributed to lightning attachments. Unfortunately, the reports do not identify if the damage was caused by initial attachment, return stroke, or arc attachments due to swept stroke.

Majority of reported damage (> 70%) occurred in the designated Zone 1, as defined in AC 20-53A. However, there was a significant number (up to 30%) of damage reports in the designated Zone 2, as defined in AC 20-53A.

There is a possibility of initial return stroke attachments outside of the AC 20-53A, defined in Zone 1. Some of these may be attributed to the sweeping leader effect. This may account for the damage reported in Zone 2 areas.

I believe the only conclusion that can be reached from the analysis of this raw data is that there is a need for a Zone 1 extension. The proposal methodology for a swept leader extension using the "d" method as per (the draft zoning advisory circular) in its present form is not justified.

The present zoning rules in AC 20-53A need redefining to take into consideration initial return stroke attachments, swept strokes. Suggest that we await the review of the proposed Zoning document from SAE-AE2/EUROCAE WG31 before making any decisions.

c. J. Hardwick (Culham Laboratories) Comments

As written, the work conducted by Tapas Mukutmoni is confusing mainly due to the plots (as outlined in appendix A-1). He (Mukutmoni) says in conclusion, "drastic extension not justified" what does he mean; he should be more quantitative. Does he mean some extension is in order? Some people think a line extension is drastic, others would reserve the use of this word for an extension to include the whole aircraft.

At face value the plots imply percentage of strikes noted in zones defined by AC 20-53A. What constitutes a strike? An arc attachment? For a single incident, on this definition, there should be a single strike in Zone 1A and one in Zone 1B, i.e., two in Zone 1 in total and any number in Zone 2, depending on the number of reattachments due to sweeping. AC 20-53A has nothing to say about the relative number of attachments in the Zone 1 and 2 regions, in fact, we would expect more arc attachments in Zone 2 as more strikes in Zone 1. However, there should be no attachments at all in Zone 3. In Mukutmoni's conclusion he does say damage for strikes in Zone 3 there should be no such strikes or does he mean one zone that can be allowed to occur in zone protected at the next level down is extremely small (see appendix A for these comments). On this basis all plots show violations against AC 20-53A given that they have strikes in Zone 3. In particular, the 23% of strikes to Dassault aircraft occurring in Zone 3 is very bad for AC 20-53A. I have never observed such as discrepancy, surely this is a mistake?

If the plots refer to initial return stroke attachments, all strikes should occur in Zone 1. I presume that cannot refer to this given that there are a lot of strikes in Zone 2. Do the plots refer to damage in the different zones? AC 20-53A says nothing about this except that if the protection has been done correctly there should be no flight safety endangering damage in any zone. Cosmetic or nonsafety critical damage can occur in all zones to any level deemed acceptable by the owner from point of view of maintenance/cost of ownership.

Therefore, the data presented either show too many attachments outside the AC 20-53A zones (Zone 3) or they are irrelevant. They say nothing about the restriction or not of severe strikes to Zone 1. Incidentally, if one reads AC 20-53A carefully it notes that occasionally first return strokes can occur aft of Zone 1A as defined and this possibility should be considered if such attachments would constitute a flight safety hazard. See 10.c.(1) last two sentences page 7. This concern I guess is why the FAA have gone for special conditions on composite aircraft and is the spirit of the new drafts.

We have been through these discussions before but the reason existing strike data do not show too much anomalous damage is because aircraft have been built out of METAL. An initial return stroke occurring in Zone 2 would not show any severe effects other than possible enhanced force effects (as noted in the recent BAe data from Max Todd maybe). On the other hand, should this occur on an inadequately protected composite structure, the effects could be catastrophic. I thought such condition of demanding an extended Zone 1 on composite engine nacelles with FADECs etc. The only data of real use for the zoning discussions are documented incidents that show the compatibility or not of the damage sustained and the damage expected for the zone where the damage has occurred, not an easy task!

1998 DATA (SPILLER)

The EEHWG Lightning Task Group solicited updated aircraft lightning strike data from aircraft manufacturers in 1998. All aircraft manufacturers that had responded to the first reporting period in 1996 were requested to provide updated aircraft lightning attachment data. The aim was to compare the data of the lightning strike incidents with the existing AC 20-53A and the draft advisory circular, "Aircraft Lightning Zoning," to validate the revised lightning attachment zoning concept.

Two aircraft manufacturers responded. This new data, though very detailed for one manufacturer, do not provide a significant statistical basis for further detailed analysis since it does not cover a wider range of aircraft models in terms of size, geometry, and flight profiles/aircraft utilization. A total of 250 reported lightning strikes are included in this data set. The data are compiled in appendix B.

1996 AND 1998 LIGHTNING ATTACHMENT DATA ASSESSMENT

The 1996 and 1998 lightning attachment data assessments were used to develop revised guidance on aircraft lightning attachment zones. The revised guidance considered the comments from the EEHWG Lightning Task Group members listed above. The revised guidance was incorporated into a draft advisory circular "Aircraft Lightning Zoning." Several key revisions were incorporated into this draft advisory circular. This draft advisory circular was provided to the SAE AE2 and the EUROCAE Working Group 31 lightning committees.

The SAE AE2 and the EUROCAE WG-31 lightning committees incorporated this draft advisory circular information into updated guidance on aircraft lightning zoning. See references 2 and 3 for these reports.

One key revision was the introduction of an expanded Zone 1, which is the initial lightning attachment zone. The 1996 and 1998 data showed a significant number of reported lightning strike attachments causing damage in Zone 2, as defining in the existing zoning guidance in AC 20-53A. This led to a major change in the draft zoning advisory circular and AC 20-53A. This change extends the area for Zone 1A and introduces the transition Zone 1C between Zone 1A and the swept stroke Zone 2A.

Zone 1A extension is defined by the equation

$$d_1 = h * TAS/V_1$$

where d_1 is the maximum leader sweep distance as a function of the aircraft altitude h and the true aircraft speed TAS (all in metric units). V_1 is the leader velocity given as $1.5*10^5$ m/s. Zone 1A is calculated for an aircraft altitude of approximately 1500 m (5000 ft).

The extension of Zone 1C is dependent on the extension of Zone 1A. For Zone 1C, the leader sweep distance d_2 is calculated using the same formula as for Zone 1A, but for an aircraft altitude of approximately 3000 m (10,000 ft). The aircraft structure between the two distances d_1 and d_2 is in Zone 1C. Also, for design considerations, the return stroke amplitude is lower than the component A (150 kA versus 200 kA) for Zone 1A, called Component A_h.

The zoning example for a transport category jet aircraft from the document is given in appendix C of this report. For further details see references 2 and 3.

LIGHTNING STRIKE DATABASE

The EEHWG Lightning Task Group recommended that this data should be incorporated into a lightning database, and that future reports of aircraft lightning attachment be added to this database. The data could be presented so that the individual aircraft model and manufacturer would not be identified, therefore, maintaining the necessary confidentiality.

The desire is to have a standardized format for reporting the lightning incidents and adding these reports into a database. Interested companies or individuals could use such a database to gain better understanding about zoning and the repercussions on a given aircraft design.

The need to establish such a database for the above given reasons is still being considered. This database activity cannot be performed by the EEHWG Lightning Task Group because EEHWG activities are complete. The EEHWG Lightning Task Group recommends that the SAE and EUROCAE lightning committees that already have contributed greatly to expanding the knowledge and understanding of the lightning phenomenon in the aerospace industry follow-up on this open item.

One recommendation is the adoption of a generic form for the purpose of reporting lightning strike/static discharge incidents in service. This should be included in the aircraft manuals. It could provide essential information from the reported lightning strike and identify any possible effects on the aircraft, which would provide for an easier analysis of aircraft lightning effects. A version of such a reporting form, currently used by one aircraft manufacturer, is given in appendix D.

REFERENCES

1. FAA AC 20-53A, "Protection of Aircraft Fuel Systems Against Fuel Vapor Ignition Due to Lightning," April 1985.

2. EUROCAE report ED-91, "Aircraft Lightning Zoning," July 1998

3. SAE report ARP5414, "Aircraft Lightning Zoning," December 1999.

APPENDIX A—1996 DATA PLOTS

The following figures are based on the zoning definition in accordance with AC 20-53A.

The following assumptions should be applied to figures A-1 through A-9.

- Assume the probability of lightning hazard should be less than 1 in 10^9 flying hours. Also assume that one lightning strike occurs approximately every 1000 flying hours. Most severe strikes on which certification levels are based are c-g (cloud to ground), and there is only one strike to ground involved with every 100 aircraft strikes. About one in ten cloud to ground strikes has current/energy levels greater than Zone 2 protection levels (i.e., peak current of 100kA and action integral of 0.25×10^6 (A^2sec)).

- These (conservative) assumptions give a lightning strike to aircraft exceeding Zone 2 requirements every 10^6 flying hours. That is, Zone 1 should contain all but 1 in 1000 initial return strokes to have a hazard probability of 1 in 10^9 which is 99.9%!!!

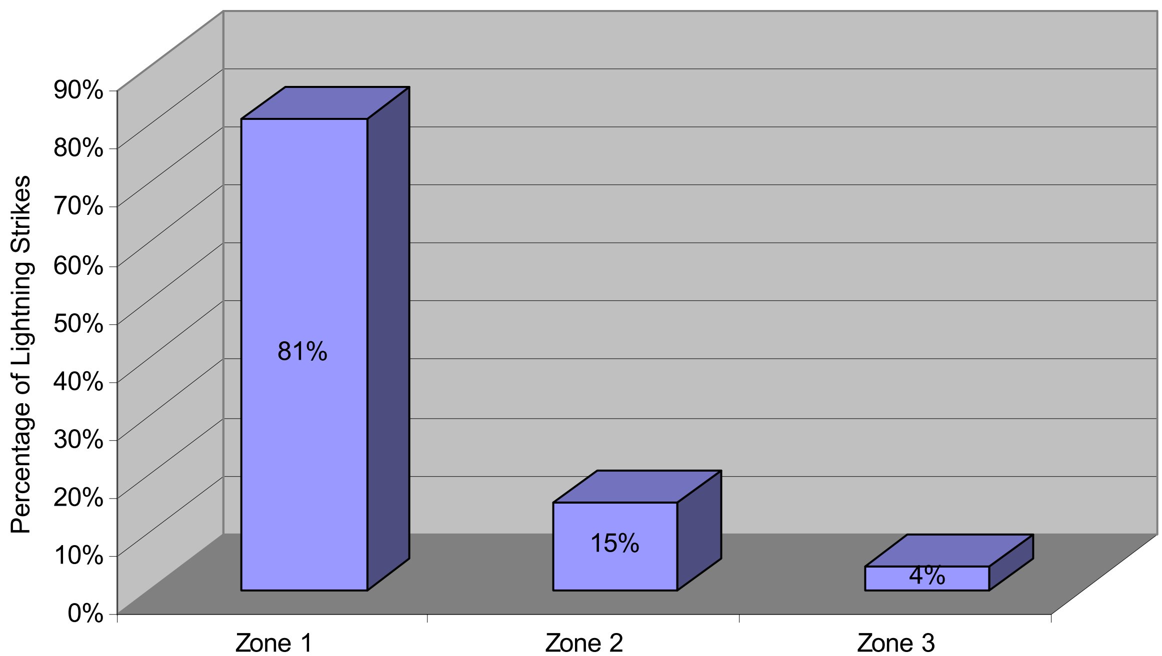


FIGURE A-1. SUMMARY OF ALL DATA – REPRESENTATION BASED ON DATA SUBSETS MUTUALLY INCLUSIVE

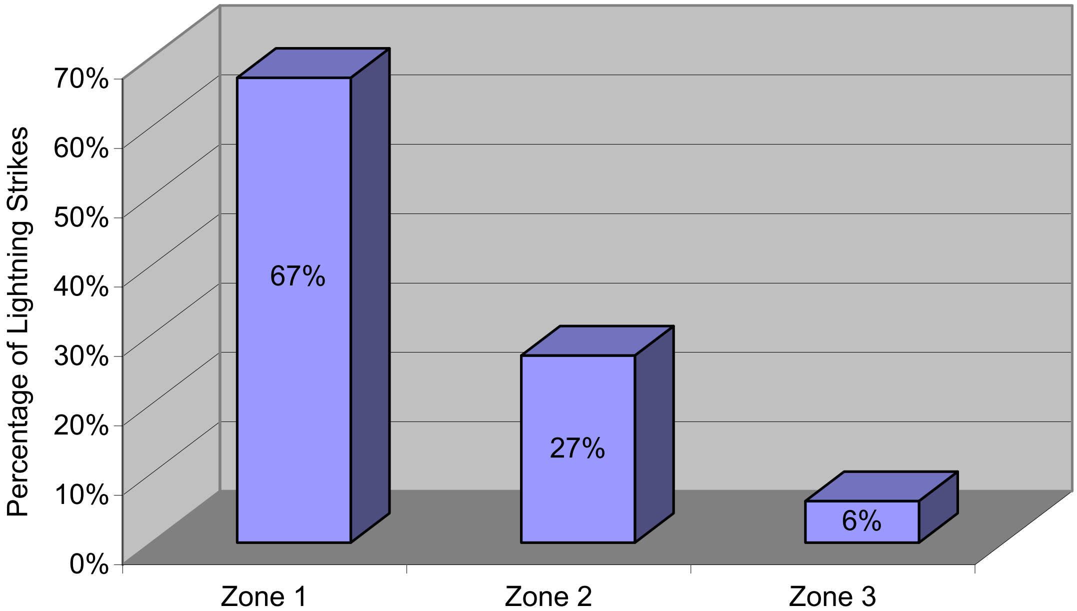


FIGURE A-2. SUMMARY OF ALL DATA – REPRESENTATION BASED ON DATA SUBSETS MUTUALLY EXCLUSIVE

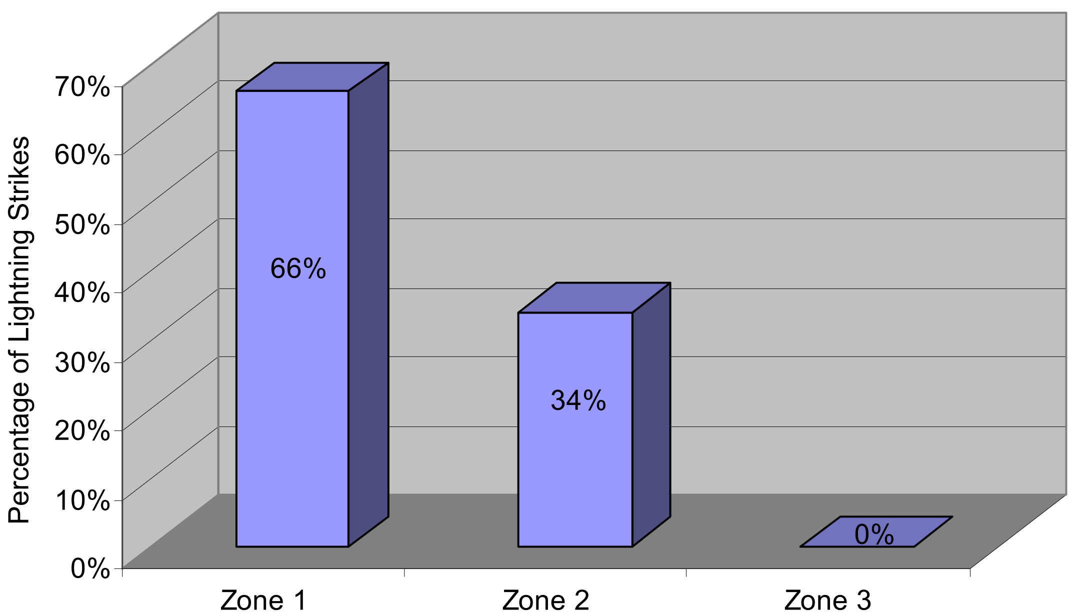


FIGURE A-3. AIRBUS DATA

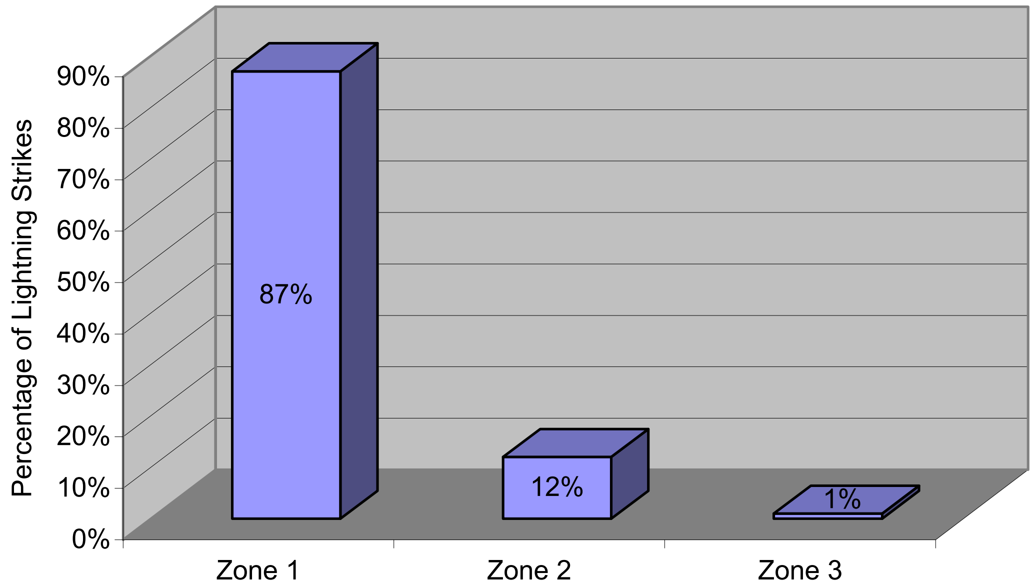


FIGURE A-4. BOEING DATA

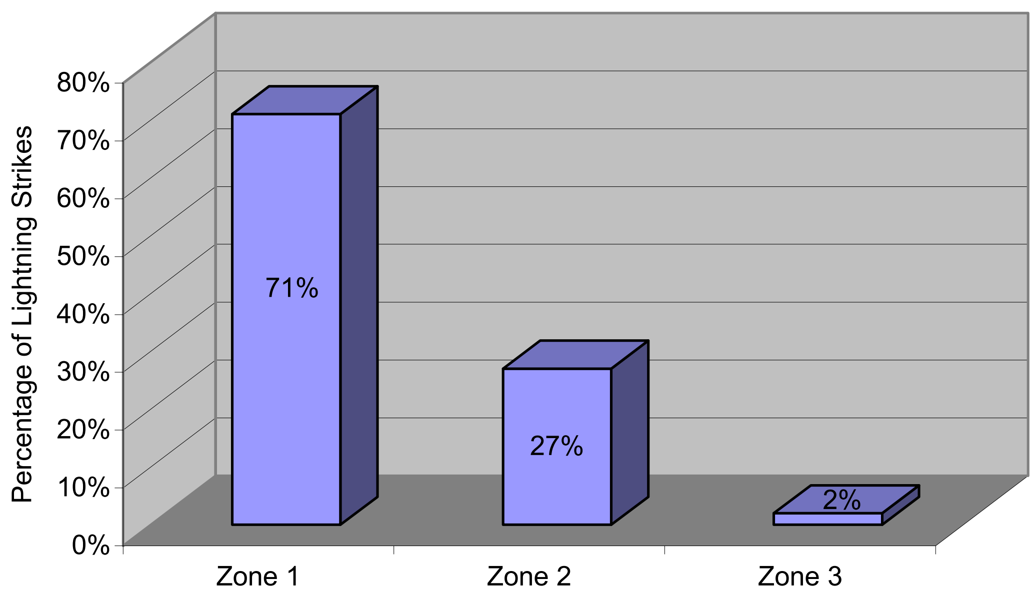


FIGURE A-5. CESSNA DATA (Citations)

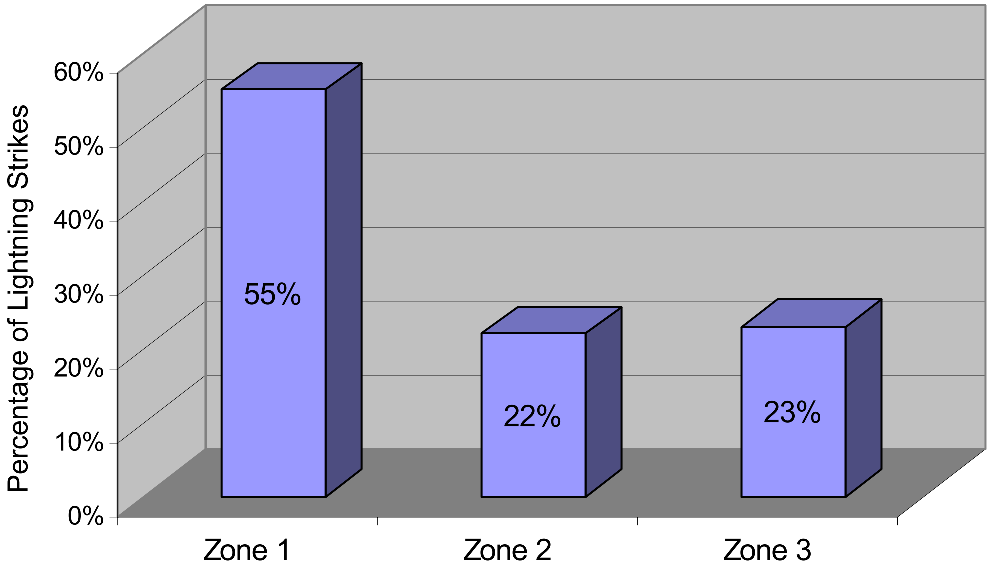


FIGURE A-6. DASSAULT DATA

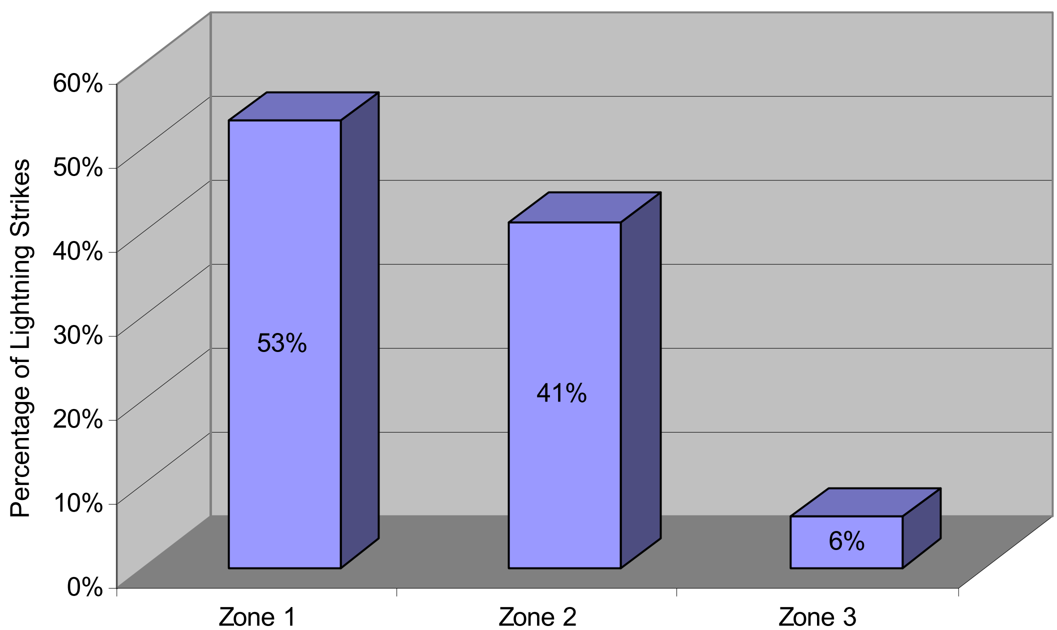


FIGURE A-7. FOKKER DATA (Jets)

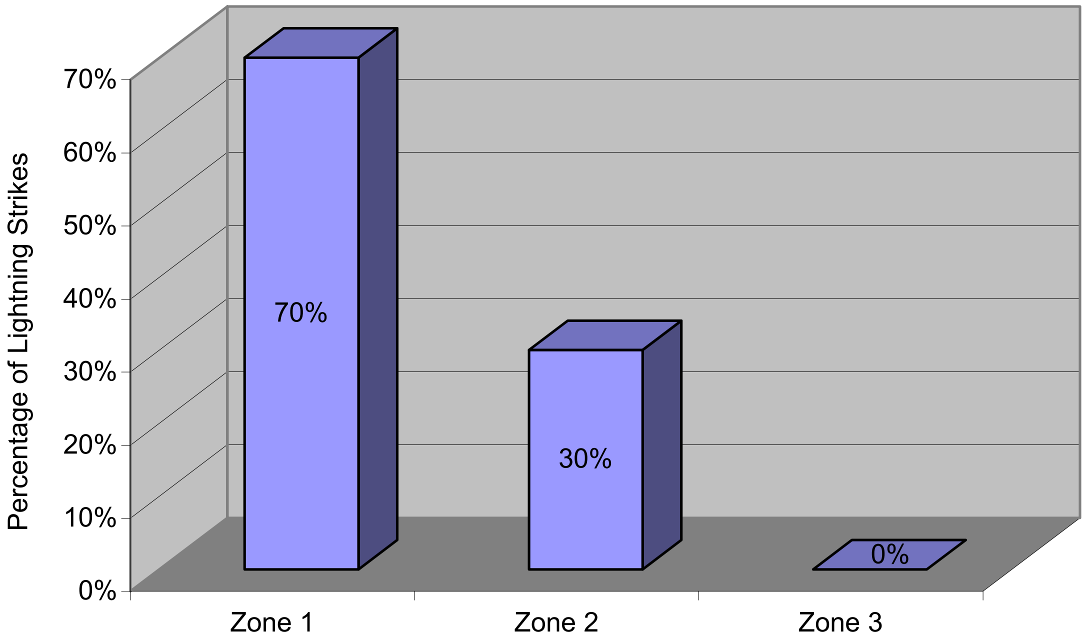


FIGURE A-8. FOKKER DATA (Props)

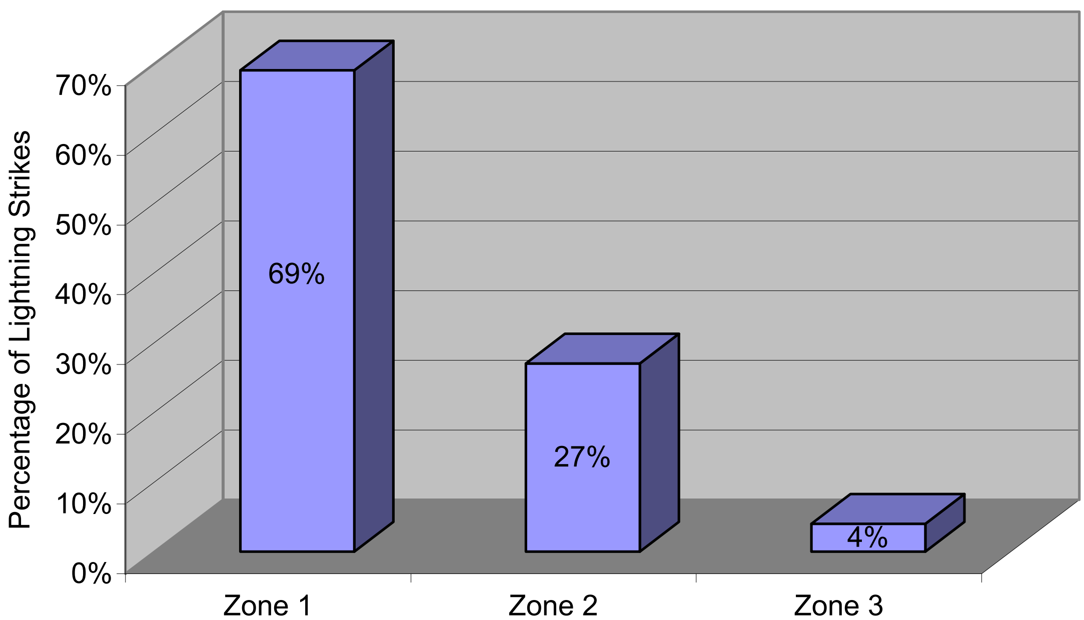


FIGURE A-9. MCDONNELL DOUGLAS DATA

APPENDIX B—1998 DATA PLOTS

The following figures are based on the zoning definition in accordance with AC 20-53A.

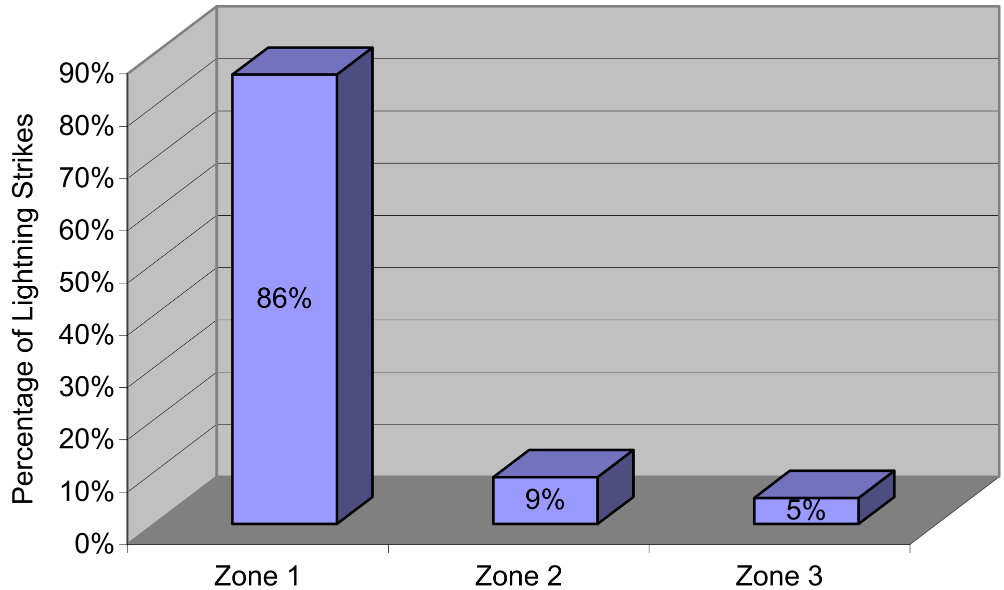


FIGURE B-1. CESSNA DATA (650 Series)

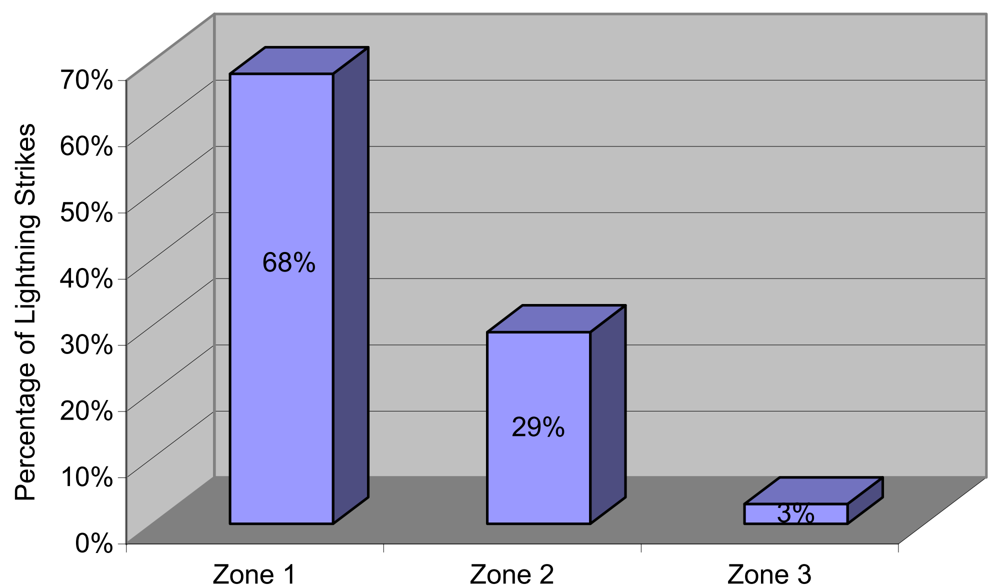


FIGURE B-2. CESSNA DATA (500 Series)

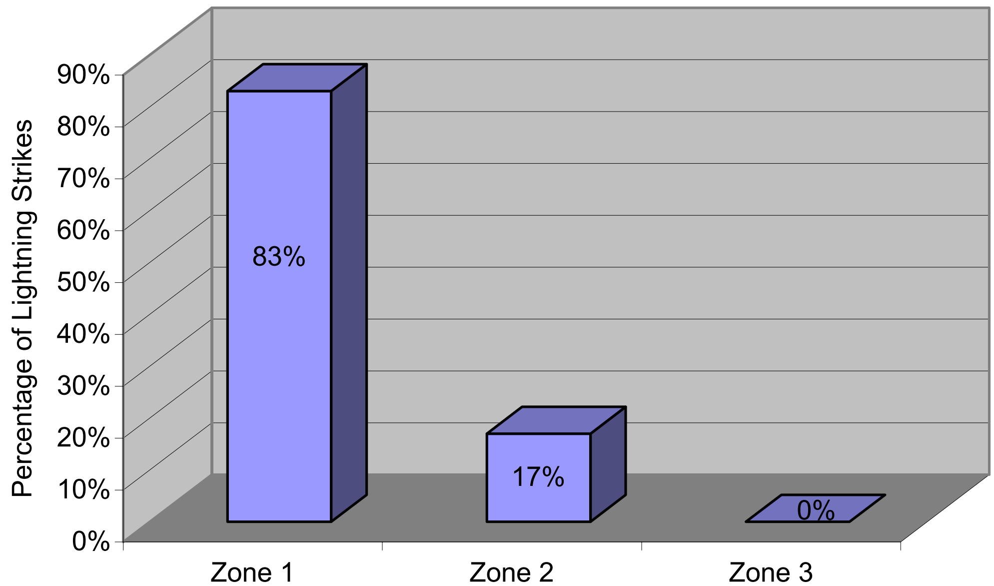


FIGURE B-3. CESSNA DATA (750 Series)

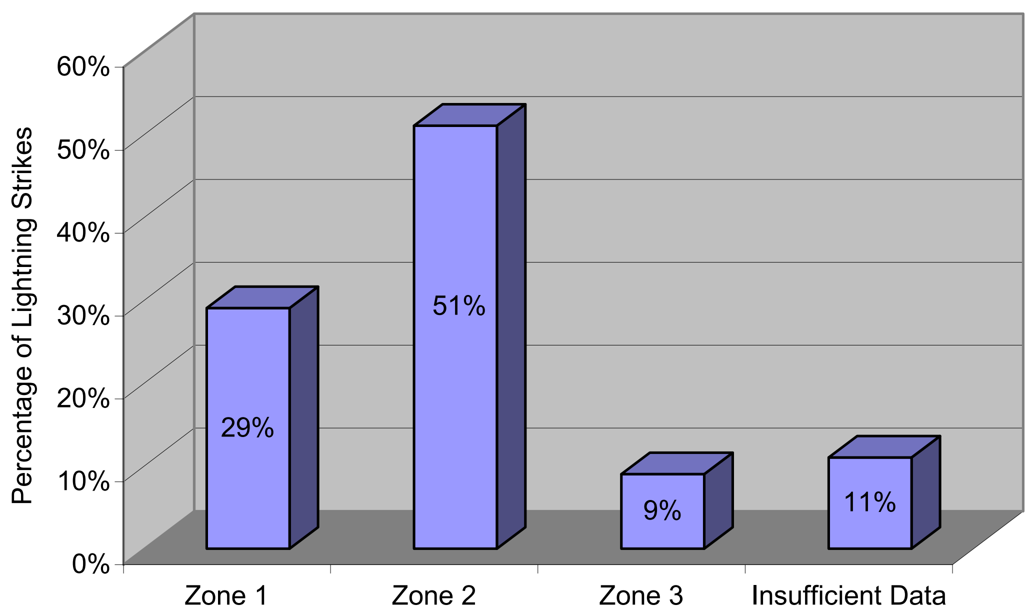
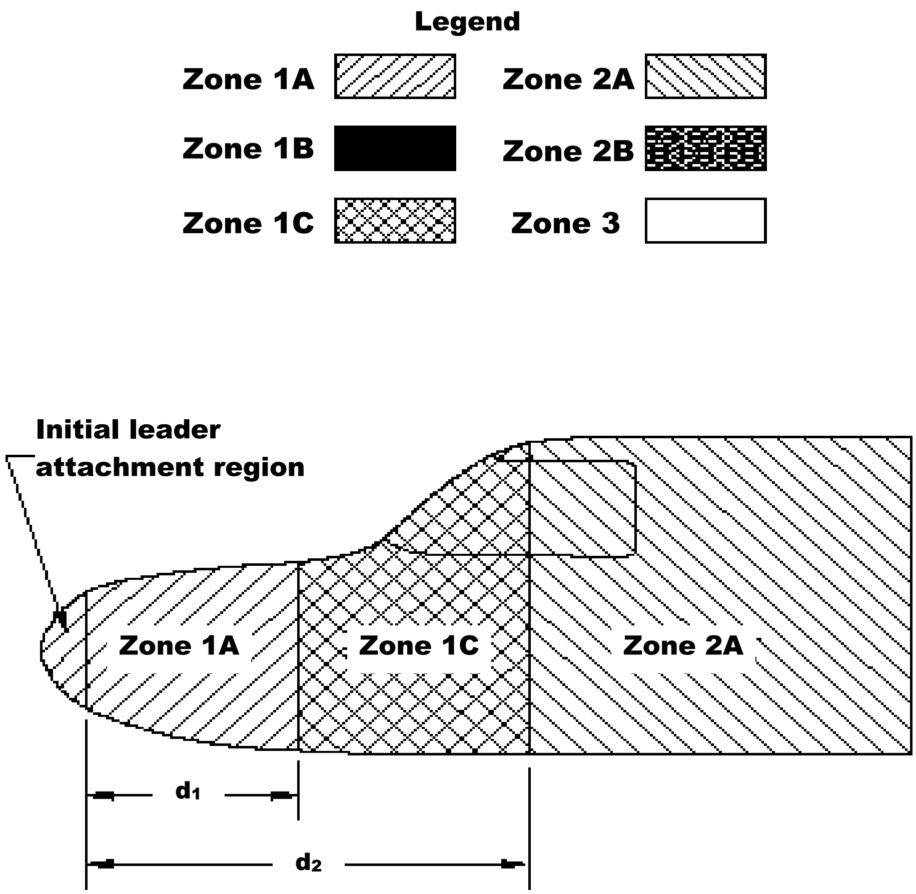


FIGURE B-4. BOEING LONG BEACH DIVISION DATA (Formerly MDD; all types)

(Note: The data for the zones in figure B-4 relate to damage caused by initial attachment and by swept stroke, i.e., an initial attachment in Zone 1 could also lead to reported damage in Zone 2.)



$$d_1 = h_1 \frac{TAS}{v_t}$$

$$d_2 = h_2 \frac{TAS}{v_t}$$

where:	v_t	=	1.5×10^5 m/s
	h_1	=	1524 m (5,000 ft)
	h_2	=	3048 m (10,000 ft)
	TAS	=	134 m/s (250 kts)

FIGURE C-1. EXAMPLES OF ZONE 1A AND 1C LOCATIONS

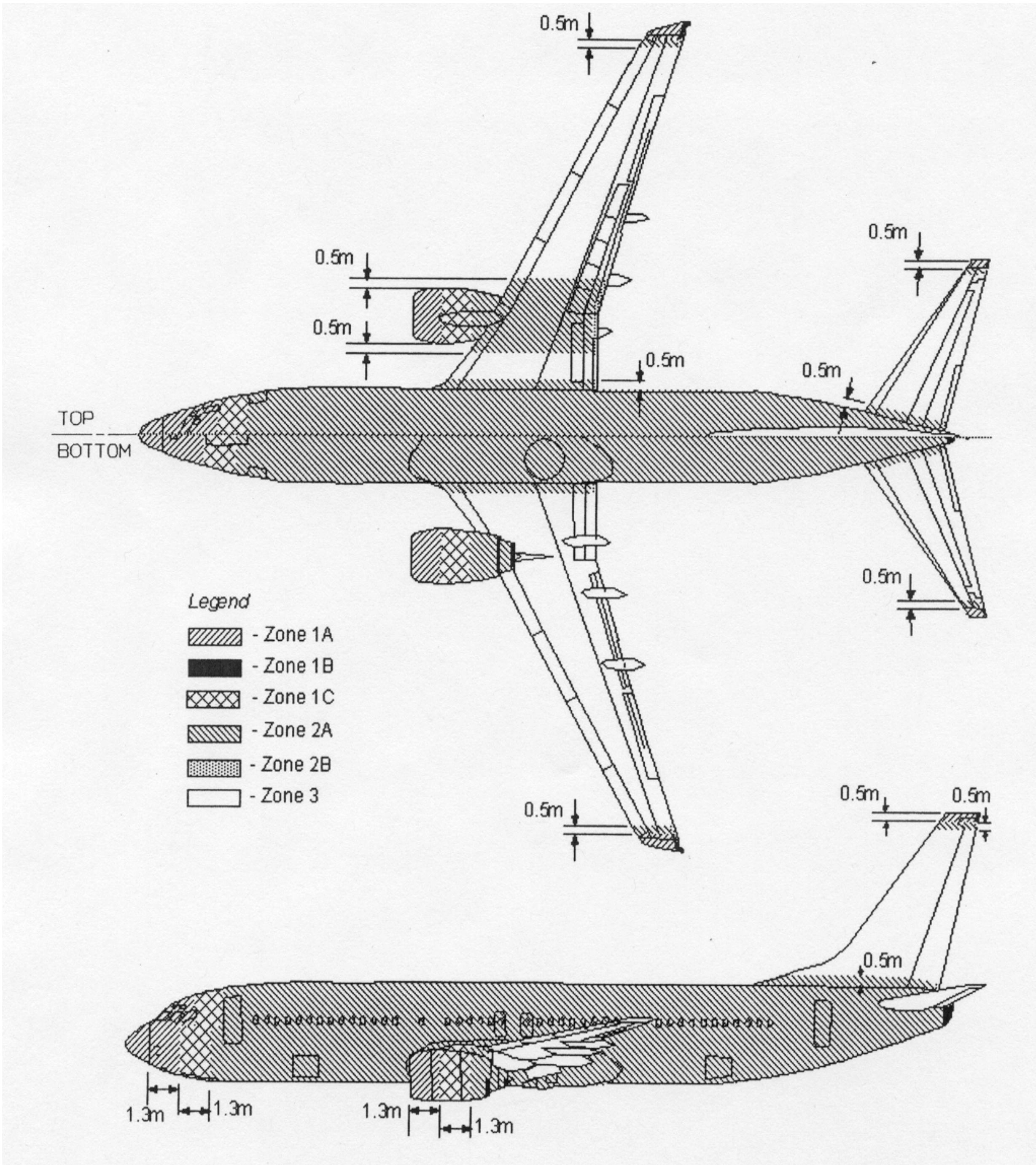


FIGURE C-2. EXAMPLE OF LIGHTNING STRIKE ZONE DETAILS FOR TRANSPORT AIRCRAFT

APPENDIX D—LIGHTNING STRIKE/STATIC DISCHARGE INCIDENT REPORTING FORM

Part 1: To be completed by the Flight Crew

Attaching extra sheets of paper to provide room for the descriptions is encouraged.

(1) Flight Number_____ Date_______ Model__________Unit/Serial Number_________

(2) Aircraft Orientation: Takeoff____ Climb_____ Level Flight_______________
Descent____ Approach______ Other_____________________

(3) At the time of the strike, the airplane was: Above clouds______ Below ceiling_______
Within clouds______

(4) Precipitation at strike: Rain______ Sleet_____ Hail______
Snow_____ None_____

(5) Lightning in vicinity: Before____ After_____ None_____

(6) Static in Comm/Nav: Before____ After_____ None_____

(7) Was St. Elmo's fire (a bluish electrical discharge or corona) visible before strike?
Yes_____ No_____

(8) Interference/Outage Report
This includes any disturbances in the avionics and electrical systems (dimming of the cabin lights, total system outage, etc...).

Please check all of the following which apply and list any other affected systems.

Engines	Interference_____	Out_____	OK_____
Navigation	Interference_____	Out_____	OK_____
Radar	Interference_____	Out_____	OK_____
Communication	Interference_____	Out_____	OK_____
Flight Control	Interference_____	Out_____	OK_____
AC Power Systems	Interference_____	Out_____	OK_____
DC Power Systems	Interference_____	Out_____	OK_____

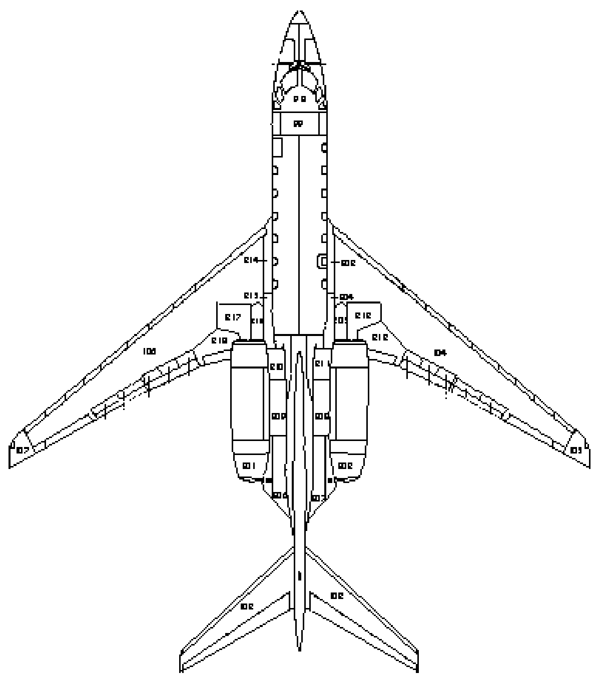
(9) Additional comments and descriptions.

Part 1 completed by:____________________ Date:__________ Phone:______________

Part 2 (Example Jet Aircraft): To be completed by the Ground Crew

Attaching extra sheets of paper to provide room for the descriptions is encouraged. Photos and sketches of the damage are recommended and need to be itemized and referenced in their descriptions.

(1) List any sweeping points (burn marks, divots, etc...), and skin penetrations (holes, missing pieces of structure, etc...) on the skin of the aircraft believed to be the result of the lightning strike. Itemize and reference the location(s) of this damage on the drawing provided (indicate top, bottom, left, or right).



(2) Describe the damage to structure and external components caused by the previously mentioned damage points. In the case of skin penetrations, indicate diameter of the hole(s). List all damage to the radome and any other composite structures separately (fairings, control surfaces, etc...). If diverter strips are damaged, include the location of the strips on the radome. For damage to composite structures, the paint thickness will need to be included in the description.

(3) List any damage to avionics and electrical components believed to be the result of the lightning strike. This includes damaged wiring, opened circuit breakers, etc. Include manufacturer, model number and serial number, of damaged units where applicable.

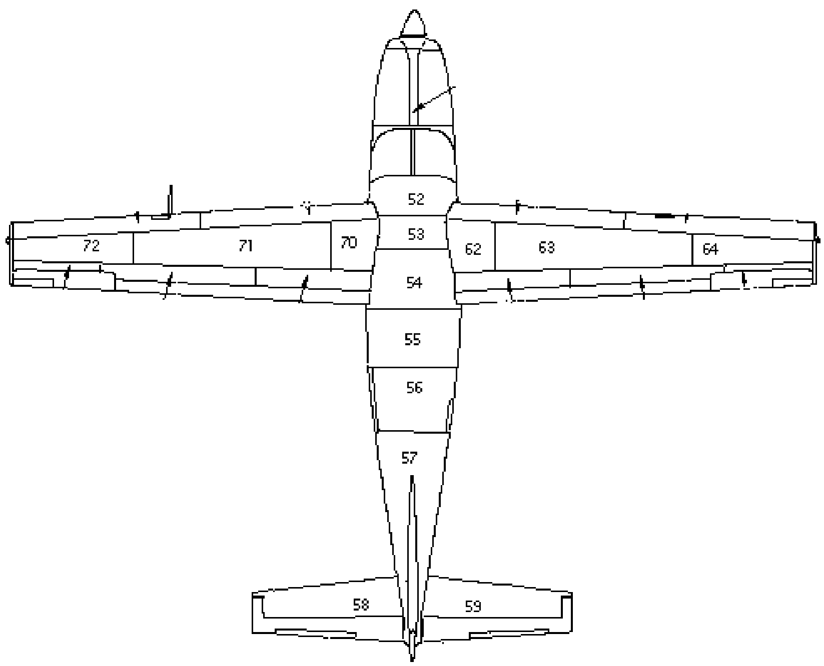
** **If damage is severe, please report the strike as soon as possible. Inspection by Engineering Representatives may be requested.**

Part 2 completed by:____________________ Date:__________ Phone:______________

Part 2 (Example Propeller Aircraft): To be completed by the Ground Crew

Attaching extra sheets of paper to provide room for the descriptions is encouraged. Photos and sketches of the damage are recommended and need to be itemized and referenced in their descriptions.

(1) List any sweeping points (burn marks, divots, etc...), and skin penetrations (holes, missing pieces of structure, etc...) on the skin of the aircraft believed to be the result of the lightning strike. Itemize and reference the location(s) of this damage on the drawing provided (indicate top, bottom, left, or right).



(2) Describe the damage to structure and external components caused by the previously mentioned damage points. In the case of skin penetrations, indicate diameter of the hole(s). List all damage to the radome and any other composite structures separately (fairings, control surfaces, etc..). If diverter strips are damaged, include the location of the strips on the radome. For damage to composite structures, the paint thickness will need to be included in the description.

(3) List any damage to avionics and electrical components believed to be the result of the lightning strike. This includes damaged wiring, opened circuit breakers, etc. Include manufacturer, model number and, serial number of damaged units where applicable.

**** If damage is severe, please report the strike as soon as possible. Inspection by Engineering Representatives may be requested.**

Part 2 completed by:____________________ Date:__________ Phone:______________