Federal Aviation Administration
Aviation Rulemaking Advisory Committee

Transport Airplane and Engine Issue Area
Electromagnetic Effects Harmonization Working Group

Task 2 – Lightning Protection Requirements

Task Assignment

Aviation Rulemaking Advisory Committee; Transport Airplane and Engine Subcommittee; Electromagnetic Effects Harmonization Working Group

AGENCY: Federal Aviation Administration (FAA), DOT.

ACTION: Notice of establishment of Electromagnetic Effects Harmonization Working Group.

SUMMARY: Notice is given of the establishment of the Electromagnetic Effects Harmonization Working Group of the Transport Airplane and Engine Subcommittee. This notice informs the public of the activities of the Transport Airplane and Engine Subcommittee of the Aviation Rulemaking Advisory Committee.

FOR FURTHER INFORMATION CONTACT: Mr. William J. (Joe) Sullivan, Executive Director, Transport Airplane and Engine Subcommittee, Aircraft Certification Service (AIR-3), 800 Independence Avenue SW., Washington, DC 20591, Telephone: (202) 267-9554; FAX: (202) 267-5364.

SUPPLEMENTARY INFORMATION: The Federal Aviation Administration (FAA) established an Aviation Rulemaking Advisory Committee (56 FR 2190, January 22, 1991) which held its first meeting on May 23, 1991 (56 FR 20492, May 3, 1991). The Transport Airplane and Engine Subcommittee was established at that meeting to provide advice and recommendations to the Director, Aircraft Certification Service, FAA, regarding the airworthiness standards for transport airplanes, engines and propellers in parts 25, 33 and 35 of the Federal Aviation Regulations (14 CFR parts 25, 33 and 35).

The FAA announced at the Joint Aviation Authorities (JAA)-Federal Aviation Administration (FAA) Harmonization Conference in Toronto, Ontario, Canada, (June 2-5, 1992) that it would consolidate within the Aviation Rulemaking Advisory Committee structure an ongoing objective to "harmonize" the Joint Aviation Requirements (JAR) and the Federal Aviation Regulations (FAR). Coincident with that announcement, the FAA assigned to the Transport Airplane and Engine Subcommittee those projects related to JAR/FAR 25, 33 and 35 harmonization which were then in the process of being coordinated between the JAA and the FAA. The harmonization process included the intention to present the results of JAA/FAA coordination to the public in the form of either a Notice of Proposed Rulemaking or an advisory circular—an objective comparable to and compatible with that assigned to the Aviation Rulemaking Advisory Committee. The Transport Airplane and Engine Subcommittee, consequently, established the Electromagnetic Effects Harmonization Working Group.

Specifically, the Working Group's tasks are the following:

The Electromagnetic Effects Harmonization Working Group is charged with making recommendations to the Transport Airplane and Engine Subcommittee concerning the FAA disposition of the following subjects recently coordinated between the JAA and the FAA:

Task 1—High Energy Radiated Fields: Develop new requirements for aircraft exposure to high energy radiated fields (new FAR 25.1316 and 25.1317 and related provisions of FAR parts 23, 27, 29, 33, and 35, as appropriate). The working group should draw members for this task from the interests represented by the General Aviation and Business Airplane, and Rotocraft Subcommittees.

Task 2—Lightning Protection Requirements: Revise advisory material on lightning protection requirements in Advisory Circulars 20-53B and 20-136 (FAR 25.1316 and related provisions of FAR parts 23, 27, 29, 33 and 35, as appropriate; AC 20-53B and 20-136). The working group should draw members for this task from the interests represented by the General Aviation and Business Airplane, and Rotorcraft Subcommittees.

Reports:

A. Recommend time line(s) for completion of each task, including rationale, for Subcommittee consideration at the meeting of the subcommittee held following publication of this notice.

B. Give a detailed conceptual presentation on each task to the Subcommittee before proceeding with the work stated under items C and D, below.

C. Draft a Notice of Proposed Rulemaking for task 1 proposing new requirements, a supporting economic analysis, and other required analysis, with any other collateral documents (such as Advisory Circulars) the Working Group determines to be needed. When the detailed briefing under item B, above, and this report are presented to the subcommittee, the Subcommittee and Working Group Chairs should arrange for a joint meeting with the General Aviation and Business Airplane and Rotorcraft Subcommittees to consider and join in the consensus on the results of those reports.

D. Draft changes to Advisory Circulars 20-53B and 20-136 for task 2 providing appropriate advisory material for the task. When the detailed briefing under item B, above, and this report are presented to the subcommittee, the Subcommittee and Working Group Chairs should arrange for a joint meeting with the General Aviation and Business Airplane and Rotorcraft Subcommittees to consider and join in the consensus on the results of those reports.

E. Give a status report on each task at each meeting of the Subcommittee.

The Installation Harmonization Working Group will be comprised of experts from those organizations having an interest in the tasks assigned. A Working Group member need not necessarily be a representative of one of the organizations of the parent Transport Airplane and Engine Subcommittee or of the full Aviation Rulemaking Advisory Committee. An individual who has exerptise in the subject matter and wishes to become a member of the Working Group should write the person listed under the caption "**FOR FURTHER INFORMATION CONTACT**" expressing that desire, describing his or her interest in the task, and the expertise he or she would bring to the Working Group. The request will be reviewed with the Subcommittee and Working Group Chairs and the individual will be advised whether or not the request can be accommodated.

The Secretary of Transportation has determined that the information and use of the Aviation Rulemaking Advisory Committee and its subcommittee are necessary in the public interest in connection with the performance of duties of the FAA by law. Meetings of the full Committee and any subcommittees will be open to the public except as authorized by section 10(d) of the Federal Advisory Committee Act. Meetings of the Installation Harmonization Working Group will not be open to the public except to the extent that individuals with an interest and expertise are selected to participate. No public announcements of Working Group meetings will be made.

Issued in Washington, DC, on December 4, 1992.

William J. Sullivan,

Executive Director, Transport Airplane and Engine Subcommittee, Aviation Rulemaking Advisory Committee.

[FR Doc. 92-30117 Filed 12-10-92; 8:45 am]

BILLING CODE 4910-13-M

Recommendation Letter

400 Main Street
East Hartford, Connecticut 06108

Pratt & Whitney
A United Technologies Company

July 28, 1999

Department of Transportation
Federal Aviation Administration
800 Independence Ave. S.W.
Washington, D.C. 20591

Attn: Ms. Brenda Courtney, Acting Director – Office of Rulemaking

Dear Ms. Courtney:

The Transport Airplane and Engine Issues Group is pleased to provide the following documents to the FAA for formal legal and economic review.

Lightning Documents :

WG-328	AC/AMJ 20-53B Lightning Protection of Fuel Systems
WG-329	AC/AMJ 20-136A
WG-330	AC/AMJ 20-TBD Lightning Environment Document
WG-331	AC/AMJ 20-TBD Zoning Document
WG-332	NPRM/NPA for Part 23
WG-333	NPRM/NPA for Part 25
WG-334	NPRM/NPA for Part 27
WG-335	NPRM/NPA for Part 29

These documents have been prepared by the Electromagnetic Effects Harmonization Working Group.

Craig R. Bolt

Craig R. Bolt
Assistant Chair, TAEIG
boltcr@pweh.com
(Ph: 860-565-9348/Fax: 860-557-2277)

CRB/amr

Attachment

cc: Marc Bouthillier – FAA-NER
Joe Cross - Raytheon
Kristin Larson – FAA-ANM
Judith Watson – FAA-NER

Acknowledgement Letter

U.S. Department
of Transportation
Federal Aviation
Administration

800 Independence Ave. S.W.
Washington, D.C. 20591

MAY 3 2004

Mr. Craig R. Bolt
Manager, Product Development and Validation
Pratt & Whitney
Mail Stop 162-12
East Hartford, CT 06108

Dear Mr. Bolt:

In an effort to clean up pending Aviation Rulemaking Advisory Committee (ARAC) recommendations on Transport Airplane and Engine Issues, the recommendations from the following working groups have been forwarded to the proper Federal Aviation Administration offices for review and decision. We consider your submittal of these recommendations as completion of the ARAC tasks. Therefore, we have closed the tasks and placed the recommendations on the ARAC website at http://www.faa.gov/avr/arm/arac/index.cfm

Date	Task	Working Group
December 1999	Interaction of Systems and Structure Part 33 Static Parts	Loads and Dynamics Harmonization Working Group
March 2000	Part 35/JARP: Airworthiness Standards Propellers	Engine Harmonization Working Group
April 2000	Flight Characteristics in Icing conditions	Flight Test Harmonization Working Group #3 ANM-94-464-A
May 2000	Thrust Reversing Systems	Powerplant Installation Harmonization Working Group
September 2000	Lightning Protection Requirements	Electromagnetic Effects Harmonization Working Group
July 2001	Main Deck Class B Cargo Compartments	Cargo Standards Harmonization Working Group
April 2002	Design Standard for Flight Guidance	Flight/Guidance Systems Harmonization Working Group

21258

I wish to thank the ARAC and the working groups for the resources they spent in developing these recommendations. We will continue to keep you apprised of our efforts on the ARAC recommendations at the regular ARAC meetings.

Sincerely,

Anthony F. Fazio
Executive Director, Aviation Rulemaking
Advisory Committee

ARM-20
Gerri

CONCURRENCES		
ROUTING SYMBOL	INITIALS/SIGNATURE	DATE
ARM-209	EMU	1/26/01
ANM-114	KLC	1/29/01
ANM-110N	DBW	1/29/01
AIR-130	JPD	1/29/01
ARM-200	Courtney	2/15/01
ARM-20	fh	2/16/01
ARM-1	T.F.	2/20/01
AVR-1	MS	2/26/01

FEB 26 2001

Mr. Craig Bolt
Assistant Chair, Transport Airplane
and Engine Issues
400 Main Street
East Hartford, CT 06108

Dear Mr. Bolt:

This letter is a follow up to your request for formal economic and legal reviews of four proposed notices and four proposed advisory circulars addressing lightning protection.

An initial review of the working group documents indicates a need to evaluate other non-regulatory options or alternatives that would address the lightning protection issue. One such option would be to issue the draft advisory material that accompanied the package. While we will keep you informed of our progress, we see no reason to keep this task open. Whatever direction we take on this issue will be coordinated with the Joint Aviation Authorities to ensure our policy is harmonized to the maximum extent possible.

I would like to thank the Aviation Rulemaking Advisory Committee, particularly those members associated with Transport Airplane and Engine issues and the Electromagnetic Effects Harmonization Working Group for their support in completing this task.

Sincerely,

Original Signed By
Margaret Gilligan

Thomas E. McSweeny
Associate Administrator for
Regulation and Certification

ARM-209:EUpshaw:fs:1/26/01;PCDOCS #5548 v1
cc: ARM-1/20/200/209; AVR-1, APO-300/320, ANM-114 (K.Carpenter), ANM-110N (D.Walen); AIR-130 (J.Dimtroff)
File #AIR-93-740-A (lightning protection requirements)

Recommendation

WG-331

FINAL
D R A F T

AC/AMJ 20-TBD

AIRCRAFT LIGHTNING ZONING

Draft of 19 Nov. 1998
December 2, 1998: Final

DRAFT

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

1.0 PURPOSE

The purpose of this AC/AMJ is to provide information to determine the lightning attachment zones which is referred to as Lightning Zoning. This AC/AMJ is used in conjunction with two other documents, *AC/AMJ 20-TBD Aircraft Lightning Environment and Relative Test Waveforms* and ED-TBD/ARP-TBD *Lightning Testing Standard(Ref. 4.1 and 4.2)*. The relationship between the three documents is shown in Figure 1-1. These three documents are used to define the aircraft lightning threat and tests required to support the aircraft lightning protection certification.

Lightning zoning is a functional step in demonstrating that the aircraft is adequately protected from both direct and indirect effects of lightning. The purpose of lightning zoning is to determine the surfaces of the aircraft which are likely to experience lightning channel attachment and the structures which may experience lightning current conduction between pairs of entry/exit points.

Zoning should be used with the aircraft hazard assessment to determine the appropriate protection for a given aircraft part or location. To determine the appropriate protection for parts and structure in a particular lightning zone, the criticality of the systems or structure in the zone should be considered.

2.0 SCOPE

This AC/AMJ defines lightning strike zones and provides guidelines for locating them on particular aircraft, together with examples. The zone definitions and location guidelines described herein are applicable to Parts 23, 25, 27, and 29 aircraft. The zone location guidelines and examples are representative of in-flight lightning exposures.

3.0 RELATED FAR AND JAR INFORMATION

3.1 Federal Aviation Regulations (FAR)

Federal Aviation Regulations 14 CFR Parts 23.867, 23.954, 23.1209(e), 23.1316, 25.581, 25.954, 25.1316, 27.610, 27.954, 27.1309(d), 27.1316, 29.610, 29.954, 29.1309(h), 29.1316 and 33.28(d).

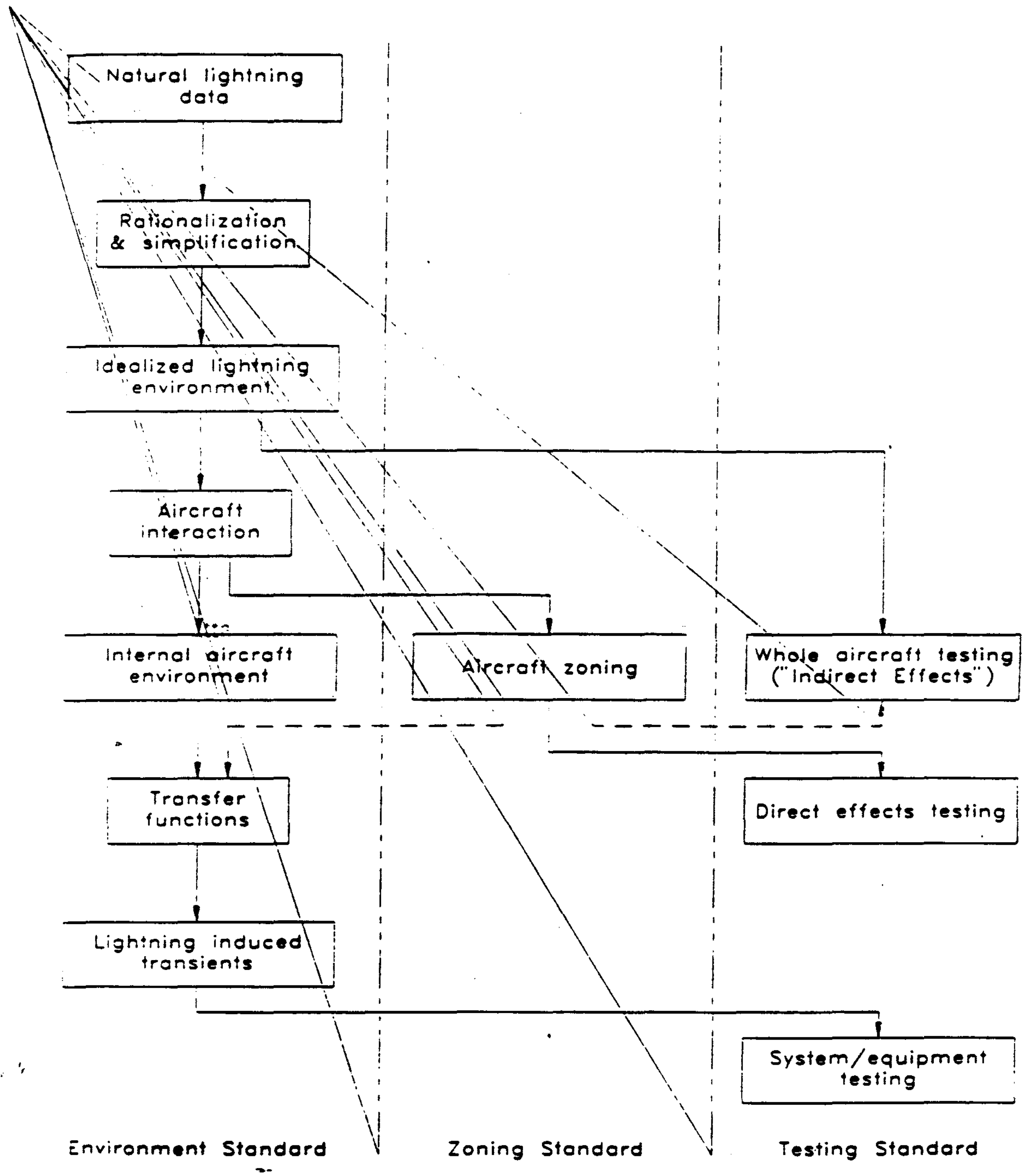


Figure 1-1 - Relationship between aircraft environment, zoning and testing standards

Note: Solid lines represent the actual AC/AMJ and Standard's materials and processes addressed in the documents. The dotted lines represent the supporting materials and processes.

3.2 FAA Advisory Circulars

The following Advisory Circulars (AC) may provide additional information.

3.2.1 AC 23.1309-1B, System and Equipment Installations in Part 23 Airplanes, dated July 28, 1995.

3.2.2 AC 25.1309-1A, System Design and Analysis, dated June 21, 1988.

3.2.3 AC 27-1A, Certification of Normal Category Rotorcraft, dated September 30, 1997.

3.2.4 AC 29-2B, Certification of Transport Category Rotorcraft, dated July 30, 1997.

3.2.5 AC 21-16D, Radio Technical Commission for Aeronautics Document DO-160D, dated March, 1998.

3.3 Joint Airworthiness Requirements (JAR)

Joint Airworthiness Requirements Parts 23.867, 23.954, 23.1209(e), 23.1316, 25.581, 25X899, 25.954, 25.1316, 27.610, 27.954, 27.1309(d), 27.1316, 29.610, 29.954, 29.1309(h), 29.1316 and 33.28(d). JAR E.50.

3.4 JAA Advisory and Interpretive Material

3.4.1 ACJ 25.581, Lightning Protection (Acceptable Means of Compliance and Interpretative Material).

3.4.2 ACJ 25X899, Electrical Bonding and Protection Against Lightning and Static Electricity (Interpretive Material and Acceptable Means of Compliance).

3.4.3 ACJ 29.610, Lightning and Static Electricity Protection (Interpretive Material and Acceptable Means of Compliance).

3.4.4 AMJ 20X-1, Certification of Aircraft Propulsion Systems Equipped with Electronic Controls.

4.0 REFERENCE DOCUMENTS

4.1 AC/AMJ 20-TBD Aircraft Lightning Environment and Relative Test Waveforms

4.2 EUROCAE WG 31 ED-TBD/SAE AE4L ARP-TBD document (in preparation) "Aircraft Lightning Testing Standard"

4.3 EUROCAE ED-14D/RTCA DO-160D
"Environmental Conditions and Test Procedures for Airborne Equipment"
Section 22: "Lightning Induced Transient Susceptibility"

4.4 EUROCAE ED-14D/RTCA DO-160D
"Environmental Conditions and Test Procedures for Airborne Equipment"
Section 23: "Lightning Direct Effects"

4.5 AC/AMJ AC 20-136A
"Protection of Aircraft Electrical/Electronic Systems against the Indirect Effects of Lightning" [EUROCAE ED-81/SAE AE4L-87-3 Revision C]

4.6 AC/AMJ 20-53B
Protection of Airplane Fuel Systems Against Fuel Vapor Ignition Due to Lightning"

4.7 User's Guide for SAE AE4L Committee Report AE4L-87-3 Revision C
EUROCAE WG 31/SAE AE4L document (in preparation).

5.0 BACKGROUND

Lightning zoning is a fundamental step in determining appropriate lightning protection for aircraft. Guidance on lightning zoning was previously incorporated into AC/AMJs pertaining to fuel and electrical/electronics systems protection. However, because of the general application of lightning zoning to protection of all parts of an aircraft, the aircraft lightning zoning information has been deleted from those AC/AMJs, updated, and presented in this AC/AMJ.

This AC/AMJ includes clarification of the original zone definitions, introduction of a transition zone between Zones 1A and 2A, consideration of the effects of swept lightning leaders, and clarification of the influence of small protrusions on zoning.

6.0 DEFINITIONS/ABBREVIATIONS/ACRONYMS

6.1 Definitions

Attachment Point	A point of contact of the lightning flash with the aircraft.
Breakdown	The production of a conductive ionized channel in a dielectric medium resulting in the collapse of a high electric field.
Dwell Point	A lightning attachment point.

Dwell Time	The time that the lightning channel remains attached to a single spot on the aircraft.
External Environment	Characterization of the natural lightning environment for design and certification purposes.
First Return Stroke	The high current surge that occurs when the leader completes the connection between the two charge centers. The current surge has a high peak current, high rate of change of current with respect to time (di/dt) and a high action integral.
Flashover	This term is used when the arc produced by a gap breakdown passes over or close to a dielectric surface without puncture.
Leader	The low luminosity, low current precursor of a lightning return stroke, accompanied by an intense electric field.
Lightning Channel	The ionized path through the air along which the lightning current pulse passes.
Lightning Flash	The total lightning event. It may occur within a cloud, between clouds or between a cloud and ground. It can consist of one or more return strokes, plus intermediate or continuing currents.
Lightning Strike	Any attachment of the lightning flash to the aircraft.
Lightning Strike Zones	Aircraft surface areas and structures classified according to the possibility of lightning attachment, dwell time and current conduction.
Reattachment	The establishment of new attachment points on the surface of an aircraft due to the sweeping of the flash across the surface of the aircraft by the motion of the aircraft.
Restrike	A subsequent high current surge attachment, which has a lower peak current, a lower action integral, but a higher di/dt than the first return stroke. This normally follows the same path as the first return stroke, but may reattach to a new location further aft on the aircraft.
Stepped Leader	See leader.

Swept Leader — A lightning leader that has moved its position relative to an aircraft, subsequent to initial leader attachment, and prior to the first return stroke arrival, by virtue of aircraft movement during leader propagation.

Swept Channel — The lightning channel relative to the aircraft, which results in a series of successive attachments due to sweeping of the flash across the aircraft by the motion of the aircraft.

Zoning — The process (or the end result of the process) of determining the location on an aircraft to which the components of the external environment are applied.

6.2 Abbreviations

A	amperes
AC	Advisory Circular
AMJ	Advisory Material Joint
C	charge transfer (coulombs or ampere - seconds)
d	distance (meters)
h	altitude above ground (meters)
kA	kiloamperes
kV	kilovolts
kV/m	kilovolts per meter
m/s	meters per second
ms	milliseconds
s	seconds
t	time
v	velocity (meters/second)

6.3 Acronyms

AGL	Above ground level
CAD	Computer aided design
EFM	Electric field modeling
HC	High current
HV	High voltage
TAS	True Air Speed
3D	Three-dimensional

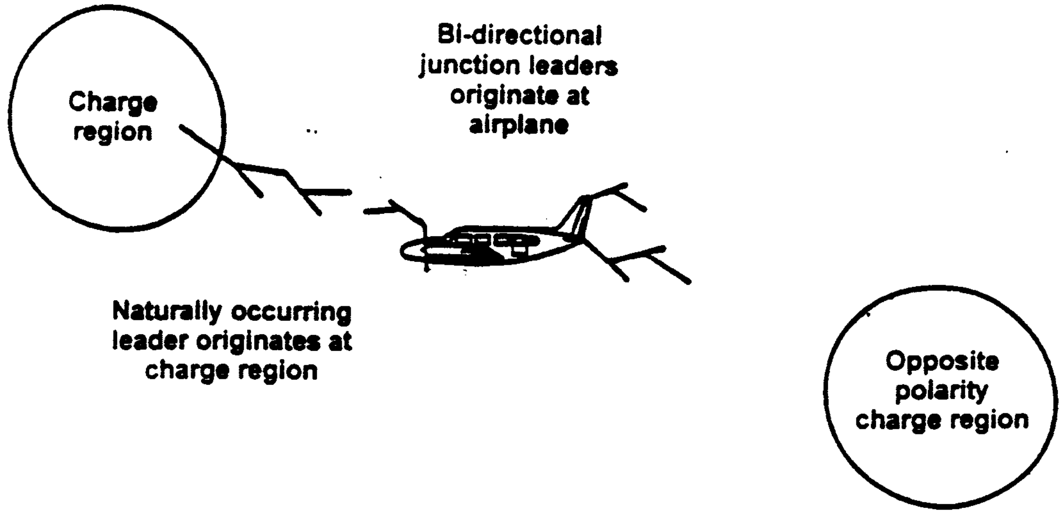
7.0 AIRCRAFT LIGHTNING INTERACTION

7.1 Initial Lightning Attachment

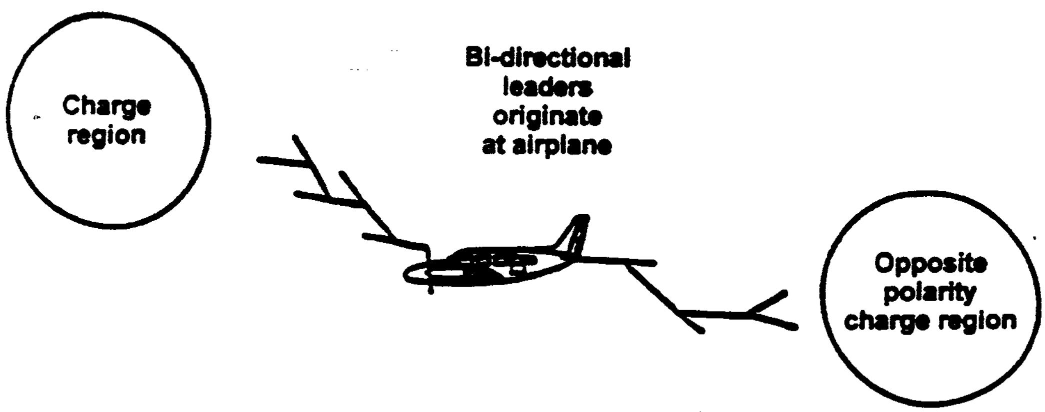
Aircraft in flight are exposed to both naturally occurring and aircraft initiated ("triggered") lightning strikes. A naturally occurring strike begins when a lightning leader which originates at a cloud charge center happens to approach an aircraft.. When this happens, the electric field associated with charge in the leader intensifies about the aircraft extremities, and discharges, called junction leaders, emanate from major extremities and, propelled by the electric field, propagate in the general direction of the lightning leader. One, and sometimes more of these junction leaders may connect with one or more branches of the lightning leader. The aircraft surfaces where these junction leaders originated from thus become the initial lightning attachment points. Often these are referred to as initial attachment (or "entry") points. At the same time additional junction leaders, originating at other extremities, are propagating away from the airplane, in the general direction of a region of opposite polarity charge. This may be the earth, or it may be a cloud charge region of opposite polarity. The location(s) from which these leader(s) leave the aircraft constitute other initial lightning attachment locations, often called exit points.

An aircraft-initiated strike may result when the aircraft is in an electric field associated with charged cloud regions and the field intensity about the aircraft's extremities is sufficient to initiate and propel bi-directional leaders, from these extremities. These leaders propagate between regions of opposite polarity charge, and conduct lightning currents through the airplane, as occurs with naturally occurring lightning. The places from which the bi-directional leaders originate are also called initial entry and exit points. There is no generic difference in the characteristics of entry and exit locations. The terms are used only for convenience in describing the overall lightning process, and are perhaps more relevant to a naturally occurring lightning strike, wherein the entry location is associated with the initially approaching leader, and the exit location means the place from which the leader continues its journey to an ultimate destination. Examples of the two lightning strike mechanisms described above are shown in Figure 7-1.

The same aircraft locations may be initial entry/ exit points for either type of lightning strike. Lightning entry/exit locations exist typically at aircraft extremities such as nose, wing and
empennage tips, tail cones, propellers and rotor blades, and some engine nacelles.



a. Naturally occurring strike



b. Aircraft initiated strike

Figure 7-1 - Lightning Strike Mechanisms

7.2 Swept Channel Process

The completed lightning channel is somewhat stationary in air. When an aircraft has been struck, currents in the channel flow through the aircraft. However, due to the speed of the aircraft and the length of time that the lightning channel exists, the aircraft can move a significant distance relative to the lightning channel. When a forward extremity, such as a nose or wing mounted engine nacelle is an initial leader attachment point, the movement of the aircraft through the lightning channel usually causes the channel to sweep back over the surface as illustrated in Figure 7-2, allowing the channel to reattach to airplane surfaces aft of the initial attachment point. This is known as the swept-channel process. The characteristics of the surface can cause the lightning channel to reattach to and dwell at various surface locations for different periods of time, resulting in a series of successive lightning attachment points along the sweeping path. These subsequent attachment points have been referred to as dwell points.

The amount of damage produced at any dwell point on the aircraft by a swept channel depends upon the type of the aircraft skin material and finish, the dwell time at that point, and the lightning currents which flow during the attachment. Stroke currents as well as intermediate currents and small portions of continuing currents may occur at any attachment point. Subsequent strokes flowing in the channel sometimes cause it to reattach to new dwell points.

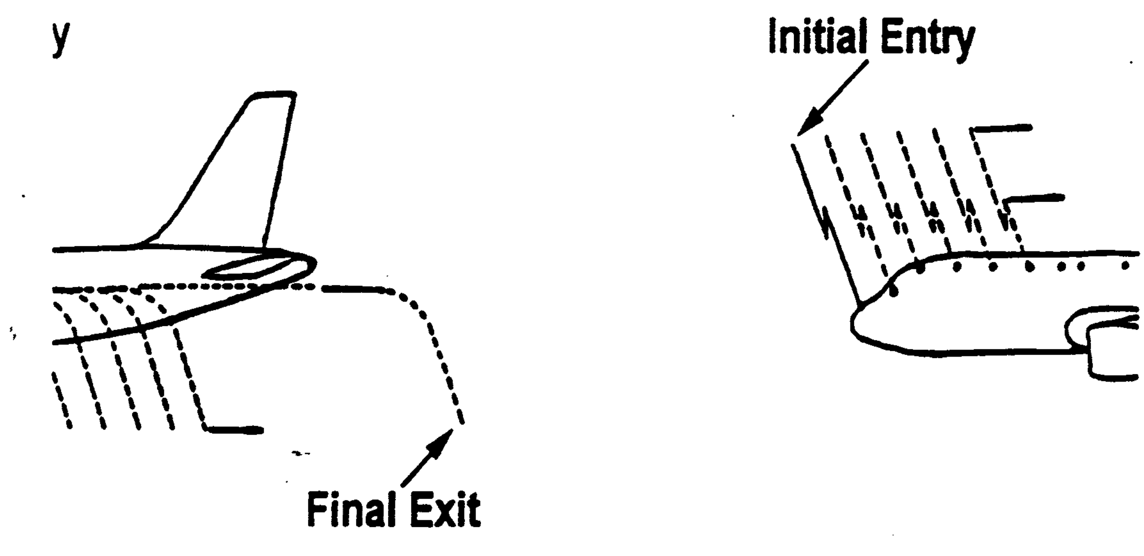


Figure 7-2 - Typical Path of Swept-Channel Attachment Points

When the lightning channel has been swept back to a trailing edge, it may remain attached at such an edge for the remaining duration of the lightning flash. An initial leader attachment location at an aircraft trailing edge, of course, could not be subjected to any swept-channel action; and therefore, all components of the lightning flash currents would enter or exit from this location.

The significance of the swept-channel phenomenon is that surfaces of the vehicle that would not be susceptible to initial lightning attachment may also be involved in the lightning strike process as the lightning channel is swept backwards, although the channel may not remain attached at any single point for very long. On the other hand, strikes that reach trailing edges should be expected to remain attached and hang on there for the balance of their natural duration.

7.3 Conduction

During the time that the lightning channel is attached to any of the aircraft initial attachment or swept channel dwell points, currents will be flowing in the aircraft. The points of entry and exit of this current from the aircraft will change as the airplane flies through the lightning channel, as described in Section 7.2.

The lightning current will distribute among all electrically conductive skins and structural elements between entry and exit locations. Some lightning current may also flow in non-structural components, such as push rods, hydraulic lines, plumbing, and electrical cables.

The magnitudes of currents that flow in various structural elements depend upon a variety of factors including geometry, material properties, and the characteristics of the lightning currents.

8.0 ZONE DEFINITIONS

The surface of an aircraft can be divided into a set of regions called lightning strike zones. These zones represent the areas likely to experience the various types of lightning currents and consequently, the various components of the lightning environment defined in Ref. 4-1. There are three major divisions representing:

1. Regions likely to experience initial lightning attachment and first return strokes.

2. Regions which are unlikely to experience first return strokes but which are likely to experience subsequent return strokes. This will happen where the aircraft is in motion relative to a lightning channel causing sweeping of the channel backwards from a forward initial attachment point.

3. Regions which are unlikely to experience any arc attachment but which will have to conduct lightning current between attachment points.

Regions 1 and 2 are subdivided into specific lightning attachment zones as follows:

Zones 1A and 2A, where long hang-on of a lightning channel is unlikely because the motion of the aircraft with respect to the channel causes the arc root to move across the surface of the aircraft in the opposite direction from the direction of motion.

Zones 1B and 2B, where the lightning channel attachment point is unlikely to move during the remainder of the flash because the location is a trailing edge or a large promontory from which the relative motion of the aircraft and channel cannot sweep the attachment point further.

Finally, an additional zone, Zone 1C, is defined, in which by virtue of the change in current parameters along a lightning channel and the time taken for sweeping of the attachment point across the surface of the aircraft, the threat to the aircraft is reduced.

Specific zone definitions are as follows:

Zone 1A - First return stroke zone

All the areas of the aircraft surfaces where a first return stroke is likely during lightning channel attachment with a low expectation of flash hang on.

Zone 1B - First return stroke zone with long hang on

All the areas of the aircraft surfaces where a first return stroke is likely during lightning channel attachment with a high expectation of flash hang on.

Zone 1C - Transition zone for first return stroke

All the areas of the aircraft surfaces where a first return stroke of reduced amplitude is likely during lightning channel attachment with a low expectation of flash hang on.

Zone 2A - Swept stroke zone

All the areas of the aircraft surfaces where subsequent return stroke is likely to be swept with a low expectation of flash hang on.

Zone 2B - Swept stroke zone with long hang on

All the areas of the aircraft surfaces into which a lightning channel carrying a subsequent return stroke is likely to be swept with a high expectation of flash hang on.

Zone 3

Those surfaces not in Zones 1A, 1B, 1C, 2A or 2B, where any attachment of the lightning channel is unlikely, and those portions of the aircraft that lie beneath or between the other zones and/or conduct substantial amount of electrical current between direct or swept stroke attachment points.

The location of these zones on any particular aircraft shall be agreed between the applicant and the appropriate certification authority.

9.0 WAVEFORM APPLICABILITY

The applicability of the lightning environment waveforms to each of the zones is described in AC/AMJ 20-TBD.

10.0 ZONE LOCATION PROCESS

The locations of the lightning strike zones on any aircraft are dependent on the geometry of the aircraft and operational factors. If a new/modified aircraft is similar to an existing aircraft whose zoning has been validated by service history, the new/modified aircraft can be zoned in the same manner as the existing aircraft, as described in Section 10.8. For aircraft that are of new or novel design (or for areas of an aircraft that incorporate new or novel design), use the eight steps below to determine the lightning zones. This process is illustrated in Figure 10-1. Note that for a new/modified aircraft, the unmodified areas can be zoned by similarity and the new/modified areas can be zoned by the following method.

10.1 Determination of Initial Lightning Leader Attachment Locations

The first step in locating the lightning strike zones is to determine the locations where lightning leaders may initially attach to an aircraft. Various methods are available to accomplish this task. They include such methods as similarity, testing and analysis (i.e., EFM, Rolling Sphere). Further descriptions of those methods are found in Section 11.0. Whichever method(s) are used, the results should be applied in the light of previous in-flight lightning strike experience of airframes with similar geometry (if available) or known aspects of lightning attachment phenomenology. These initial attachment locations typically include extremities such as the nose, wing and empennage tips, propellers and rotor blade tips, some engine nacelles, cockpit window frames, and other significant projections.

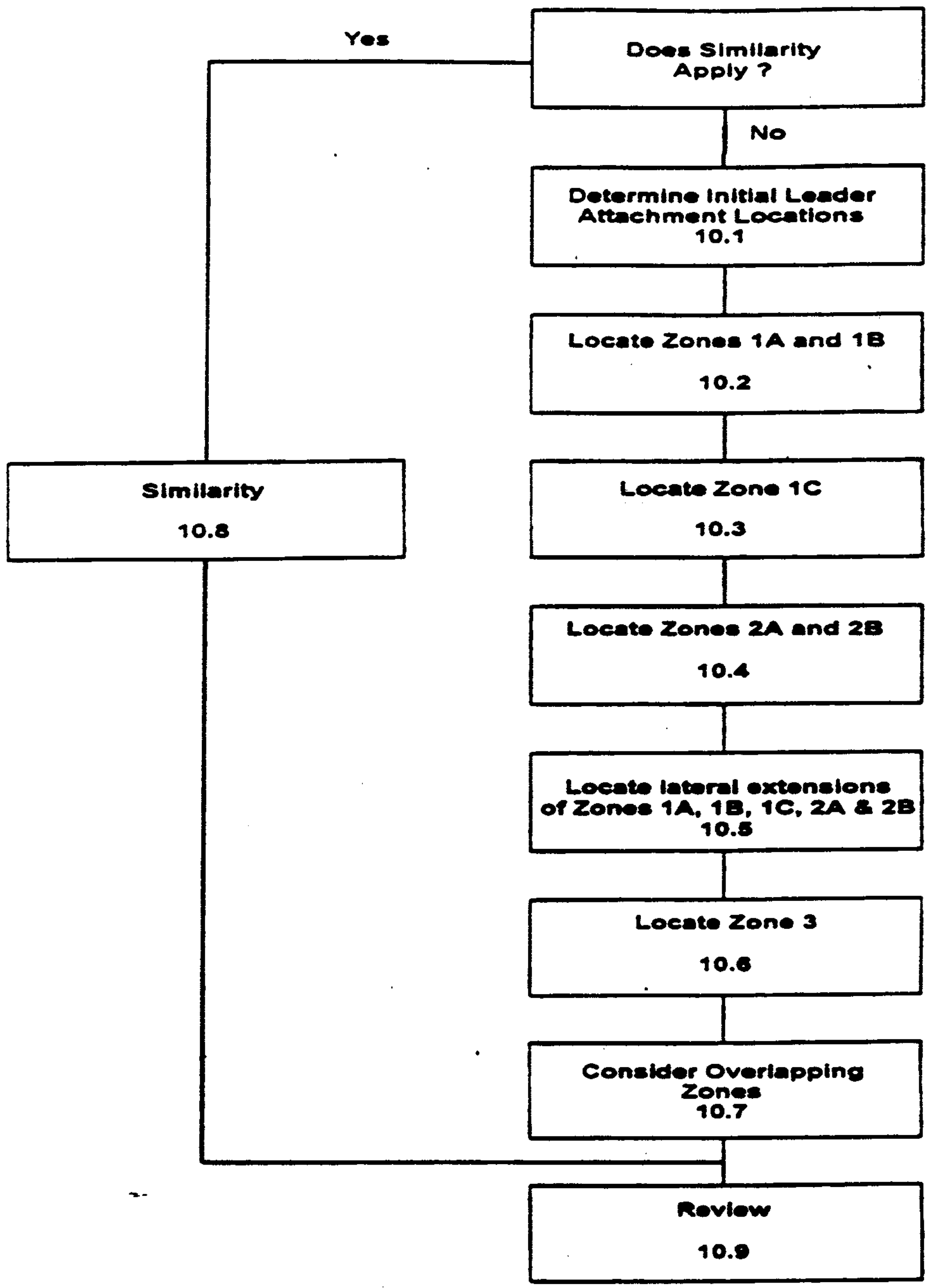


Figure 10-1 - Zone Location Process

Lightning strikes to typical initial entry/exit locations on an airplane do not always occur to the same spot, but may, due to statistical variations in air breakdown phenomena, occur to a variety of locations on the same overall extremity, especially if the extremity does not have a significant protrusion, or a sharp edge where an electric field would be especially enhanced. Thus large surface areas comprising the rounded nose of an airplane are susceptible to initial leader attachment, whereas only the forward-most tip of a narrow, sharp-nosed airplane would be likely to experience initial leader attachment.

Initial leader attachment locations found in the first step that are on trailing edges are likely to experience all or a significant part of the lightning flash as the arc cannot sweep from these surfaces to anything further rearward in the airflow. Thus, these initial attachment locations will also experience long hang-on of the lightning channel and are therefore defined as being within Zone 1B.

10.2 Location of Zones 1A and 1B

The second step in locating the lightning strike zones is to determine the additional locations for possible first return stroke arrival. These locations will include Zones 1A, 1B, and 1C. In most cases the aircraft will be moving forward when struck and the leader will have swept aft from its original forward attachment point by the time the leader reaches the earth (or other charge center) and initiates the first return stroke. A distance, flown by the aircraft during this period determines the aft extension of Zone 1A surfaces from the initial leader attachment points and is dependent upon aircraft speed, aircraft altitude above the earth (for a cloud-to-ground strike), and leader velocity. The starting point for the Zone 1A extension should be the aft extremity of the initial attachment region.

Equation 10-1 shows the relationship of the maximum leader sweep distance (d) as a function of aircraft altitude (h), leader velocity (V_l), and true aircraft speed (*TAS*).

$$d = h\ TAS / V_l \qquad (10\text{-}1)$$

Note: It is important to note that all values used in this formula must be in metric units.

The application is shown in Figure 10-2.

Experience indicates that most severe strike encounters, which include current Component A, involve cloud-to-ground flashes that strike the aircraft at altitudes of 1500 m (5,000 ft) or less, so Zone 1A extensions can be based on this altitude. The leader velocity should be taken as 1.5×10^5 m/s.

Typical aircraft speeds below 1500 m (5,000 ft) are less than 130 m/s (250 knots.) Therefore a Zone 1A extension d_1 of 1.3 m should be used. For aircraft with lower operating speeds the extension distance d_1 may be reduced proportionally to a minimum of 0.5 m.

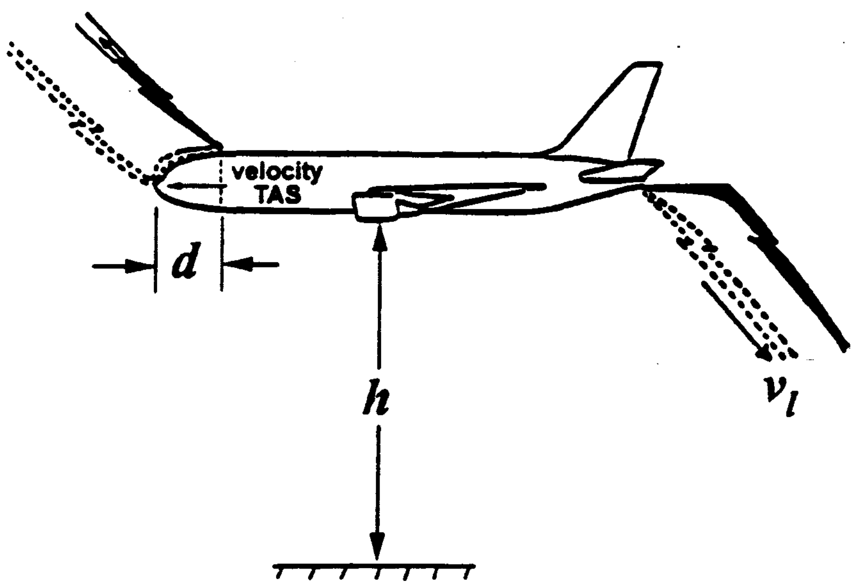


Figure 10-2 - Leader Sweep, Aircraft Altitude and Aircraft Leader Velocities

Initial leader attachment locations where the lightning channel must hang on for the duration of its lifetime are in Zone 1B. Because Zone 1B locations cannot involve sweeping as they are already as far back on aircraft surfaces as it is possible for them to be, no additional analysis is required for them.

10.3 Location of Zone 1C

Zone 1C is applicable to surfaces aft of Zone 1A which can be reached by swept leaders at flight altitudes between 1500 m (5,000 ft) and 3000 m (10,000 ft). In this range a return stroke of lower amplitude than Component A, called current Component A_h, is applicable. The rearward limit of this channel sweep distance is calculated from the formula shown in Equation 10-1, using an altitude (h) of 3000 m (10,000 ft). This gives a distance d_2 from the rearward edge of initial attachment regions.

Typical aircraft speeds below 3000 m (10,000 ft) are less than 130 m/s (250 knots.) Therefore a total leader sweep distance d_2 of 2.6 m should be used. The aircraft surfaces lying between distances d_1 and d_2 limits are Zone 1C. For aircraft with lower operating speeds or lower operating altitudes, the total leader sweep distance d_2 may be reduced accordingly. Therefore, in some circumstances Zone 1C may not be present.

An example of the Zone 1A and Zone 1C locations is shown on Figure 10-3.

10.4 Location of Zones 2A and 2B

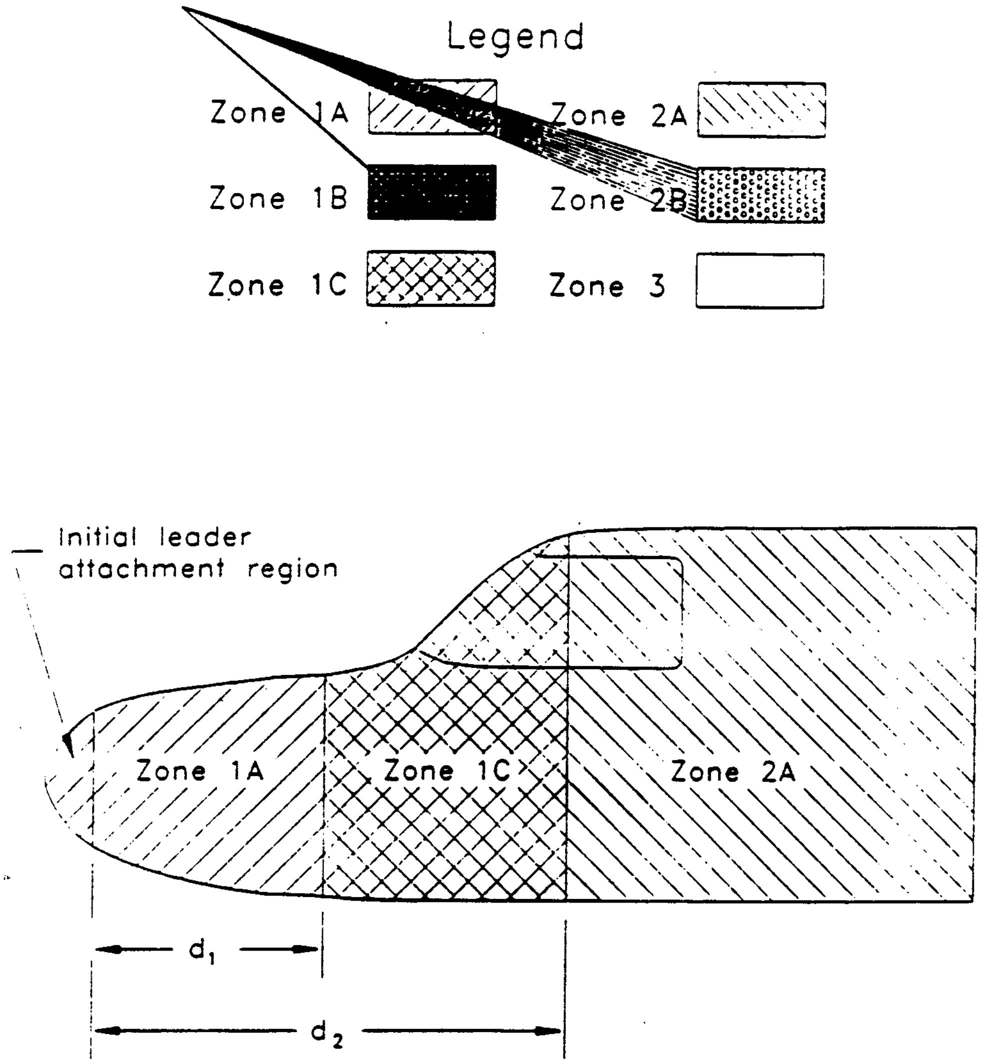
Since all aircraft can travel more than their entire length in the one or two second duration of a lightning flash, the remainder of the surfaces aft of Zone 1C should be considered within Zone 2A. Trailing edge surfaces aft of Zone 2A should be considered in Zone 2B unless they have already been located within Zone 1B.

10.5 Location of Lateral Extensions of Zones 1A, 1B, 1C, 2A and 2B

In the determination of the Zone 1A and 1B surface area of wing and empennage tips that are curved or swept or have winglets, it is advisable to determine the horizontal tangent point of the tip curvature and extend the Zone 1A and 1B inboard 0.5 m.

In addition, to account for the lower probability of a direct attachment of a reduced amplitude strike and/or small lateral movements of the lightning channel inboard of Zones 1A and 1B at wing and empennage tips, the surfaces 0.5 m inboard of Zones 1A and 1B should be considered as within Zones 2A and 2B.

Examples of this are provided in Figure 10-4.

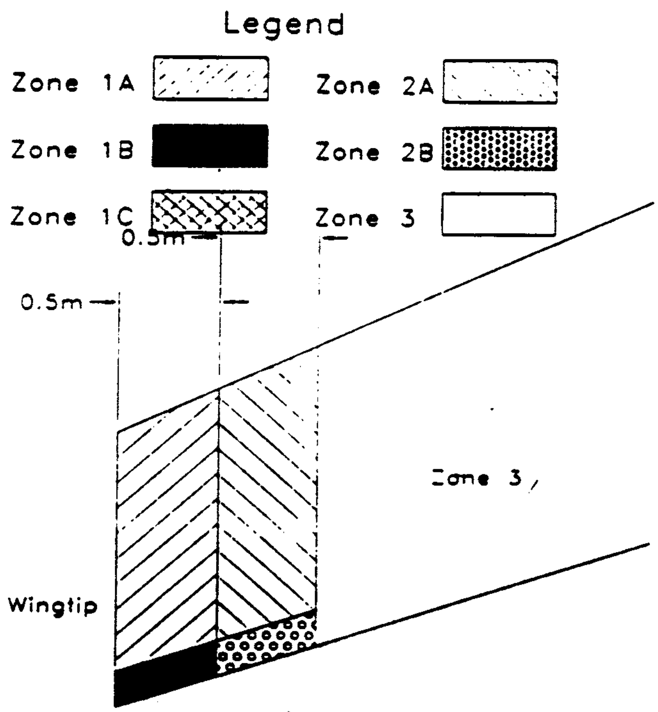


$$d_1 \quad h_1 \frac{TAS}{v}$$

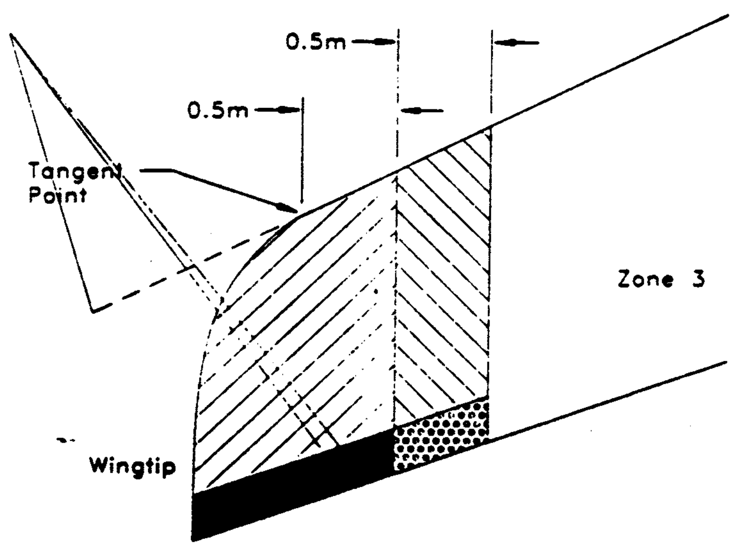
$$d_2 \quad h_2 \frac{TAS}{v}$$

where: v□ = 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 10-3 - Examples of Zones 1A and 1C Locations



a) Straight Wingtip



b) Curved Wingtip

Figure 10-4 - Examples of Wing and Empennage Tip Zones

Surfaces 0.5 m (18 in.) to either side (i.e. outboard or inboard) of Zones 1A, 1C, 1B, 2A, and 2B along the wing roots, wing-mounted engines, and vertical and horizontal stabilizer roots determined by Steps 10.1 through 10.4 should also be considered within these same zones to account for small lateral movements of the lightning channel.

10.6 Location of Zone 3

Those surfaces not in Zones 1A, 1C, 1B, 2A and 2B and where any attachment of the lightning channel is unlikely are considered to be in Zone 3. Zone 3 includes those portions of the aircraft that lie beneath or between the other zones and which conduct lightning current between areas of direct or swept-channel attachment.

10.7 Overlapping Zones

Surfaces within Zones 1A and 1C are also in Zone 2A, as in some cases the first return stroke may occur near the initial leader attachment point, as at a nose or engine inlet cowl, with subsequent strokes occurring within the rest of the Zone 1A areas. Zone 3 also underlies all other zones. Protection designs should be based on the worst case zones.

10.8 Zoning by Similarity

Similarity with a previously certified aircraft may be used as the basis for zoning a new or derivative aircraft. In making a similarity assessment, the following should be considered:

1. No significant differences exist between the geometry of the previously certified aircraft and that of the new or derivative aircraft, such as differences in:

   - Radius of curvature and size of structure, or sweep of the wing
   - Configuration, such as number of engines, empennage type, or low/high wing
   - Large protrusions such as a large blade antenna, aerodynamic fence, or fuel dump

2. Service lightning strike experience indicates that no changes in the zone locations are warranted.

3. No significant change in the electrical conductivity of the aircraft surfaces such as replacement of an aluminum surface with a non-conductive fiberglass surface. See also Section 12.2.

4. No significant changes in flight characteristics, such as aircraft speed and altitude envelope.

If only certain parts of an aircraft are similar to the previously certified aircraft those similar parts may be zoned by similarity. The non-similar parts should be zoned in accordance with applicable steps in Section 10.
For example, a transport aircraft whose nose, cockpit, and wing geometries are similar to those of a previously certified aircraft but whose fuselage is to be longer than the previously certified aircraft could be zoned completely based on the previously certified aircraft.

An aircraft whose wings are to be swept as compared with a previously certified straight wing aircraft but whose forward fuselage geometry is to be similar could utilize the previously certified aircraft zones to zone the nose and fuselage areas, but not the wing. Zoning of the wing surfaces should be accomplished in accordance with the process described in Section 10.

Also, the rotor blades and upper surfaces of a helicopter whose fuselage and rotor blade geometries are similar to a previously certified helicopter, but whose undercarriage is different (i.e., retractable instead of fixed landing gear) could be zoned based on the previously certified helicopter, but the lower surfaces would have to be zoned in accordance with the process of Section 10, or the zones of a previously certified helicopter whose lower fuselage and undercarriage geometrics are similar to those of the helicopter to be zoned.

10.9 Review

Once the lightning strike zones have been established, they should be documented on a drawing of the aircraft, with boundaries identified by appropriate station numbers or other notations. The zone locations should be reviewed with the certifying authority and concurrence of the certifying authority should be obtained.

10.10 Examples of Zone Locations

Lightning strike zones located in accordance with the above guidelines are illustrated in Figures 10-5 through 10-11 for transport and general aviation aircraft and rotorcraft.

Rotorcraft may be airborne with motion in any direction relative to a lightning channel, or have no motion at all. Thus, with the exception of rotor blades, any potential initial attachment points may experience all components of the standard lightning environment, and, therefore, need to be treated as being within Zone 1B. Swept channel attachments may occur in any direction from these Zone 1B regions, therefore, all undersurfaces not already designated Zone 1B should be considered as within Zone 1A. Rotor blades may sustain initial leader attachments to their tips and thus surfaces 0.5 m inboard of blade tip should be considered as within Zone 1A. Blade surfaces inboard of Zone 1A should be considered in Zone 2A. Much of the upper fuselage surfaces are normally protected from lightning attachment by the rotor blades and may be treated as within Zone 3. An example of these lightning strike zones is shown in Figure 10-11.

Propellers are usually in Zone 1A as illustrated in Figures 10-9 and 10-10, although other zones may be applicable based on the propeller locations with respect to other parts of the airframe. The zone location process described in Sections 10.1 through 10.7 should be followed.

The dwell times of intermediate or continuing currents (Components B and C*) on propeller and rotor blade surfaces may differ from those described in Ref. 4.1 for conventional aircraft surfaces and should be determined by analysis.

Nacelle and other aircraft surfaces within a 45□ projection aft of the propeller blade tips may be considered as within Zone 3 as illustrated in Figures 10-9 and 10-10 unless such surfaces are designated as within an attachment zone for other reasons, e.g., the exposed specimen on a pusher propeller, which is normally in Zone 1B.

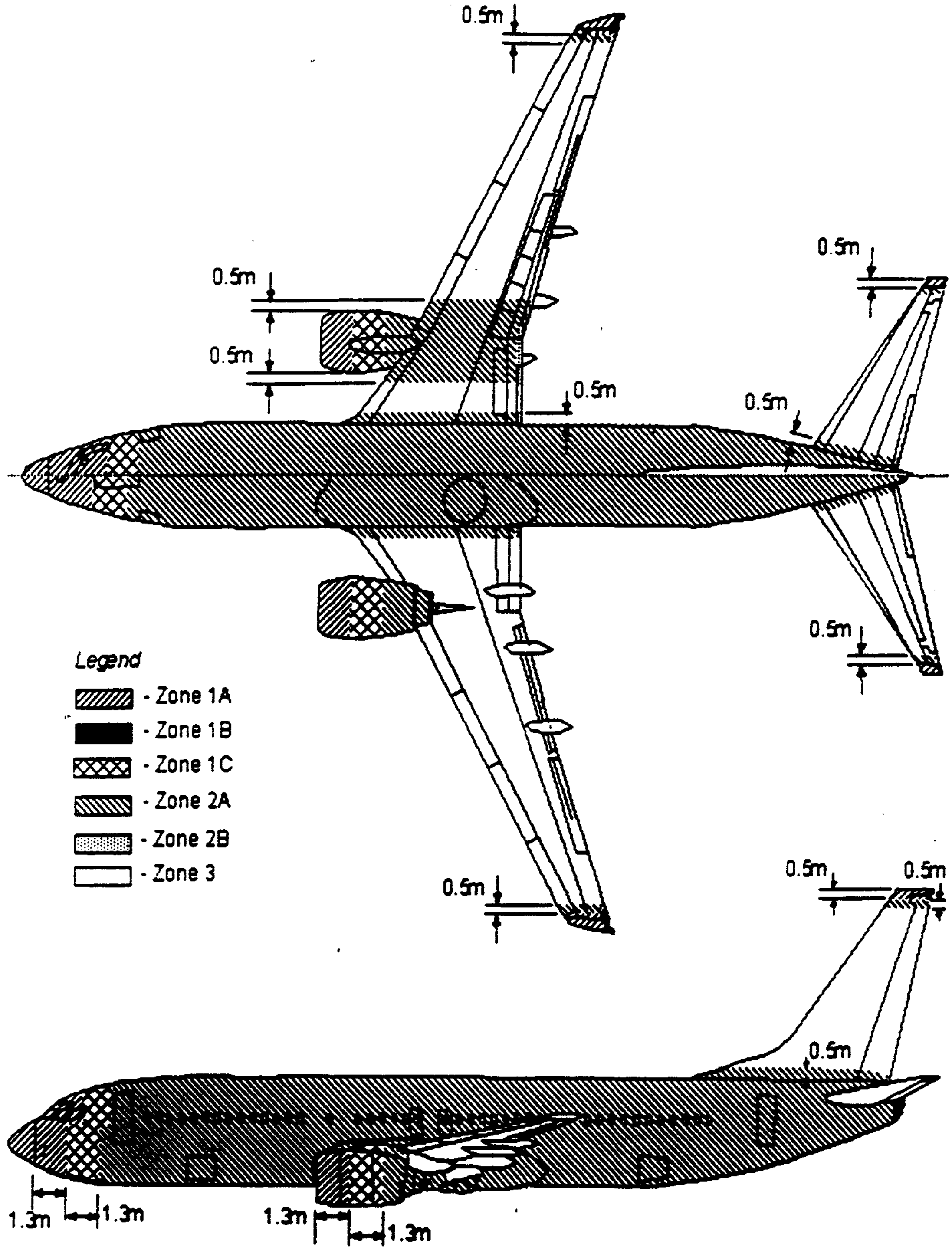


Figure 10-5 - Example of Lightning Strike Zone Details for Transport Aircraft

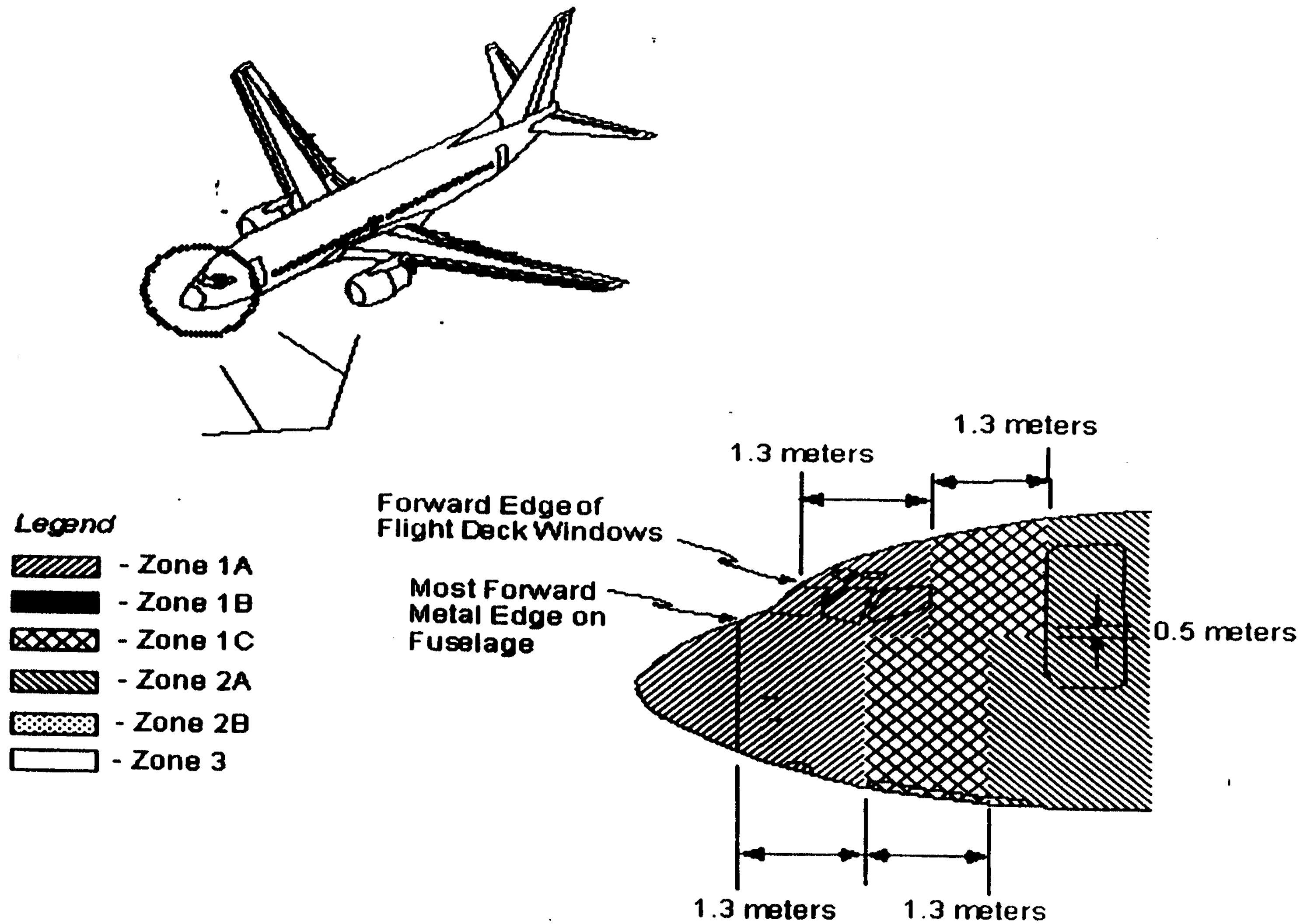


Figure 10-6 - Example of Lightning Strike Zone Details for Transport Aircraft Nose and Flight Deck

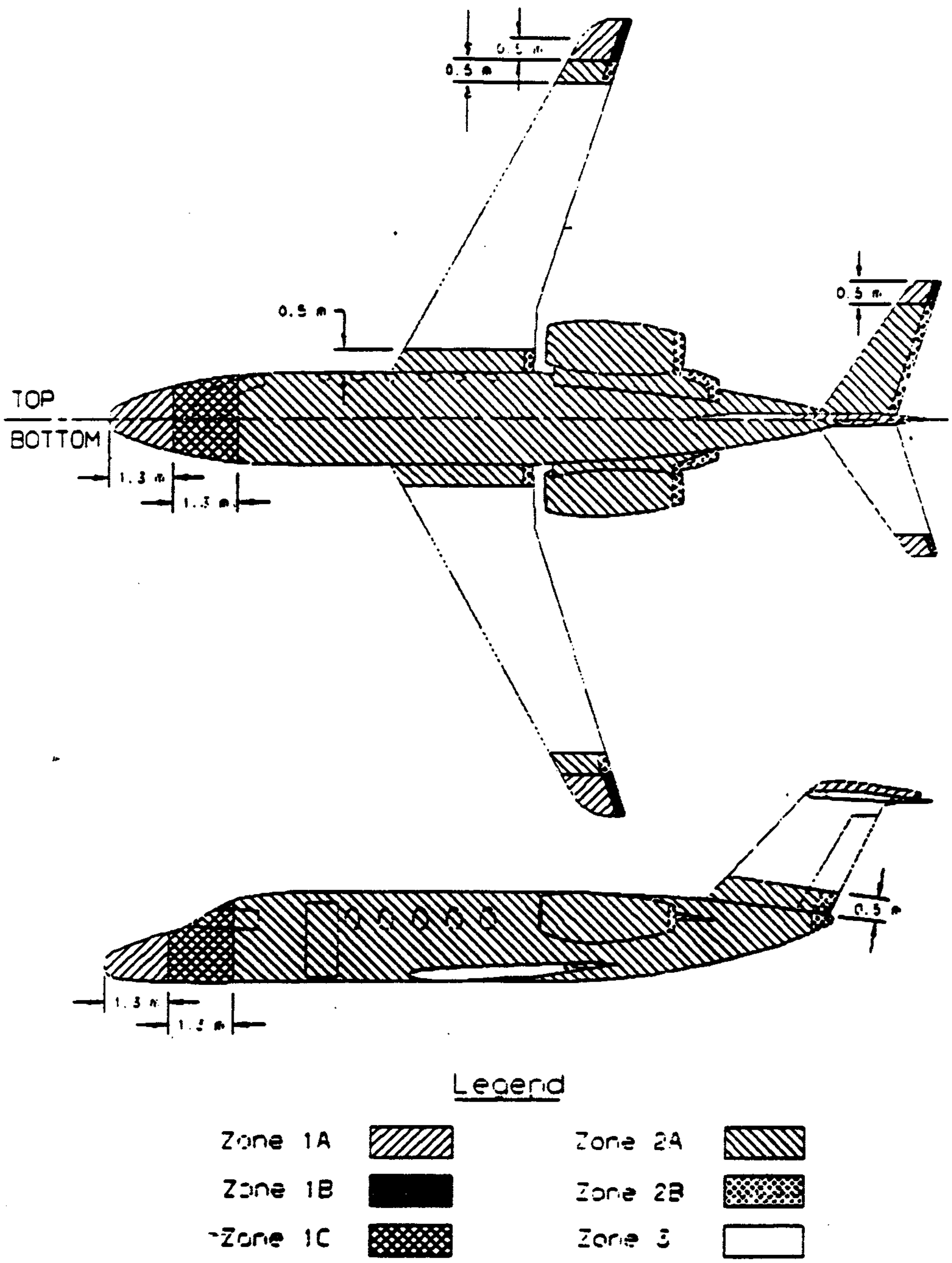


Figure 10-7 - Example of Lightning Strike Zone Details for Swept Wing Business Jet

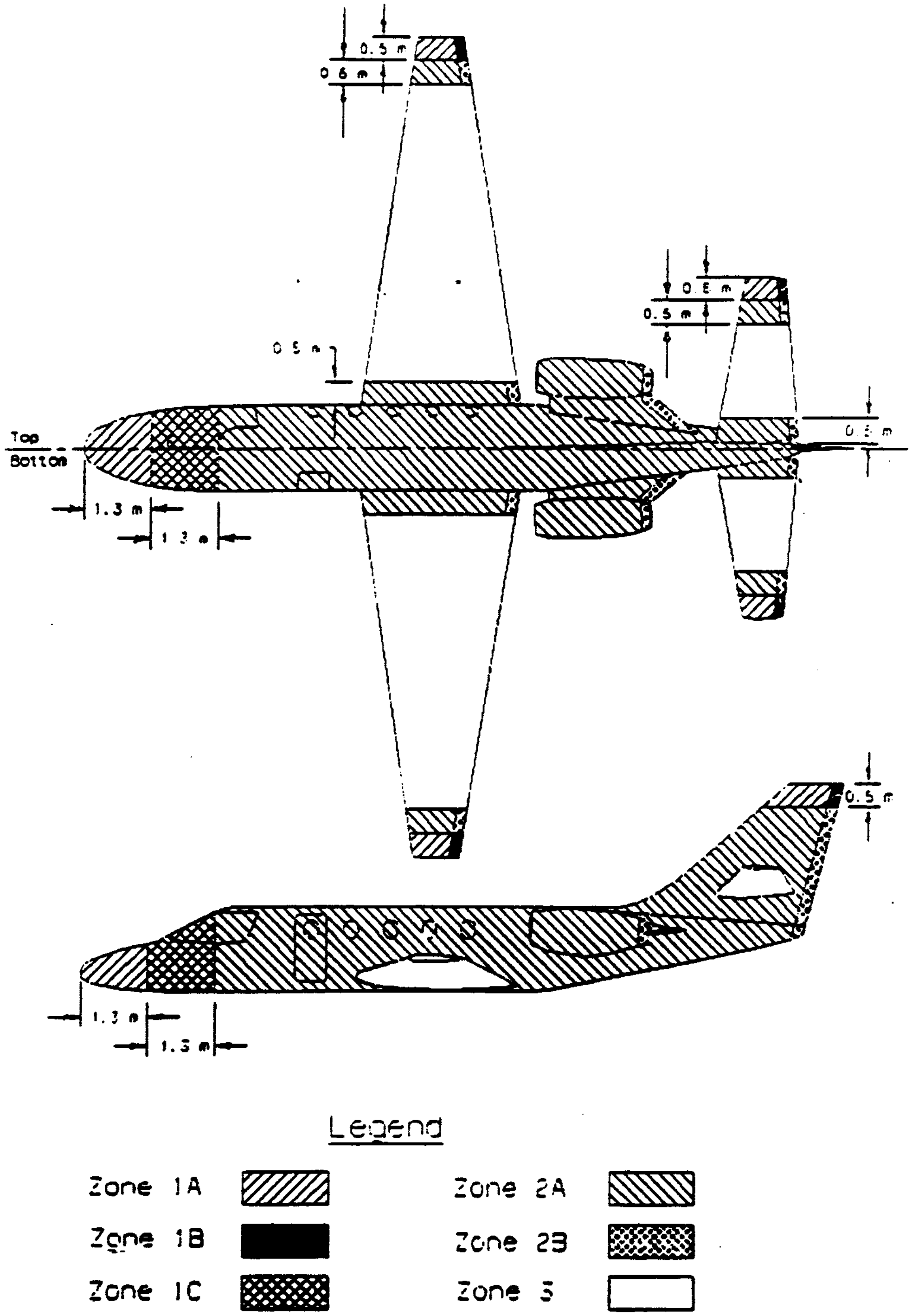


Figure 10-8 - Example of Lightning Strike Zone Details for Straight Wing Business Jet

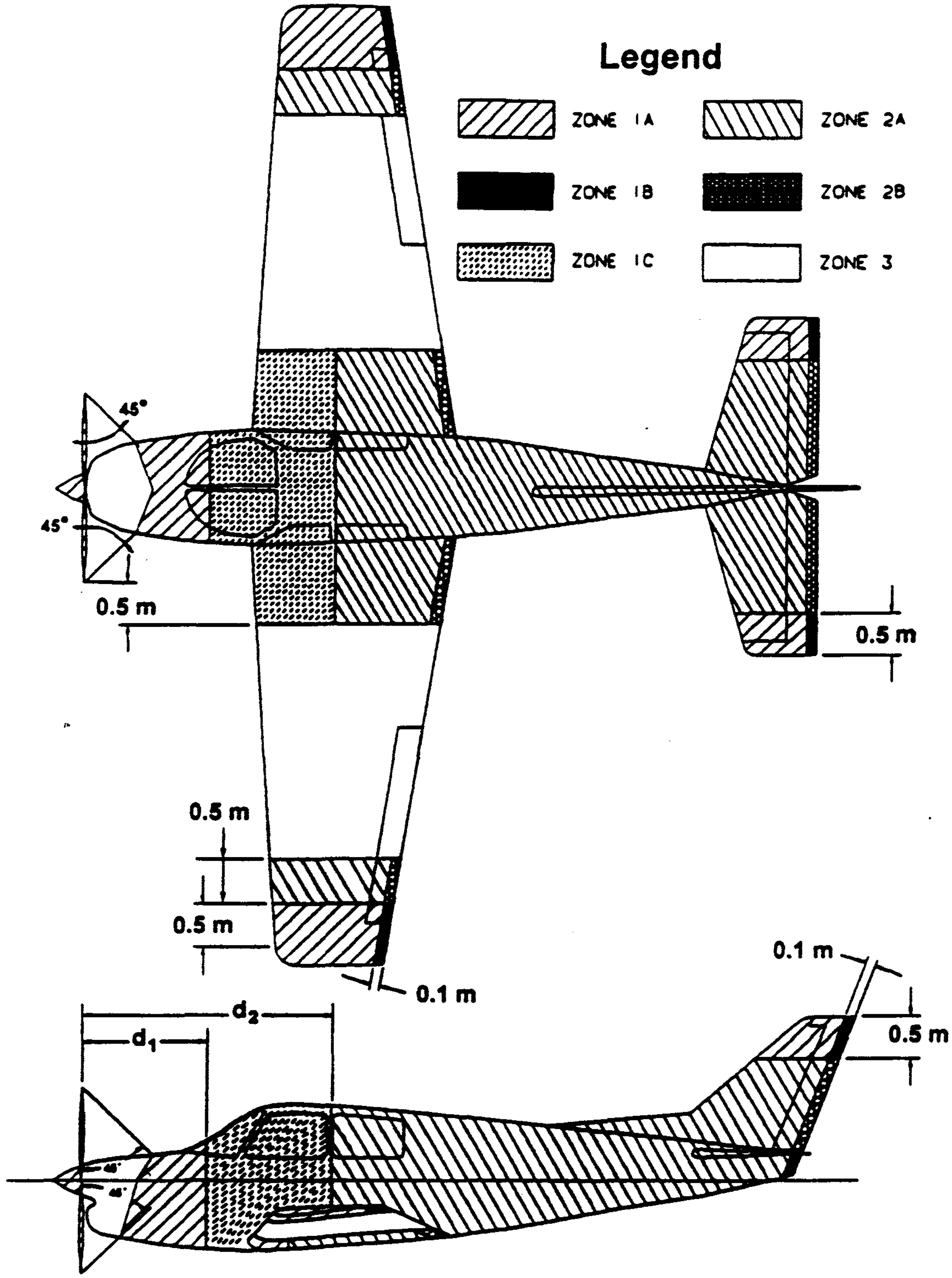


Figure 10-9 - Example of Lightning Strike Zone Details for Single Engine Propeller Driven Aircraft

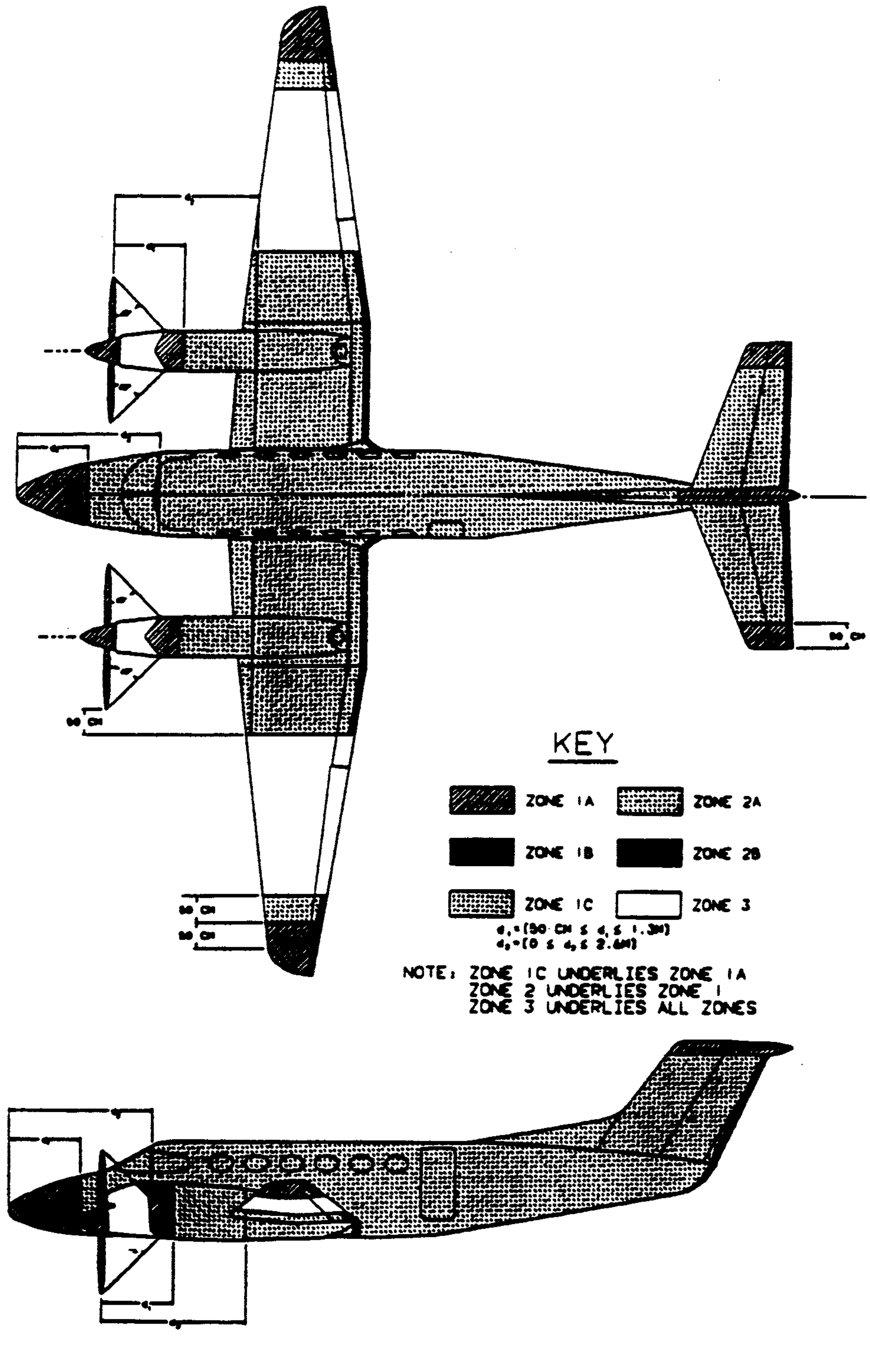
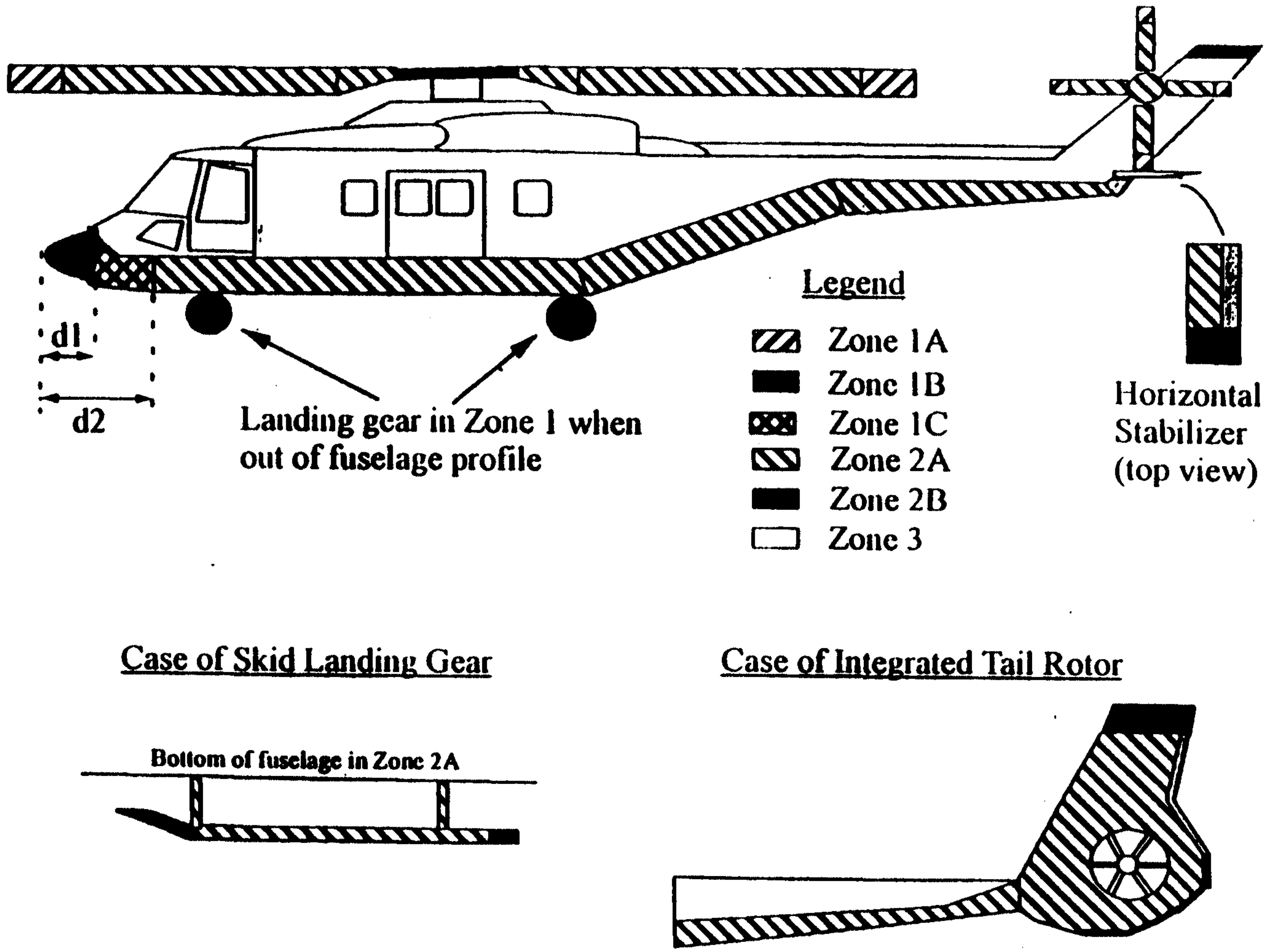


Figure 10-10 - Example of Lightning Strike Zone Details for Multi-Engine Propeller Driven Aircraft



Note: Surfaces on bottom of fuselage and tail may be in Zone 1B where landing gear is retracted.

Figure 10-11 - Example of Lightning Strike Zone Details for Rotorcraft

11.0 INITIAL LEADER ATTACHMENT LOCATION METHODS

11.1 Similarity

For new aircraft designs, previous lightning attachment experience on similar aircraft can be used to define the initial leader attachment areas. Similarity basis may include: Scale model test data and/or analysis results for an aircraft (or part of an aircraft) that has been previously certified. Specific features of the new aircraft design and the existing design should be assessed, as described in Section 10.8.

11.2 Service Experience

In flight lightning strike experience to an aircraft of similar geometry to the one whose zones are to be located can be utilized as the basis for establishing the surfaces where initial leader attachment may occur, if sufficient initial leader attachment data is available. The necessary data includes locations of initial leader attachments to existing aircraft. Since leader currents are of low intensity the marks left by them on existing airplanes may be difficult to discern from other lightning attachment marks, or other blemishes. Inspection of aircraft and documentation of strike locations over a period of years can (could) provide sufficient data. Initial leader attachments to frontal surfaces and edges are of greatest interest, since these define the starting region from which leader sweep distances d_1, and d_2 are determined as described in Sections 10.2 and 10.3.

When using service lightning strike experience, care should be taken to distinguish initial leader attachments from marks left by swept flashes and the stroke and continuing currents that flow in these channels, which are indicative of Zones 1A, 1C, and 2A. There will be some overlap, so that stroke and continuing current evidence will also appear in regions susceptible to initial leader attachment. The initial leader attachment for a specific strike will be the forward-most mark. The exception to this is for those trailing edges which are in Zone 1B, where all components of the lightning flash will enter/exit at the same spot.

11.3 Test

11.3.1 Objectives

Initial leader attachment region may be determined by tests of aircraft scale models, or in some cases by tests of full scale parts, where a more detailed assessment of zone boundaries may be desired.

11.3.2 Scale Model Tests

High voltage strike attachment tests to aircraft scale models have been used to determine initial lightning strike attachment locations. The test method has some limitations because of the physics of the simulation, where corona processes, and space charge distributions around the aircraft do not scale linearly with the model dimension. In addition, scale model tests are typically done without a representative net charge on the scale model. Moreover, the effects of airflow and altitude on space charge distributions and local pressure variations are not represented in model tests. Nevertheless, test results from model test arrangements that are possible have compared well with subsequent flight lightning strike experience. The basic procedure is to subject the model to impulsed electric fields in a variety of field orientations to represent possible electric field or oncoming leader orientations. Photographs are taken of the spark attachments to the model, and these indicate the initial leader attachment locations. Instructions for performing model tests are found in Reference 4.2.

11.3.3 Full Scale Tests

Model tests can indicate the regions on the aircraft where initial leader attachments are possible, however, these tests are not adequate to identify detailed attachment possibilities on especially complex geometrical shapes, or on regions which include combinations of electrically conductive and non-conductive surfaces. Should such high voltage strike attachment tests of full scale parts be necessary they must be conducted with representative materials and geometries, to evaluate specific attachment points and breakdown or flashover paths through or across non-conductive surfaces. Instructions for performing high voltage strike attachment tests on full scale parts are given in Reference 4.2.

11.4 Analysis

Initial leader attachment regions may be determined by one or more analytical methods such as electrical field modeling and rolling sphere analysis.

12.0 OTHER ZONING CONSIDERATIONS

12.1 Small Protrusions

Small protrusions produce electric field enhancements over relatively small volumes. These volumes are not usually large enough to initiate a leader discharge from the aircraft. Elements such as antennas, pitot static probes, drain masts, vents, stall fences, nacelle strakes, vortex generators, etc., are typically considered small protrusions provided their height is at least an order of magnitude smaller than the distance between their location and a zone boundary. Small protrusions don't normally affect the general electric field distribution and zoning of the aircraft, but if a small protrusion exists in a Zone 1 or 2 attachment area, it will be one of the more probable attachment points. Aircraft in-flight experience shows that these protrusions are not likely to experience a lightning attachment if they are not already located in Zone 1 or 2 attachment zones.

12.2 Non-conducting Surfaces

Within any of the lightning attachment zones (1A, 1B, 1C, 2A, 2B) there may be surfaces which are not electrically conductive and thus not susceptible to being directly struck by lightning. Initial leader or swept channel attachments may occur to surrounding conductive surfaces, but may, ideally, be swept across non-conductive surfaces to attach to surrounding conductive areas. In some cases, the non-conducting surfaces will have insufficient dielectric strength to prevent lightning from puncturing them, in which case attachment may occur to a conducting object beneath the non-conducting surface. Examples of this situation include a nose radome or a wheel well door fabricated of non-conducting composite material. Such surfaces may not themselves be susceptible to lightning attachment. They should initially, be considered part of the surrounding zone.

13.0 PROTECTION CONSIDERATIONS

In addition to zoning, the consequences of not adequately protecting a given part of the aircraft should be taken into account when determining the appropriate level of protection. It is usually, but not always, more practical to protect the aircraft from the external lightning environment predicted by this zoning standard than to allow the aircraft to suffer the likely damage. However, if it can be clearly demonstrated that there are only minor effects on the aircraft then the level of protection to be provided is discretionary.

Conversely, although areas defined in this standard as Zone 3 have a low probability of direct lightning attachment, components whose failure due to direct lightning attachment would have catastrophic effects, and are located in Zone 3 areas, should be located as far from Zone 1 and Zone 2 boundaries as practicable.

Furthermore, new or novel design features located in Zone 3, which could significantly reduce the level of protection provided by traditional designs, or which have no proven service history, must be shown by test or analysis to withstand a nominal lightning attachment (see reference 4.1) without catastrophic failure. The verification for these design features should be agreed between the applicant and the cognizant certification authority.

Document No. WG-335

FAA NOTICE OF PROPOSED RULEMAKING (NPRM)

and

JAA NOTICE OF PROPOSED AMENDMENT (NPA)

applicable to: -FAR Part 29 Transport Category Rotorcraft
-JAR 29 Large Rotorcraft

SYSTEM LIGHTNING PROTECTION

Produced by Electromagnetic Effects Harmonization Working Group (EEHWG)

Date: 20 Nov. 1998

[4910-13]

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

14 CFR Part 29

[Docket No. ; Notice No.]

RIN 2120-

Airworthiness Standards; System Lightning Protection

AGENCY: Federal Aviation Administration, DOT.

ACTION: Notice of proposed rulemaking (NPRM).

SUMMARY: This amendment revises lightning protection certification standards for electrical and electronic systems installed in Transport Category Rotorcraft. The accepted means of assessing and classifying the criticality of systems and equipment, as well as the related terminology, have changed since the original rule was promulgated. This regulation is being revised to reflect those changes while preserving the original intent.

DATES: Comments must be received on or before **[INSERT DATE 120 DAYS AFTER OF PUBLICATION IN THE FEDERAL REGISTER.]**

ADDRESSES: Comments on this notice may be delivered or mailed, in triplicate, to: Federal Aviation Administration, Office of the Chief Counsel, Attn: Rules Docket (AGC-200), Docket No., Room 915G, 800 Independence Avenue, SW., Washington, DC 20591. Comments submitted must be marked: "Docket No. ." Comments may also be sent electronically to the following internet address: nprmcmts@mail.hq.faa.gov. Comments may be examined in Room 915G on weekdays, except Federal holidays, between 8:30 a.m. and 5:00 p.m.

FOR FURTHER INFORMATION CONTACT:.

SUPPLEMENTARY INFORMATION:

Comments Invited

Interested persons are invited to participate in the making of the proposed rule by submitting such written data, views, or arguments as they may desire. Comments relating to the environmental, energy, federalism, or economic impact that might result from adopting the proposals in this notice are also invited. Substantive comments should be accompanied by cost estimates. Comments must identify the regulatory docket or notice number and be submitted in triplicate to the Rules Docket address specified above.

All comments received, as well as a report summarizing each substantive public contact with FAA personnel on this rulemaking, will be filed in the docket. The docket is available for public inspection before and after the comment closing date.

All comments received on or before the closing date will be considered by the Administrator before taking action on this proposed rulemaking. Late-filed comments will be considered to the extent practicable. The proposals contained in this notice may be changed in light of the comments received.

Commenters wishing the FAA to acknowledge receipt of their comments submitted in response to this notice must include a pre-addressed, stamped postcard with those comments on which the following statement is made:

"Comments to Docket No.." The postcard will be date stamped and mailed to the commenter.

Availability of NPRM

An electronic copy of this document may be downloaded using a modem and suitable communications software from the FAA regulations section of the FedWorld electronic bulletin board service (telephone: 703-321-3339), the FEDERAL REGISTER's electronic bulletin board service (telephone: 202-512-1661), or the FAA's Aviation Rulemaking Advisory Committee Bulletin Board service (telephone: 202-267-5948).

Internet users may reach the FAA's web page at http://www.faa.gov or the FEDERAL REGISTER's webpage at http://www.access.gpo.gov/su_docs for access to recently published rulemaking documents.

Any person may obtain a copy of this NPRM by submitting a request to the Federal Aviation Administration, Office of Rulemaking, ARM-1, 800 Independence Avenue, SW., Washington, DC 20591, or by calling (202) 267-9680. Communications must identify the notice number or docket number of this NPRM.

Persons interested in being placed on the mailing list for future NPRM's should request from the above office a copy of Advisory Circular No. 11-2A, Notice of Proposed Rulemaking Distribution System, that describes the application procedure.

Background

Statement of the Problem

The concern for the vulnerability of rotorcraft electronic systems to the effects of lightning has increased substantially over the past few years. . Fundamentally, this concern is a result of greater reliance on such systems to provide functions whose failure may prevent the continued safe flight and landing of the aircraft. Also, the use of solid-state components in the design of electronic control systems in rotorcraft has made such systems potentially susceptible to transient effects of induced electrical current and voltage caused by a direct lightning strike to the rotorcraft. These induced transient currents and voltages can degrade electronic system performance by damaging components or upsetting system functions. Component damage means a permanently altered electrical characteristic that can include dielectric breakdowns and effects from heat in semiconductor junctions, resistors, and component interconnections. Functional upset refers to an impairment of system operation, either permanent or momentary (e.g., a change of digital or analog state), that includes logic changes in computer and processing systems, electronic engine and flight controls, and power generating and distribution systems.

Another factor that has contributed to this increased concern is the reduced electromagnetic shielding afforded rotorcraft electronic systems by advanced technology rotorcraft materials.

The accepted means of assessing and classifying the criticality of systems and equipment has been continuously evolving and maturing (e.g. SAE ARP4754/EUROCAE ED-79, SAE ARP4761, AC 25.1309-1A, AC 23.1309-1B, AC 29-2A Paragraph f(2) Change 3, RTCA DO-178/EUROCAE ED-12, etc.). The earlier classification concept of failure conditions as either "Critical," "Essential," or "Non-Essential" functions was fundamental to the wording of the original rule and the associated Advisory Circular, AC/AMJ 20-136, Protection of Aircraft Electrical/Electronic Systems against the Indirect Effects of Lightning. For a number of reasons, this classification concept has given way to the perspective that systems and equipment failure conditions can have "Catastrophic," "Hazardous/Severe-Major," "Major," or "Minor" effects on rotorcraft safety. The revision herein proposed is intended to render this lightning protection regulation compatible and consistent with the latest classification concepts, terminology, and practices, such as the certification levels that are related to the classification of the failure conditions, with the focus on functions rather than systems.

Since trends indicate that future aircraft designs will incorporate similar systems, the cognizant aviation certification authorities have determined that a change in the design standards of 14 CFR part 29 and JAR 29 is necessary.

There are three sections in FAR/JAR part 29 that specifically pertain to lightning protection, one for the rotorcraft in general (§ 29.610), one for the fuel system (§ 29.954) and the third for electrical and electronic systems (§ 29.1309). Section 29.610 now requires the rotorcraft structure to be protected from the effects of lightning. This regulation states that compliance can be shown either by bonding components to the rotorcraft or by designing components so that a strike will not endanger the rotorcraft. Section 29.954 now requires the rotorcraft fuel system to be protected from the effects of lightning. The emphasis of § 29.954 is on the external aspects of lightning protection and the occurrence of catastrophic accidents directly attributed to lightning-related fuel vapor ignition.

Section 29.1309(h) requires, when showing compliance with paragraphs (a) and (b) of this section, the effects of lightning strikes on the rotorcraft must be considered. This section is being retained, as this requirement focuses attention to the need to assess the effects of lightning when carrying out the Functional Hazard Assessment (FHA).

Discussion of the Proposals

Section-by-Section Discussion of the Proposals

Section 29.1316 System Lightning Protection

A new section, 29.1316, would be added by this proposal to address lightning protection for electrical and electronic systems, equipment, and installations. Since lightning protection for electrical and electronic systems is a significant, certification effort, these requirements should be separated from section 29.1309 and expanded in a separate section.

Safety Analysis

A means of compliance as defined in AC/AMJ 20-136A would use established development assurance levels for electrical and electronic systems, which are related to the classification of the functional failure conditions. The functional failure condition classification would be assessed by performing a Functional Hazard Assessment (FHA) during the certification process and would be approved by the FAA/JAA. An FHA is conducted to identify all failures and classify them in functional and operational terms.

The results of the FHA should be reviewed to ensure that any unique indirect effects of lightning have been identified, such as common mode failures. It should also be noted that functional failure condition classifications are originally assessed and established by the FHA early in the certification process. It is therefore possible that unforeseen conditions may be identified during subsequent phases of the safety assessment process, which may result in a change to some of these classifications.

Airworthiness requirements for classifying these functions are based on AC/AMJ 25.1309-1A, System Design Analysis, which provides guidance in classifying these functional failure condition classifications according to their severity. The functional failure condition classifications listed are derived from this guidance material and are included to assist in the use of this document. The classifications are:

Classifications

(a) Catastrophic: Failure conditions that would prevent the continued safe flight and landing of the rotorcraft.

(b) Hazardous/Severe-Major: Failure conditions that would reduce the capability of the rotorcraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be:

(1) A large reduction in safety margins or functional capabilities,

(2) Physical distress or higher workload such that the flight crew could not be relied on to perform their tasks accurately or completely, or

(3) Serious (or fatal)@ injury to a relatively small number of the occupants.

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(c) Major. Failure conditions that would reduce the capability of the rotorcraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be, for example, a significant reduction in safety margins or functional capabilities, a significant increase in crew workload or in conditions impairing crew efficiency, or discomfort to occupants, possibly including injuries.

(d) Minor. Failure conditions that would not significantly reduce rotorcraft safety, and that involve crew actions well within their capabilities. Minor failure conditions may include, for example, a slight reduction in safety margins or functional capabilities, a slight increase in crew workload such as routine flight plan changes, or some inconvenience to occupants.

(e) No Effect. Failure conditions that do not affect the operational capability of the rotorcraft or increase crew workload.

Development assurance levels are related to the functional failure condition classification and are assigned to systems according to the following:.

Development Assurance Levels

(a) Level A: Electrical and electronic systems whose failure would cause or contribute to a failure of function resulting in a catastrophic failure condition for the rotorcraft.

(b) Level B: Electrical and electronic systems whose failure would cause or contribute to a failure of function resulting in a hazardous/severe-major failure condition for the rotorcraft.

(c) Level C: Electrical and electronic systems whose failure would cause or contribute to a failure of function resulting in a major failure condition for the rotorcraft.

(d) Level D: Electrical and electronic systems whose failure would cause or contribute to a failure of function resulting in a minor failure condition for the rotorcraft. Once a system has been confirmed, by the cognizant aviation certification authority, as being level D, no further application of this regulation is required.

(e) Level E: Electrical and electronic systems whose failure would cause or contribute to a failure of function resulting in no effect on rotorcraft operational capability or crew workload. Once a system has been confirmed, by the cognizant aviation certification authority, as being level E, no further application of this regulation is required.

A summary of the requirements is presented in Table 1, Compliance Summary.

Level A Requirements

Functions performed by electrical and electronic systems whose failure to provide that function correctly could lead to a catastrophic failure condition, would require protection to the extent that the function must not be adversely affected when the rotorcraft is exposed to lightning. These functions must continue to be provided during and after the time the rotorcraft is exposed to lightning.

If the function is provided by multiple systems, then loss of one or more systems, during exposure of the rotorcraft to lightning, shall not result in the loss of the function. After the rotorcraft is exposed to lightning, each affected system that performs these functions shall automatically recover normal operation, unless this conflicts with other operational or functional requirements of that system. Any failure or malfunction which occurs during the qualification process must be considered in the overall safety assessment as required by section 29.1309.

Level B and C Requirements

Functions performed by electrical and electronic system(s) whose failure could cause a hazardous/severe-major or major effect would require protection from the indirect effects of lightning to the extent that, when the equipment of which the system(s) is/are comprised, is exposed to the lightning threat or equivalent test level, the electrical and electronics systems that perform the functions must not be damaged and the functions must be recoverable in a timely manner. The equivalent test level is defined in AC/AMJ 20-136A, Certification of aircraft Electrical/Electronic Systems for the Indirects Effects of Lightning.

Compliance

To demonstrate compliance with the proposed requirements, an applicant should show that the requirements outlined in Table 1, Compliance Summary, are met for each electrical and electronic system whose failure to function may produce failure conditions ranging from catastrophic to major.

Acceptable operation during exposure to system or equipment level tests may be shown using analysis, modeling, testing, and/or similarity methods as agreed to by the FAA/JAA.

Deviations from the performance specifications of systems under consideration may be acceptable. These deviations would need to be assessed to demonstrate that the effects of the deviations neither cause nor contribute to conditions that would adversely affect rotorcraft operational capabilities. When deviations in performance occur as a consequence of system or equipment exposure to a test level, an assessment of the acceptability of the performance should be made. This assessment should be supported by analysis and data.

Compliance Criteria for Level A Systems

Compliance of systems classified as Level A will be demonstrated by test and/or analysis. This may be considered adequate, when:

(a) The functions performed by these systems are not adversely affected during and after the period of a system level test, when the systems are exposed to a test level determined for the rotorcraft installation in accordance with the method defined in AC/AMJ 20-136A.

AND

(b) Each affected system that performs such a function must automatically recover normal operation following aircraft exposure to the lightning environment unless this conflicts with other operational or functional requirements of that system.

AND

(c) Any system interruption should be evaluated to assure continued performance of the aircraft function and should be approved by the FAA/JAA)

Compliance Criteria for Level B and C Systems

Compliance of systems classified as Level B or C will be demonstrated by equipment test and/or analysis. Test levels are defined in AC/AMJ 20-136A. The systems must not be damaged and the functions must be recoverable in a timely manner after exposure to the lightning threat or equivalent test level as defined in AC/AMJ 20-136A.

As an alternative for demonstrating compliance to lightning protection for Level B and Level C systems, Rotorcraft Flight Manual limitations may be applied for aircraft that are limited to VFR flight conditions. For aircraft that are limited to VFR flight conditions, the aviation certification authority may accept the probability of exposure and/or loss of Level B and Level C functions with a Rotorcraft Flight Manual restriction, providing that an acceptable level of safety for the type of rotorcraft and its operation can be demonstrated. The Type Certificate Data Sheet , Rotorcraft Flight Manual (RFM), supplemental RFM, and/or placard should contain the statement as follows: "This aircraft is only approved for VFR flight conditions and must not be operated into known or forecast lightning conditions."

Compliance by Similarity

As an alternative to the test methods described in the preceding paragraphs for the approval of electrical and electronic systems whose failure may produce failure conditions ranging from catastrophic, hazardous/severe-major to major, an applicant may submit previously approved data for consideration by the FAA/JAA in determining compliance with the proposed requirements. Guidance for compliance by similarity is provided in AC/AMJ 20-136A. Certification by similarity is not applicable for a combination of new aircraft design and new equipment design.

TABLE I

COMPLIANCE SUMMARY

DEVELOPMENT ASSURANCE LEVEL	COMPLIANCE REQUIREMENTS
LEVEL A	1. Function must not be adversely affected during and after exposure to the lightning threat as defined in AC/AMJ 20-136A. 2. Any system interruption should be evaluated to assure continued performance of the rotorcraft function and should be approved by the FAA/JAA. 3. Affected systems must automatically recover upon removal of the lightning threat, unless this conflicts with other operational or functional requirements of that system.
LEVEL B or C	1. Functions must be recovered in a timely manner after exposure to the lightning threat or equivalent test level as defined in AC/AMJ 20-136A.

Paperwork Reduction Act

In accordance with the Paperwork Reduction Act of 1980 (Pub. L. 96-511), there are no requirements for information collection associated with this proposed rule.

International Compatibility

The FAA has reviewed corresponding International Civil Aviation Organization regulations and Joint Airworthiness Authority regulations and has identified no differences in these proposed amendments and the foreign regulations.

Regulatory Evaluation Summary

[TO BE DEVELOPED BY APO]

Initial Regulatory Flexibility Determination

[TO BE DEVELOPED BY APO]

International Trade Impact Analysis

[TO BE DEVELOPED BY APO]

Federalism Implications

[DEPENDS UPON APO ECONOMIC ANALYSIS]

Conclusion

[First paragraph depends on APO economic analysis]

The FAA proposes to add a new section to provide lightning standards for Transport Category Rotorcraft and to harmonize them with the standards that have been proposed by the Joint Aviation Authorities in Europe. If adopted, the proposed section would create uniform standards for the protection of electrical and electronic systems, equipment, and installations for these Rotorcraft.

List of Subjects in 14 CFR Part 29

Air Transportation, Aircraft, Aviation Safety, Rotorcraft, Safety

The Proposed Amendment

Accordingly, the FAA proposes to amend part 29 of Title 14, Code of Federal Regulations (14 CFR part 29) as follows:

PART 29--Airworthiness Standards: Transport Category Rotorcraft

1. The authority citation for part 29 continues to read as follows:

Authority: 49 USC 106(g), 40113, 44701, 44702, 44704

2. A new Section 29.1316 is added to read as follows:

§ 29.1316 System Lightning Protection

Rotorcraft electrical and electronic systems, equipment, and installations considered separately and in relation to other systems must be designed and installed according to the following:

(a.) Each function, the failure of which would prevent the continued safe flight and landing of the rotorcraft--

(1) Must not be adversely affected during and after exposure of the rotorcraft to the lightning environment; and

(2) Each affected system that performs such a function must automatically recover normal operation following rotorcraft exposure to the lightning

environment unless this conflicts with other operational or functional requirements of that system.

(b) Each system that performs a function, the failure of which would cause large reductions in the capability of the rotorcraft or the ability of the crew to cope with adverse operation conditions, may not be damaged and must be recoverable in a timely manner after exposure to the lightning environment.

(c) Each system that performs a function, the failure of which would reduce the capability of the rotorcraft or the ability of the crew to cope with adverse operation conditions, may not be damaged and must be recoverable in a timely manner after exposure to the lightning environment.

Issued in Washington, DC, on

CERTIFICATION OF AIRCRAFT ELECTRICAL/ELECTRONIC SYSTEMS FOR THE INDIRECT EFFECTS OF LIGHTNING

FINAL

DRAFT 20-136A

Produced by Electromagnetic Effects Harmonization Working Group (EEHWG)

Issue 3

Nov. 20, 1998

TABLE OF CONTENTS

CERTIFICATION OF AIRCRAFT ELECTRICAL/ELECTRONIC SYSTEMS FOR THE INDIRECT EFFECTS OF LIGHTNING

NOTE: *Whenever a reference document appears in this AC/AMJ, it carries the minimum revision level of the reference document acceptable to meet the intended requirements. Later versions of the reference document are also acceptable but earlier versions are not acceptable. In all cases, other documents shown to be equivalent to the referenced document are also acceptable.*

1. PURPOSE. This AC/AMJ provides information and guidance concerning a means, but not the only means, of compliance with Parts 23, 25, 27, and 29 of the Federal Aviation Regulations (FAR) and Joint Airworthiness Requirements (JAR), as applicable for preventing hazards, due to lightning indirect effects, from occurring to electrical/electronic systems.

2. SCOPE. This AC/AMJ provides guidance for a means of showing compliance with the regulations for hazards caused by the lightning environment to electrical/electronic systems installed either on or within aircraft. Equipment hazards addressed include those due to indirect effects on equipment and its associated wiring that is mounted on the aircraft exterior as well as indirect effects on equipment and its associated wiring located within the aircraft interior. This document applies to new aircraft and equipment designs, modifications of existing aircraft or equipment, and applications of existing (off the shelf) equipment on new aircraft.

Note: *This AC/AMJ does not address direct effects such as burning, eroding, blasting, of aircraft structure nor does it address fuel ignition hazards (see related reading material in Section 4 of this document). This AC/AMJ does not address lightning zoning methods or lightning test requirements, methods, and techniques. Coverings (fairing, skin, cowl, etc.) should normally prevent direct attachment of the lightning channel to underlying system components. However, if a direct lightning strike attachment to a system component can occur, a complete evaluation of both direct and indirect effects will be necessary.*

It should be noted that electrical/electronic systems or components *are sometimes exposed to lightning currents directly conducted from the aircraft exterior. as may happen when an antenna is struck and a portion of lightning current flows in its cable. Care should be taken to identify any such possibilities and either eliminate these situations by design modifications. or address them in the certification plan. No further discussion of these situations is included in this AC/AMJ.*

3. RELATED FAR and JAR INFORMATION.

a. *Federal Aviation Regulations (FAR). Federal Aviation Regulations 14 CFR* Parts 23. 25. 27. 29 and 33: Sections .901. .903. .1301. .1309. .1316. .1431. and .1529 (as applicable). 14 CFR Part 33. Sections .28 and .91 (as applicable).

b. *FAA Advisory Circulars. The following Advisory Circulars (AC) may provide additional information.*

(1) AC 23.1309-1B. System and Equipment Installations in Part 23 Airplanes. dated July 28. 1995.

(2) AC 25.1309-1A. System Design and Analysis. dated June 21. 1988.

(3) AC 27-1. Certification of Normal Category Rotorcraft. dated August 8. 1985. including to Change 4 dated August 18. 1995.

(4) AC 29-2A. Certification of Transport Category Rotorcraft. dated September 16. 1987. including to Change 3 dated June 1. 1995.

(5) AC 21-16C. Radio Technical Commission for Aeronautics Document DO-160D. dated March. 1998.

(6) AC 20-TBD. Aircraft Lightning Zoning

(7) AC 20-TBD. Aircraft Lightning Environment and Related Test Waveforms

c. *Joint Airworthiness Requirements (JAR). Joint Airworthiness Requirements Parts 23.1309. 25X899. 25.1309. 25.1431. 27.610. 27.1309. 29.610. 29.1431. JAR E AMJ 20X-1.*

d. *JAA Advisory and Interpretive Material.*

(1) *ACJ 25X899. Electrical Bonding and Protection Against Lightning and Static Electricity (Interpretive Material and Acceptable Means of Compliance).*

(2) *ACJ 29.610. Lightning and Static Electricity Protection (Interpretive Material and Acceptable Means of Compliance).*

(3) *AMJ 20X-1. Certification of Aircraft Propulsion Systems Equipped with Electronic Controls.*

(4) *AMJ 25.1309. System Design and Analysis*

(5) *AMJ 29.1309. Equipment. System and Installation*

(6) *AMJ 20.TBD. Aircraft Lightning Zoning*

(7) *AMJ 20.TBD. Aircraft Lightning Environment and Related-Test Waveforms*

4. **RELATED READING MATERIAL.** A comprehensive discussion on the material in this AC/AMJ. with additional guidance information. is available in the following documents:

a. ***EUROCAE Documents.***

(1) ***EUROCAE ED-14D. Environmental Conditions and Test Procedures for Airborne Equipment. dated July 1997***

b. ***RTCA. Inc.. Documents.*** ***These documents are available from RTCA. Inc.. 1140 Connecticut Avenue. NW. Suite 1020. Washington. DC 20036-4001:***

(1) ***RTCA. Inc.. DO-160D. Environmental Conditions and Test Procedures for Airborne Equipment. dated July. 1997***

c. *SAE Documents*. *These documents are available from the Society of Automotive Engineers, Inc., (SAE), 400 Commonwealth Drive, Warrendale, PA 15096:*

(1) *Aerospace Recommended Practice (ARP) 4754, Certification Considerations for Highly Integrated or Complex Aircraft Systems.*

d. *SAE/EUROCAE Joint Documents*.

(1) *User's Manual for this AC/AMJ.*

(2) *Aircraft Lightning Test Standard*.

5. BACKGROUND

a. Aircraft electrical/electronic systems may be vulnerable to lightning hazards. Aircraft which utilize an increasing number of electrical/electronic systems are currently being and will continue to be certified.

b. Lightning indirect effects may result when the electromagnetic fields produced by a direct strike to the aircraft induce voltage and current transients into the electrical/electronic equipment or components. These transients can be produced by electromagnetic field penetration into the aircraft interior or by structural IR (current times resistance) voltage rises due to current flow on the aircraft. Physical damage (direct effects) can also result from a direct lightning attachment to the aircraft.

c. The trend toward increased reliance on electrical/electronic systems for flight and engine control functions, navigation, and instrumentation requires that effective protection against lightning induced transients be designed and incorporated into these systems. Reliance upon redundancy as a sole means of protection against lightning indirect effects is generally not adequate because the electromagnetic fields and structural IR voltages can interact concurrently with all electrical wiring aboard an aircraft.

6. <u>DEFINITIONS</u>. See Appendix I for list of Definitions.

7. <u>APPROACHES TO COMPLIANCE</u>. The following seven (7) activities are elements of an iterative process for certification of aircraft electrical/electronic systems with respect to the indirect effects of lightning. The particular order of activities addressed, and the iterative application of the elements appropriate for a particular situation, are left to the applicant and strict adherence to the particular ordering of the elements in the list is not intended.

a. Review the safety analysis with respect to the indirect effects of lightning on the aircraft.

b. Determine the lightning strike zones for the aircraft.

c. Establish the airframe lightning current paths for the zones.

d. Establish the effects of the internal environment.

e. Establish Transient Control Levels (TCL) and Equipment Transient Design Levels (ETDL).

f. Verify Compliance.

g. Corrective Measures.

The elements are described in more detail in paragraphs (a) through (g).

a. <u>Review the safety analysis with respect to the indirect effects of lightning</u>. A Functional Hazard Assessment (FHA) is conducted to identify all failures and classify them in functional and operational terms. The results of the FHA should be reviewed to ensure that any unique indirect effects of lightning have been identified, such as common mode failures. Airworthiness requirements for classifying these functions are based on Section .1309 of FAR/JAR Parts 23, 25, 27, and 29. FAA/JAA advisory circulars which provide guidance in classifying these failure conditions according to their severity are as follows: AC 23.1309-1B, 25.1309-1A, 27-1.29-2A, AMJ 25.1309 and ACJ 29.1309.

The failure condition classifications listed below are derived from this guidance material and are included to assist in the use of this document. The classifications are:

(1) Catastrophic: Failure conditions which would prevent continued safe flight and landing.

(2) Hazardous/Severe-Major: Failure conditions which would reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be:

(i) A large reduction in safety margins or functional capabilities.

(ii) Physical distress or higher workload such that the flight crew could not be relied on to perform their tasks accurately or completely, or

(iii) Serious (or fatal*) injury to a relatively small number of the occupants.

* JAA only

(3) Major: Failure conditions which would reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be, for example, a significant reduction in safety margins or functional capabilities, a significant increase in crew work load or in conditions impairing crew efficiency, or discomfort to occupants, possibly including injuries.

(4) Minor: Failure conditions which would not significantly reduce aircraft safety, and which involve crew actions that are well within their capabilities. Minor failure conditions may include, for example, a slight reduction in safety margins or functional capabilities, a slight increase in crew workload, such as routine flight plan changes, or some inconvenience to occupants.

(5) No Effects: Failure conditions which do not affect the operational capability of the aircraft or increase crew workload.

The system development assurance level would also be assessed when performing the FHA and would be approved by the cognizant aviation certification authority. Guidance for selecting the system development assurance level is provided in SAE ARP 4754.

The following development assurance levels are related to the failure condition classifications.

Level A: Electrical and electronic systems whose failure would cause or contribute to a failure of function resulting in a catastrophic failure condition for the aircraft.

Level B: Electrical and electronic systems whose failure would cause or contribute to a failure of function resulting in a hazardous/severe-major failure condition for the aircraft.

Level C: Electrical and electronic systems whose failure would cause or contribute to a failure of function resulting in a major failure condition for the aircraft.

Level D: Electrical and electronic systems whose failure would cause or contribute to a failure of function resulting in a minor failure condition for the aircraft. Once a system has been confirmed, by the cognizant aviation certification authority, as being Level D, no further application of this regulation is required.

Level E: Electrical and electronic systems whose failure would cause or contribute to a failure of function resulting in no effect on aircraft operational capability or crew workload. Once a system has been confirmed, by the cognizant aviation certification authority, as being Level E, no further application of this regulation is required.

b. Determine the lightning strike zones for the aircraft. The characteristics of currents entering the aircraft vary according to attachment point locations on the aircraft. To establish the lightning characteristics appropriate for different portions of the aircraft, lightning strike zones have been defined in the AC/AMJ 20-TBD Aircraft Lightning Zoning.

Zones are the means by which the external environment is applied to the aircraft. _*The locations of these zones on any aircraft are dependent on the aircraft's geometry, materials, and operational factors, and often vary from one aircraft type to another; therefore, a determination must be made for each aircraft configuration.*_ Guidance for location of the strike zones on particular aircraft is given in the AC/AMJ 20-TBD. Aircraft Lightning Zoning .

c. Establish the airframe lightning current paths for the zones. The external lightning environment is a consequence of the interation of the lightning flash with the exterior of the aircraft. The external environment is represented by synthesized waveforms of the lightning current components at the aircraft surface. These waveforms and their applications are provided in the AC/AMJ 20-TBD. Aircraft Lightning Environment and Related Test Waveform.

Zones 1 and 2 define where lightning is likely to attach, and, as a result, the entrance and exit points for current flow through the vehicle. By definition, Zone 3 areas carry lightning current flow between pairs of direct or swept stroke lightning attachment points. Therefore, design and analysis using Zone 3 current levels as the external environment is generally acceptable.

d. Establish the effects of the internal environment. The internal lightning environment consists of the electromagnetic fields and structural IR voltages, which are produced by the external environment, as a result of current flow through the airframe and the penetration of electromagnetic fields. The fields and structural IR voltages cause voltages and currents on interconnecting wiring which in turn appear at equipment interfaces. In some cases, electromagnetic fields within the aircraft may penetrate equipment enclosures and compromise system operation.

For each system to be qualified, determine the lightning induced voltage and current waveforms and actual transient levels (ATL) that can appear at the electrical/electronic equipment interfaces. In many cases, the induced transients will be defined in terms of the open circuit voltage (v_{oc}) and the short circuit current (i_{sc}) appearing at wiring/equipment interfaces. The "v" and "i" will be related by the source impedances (i.e., loop impedance) of interconnecting wiring, and there may be different levels determined for different circuit functions or operating voltages.

e. Establish transient control levels (TCL) and equipment transient design levels (ETDL). The ETDLs represent the amplitude of voltage and/or current that the equipment is required to withstand or tolerate and remain operational (e.g., no damage or system functional upset). The TCLs, in turn, are set equal to or higher than the maximum ATL. The difference between ETDL and TCL is the margin. The equipment transient susceptibility level (ETSL) is the amplitude of voltage or current which, when applied to the equipment, will result in damage to components, or upset such that the equipment can no longer perform its intended function. The relationship between ATLs, TCLs, ETDLs, and ETSLs is illustrated in Figure 1. The ETDL is usually stated in the specifications for electrical/electronic equipment and constitutes a qualification test level for this equipment. Since ETDLs are typically represented by these standardized requirements, their use greatly simplifies compliance evaluation. Normally, the TCLs and ETDLs will be established by the airframe manufacturer or system integrator, who will compare the penalties of vehicle or interconnecting wiring protection or equipment hardening to establish the most logical combination of TCLs and ETDLs.

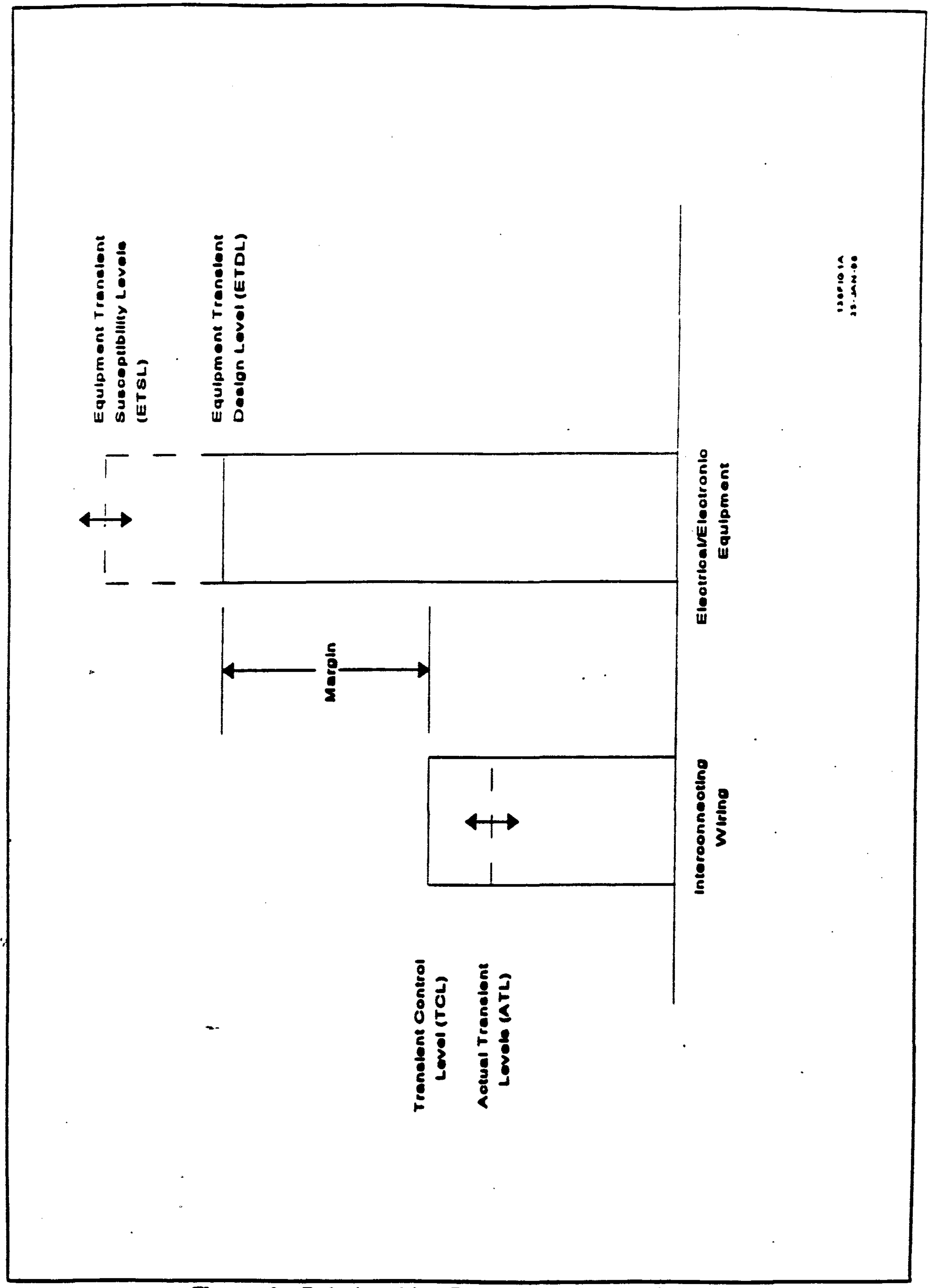


Figure 1 - Relationships Between Transient Levels

f. Verify compliance. Verify compliance by demonstrating that the ATLs appearing at wiring/equipment interfaces do not exceed the established TCLs. and that the equipment can tolerate the ETDLs.

(1) Verification may be accomplished by demonstrating similarity with previously installed systems and/or equipment. by tests. or by analysis. Appropriate margins to account for uncertainties in the verification techniques may be required as discussed in Section 9. Developmental test data may be used for certification when properly documented and coordinated with the cognizant aviation certification authority.

(2) Experience has shown, particularly on aircraft with new technology and/or complex systems. that discussion of and concurrence with the certification plan by the cognizant aviation certification authority early in the program is desirable. This plan is beneficial to both the applicant and the cognizant aviation certification authority because it identifies and defines an acceptable resolution of the critical issues early in the certification process. It should be understood that. as the process proceeds. analysis or test results may warrant modifications in design and/or verification methods. As necessary. when significant changes occur. the plan should be updated. The plan may include the following items:

(i) A description of the system(s). its installation configuration including any unusual or unique features. the operational aspects being addressed. zone locations. lightning environment. and preliminary estimate of ETDL/TCLs.

(ii) A description of the method to be used to verify compliance. Typically. the verification method includes a combination of similarity. analytical procedures. and/or tests. If analytical procedures are used. the methodology for verification of these procedures should be described. For further discussion see Section 10.

(iii) Acceptance Criteria for each system under consideration should be determined by a safety analysis. This safety analysis is to evaluate the aircraft in its various operational situations, taking into account the failure and disruption modes caused by lightning indirect effects.

(iv) Test Plans for each test should be prepared when tests are to be a part of the certification process. Test plans can be separate documents or a part of the compliance plan at the applicant's option and should address an appropriate test sequence.

g. Corrective Measures. When test and/or analysis show that acceptance criteria are not achieved, a review of the installation and/or component design should be conducted to determine where lightning protection methodology can be improved. The approach is to optimize the use of installation design techniques and equipment design.

8. **EFFECTS OF INDUCED TRANSIENTS**. Induced transients may be characterized by voltages impressed across or currents flowing into equipment interfaces. Equipment interface circuit impedance(s) and configuration(s) will determine whether the induced transient(s) are predominantly voltage or current. These transient voltages and currents can degrade system performance permanently or temporarily. Component damage and system functional upset are the primary types of degradation. Component damage is a permanent condition while functional upset refers to an impairment of system operation, either permanent or momentary (e.g., a change of digital or analog state which may or may not require manual reset), which may adversely affect flight safety.

a. Component Damage. Devices which may be susceptible to damage due to electrical transients are (1) active electronic devices, especially high frequency transistors, integrated circuits, microwave diodes and power supply components, (2) passive electrical and electronic components, especially those of very low power or voltage rating; (3) electro-explosive devices such as squibs and detonators, (4) electromechanical devices such as indicators, actuators, relays, and motors, and (5) insulating materials (e.g., insulating materials used in printed circuit boards and connectors) and electrical connections which can be burned or melted.

b. System Functional Upset. Functional upset is primarily a system problem. Permanent or momentary upset of a signal, circuit, or a system component can adversely affect system performance to a degree which compromises flight safety. In general, functional upset depends on circuit design and operating voltages, signal characteristics and timing, and system and software configuration. Systems or devices which may be susceptible to functional upset due to electrical transients include (1) computers and data or signal processing systems, (2) electronic engine and flight controls, and (3) power generating and distribution systems.

9. MARGINS AND VERIFICATION METHODS. Margins are incorporated to account for the uncertainties involved in the verification process. The magnitude of the margin required is inversely proportional to the confidence which is placed in the verification methods being used. The magnitude of the margin is also directly proportional to the degree that each system contributes to continued safe flight and landing as determined by the aircraft safety analysis. An acceptable margin is an essential element in the compliance process.

10. MAJOR ELEMENTS OF COMPLIANCE. Various methods for the establishment of TCLs and ETDLs (7e), verification of compliance (7f), and corrective measures (7g) are available. These methods, testing, analysis, and similarity, are outlined in the following sections. The methods outlined represent those which have evidence of practical application. The routes to compliance for Level A Control, Level A Display, and Levels B and C systems are provided in the flow diagrams of Figures 2, 3, and 4. It should be noted that there is a corresponding increase in the rigor of compliance with an increase in the failure condition classification of the function performed by the system/equipment.

Note:

Control System failures and malfunctions can more directly and abruptly contribute to a catastrophic event than display system failures and malfunctions. Based upon this, it is appropriate to require a more rigorous verification method for Level A Control Systems than for Level A Display Systems.

a. Level A Requirements

The translation of the external environment into the internal environment involves application of elements b., c., and d., delineated in Section 7. These activities, as well as those associated with the translation of the internal environment into the equipment interface currents and voltages, comprise the system level assessment of the aircraft electromagnetic (EM) response to a lightning strike and are associated with showing compliance of Level A systems.

Functions performed by electrical and electronic systems whose failure to provide that function correctly could lead to a catastrophic failure condition, would require protection to the extent that the function must not be adversely affected when the aircraft is exposed to lightning. These functions must continue to be provided during and after exposure to lightning.

If the function is provided by multiple systems, then loss of a system or systems, during exposure of the aircraft to lightning shall not result in the loss of the function. After the aircraft is exposed to lightning, each affected system that performs these functions shall automatically recover normal operation, unless this conflicts with other operational or functional requirements of that system.

Any Failure or Malfunction which occurs during the qualification process must be considered in the overall safety assessment

(1) Systems Performing Level A Control Functions

The applicant must demonstrate that systems performing Level A Control functions are not adversely affected by a lightning strike to the aircraft in which the systems are installed. The Level A Control function must be maintained during and after exposure to lightning.

Figure 2 is a flow diagram showing possible routes to compliance. In all cases, data from aircraft level test or analysis of the specific aircraft under consideration or one of sufficiently similar construction is necessary to obtain certification.

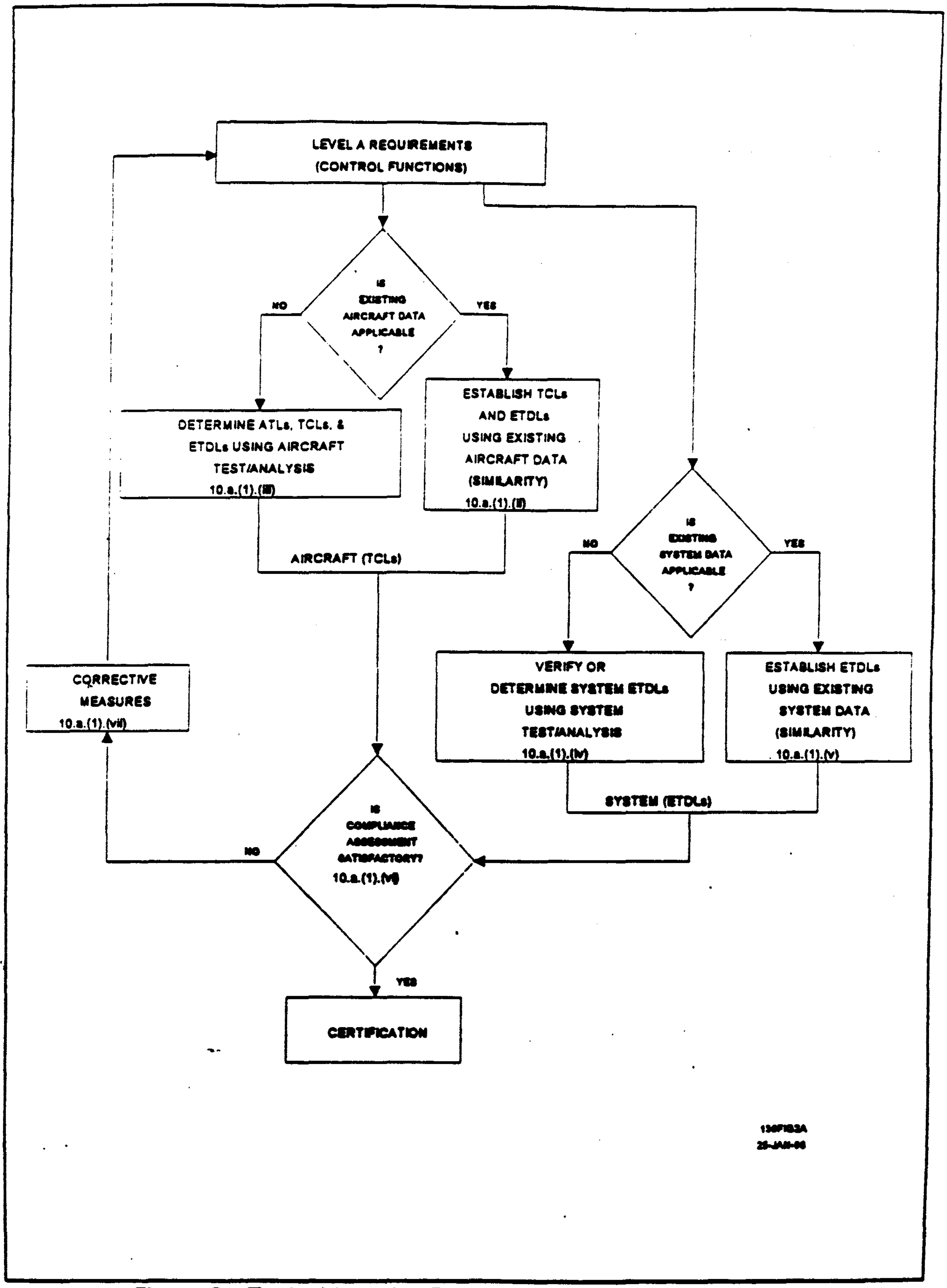


Figure 2 - Typical Iterative Process for Level A Requirements (Control Functions)

(i) Similarity

Similarity may be used as the basis for certification without the need for additional tests provided:

- only minimal differences exist between the previously certified system and installation and the system and installation to be certified, and
- there have been no unresolved in-service history of problems related to lightning strikes to the aircraft.

If there is uncertainty about the effects of the differences, additional tests and/or analysis should be conducted as necessary and appropriate to resolve the open issues.

Similarity may be used to verify compatibility of systems and equipment with ETDLs, or compatibility of interconnecting wiring with TCLs. The former situation might occur when a previously tested system is to be certified in a new aircraft, and the latter situation may occur when a new system is to be installed in an existing aircraft using interconnecting wiring for which ATLs and TCLs are known.

Similarity requires an evaluation of both the system and installation differences which may adversely affect the system susceptibility. An assessment of a new installation should consider differences affecting the internal lightning environment of the aircraft and its effects on the system. The assessment may cover:

(A) the aircraft type, equipment locations, airframe construction, and apertures which could affect attenuation of the external lightning environment;

(B) the system interfaces, wiring size and routing, connectors, whether parallel or twisted wires, and cable shielding;

(C) grounding and bonding;

(D) system modification status including software, firmware, and hardware.

Systems previously certified by test or analysis may be transferable to other applications. Every system needs to be assessed even though it may utilize equipment and installation techniques which have been the subject of a previous certification.

The use of similarity for Level A Control systems requires that the applicant show that any differences of either the system or its installation cause NO ADVERSE CHANGES on the TCL and ETDL values.

Similarity is NOT APPLICABLE for a combination of a new aircraft design and a new system design.

(ii) Establish TCLs and ETDLs Using Existing Aircraft Data (Similarity)

Existing aircraft data generated by test and/or analysis may be used to establish TCLs provided the aircraft and system installation under consideration are similar to the aircraft and system installation used to generate the data. Guidance in determining aircraft similarity is given in Section 10.a.(1).(i).

(iii) Determine ATLs, TCLs, and ETDLs Using Aircraft Test/Analysis

The ATLs, TCLs, and ETDLs may be determined by aircraft test and/or analysis. Guidance for performing tests is contained in the Aircraft Lightning Test Standard and guidance for performing analysis is contained in the User's Manual.

Analysis is a valid method for obtaining ATLs. Methods are available for full 3D simulations of entire aircraft including the internal structure and cables. In order to be accepted by the cognizant aviation certification authority, the methods' accuracy must be demonstrated. Some methods have been validated with experimental data under a wide variety of circumstances.

(iv) Verify or Determine System ETDLs Using System Test/Analysis

The ETDLs provided by aircraft test and/or analysis are used for single stroke, multiple stroke, and multiple burst testing. For multiple stroke and multiple burst testing. the system should be tested in accordance with procedures described in the Aircraft Lightning Test Standard. For pin and single stroke cable bundle testing. the system should be tested in accordance with procedures described in DO-160D/ED-14D. Section 22. Whenever cable bundle test methods are used. the system should be tested in an operational state.

Multiple stroke and multiple burst testing to the ETDLs or an analysis of the circuit response to these environments is required. When an analysis is performed. a description of the system architecture. including hardware and software data handling procedures may be necessary. Such a description should clearly establish the reasons why the system will not experience functional upset when exposed to these environments. Pin testing or single stroke cable bundle testing per Section 22 of DO-160D/ED-14D. is sufficient to demonstrate the system's ability to withstand the ETDLs without component damage.

(v) Establish ETDLs Using Existing System Data (Similarity)

Existing system data generated by test and/or analysis may be used to establish ETDLs provided the system under consideration is similar to the system used to generate the data. Guidance in determining system similarity is given in Section 10a(1)(i).

(vi) Compliance Assessment

An assessment is required to determine the system's functional compatibility with the internal lightning environment. and must show the following.

(A) The function on the aircraft must remain available during and after exposure to the indirect effects of lightning.

(B) Any system interruption or susceptibility must be evaluated to assure that there are no adverse effects on continued performance of the function and must be approved by the cognizant aviation certification authority.

(C) The affected systems must automatically recover upon removal of the internal lightning environment unless this conflicts with other requirements of that system.

(D) The equipment/system must tolerate the ETDLs, and the ATLs in the interconnecting wiring must be less than or equal to the TCLs.

(vii) Corrective Measures

Should the system fail to satisfy the certification requirements, a decision will be required on the corrective action to be taken. The resultant changes or modifications to the installation and/or the equipment may generate the need for additional testing/analysis. It may be necessary, therefore, to repeat the relevant equipment qualification testing/analysis and/or aircraft testing/analysis, in whole or in part, in order to satisfy the certification requirements. Modification of the equipment and/or installation may be necessary to achieve certification.

(2) Systems Performing Level A Display Functions

Figure 3 is a flow diagram showing possible routes to compliance for systems performing Level A Display functions. The objective of this approach is to demonstrate that the Level A function is maintained and the Level A system does not generate hazardously misleading information (HMI) when exposed to the indirect effects of lightning. In Figure 3, a review of any existing aircraft and/or system data is accomplished and a decision must be made on the direction the applicant chooses to achieve certification in each case.

(i) Similarity

Similarity may be used as the basis for certification without the need for additional tests provided:

- only minimal differences exist between the previously certified system and installation and the system and installation to be certified, and
- there have been no unresolved in-service history of problems related to lightning strikes to the aircraft.

If there is uncertainty about the effects of the differences, additional tests and/or analysis should be conducted as necessary and appropriate to resolve the open issues.

Similarity may be used to verify compatibility of systems and equipment with ETDLs, or compatibility of interconnecting wiring with TCLs. The former situation might occur when a previously tested system is to be certified in a new aircraft, and the latter situation may occur when a new system is to be installed in an existing aircraft using interconnecting wiring for which ATLs and TCLs are known.

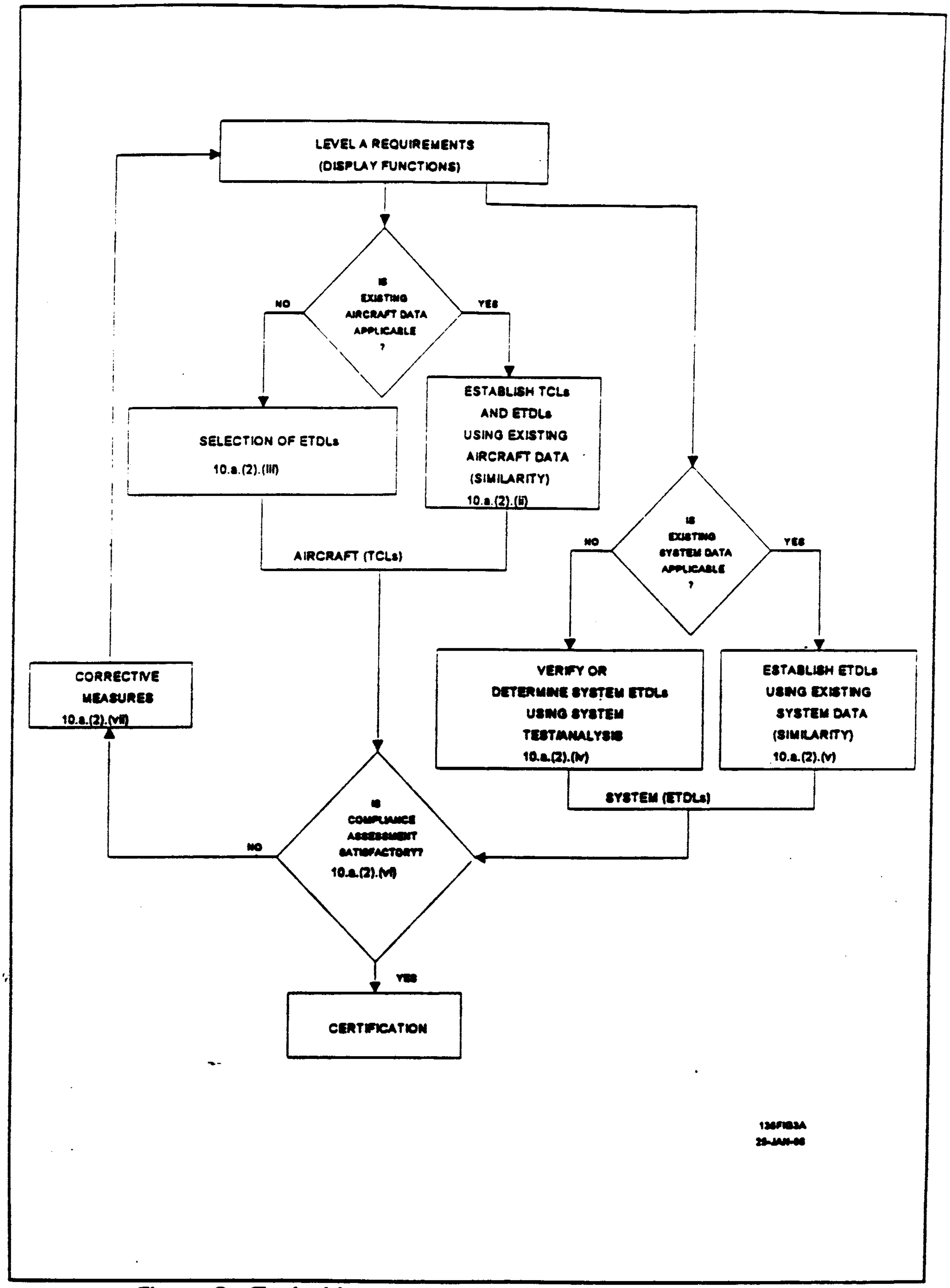


Figure 3 - Typical Iterative Process for Level A Requirements (Display Functions)

Similarity requires an evaluation of both the system and installation differences which may adversely affect the system susceptibility. An assessment of a new installation should consider differences affecting the internal lightning environment of the aircraft and its effects on the system. The assessment may cover:

(A) the aircraft type, equipment locations, airframe construction, and apertures which could affect attenuation of the external lightning environment;

(B) the system interfaces, wiring size and routing, connectors, whether parallel or twisted wires, and cable shielding;

(C) grounding and bonding;

(D) system modification status including software, firmware, and hardware.

Systems previously certified by test or analysis may be transferable to other applications. Every system needs to be assessed even though it may utilize equipment and installation techniques which have been the subject of a previous certification.

The use of similarity for Level A Display systems requires that the applicant show that any differences of either the system or its installation cause <u>MINIMAL ADVERSE CHANGES</u> on the TCL and ETDL values. If minimal adverse changes are discovered, then those differences should be discussed with the cognizant aviation certification authority.

Similarity is <u>NOT APPLICABLE</u> for a combination of a new aircraft design and a new system design.

(ii) Establish TCLs and ETDLs Using Existing Aircraft Data (Similarity)

This option provides a means of using existing aircraft data on a similar type aircraft to establish TCLs for the intended installation. This may be accomplished provided the aircraft and system installation under consideration are similar to the aircraft and system installation used to generate the data. Guidance in determining aircraft similarity is given in 10.a.(2).(i).

(iii) Selection of ETDLs

This section examines two options:

1) Determine ATLs, TCLs, and ETDLs using whole aircraft test/analysis.

   This option is the same method which is used for control systems and is outlined in Section 10a(1)(ii).

2) Selection of ETDLs per DO-160D/ED-14D.

   This option provides a means of selecting the ETDLs for the equipment without the benefit of specific aircraft test data. Section 22 of DO-160D/ED-14D, tables 22-2 and 22-3 provide predicted ETDLs. It must be noted, however, that substantiating evidence must show all the factors necessary to enable comparison of the ETDLs selected from DO-160D/ED-14D, Section 22, to the proposed aircraft installation. Each ETDL level selected should reflect all the significant aspects of the aircraft installation.

The following guidelines are included to assist the applicant in the proper selection of ETDLs given in DO-160D/ED-14D. It should be noted that different ETDL levels may be appropriate for different waveforms, reflecting proportionately higher or lower structural resistance voltages as compared with induced voltages due to changing magnetic fields. In such cases, the appropriate levels should be used.

Level 5: This level can be used when the equipment under consideration, or the cable bundle, or interfaces to/from the equipment are located in very severe electromagnetic environments which are defined as areas with composite materials demonstrating poor shielding effectiveness, areas where there is no guarantee of structural bonding, and other open areas where minimal shielding is provided. This level may also be used when a broad range of installations is to be covered. Note that in some cases(essentially high current density regions on mixed conductivity structures such as wing tips,engine nacelle fin, etc) where the wiring may divert some of the lightning current, higher ETDL's may be appropriate unless design measures are applied to reduce them.

Level 4: This level can be used when the equipment under consideration, or the cable bundle, or interfaces to/from the equipment are located in severe electromagnetic areas which are defined as areas outside the fuselage such as wings, fairings, wheel wells, pylons, control surfaces, etc. This definition is not appropriate for equipment installations more appropriately described by the definition of Level 5.

Level 3: This level can be used when the equipment under consideration, all interfaces to/from the equipment, and the cable bundle are contained entirely within a moderate electromagnetic environment which is defined as the inside of a metallic aircraft structure or composite aircraft structure demonstrating equivalent shielding effectiveness, without particular shielding enhancement measures. Examples of such an environment are avionics bays not enclosed by bulkheads, cockpit areas, and locations with large apertures, i.e., doors without EMI gaskets, windows, access panels, etc. Current carrying conductors in this environment such as hydraulic tubing, control cables, cable bundles, metal cable trays, etc., are not necessarily electrically grounded at bulkheads. When a small number of wires exit the environment, either a higher level (i.e. Level 4 or 5) should be used for these interfaces or additional protection for these wires should be provided. This definition is not appropriate for equipment installations more appropriately described by the definitions of Levels 4 and 5.

Level 2: This level can be used when the equipment under consideration, all interfaces to/from the equipment, and the cable bundle are contained entirely within a partially protected environment which is defined as the inside of a metallic aircraft structure or composite aircraft structure demonstrating equivalent shielding effectiveness, where measures have been taken to reduce the electromagnetic coupling onto cables. Cable bundles in this environment passing through bulkhead(s) have shields terminated at the bulkhead connector. When a small number of wires exit the environment, either a higher level (i.e. Level 3 or 4) should be used or additional protection for these wires should be provided. Cable bundles are installed close to the ground plane and take advantage of other inherent shielding characteristics provided by metallic structures. Current carrying conductors such as hydraulic tubing, cables, metal cable trays, etc., are electrically grounded at all bulkheads. This definition is not appropriate for equipment installations more appropriately described by the definitions of Levels 3, 4 and 5.

Level 1: This level can be used when the equipment under consideration, all interfaces to/from equipment, and the cable bundles are contained entirely within a well protected environment which is defined as an electromagnetically enclosed area which is not subjected to direct attachment of lightning strikes. This definition is not appropriate for equipment installations more appropriately described by the definitions of Levels 2, 3, 4, and 5.

(iv) Verify or Determine System ETDLs Using System Test/Analysis

The ETDLs selected are then used in the application of the multiple stroke and multiple burst environments as defined in the AC/AMJ 20-TBD, Aircraft Lightning Environment and Related Test Waveform Standard and tested in accordance with procedures described in the AC/AMJ 20-TBD, Aircraft Lightning Test Standard. For pin and single stroke cable bundle testing, the system should be tested in accordance with procedures described in DO-160D/ED-14D, Section 22. Whenever cable bundle test methods are used, the system should be tested in an operational state. Pin testing or single stroke cable bundle testing per Section 22 of DO-160D/ED-14D, is sufficient to demonstrate the system's ability to withstand the ETDLs without component damage.

(v) Establish ETDLs Using Existing System Data (Similarity)

Existing system data generated by test and/or analysis may be used to establish ETDLs provided the system under consideration is similar to the system used to generate the data. Guidance in determining system similarity is given in 10.a.(2).(i).

(vi) Compliance Assessment

An assessment is required to determine the system's functional compatibility with the effects of the internal lightning environment and must show the following:

(A) The function on the aircraft must remain available during and after exposure to the indirect effects of lightning.

(B) Any system interruption or susceptibility must be evaluated to assure that there are no adverse effects on continued performance of the function and must be approved by the cognizant aviation certification authority.

(C) The affected systems must automatically recover upon removal of the internal lightning environment unless this conflicts with other requirements of that system.

(D) The equipment/system must tolerate the selected ETDLs, and the implied TCLs must be appropriate for the specific aircraft installation.

(vii) Corrective Measures

Should the system fail to satisfy the certification requirements, a decision will be required on the corrective action to be taken. The resultant changes or modifications to the installation and/or the equipment may generate the need for additional testing/analysis. It may be necessary, therefore, to repeat the relevant equipment qualification testing/analysis and/or aircraft testing/analysis, in whole or in part, in order to satisfy the certification requirements. Modification of the equipment and/or installation may be necessary to achieve certification.

b. Level B and C Requirements

Functions performed by electrical and electronic systems whose failure could cause a hazardous/severe-major effect or major effect would require protection from the indirect effects of lightning to the extent that, when the equipment of which the system is comprised, is exposed to a defined test level, the electrical and electronic systems that perform the functions must not be damaged and the functions must be recoverable in a timely manner.

Systems requiring Level B or Level C protection, by the nature of the functions being performed, may be qualified using the methods defined in DO-160D/ED-14D, Section 22. Multiple stroke and multiple burst testing is not required if an analysis shows: (1) The equipment is not susceptible to upset or: (2) The equipment may be susceptible to upset. but a reset capability exists that will recover the function in a timely manner. Possible routes to compliance are shown in Figure 4.

As an alternative for demonstrating compliance to lightning protection for Level B and Level C systems. Aircraft Flight Manual limitations may be applied on non-Part 25 aircraft that are limited to VFR flight conditions. For aircraft that are limited to VFR flight conditions. the aviation certification authority may accept the probability of exposure and/or loss of Level B and Level C functions with an Aircraft Flight Manual restriction.providing that an acceptable level of safety for the type aircraft and it's operation can demonstrated. The Type Certification Data Sheet. Aircraft Flight Manual (AFM). Supplemental AFM. and/or Placard should contain the statement as follows: "This aircraft is only approved for VFR flight conditions and must not be operated into known or forecast lightning conditions"

(1) Similarity

In any similarity evaluation. all changes to the system or its installation must be assessed for their effect on a system to meet the certification requirements. Unless the system used as the certification basis for similarity has been demonstrated to withstand the testing defined in 10.b.(4). a review of the service experience and modification history of the system should be conducted for evidence of possible unresolved susceptibilities to the indirect effects of lightning. A qualitative demonstration of similarity for Level B and C systems rather than a quantitative assessment as defined for Level A Control and Display systems is sufficient.

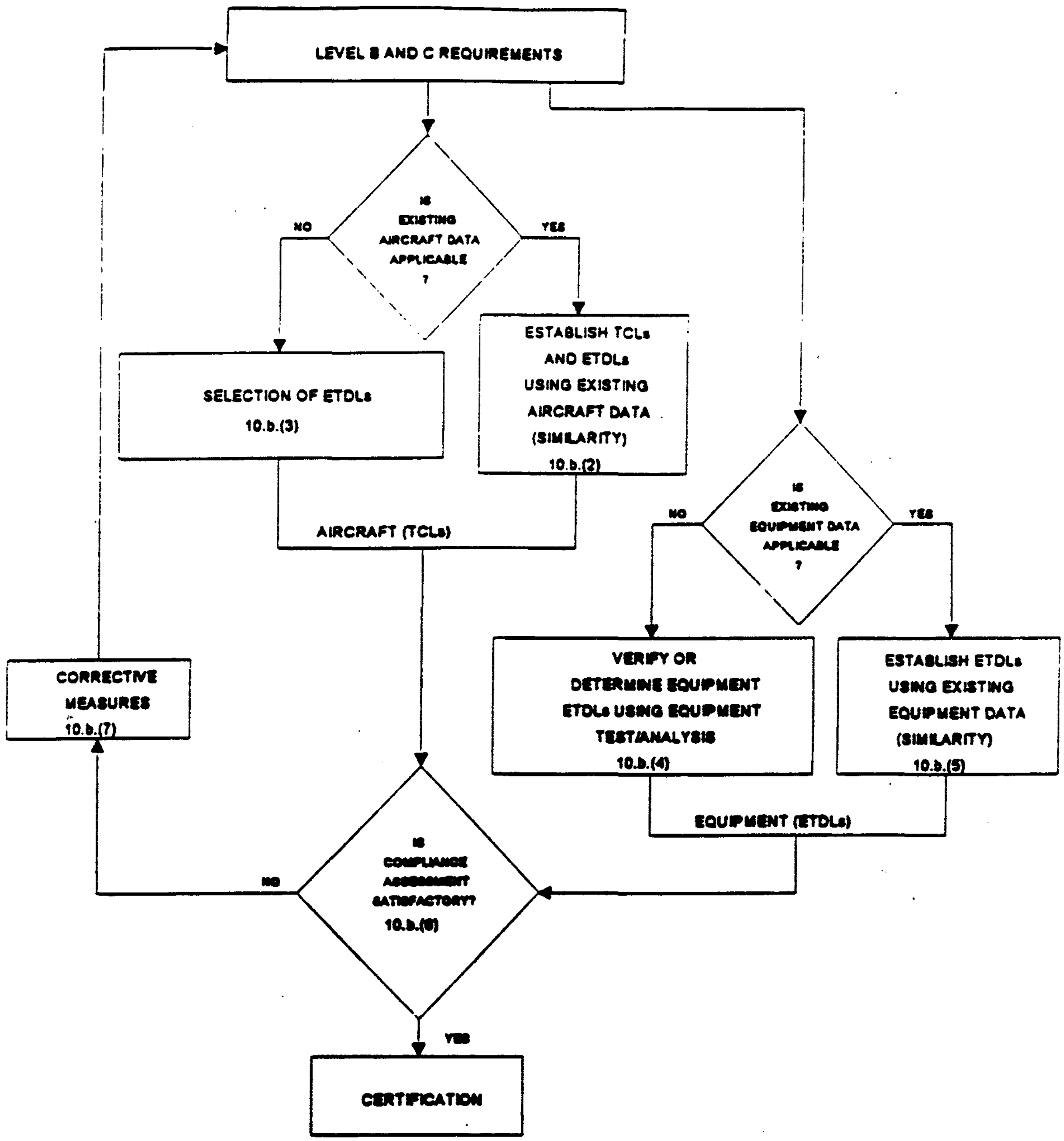


Figure 4 - Typical Iterative Process for Level B and C Requirements

(2) Establish TCLs and ETDLs Using Existing Aircraft Data (Similarity)

This option provides a means of using existing aircraft data on a similar type aircraft to establish TCLs for the intended installation. This may be accomplished provided the aircraft and system installation under consideration are similar to the aircraft and system installation used to generate the data. Guidance in determining aircraft similarity is given in 10.a.(1).(i) and 10.a.(2).(i).

(3) Selection of ETDLs

The aircraft test or analysis methods used to determine the ETDLs for Level A systems are acceptable for determination of ETDLs for Level B and C systems. Alternately, Level 3 as defined in DO-160D/ED-14D, Section 22 may be used for most Level B systems. For Level B systems and associated wiring installed in more severe electromagnetic environments such as areas external to the fuselage, areas with composite structures demonstrating poor shielding effectiveness, and other open areas, select a level appropriate to the environment. [See paragraph 10.a.(2).(iii).]

Level 2 as defined in DO-160D/ED-14D, Section 22, may be used for most Level C systems. For Level C systems installed in more severe electromagnetic environments such as areas external to the fuselage, areas with composite structures demonstrating poor shielding effectiveness, and other open areas, use Level 3. If a group of Level C systems are installed in more severe electromagnetic environments, the FHA should consider the simultaneous failure of that group as a result of a lightning strike. If the combined failure of that group is classified as Hazardous/Severe-major, the ETDL for a number (determined by the FHA) of Level C systems in that group should be selected as if they were Level B systems.

(4) Determine Equipment ETDLs Using Equipment Test/Analysis

Perform equipment testing in accordance with the procedures of DO-160D/ED-14D, Section 22, to ETDLs determined in 10.b.(2) [i.e., TCLs +

margin (if any)] or 10.b.(3).

(5) Establish ETDLs Using Existing Equipment Data (Similarity)

Existing system data generated by test and/or analysis may be used to establish ETDLs provided the system under consideration is similar to the system used to generate the data. Guidance in determining similarity is given in 10.b.(1).

(6) Compliance Assessment

The test results should be reviewed. The cause(s) of any result(s) that do not meet the acceptance criteria must be corrected prior to certification.

(7) Corrective Measures

Should the system fail to satisfy the certification requirements, a decision will be required on the corrective action to be taken. The resultant changes or modifications to the installation and/or the equipment may generate the need for additional testing/analysis. It may be necessary, therefore, to repeat the relevant equipment qualification testing/analysis and/or aircraft testing/analysis, in whole or in part, in order to satisfy the certification requirements. Modification of the equipment and/or installation may be necessary to achieve certification.

c. <u>Level D and E Requirements</u>

No further applications of these regulations are required.

11. <u>MAINTENANCE AND SURVEILLANCE</u>. The minimum maintenance required to support certification must be identified in instructions for continued airworthiness (e.g., XX.1529, MRB, MMEL, etc.). When dedicated protection devices or specific techniques are required to provide the protection for a system or equipment on an installation, the periodic/conditional maintenance and/or requirements for surveillance of these devices or techniques should be

defined to ensure the protection integrity is not degraded in service. In addition, the use of devices which may degrade with time due to corrosion, fretting, flexing cycles or other causes should be avoided where possible or dedicated replacement times identified.

Aircraft/system modifications need to be assessed for the impact of changes to the protection level against the direct and indirect effects of lightning. In principle, this assessment will be based on analysis and/or measurement.

The techniques and time intervals for evaluating or monitoring the integrity of the system protection should be defined. Built in test equipment, resistance measurements, continuity checks of the entire system or other means need to be identified to provide periodic/conditional surveillance of the system integrity.

The User's Manual provides further information on these topics.

APPENDIX I - Glossary of Terms

The following are definitions of terms as they are utilized in this document.

Actual Transient Level (ATL). The actual transient level is the level of transient voltage and/or current which appears at the equipment interfaces as a result of the external environment. This level may be less than or equal to the transient control level but should not be greater.

Aperture. An electromagnetically transparent opening.

Attachment Point. A point of contact of the lightning flash with the aircraft.

Component Damage. That condition where the electrical characteristics of a circuit component are permanently altered so that it no longer performs to its specifications.

Continued Safe Flight and Landing. This phrase means that the aircraft is capable of safely aborting or continuing a takeoff or continuing controlled flight and landing, possibly using emergency procedures but without requiring exceptional pilot skill or strength. Some aircraft damage may occur as a result of the failure condition or upon landing. For airplanes, the safe landing must be accomplished at a suitable airport. For rotorcraft, this means maintaining the ability of the rotorcraft to cope with adverse operating conditions and to land safely at a suitable site. See the AC/AMJ XX.1309

Control Function. A function that has some automated influence on a system (i.e., engine control system, flight control system) and whose failure would prevent the continued safe flight and landing of the aircraft.

Direct Effects. Any physical damage to the aircraft and/or elec-trical/electronic systems due to the direct attachment of the lightning channel. This includes tearing, bending, burning, vaporization, or blasting of aircraft surfaces/structures and damage to electrical/electronic systems.

Display Systems. Those Flight, Navigation and Power Plant Instruments required by FAR XX.1303 and XX.1305

Equipment Interface. A location on an equipment boundary where connection is made to the other components of the system of which it is part. It may be an individual wire connection to an elec-trical/electronic item, or wire bundles that interconnect equipment. It is at the equipment interface that the equipment transient design level (ETDL) and transient control level (TCL) are defined and where the actual transient level (ATL) should be identified.

Equipment Transient Design Level (ETDL). The peak amplitude of transients to which the equipment is qualified.

Equipment Transient Susceptibility Level (ETSL). The transient peak amplitude which will result in damage or upset to the system components.

External Environment. Characterization of the natural lightning environment for design and certification purposes as defined in the AC/AMJ 20-TBD, Aircraft Lightning Environment and Related Test Waveform Standard.

Indirect Effects. Electrical transients induced by lightning in aircraft electric circuits.

Internal Environment. The fields and structural IR potentials inside the aircraft produced by the external environment.

Lightning Flash. The total lightning event. It may occur within a cloud. between clouds. or between a cloud and ground. It can consist of one or more return strokes. plus intermediate or continuing currents.

Lightning Strike. Any attachment of the lightning flash to the aircraft.

Lightning Strike Zones. Aircraft surface areas and structures classified according to the possibility of lightning attachment. dwell time. and current conduction. See the AC/AMJ 20-TBD. Aircraft Lightning Zoning Standard.

Lightning Stroke (Return Stroke). A lightning current surge that occurs when the lightning leader makes contact with the ground or another charge center.

Margin. The difference between the equipment transient design level and the transient control level.

Multiple Burst. A randomly spaced series of bursts of short duration. low amplitude current pulses. with each pulse characterized by rapidly changing currents (i.e.. high di/dt's). These bursts may result from lightning leader progression or branching. and are associated with the cloud-to-cloud and intra-cloud flashes. The multiple bursts appear to be most intense at the time of initial leader attachment to the aircraft. See AC/AMJ 20-TBD Aircraft Lightning Environment and Related Test Waveform Standard.

Multiple Stroke. Two or more lightning return strokes occurring during a single lightning flash. See AC/AMJ 20-TBD. Aircraft Lightning Environment and Related Test Waveform Standard.

Return Stroke. (see Lightning Stroke)

Structural IR Voltage. The portion of the induced voltage resulting from the product of the distributed lightning current (I) and the resistance (R) of the aircraft skin or structure.

Swept Channel. The lightning channel relative to the aircraft. which results in a series of successive attachments due to sweeping of the flash across the aircraft by the motion of the aircraft.

System Functional Upset. An impairment of system operation, either permanent or momentary (e.g., a change of digital or analog state) which may or may not require manual reset.

Transient Control Level (TCL). The transient control level is the maximum allowable level of transients appearing at the equipment interfaces as a result of the defined external environment.

Upset. (See System Functional Upset)

WG-330

Final Draft

AC/AMJ 20-TBD

AIRCRAFT LIGHTNING ENVIRONMENT AND RELATED TEST WAVEFORMS

Issue 2: Nov. 20, 1998
(18th EEHWG meeting)

TABLE OF CONTENTS

1.0 PURPOSE

This Advisory Circular/Advisory Material Joint (AC/AMJ) is one of the set of three documents covering the whole spectrum of aircraft interaction with lightning. The purpose of this AC/AMJ is to provide the characteristics of lightning that are encountered by aircraft as well as transients appearing at the interfaces of equipment associated with electrical/electronic systems as a result of that interaction. These characteristics are referred to as the aircraft lightning environment. The two other documents provide advisory material on aircraft lightning zoning (Reference 4.1) and aircraft lightning testing (Reference 4.2), and are hereinafter referred to as the Zoning AC/AMJ and the Testing Standard. The relationship between the three documents is shown in Figure 1-1.

2.0 SCOPE

The environment and test waveforms defined in this AC/AMJ account for the best lightning data and analysis currently available. The quantified environment and levels herein represent the minimum currently required by certifying authorities, consistent with the approach applied in related lightning documents.

Lightning, like any natural phenomenon, is probabilistic in nature. Levels and waveforms vary considerably from one flash to the next. These standardized voltage and current waveforms have been derived to represent the lightning environment, and are used to assess the direct effects of lightning on aircraft. The standardized external current waveforms have in turn been used to derive standardized transient voltage and current waveforms which can be expected to appear on the cable bundles and at equipment interfaces.

In addition, test waveforms based on current industry best practice are included to supplement these waveforms that are derived directly from the lightning environment. Considerations such as testability and important waveform characteristics that can demonstrate lightning design effectiveness are taken into account.

The parameters of the standardized waveforms, both external and derived transients, represent severe versions of each of the characteristics of natural lightning flashes and include all parameters of interest with respect to lightning protection for aircraft. However, it should be noted that in every case more severe versions of each of the characteristics of the standardized waveforms have been recorded in natural lightning flashes as well as additional parameters such as electric field effects in non-conductive structures.

The test waveforms provided in this AC/AMJ are considered to be adequate for the demonstration of compliance for the protection of an aircraft and its systems against the lightning environment and should be applied in accordance with the aircraft lightning strike zones (Reference 4.1) and test methods (Reference 4.2), and applicable FAA and JAA advisory and interpretive material.

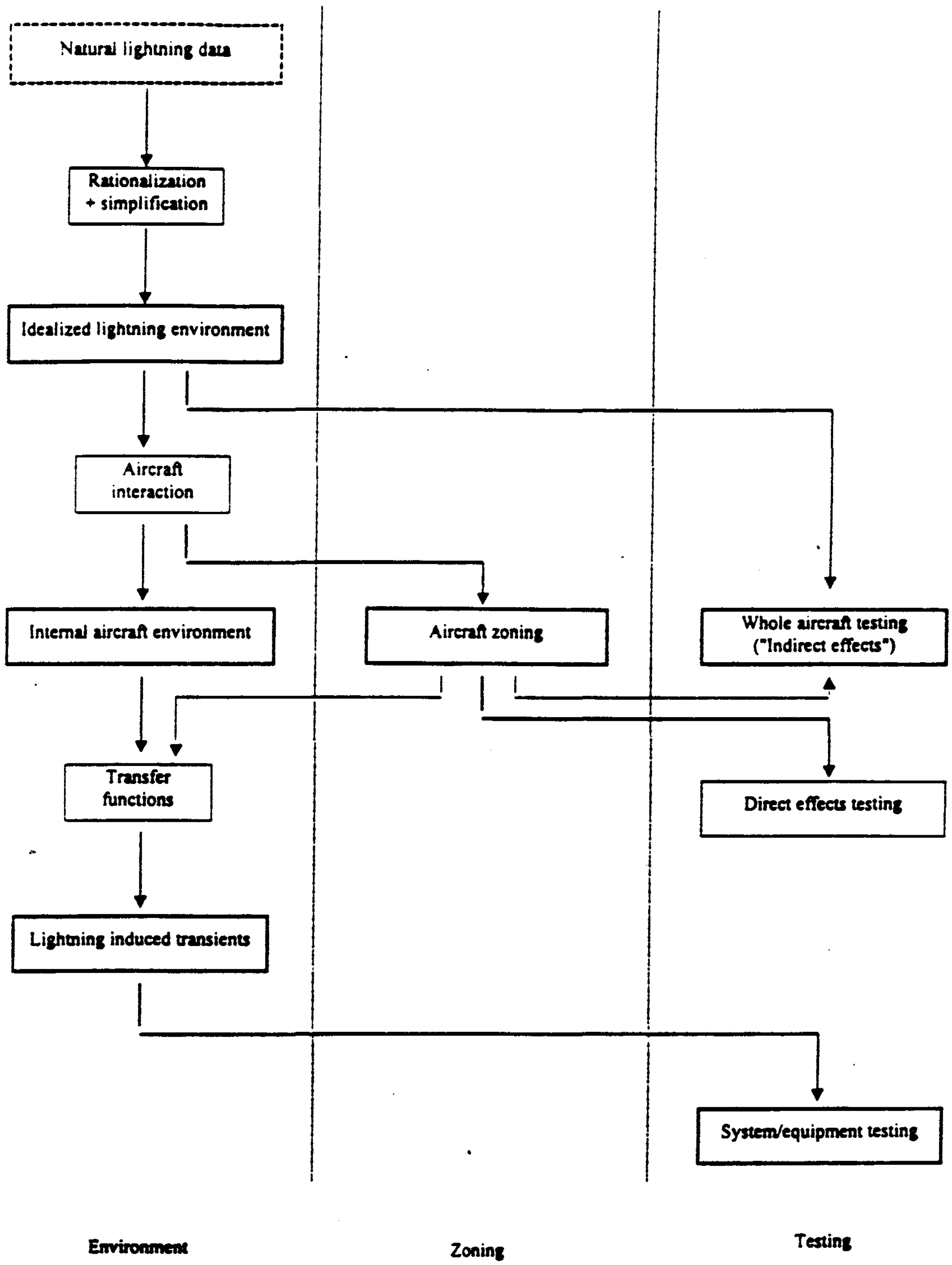


Figure 1-1. Relationship between aircraft environment, zoning and testing

Note: Solid lines represent the actual AC/AMJ and Standard's materials and processes addressed in the documents. The dotted lines represent the supporting materials and processes.

3.0 RELATED FAR AND JAR INFORMATION

3.1 Federal Aviation Regulations (FAR).

Federal Aviation Regulations 14 CFR Parts 23.867, 23.954, 23.1309(e), 23.1316, 25.581, 25.954, 25.1316, 27.610, 27.954, 27.1309(d), 27.1316, 29.610, 29.954, 29.1309(h), 29.1316 and 33.28(d).

3.2 FAA Advisory Circulars.

The following Advisory Circulars (AC) may provide additional information.

3.2.1 AC 23.1309-1B, System and Equipment Installations in Part 23 Airplanes, dated July 28, 1995.

3.2.2 AC 25.1309-1A, System Design and Analysis, dated June 21, 1988.

3.2.3 AC 27-1, Certification of Normal Category Rotorcraft, dated August 8, 1985, including to Change 4 dated August 18, 1995.

3.2.4 AC 29-2A, Certification of Transport Category Rotorcraft, dated September 16, 1987, including to Change 3 dated June 1, 1995.

3.2.5 AC 21-16D, Radio Technical Commission for Aeronautics Document DO-160D, dated March, 1998.

3.3 Joint Airworthiness Requirements (JAR).

Joint Airworthiness Requirements Parts 23.867, 23.954, 23.1309(e), 23.1316, 25.581, 25X899, 25.954, 25.1316, 27.610, 27.954, 27.1309(d), 27.1316, 29.610, 29.954, 29.1309(h), 29.1316, 33.28(d) and JAR E.50.

3.4 JAA Advisory and Interpretive Material.

3.4.1 ACJ 25X899, Electrical Bonding and Protection Against Lightning and Static Electricity (Interpretive Material and Acceptable Means of Compliance).

3.4.2 ACJ 29.610, Lightning and Static Electricity Protection (Interpretive Material and Acceptable Means of Compliance).

3.4.3 AMJ 20X-1, Certification of Aircraft Propulsion Systems Equipped with Electronic Controls.

4.0 REFERENCE DOCUMENTS

4.1 AC/AMJ 20-TBD (in preparation)
"Aircraft Lightning Zoning "

4.2 EUROCAE WG 31/SAE AE4L document APR-TBD (in preparation)
"Aircraft Lightning Testing Standard"

4.3 EUROCAE ED-14D/RTCA DO-160D
"Environmental Conditions and Test Procedures for Airborne Equipment"
Section 22: "Lightning Induced Transient Susceptibility"

4.4 EUROCAE ED-14D/RTCA DO-160D
"Environmental Conditions and Test Procedures for Airborne Equipment"
Section 23: "Lightning Direct Effects"

4.5 AC/AMJ 20-136A
"Protection of Aircraft Electrical/Electronic Systems against the Indirect Effects of Lightning"

4.6 AC/AMJ 20-53B
"Protection of Airplane Fuel Systems Against Fuel Vapor Ignition Due to Lightning"

4.7 User's Guide for SAE AE4L Committee Report AE4L-87-3 Revision C
EUROCAE WG 31/SAE AE4L document (in preparation).

5.0 BACKGROUND

The environment information and the test waveforms have been removed from AC/AMJ 20-136 and AC/AMJ 20-53, and included in this AC/AMJ. This AC/AMJ also explains the idealized external waveforms and gives a brief discussion of the mechanisms for transforming the external environment into an internal environment and the resulting transients on cable bundles and at equipment interfaces.

6.0 DEFINITIONS/ABBREVIATIONS/ACRONYMS

6.1 Definitions

Action Integral	The integral of the square of the time varying current over its time duration. It is usually expressed in units of ampere squared seconds (A^2s).
Aperture	An electromagnetically transparent opening.
Aperture Coupling	The process of inducing voltages or currents in avionics wiring or systems by electric or magnetic fields passing through apertures.
Attachment Point	A point of contact of the lightning flash with the aircraft.
Breakdown	The production of a conductive ionized channel in a dielectric medium resulting in the collapse of a high electric field.
Cable Bundle	A group of wires and/or cables bound or routed together that connect two pieces of equipment.
Charge Transfer	The time integral of the current over its entire duration, in units of coulombs ($A \times s$).
Continuing Current	A low level long duration lightning current that occurs between or after the high current strokes.
Dart Leader	A leader which occurs before subsequent strokes without stepping but with a continuous progression of the leader tip.
Diffusion	The process by which electric current flow spreads through the thickness of a conductive material which results in a slower increase in current density on interior surfaces as compared with exterior surfaces.
Direct Effects	Any physical effects to the aircraft and/or equipment due to the direct attachment of the lightning channel and/or conduction of lightning current. This includes dielectric puncture, blasting, bending, melting, burning and vaporization of aircraft or equipment surfaces and structures. It also includes directly injected voltages and currents in associated wiring, plumbing, and other conductive components.
Dwell Time	The time that the lightning channel remains attached to a single spot on the aircraft.

Equipment Interface — A location on an equipment boundary where connection is made to the other components of the system of which it is part. It may be an individual wire connection to an electrical/electronic item, or wire bundles that interconnect equipment. It is at the equipment interface that the equipment transient design level (ETDL) and transient control level (TCL) are defined and where the actual transient level (ATL) should be identified.

External Environment — Characterization of the natural lightning environment for design and certification purposes.

First Return Stroke — The high current surge that occurs when the leader completes the connection between the two charge centers. The current surge has a high peak current, high rate of change of current with respect to time (di/dt) and a high action integral.

Flashover — This term is used when the arc produced by a gap breakdown passes over or close to a dielectric surface without puncture.

Indirect Effects — Electrical transients induced by lightning in aircraft conductive components such as electric circuits.

Induced Voltages — A voltage produced in a circuit by changing magnetic or electric fields or structural IR voltages.

Interface Transients — Induced voltages and currents appearing in cable bundles or in individual conductors, and which appear at equipment interfaces.

Internal Environment — The fields and structural IR voltages inside the aircraft produced by the external environment.

K Changes — Electric (E) field changes and current pulses seen inside the cloud during cloud to ground flashes and often associated with current pulses.

Leader — The low luminosity, low current precursor of a lightning return stroke, accompanied by an intense electric field.

Lightning Channel — The ionized path through the air along which the lightning current pulse passes.

Lightning Flash — The total lightning event. It may occur within a cloud, between clouds or between a cloud and ground. It can consist of one or more return strokes, plus intermediate or continuing currents.

Lightning Strike	Any attachment of the lightning flash to the aircraft.
Lightning Strike Zones	Aircraft surface areas and structures classified according to the possibility of lightning attachment, dwell time and current conduction. (See the Zoning Adversary Circular.)
Multiple Burst	Randomly spaced groups of short duration, low amplitude current pulses, with each pulse characterized by rapidly changing currents (i.e. high di/dt's). These pulses may result from lightning leader progression or branching. The pulses appear to be most intense at the time of initial leader attachment to the aircraft.
Multiple Strike	Two or more lightning strikes during a single flight.
Multiple Stroke	Two or more lightning return strokes occurring during a single lightning flash.
Peak Rate of Rise	The maximum value of the derivative with respect to time of i(t) and may be expressed as follows: Peak rate of rise = maximum of di(t)/dt
Recoil Streamer	Equivalent to restrike during a cloud to cloud or intra cloud discharge and associated with isolated current pulses.
Restrike	A subsequent high current surge attachment, which has a lower peak current, a lower action integral, but a higher di/dt than the first return stroke. This normally follows the same path as the first return stroke, but may reattach to a new location further aft on the aircraft.
Shield	A conductor which is grounded to an equipment case or aircraft structure at both ends and is routed in parallel with and bound within a cable bundle. It usually is a wire braid around some of the wires or cables in the cable bundle or may be a metallic conduit, channel or wire grounded at both ends within the cable bundle. The effect of the shield is to provide a low impedance path between equipment to be connected.
Slow Components	The intermediate current and the continuing current collectively.
Stepped Leader	See leader.

Structural IR Voltage — The structural IR voltage is the portion of the induced voltage resulting from the product of the distributed current (I) and the resistance R of the aircraft skin or structure.

Swept Channel — The lightning channel relative to the aircraft, which results in a series of successive attachments due to sweeping of the flash across the aircraft by the motion of the aircraft.

Swept Leader — A lightning leader that has moved its position relative to an aircraft, subsequent to initial leader attachment, and prior to the first return stroke arrival, by virtue of aircraft movement during leader propagation.

System Functional Upset — An impairment of system operation, either permanent or momentary (e.g., a change of digital or analog state) which may or may not require manual reset.

Upset — See system functional upset.

V_{90} — This is normally the voltage to which an HV impulse generator must be erected in order that 90% of all discharges will result in gap breakdown.

Zoning — The process (or the end result of the process) of determining the location on an aircraft to which the components of the external environment are applied.

6.2 Abbreviations

kV	kilovolts
kV/m	kilovolts per meter
A	amperes
m/s	meters per second
µs	microseconds
s	seconds
ms	milliseconds
kA	kiloamperes
t	time
C	charge transfer (coulombs or ampere - seconds)
A/s	amperes per second
A^2s	action integral (ampere squared seconds)

6.3 Acronyms

ETDL	Equipment Transient Design Level
FWHM	Full Width Half Maximum: The time interval between 50% amplitudes of a pulse.
HC	High current.
HV	High voltage.
LRU	Line replaceable unit: An element of a system which may be removed and replaced by a line maintenance crew while the aircraft is in operational status.
MB	Multiple Burst
MS	Multiple Stroke
N/A	Not Applicable
TCL	Transient Control Level

7.0 NATURAL LIGHTNING DESCRIPTION

7.1 General

Lightning flashes usually originate from charge centers in a cloud, particularly the cumulonimbus cloud, although they can occur in other atmospheric conditions. The charges in clouds are produced by complex processes of freezing and melting and by movements of raindrops and ice crystals involving collisions and splintering. Typically, most positive charges accumulate at the top of the cumulonimbus clouds, leaving the lower regions negative, although there may be a small positive region near the base. The result is the typical structure of Figure 7-1 depicted by Malan (Reference 7.5.1), who extensively studied thunderstorms in South Africa.

During their process of development thunder clouds extend vertically over more than 3 km. The strong electric fields can initiate discharges, called lightning flashes, which may be of three types, namely:

a) Flashes between regions of opposite polarity within a cloud (intra cloud discharges),
b) Flashes between regions of opposite polarity in different clouds (inter cloud charges), and,
c) Flashes from clouds to ground and from ground to clouds of either polarity. Ground to cloud flashes, however, become only relevant to taller objects, e.g. towers and mountains.

Over 50% of all flashes are intra cloud flashes.

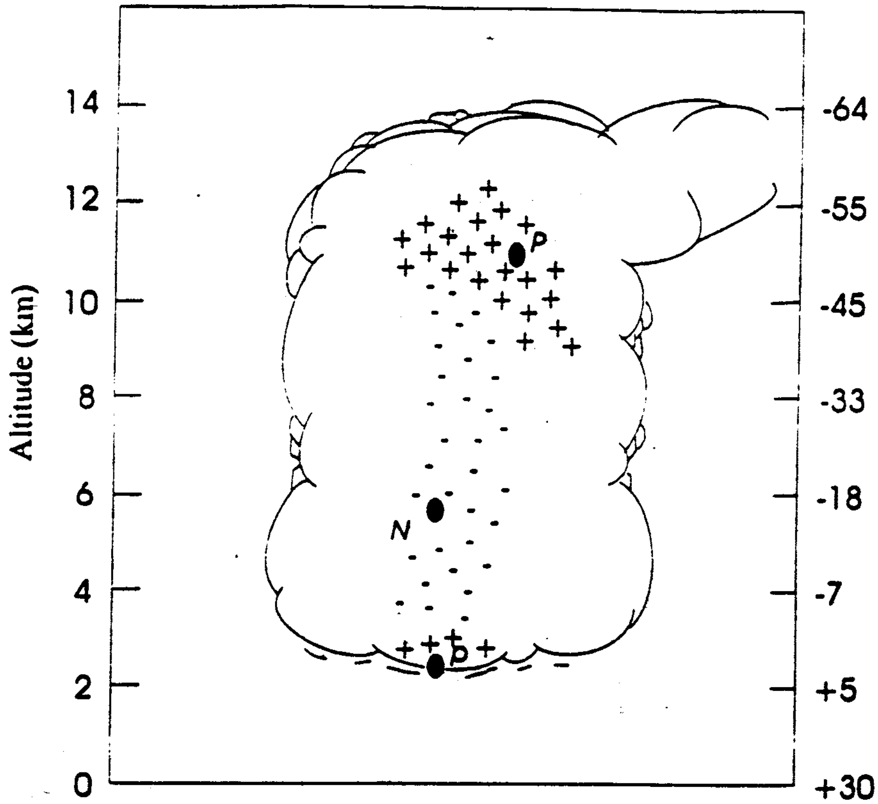


Figure 7-1. Generalized diagram showing distribution of air currents and electrical charge in typical cumulonimbus cloud.

7.2 Cloud-to-Ground Flashes

7.2.1 The discharge process

A positive flash lowers positive charge to earth while a negative flash lowers negative charge.

It is common for a negative flash to discharge several charge centers in succession, with the result that the flash contains several distinct pulses of current, and these are usually referred to as strokes.

The process that culminates in a lightning flash begins with the formation of an ionized column called a leader which travels out from a region where the electric field is so high that it initiates progressive breakdown; this critical field is thought to be about 900kV/m for water droplets or 500kV/m for ice crystals. For a negative discharge to earth the column advances in zigzag steps (hence the name stepped leader) each about 50m long and separated by pauses of 40 - 100ms.

The diameter of the stepped leader is between 1m and 10m although the current, which is low (about 100A), is probably concentrated in a small highly ionized core, about 1cm diameter. The average velocity of propagation is 1.5×10^5m/s. The leader may form branches on its downward path to the ground. When a branch is near to the ground, it causes high fields to form at projections such as trees and buildings and these then send up leaders, one of which will make contact with the tip of the downward propagating leader. This has the effect of closing a switch and the position in the channel where it occurs is known as the switching point. When that occurs, a return stroke is initiated which retraces and discharges the leader channel at a velocity of about 5×10^7m/s. This initial return stroke is characterized by a current pulse of high amplitude accompanied by high luminosity. After the first return stroke, further strokes may occur as higher areas of the negative charge regions are discharged; the dart leaders for these usually traverse the same path as the first but in one continuous sweep at a velocity of 2×10^6 m/s.

Return stroke modeling indicates that there is a decrease of the value of the return stroke current versus an increase in altitude (Reference 7.5.2). This is typical of a negative flash to open ground, but over mountains and tall buildings the leader may be of the upward moving type, originating from a high point such as a mountain peak. When such a leader reaches the charge pocket in the cloud, a return stroke is initiated and subsequent events follow the same pattern as for initiation by a downward moving leader. Thus the "switching" point is near the ground for downward leaders but near the charge pocket in the cloud for upward leaders. This can make a significant difference to the waveform and amplitude of the current experienced by an airborne vehicle that forms part of the lightning path.

7.2.2 The negative flash to ground

An example of the return stroke current in a severe negative flash is sketched in Figure 7-2(a). The number of strokes in a negative flash is usually between 1 and 11, the mean value being 3; the maximum number is up to 24. The total duration is between about 20ms and 1s, with a mean value of 0.2s. The time interval between the strokes is typically about 60ms. There is some correlation among these parameters, the flashes with the most strokes tending also to be the longest duration. The rise time of the first stroke is about 2μs, with a decay time (to half the peak amplitude) of 45μs. Subsequent strokes in the flash tend to have a higher rate-of-rise although lower peak amplitudes than the initial stroke and they can therefore be significant for inducing voltages in wiring, where the inductively coupled voltages are proportional to the rate of change of the lightning current.

Near the end of some of the strokes in a negative flash, there is often a lower level current of a few kA persisting for several milliseconds, known as an "intermediate current," as shown in Figure 7-2(a). After some strokes a "continuing current" of 100-400A flows with a duration of 100-800ms, so that there is substantial charge transfer in this phase. It is particularly common for there to be a continuing current after the last stroke.

It is generally thought that before a restrike can occur the continuing current must cease, as illustrated after stroke 5 in Figure 7-2(a).

7.2.3 The positive flash to ground

Positive flashes to ground generally occur less frequently than negative flashes, however in certain geographic locations there may be more positive flashes to ground. Present standards have assumed an average of around 10% positive flashes to ground. Positive flashes are usually initiated by upward moving leaders and more commonly occur over mountains than over flat terrain. Normally they consist of one stroke only. They have slower rise times than negative flashes, with high peak current and charge transfer; the duration is longer than a single stroke of a negative flash but usually shorter than a complete negative flash. The stroke may be followed by a continuous current.

An example of the current in a positive flash is shown in Figure 7-2(b); it is a moderately severe example although not the "super flash" which occurs occasionally. Typically the rise time of a positive flash is 20μs and the total duration 0.1s. Although positive flashes are far less globally frequent than negative, they have to be taken into consideration in the selection of design and test parameters.

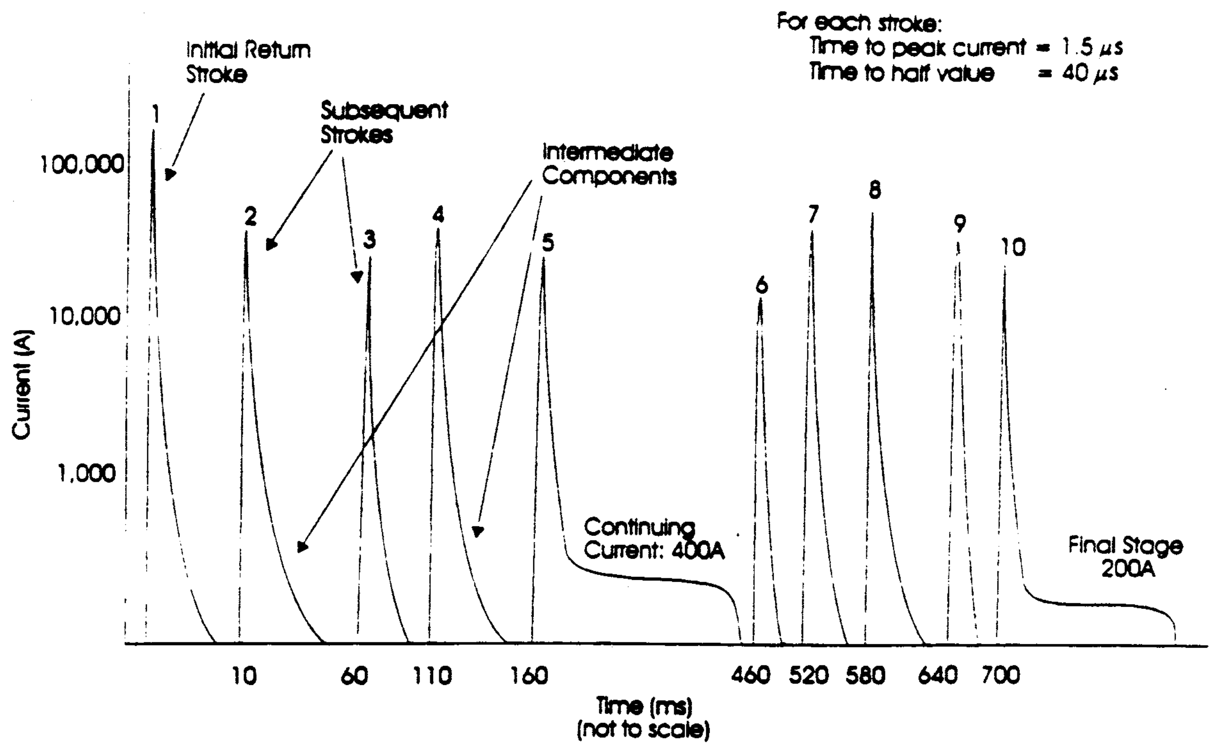


Figure 7-2(a). Model of a severe negative lightning flash current waveforms.

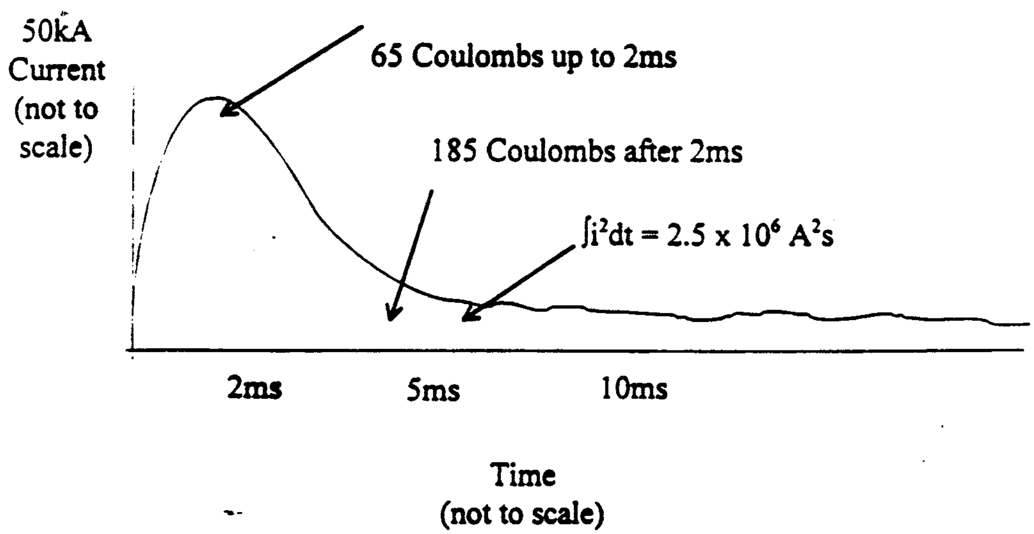


Figure 7-2(b). Model of a moderate positive lightning flash current waveform.

7.3 Inter and Intra Cloud Flashes

The preceding discussion relates to flashes of either polarity to ground since most available knowledge relates to flashes of that type. Instrumented aircraft have been employed in U.S.A. and France to record the characteristics of cloud flashes. Generally speaking, the conclusion is that cloud flashes are less severe than flashes to the ground, certainly with respect to peak current, charge transfer and action integral. However, the airborne measurements show some evidence that over a portion of some pulse wavefronts the rate-of-rise for a short time (less than 0.4μs) may be higher than the figure related to cloud to ground flashes. Short pulses of low amplitude but high rate-of-rise have been observed during intra-cloud flashes. Similar pulses due to charge redistribution in a cloud have been observed between return stokes in flashes to ground.

For intra-cloud discharges, recoil streamers of up to 60kA peak current have been recorded, but are more typically 20-30kA (Reference 7.5.3). A typical intra-cloud lightning flash is presented in Figure 7-3. The pulses occurring during the initial attachment phase might also occur in negative cloud to ground flashes.

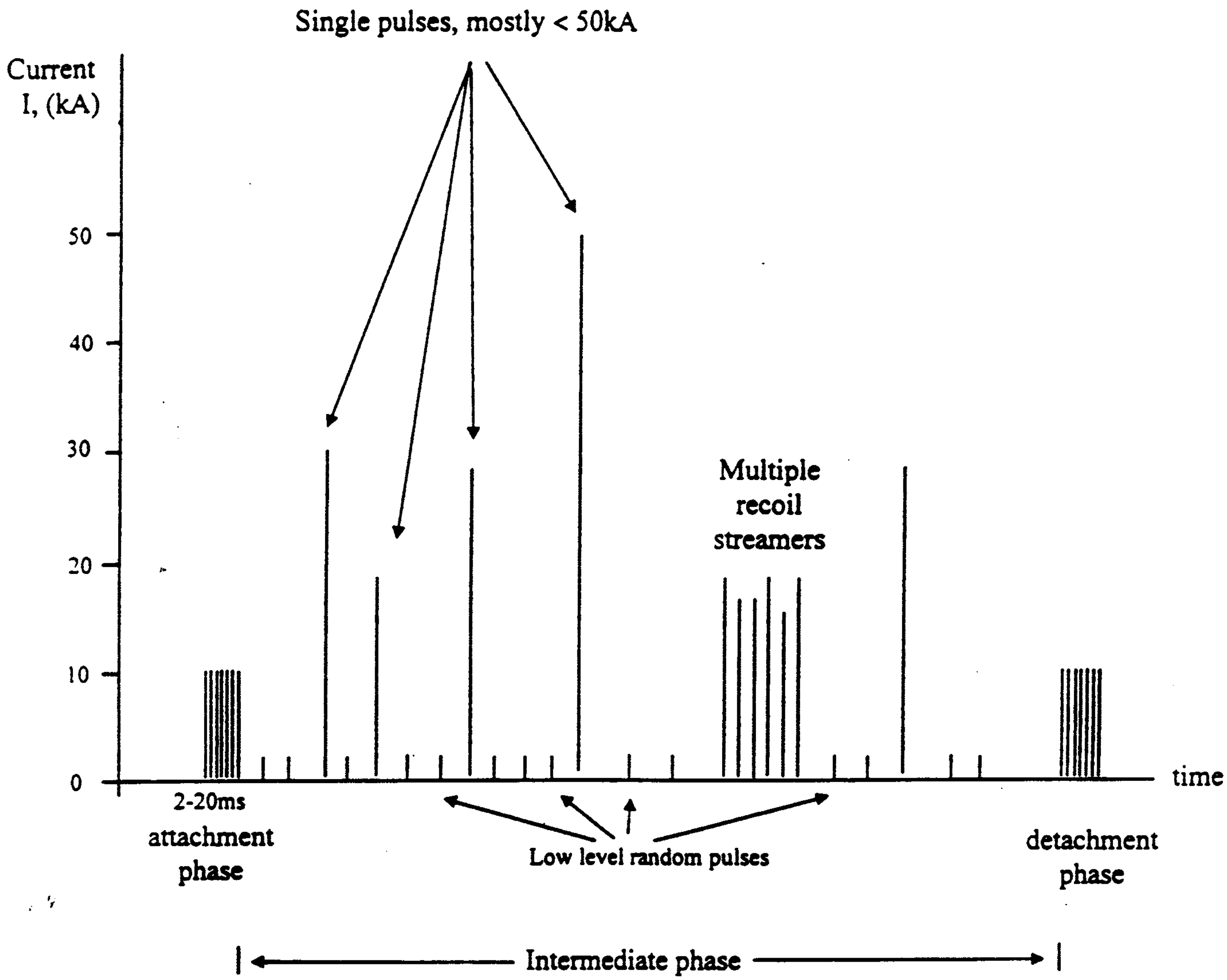


Figure 7-3. Typical intra-cloud lightning flash to an aircraft.

7.4 Flash Parameters

Most of the available statistical data are from cloud to ground and ground to cloud lightning flashes. The relevant data are presented in Tables 7-1 and 7-2 divided into negative and positive flashes. The tables include statistical data for the lightning currents and all related parameters of interest for the definition of the external environment. For a given flash or stroke parameter, the tables show that as the magnitude increases, the percentage of occurrence decreases. The extreme parameters do not occur together in one flash.

Less data are available with respect to inter and intra cloud lightning flashes (Section 7.3). The available data indicate that the cloud to ground and ground to cloud flashes represent the most severe lightning threat to the aircraft with the only exception being the high rate of rise pulse wavefronts measured during the initial and the final attachment phases to the Instrumented aircraft referred to in Section 7.3. Similar pulses with fast rates of change have also been reported in cloud-to-earth flashes which convey negative charge to the earth.

In addition to the lightning currents, electric fields exist before and during a lightning strike event. Initially, these fields result in breakdown of the air to form the attachment and may also cause breakdown of dielectric materials on an aircraft. The magnitudes of these fields are dependent upon air breakdown thresholds and range between 400 and 3000kV/m, with rates of rise of up to 1000kV/m/µs.

7.5 References

7.5.1 "The Distribution of Electricity in Thunderclouds"
Malan, D. J. and Schonland, B. F. J.:
Proc. Roy. Soc. London, A 209 (1951)

7.5.2 "Lightning"
Uman, M. A.
McGraw Hill Book Company, London 1988

7.5.3 "Aircraft Triggered Lightning: Process Following Strike Ignition that Affect Aircraft"
Mazur, V. and Moreau J. P.
Journal of Aircraft, Volume 29, Nr. 4, July/August 1992, pages 575-580.

Table 7-1. Parameters for negative lightning flashes measured at ground.

Parameters **Negative Flashes**	Unit	Lightning Parameters 95%	 50%	 5%
Number of strokes		1 - 2	3 - 4	12
Time intervals between strokes	ms	8	35	140
Flash duration	s	0.03-0.04	0.2	1
Charge in flash	C	1.3	7.5	40
Negative first stroke				
Peak current	kA	14	30	80
Peak rate-of-rise	A/s	5.5×10^9	1.2×10^{10}	3.2×10^{10}
Time to peak	µs	1.8	5.5	18
Time to half value	µs	30	75	200
Impulse charge	C	1.1	5.2	24
Action integral	A^2s	6×10^3	5.5×10^4	5.5×10^5
Negative subsequent strokes				
Peak Current	kA	4.6	12	30
Peak rate-of-rise	A/s	1.2×10^{10}	4×10^{10}	1.2×10^{11}
Time to peak	µs	0.22	1.1	4.5
Time to half value	µs	6.5	32	140
Impulse charge	C	0.2	1.4	11
Action integral	A^2s	5.5×10^2	6×10^3	5.2×10^4
Continuing current		**98%**	**50%**	**2%**
Amplitude	A	33	140	520
Duration	s	0.058	0.16	0.40
Charge	C	7	26	110

Note 1: The above lightning parameters do not necessarily occur together in one flash.
Note 2: The percentage figures represent percentiles, that is, the percentage of events having a greater amplitude than those given.

Table 7-2. Parameters for positive lightning flashes measured at ground.

Parameters	Unit	Lightning Parameters		
Positive Flashes		**95%**	**50%**	**5%**
Flash duration	ms	14	85	500
Total charge	C	20	80	350
Positive Stroke		**95%**	**50%**	**5%**
Peak current	kA	4.6	35	250
Peak rate-of-rise	A/s	2×10^8	2.4×10^9	3.2×10^{10}
Time to peak	μs	3.5	22	200
Time to half value	μs	25	230	2000
Impulse charge	C	2	16	150
Action integral	A^2s	2.5×10^4	6.5×10^5	1.5×10^7

Note: The individual parameters listed above do not necessarily occur together in one flash.

8.0 LIGHTNING INTERACTIONS WITH AIRCRAFT

A lightning strike to an aircraft will either be triggered (i.e. initiated) by the presence of the aircraft in a strong electric field and will originate at the aircraft, or will occur as a result of encounter with a naturally occurring leader which originated elsewhere.

8.1 Strike Occurrence

The probability of a lightning strike to an aircraft depends on various parameters, e.g. the local climate, flight profile, type of aircraft. From a significant sample of reported strikes to large transport aircraft operating in scheduled airline service, the average probability of a lightning strike has been estimated to be approximately one strike in every 10,000 flight hours. A separate study of transport aircraft experience within a region known to be prone to lightning estimated the average probability of a lightning strike to be approximately one strike in every 1,000 flight hours. Therefore, the average probability of a lightning strike to a given aircraft will be likely to fall somewhere between one strike per 1,000 and 20,000 flight hours.

These data are based on reported strikes, which get noticed because of bright light, (especially at night), loud noises or associated physical damage effects or interference or damage to cockpit avionics. Other strikes to aircraft undoubtedly occur but go unnoticed or are not reported.

8.2 Aircraft Intercepted Lightning

An intercepted flash can occur when a lightning leader advances sufficiently close to the aircraft to be diverted to it. This latter interaction can occur for all types of discharges: inter, intra and cloud to ground.

As noted, most intra-cloud flashes are probably less severe than cloud-to-ground flashes. If we consider only ground flashes however, it is likely that the parameters at the altitude of an aircraft in flight will be different from those measured at stations on the ground. This is because the lightning channel acts as a lossy transmission line and the return stroke current experiences changes in both shape and amplitude as it develops from the switching point towards the vehicle.

8.3 Aircraft Triggered Lightning

Aircraft may also trigger the flashes that they interact with in regions where there are strong electric fields. These flashes would not have occurred in the absence of the aircraft. Many storm cloud penetrations made during in-flight measurement programs (References 8.7.1, 8.7.2, and 8.7.3) produced lightning strikes which were probably triggered by the aircraft.

It is thought that most triggered lightning flashes have a lower amplitude than most cloud to ground flashes. The latter will, however, continue to be the basis of protection design.

8.4 Swept Channel Process

If a fast moving vehicle such as an aircraft experiences a direct strike, then throughout the flash, the point(s) of arc attachment is likely to be swept backwards along the vehicle, since the lightning channel tends to remain stationary relative to the surrounding air. Except possibly on smooth unpainted surfaces, this movement of the attachment point is not continuous but progresses in a series of discrete irregular steps. The dwell time at any particular step is not likely to exceed 50ms, being chiefly dependent on the nature of the surface and the velocity of the vehicle. The movement of the points of arc attachment is known as the "Swept Channel" phenomenon. This area of the aircraft is defined as the Swept Stroke Zone. For an airspeed of 300 knots an aircraft moves through its own length of (say) 15m in 100ms, which is well within the average duration of a lightning flash. When the lightning channel has swept back to a trailing edge, it can progress no further and may remain there, or "hang on," for the remainder of the flash. When the entry and exit portions of the lightning channel have swept aft to trailing edges, the channel may rejoin behind the aircraft and the aircraft is no longer in the lightning current path.

The sweeping action of the channel can have several consequences. For example, inboard areas of an aircraft wing such as those behind an inboard engine will be subjected to the Swept Channel phenomenon because they are in the path of a sweeping channel. On the other hand, the effects of the flash are spread out over a considerable number of points so that except for an attachment point at a trailing edge, no single point receives the full energy of the flash. The proportion of the flash experienced by any particular point depends on its location on the vehicle surface and this has lead to the concept of dividing the surface into lightning strike zones depending on the probability of initial attachment, sweeping and hang-on.

8.5 Nearby Lightning

Nearby flashes might cause some indirect effects. These effects, due predominantly to magnetic field coupling, are in general significantly smaller than those caused by direct lightning strikes to the aircraft.

The magnetic fields (H-fields), which can be expected from a nearby lightning strike, can be estimated by the following expression:

$$H = \frac{I}{2\pi r}$$

where:

H = field strength in amperes per meter

I = lightning current in amperes

r = distance between the lightning channel and the aircraft in meters.

8.6 Lightning Strike Zones

Due to the lightning attachment process, not all locations on an aircraft are exposed to the same lightning environment components. To optimize lightning protection, the aircraft will, therefore, be divided into different lightning strike zones. These zones will then be protected against their applicable components of the lightning environment.

In general an aircraft can be divided into the following zones:

Zone 1A:	First Return Stroke Zone,
Zone 1B:	First Return Stroke Zone with Long Hang-On,
Zone 1C:	Transition Zone for First Return Stroke,
Zone 2A:	Swept Stroke Zone,
Zone 2B:	Swept Stroke Zone with Long Hang-On, and,
Zone 3:	Current Conduction Zone.

Zone definitions and methods of locating them on particular aircraft are given in Reference 4.1.

8.7 References

8.7.1 "New Results for Quantification of Lightning/Aircraft Electrodynamics"
F. L. Pitts, R. A. Perala, L. Dee
Electromagnetics Vol.7, 1987.

8.7.2 "Analysis of Correlated Electromagnetic Fields and Current Pulses during Airborne Lightning Attachments"
J. S. Reaser, A. V. Serrano, L. C. Walko, and H. D. Burket
Electromagnetics, Vol. 7, 1987.

8.7.3 "Analysis of the First Milliseconds of Aircraft Lightning Attachments"
J. P. Moreau, J. C. Alliot
11th International Aerospace and Ground Conference on Lightning and Static Electricity, Dayton, OH, 1986.

9.0 IDEALIZED STANDARD LIGHTNING ENVIRONMENT

9.1 General

The environment waveforms presented in this chapter represent idealized environments which are to be applied to the aircraft for purposes of analysis and testing. The waveforms are not intended to replicate a specific lightning event, but they are intended to be composite waveforms whose effects upon aircraft are those expected from natural lightning.

The standard lightning environment is comprised of individual voltage waveforms and current waveform components which represent the important characteristics of the natural lightning flashes.

In the waveform descriptions that follow, parameters of particular importance to the effects (direct or indirect) to be considered, are included whereas other parameters are omitted. For example, for direct effects evaluations, peak current amplitude, action integral and time duration are of primary importance, whereas for indirect effects evaluations, rates of current rise and decay as well as peak amplitude are important.

Not all surfaces of an aircraft need to be designed to survive the same lightning threat. The applicable design parameters and test waveforms for each zone are presented in Section 9.4.

This section presents waveforms and their related parameters to be applied for aircraft structures and equipment lightning protection design and verification purposes.

9.2 Idealized Voltage Waveforms

The idealized Voltage Waveform represents that portion of the electric field important for assessment of lightning attachment to aircraft structures.

The basic Voltage Waveform to which vehicles are subjected for analysis or test is one that represents an electric field which increases until breakdown occurs either by puncture of solid insulation such as the fiberglass skin of a radome, or flashover through the air or across an insulating surface. The path that the flashover takes, either puncture or surface flashover, depends in part on the waveshape of the electric fields.

It is sometimes necessary to determine the critical voltage amplitude at which breakdown occurs. This critical voltage level depends upon both the rate-of-rise of voltage and the rate of voltage decay. Two examples are: (1) determining the strength of the insulation used on electrical wiring; and, (2) determining the points from which electrical streamers appear on a vehicle as a lightning flash approaches.

Since there is a wide range of possible electric field waveforms produced by natural lightning, two voltage waveforms have been established, representing fast and slow rates of field rise. These are Waveform A described in Section 9.2.1 and Waveform D presented in Section 9.2.4.

Two other high voltage Waveforms designated B and C are described in Sections 9.2.2 and 9.2.3 respectively. The first is a full voltage Waveform to be used wherever an impulsive field that does not reach breakdown is required, i.e. streamer testing. The second Waveform is employed for fast front model tests. Waveform D can also be used for slow front model tests.

It has been determined in laboratory testing that the results of attachment point testing of aircraft models are influenced by the voltage Waveform. Fast rising waveforms (rise in the order of a few microseconds) produce a relatively small number of attachment points, usually to the apparent high field regions on the model and may produce a greater likelihood of puncture of dielectric skins. Slow front waveforms (in the order of hundreds of microseconds) produce a greater spread of attachment points, possibly including attachments to lower field regions.

The voltage waveforms presented in this Adversary Circular are intended for evaluation of possible lightning attachment locations and/or dielectric breakdown paths through non-conducting surfaces or structures.

9.2.1 Voltage Waveform A

This waveform rises at a rate of 1000 kV/µs (± 50%) until its increase is interrupted by puncture of, or flashover across, the object under test. At that time the voltage collapses to zero. The rate of voltage collapse or the decay time of the voltage if breakdown does not occur (open circuit voltage of a lightning voltage generator) is not specified. The voltage Waveform A is shown in Figure 9-1.

9.2.2 Voltage Waveform B

Waveform B is a 1.2 x 50μs waveform which is the electrical industry standard for impulse dielectric tests. It rises to crest in 1.2μs (± 20%) and decays to half of crest amplitude in 50μs (± 20%). Time to crest and decay time refer to the open circuit voltage of a lightning voltage generator, and assume that the waveform is not limited by puncture or flashover of the object under test. This waveform is shown in Figure 9-2.

9.2.3 Voltage Waveform C

This is a chopped voltage waveform in which breakdown of the gap between an object under test and the test electrodes occurs at 2μs (± 50%). The amplitude of the voltage at time of breakdown and the rate-of-rise of voltage prior to breakdown are not specified. The waveform is shown in Figure 9-3.

9.2.4 Voltage Waveform D

The slow fronted waveform has a rise time between 50 and 250μs so as to allow time for streamers from an object to develop. It should give a higher strike rate to the low probability regions than otherwise might have been expected. This waveform is shown in Figure 9-4.

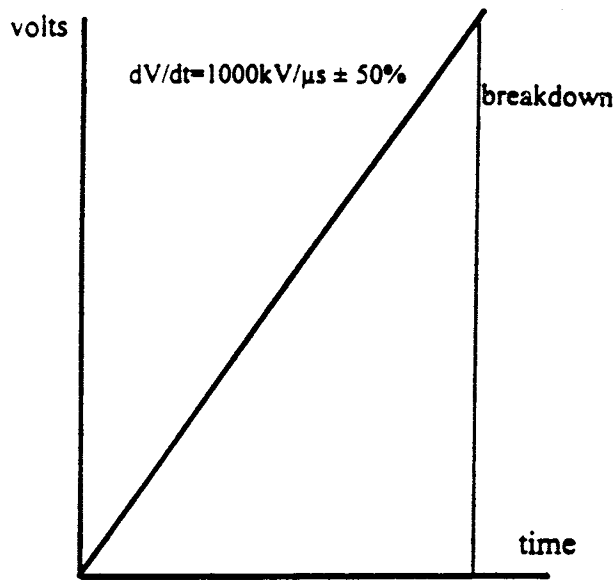


Figure 9-1. Voltage Waveform A.

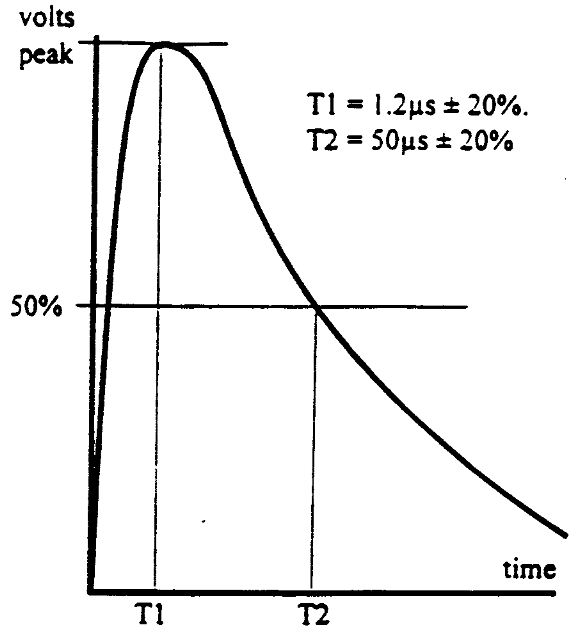


Figure 9-2. Voltage Waveform B.

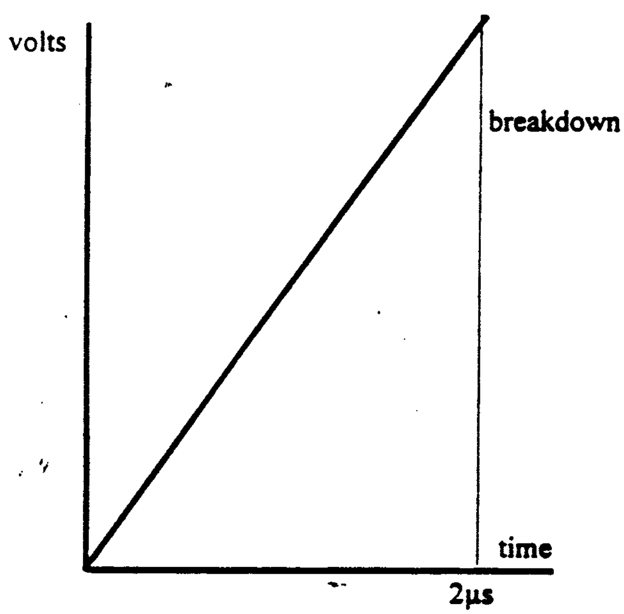


Figure 9-3. Voltage Waveform C.

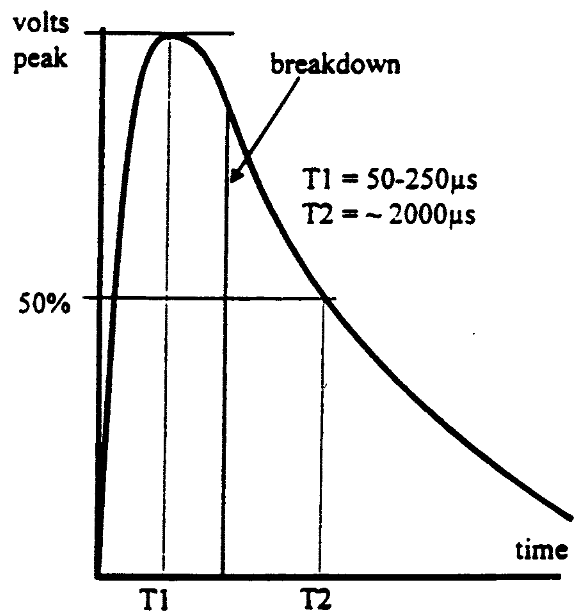


Figure 9-4. Voltage Waveform D.

9.3 External Idealized Current Components

The external lightning environment is comprised of current components A, A_h, B, C, D and H, and the Multiple Stroke (MS) and Multiple Burst (MB) Waveform sets. The MS is comprised of components D and D/2, and the MB is comprised of component H pulse sequences.

Current components A, B, C, and D comprise the lightning flash current waveform for evaluating direct effects and are shown in Figure 9-5. Current components A and D, and Waveform sets MS and MB are applicable for evaluating indirect effects. The latter two are shown in Figures 9-14 and 9-15.

The current components are defined as follows:

9.3.1 Current component A - first return stroke

This waveform combines the severe parameters of both the negative and the positive first return strokes. It occurs most frequently to aircraft flying at lower altitudes.

For analysis purposes and indirect effect considerations the double exponential waveform shown in Figure 9-6(a) shall be applied.

This waveform is defined mathematically by the double exponential expression shown below:

$$i(t) = I_0\left(e^{-\alpha t} - e^{-\beta t}\right)$$

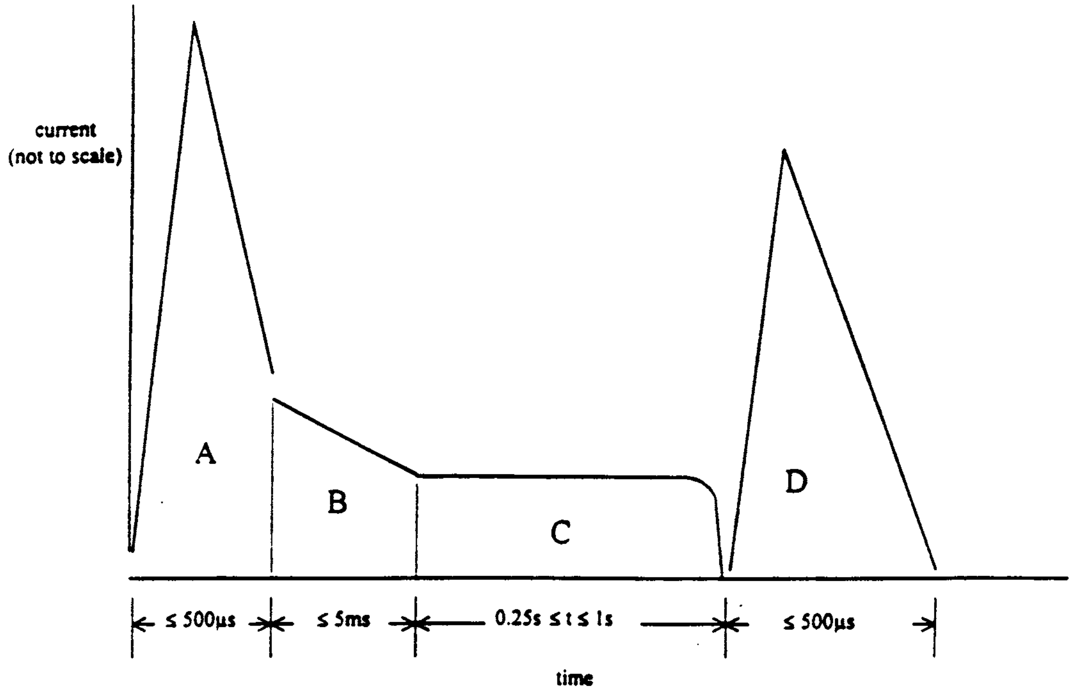
where:

$I_0 = 218{,}810$ A
$\alpha = 11{,}354\ s^{-1}$
$\beta = 647{,}265\ s^{-1}$
t is time (s)

The frequency content of current component A is given in Figure 9-6(b).

For direct effects testing purposes component A can be simulated by an oscillatory or unidirectional waveform like those presented in the Figures 9-7(a) and 9-7(b). The current must have an amplitude of 200kA (± 10%) with a rise time of up to 50μs (the time between 10% and 90% of peak amplitude). The action integral has to be $2 \times 10^6 A^2s$ (± 20%), and the total time to 1% of peak value shall not exceed 500μs.

The action integral, $\int i^2dt$, is a critical factor in the extent of damage. It relates to the energy deposited or absorbed in a system. However, the actual energy deposited cannot be defined without a knowledge of the resistance of the system. For example, the instantaneous power dissipated in a resistor is i^2R, and is expressed in Watts. For the total energy expended, the power must be integrated over time to get the total Watt-seconds (or Joules). Action integral can be applied to any resistance value to identify the total energy deposited.



COMPONENT A (First Return Stroke)

Peak Amplitude	:	200kA (± 10%)
Action Integral	:	2 x $10^6 A^2 s$ (± 20%) (in 500μs)
Time Duration	:	≤ 500μs

COMPONENT B (Intermediate Current)

Max. Charge Transfer	:	10 Coulombs (± 10%)
Average Amplitude	:	2kA (± 20%)
Time Duration	:	≤ 5ms

COMPONENT C (Continuing Current)

Amplitude	:	200 - 800A
Charge Transfer	:	200 Coulombs (± 20%)
Time Duration	:	0.25 to 1 s

COMPONENT D (Subsequent Return Stroke)

Peak Amplitude	:	100kA (± 10%)
Action Integral	:	0.25 x $10^6 A^2 s$ (± 20%) (in 500μs)
Time Duration	:	≤ 500μs

Figure 9-5. Current components A through D for Direct Effects testing.

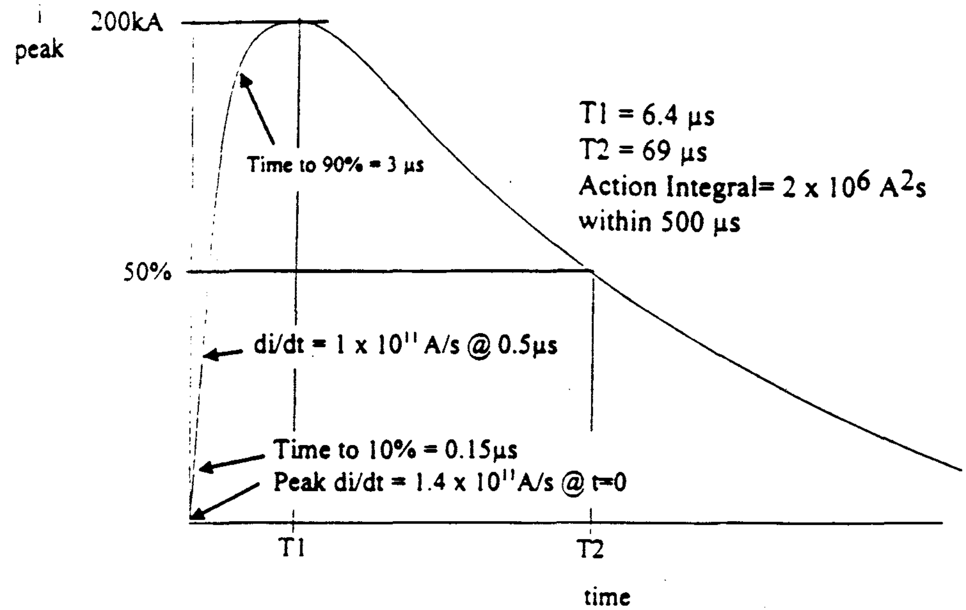


Figure 9-6(a). Current component A for analysis and indirect effects test purposes.

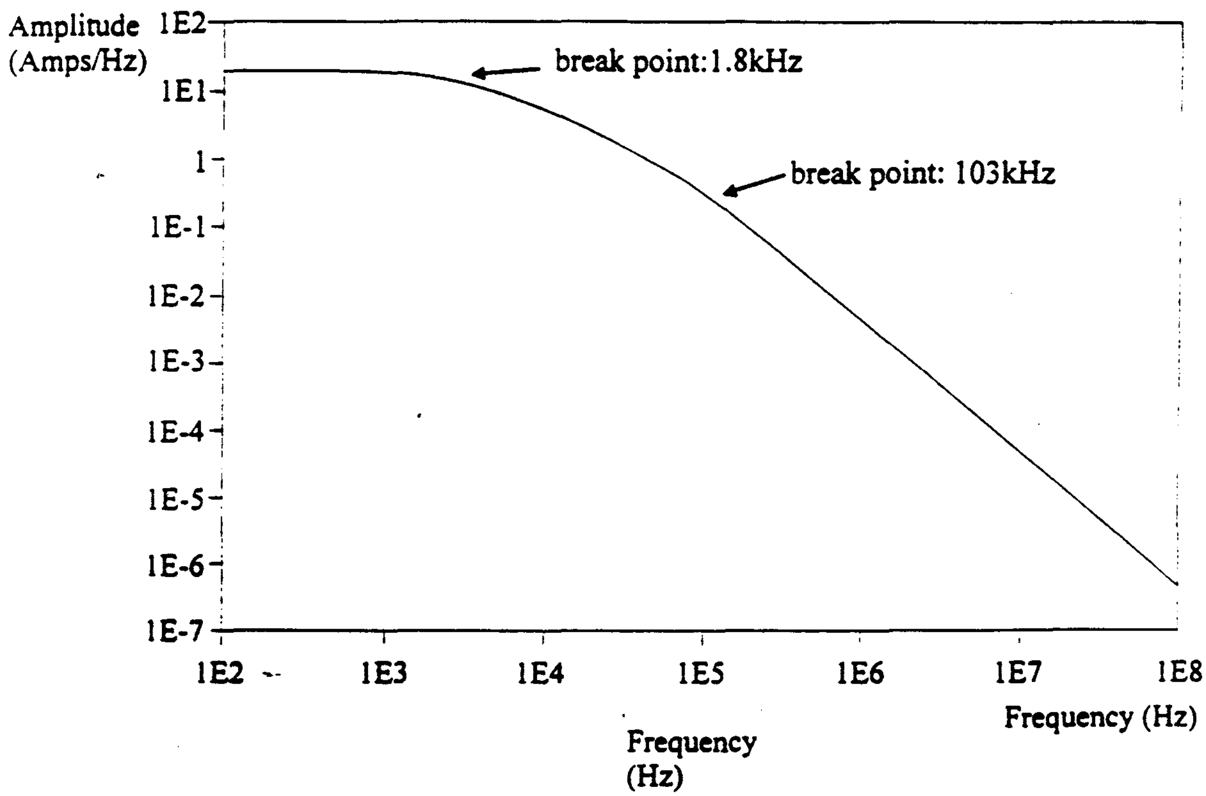


Figure 9-6(b) Frequency content (amplitude spectrum) of component A.

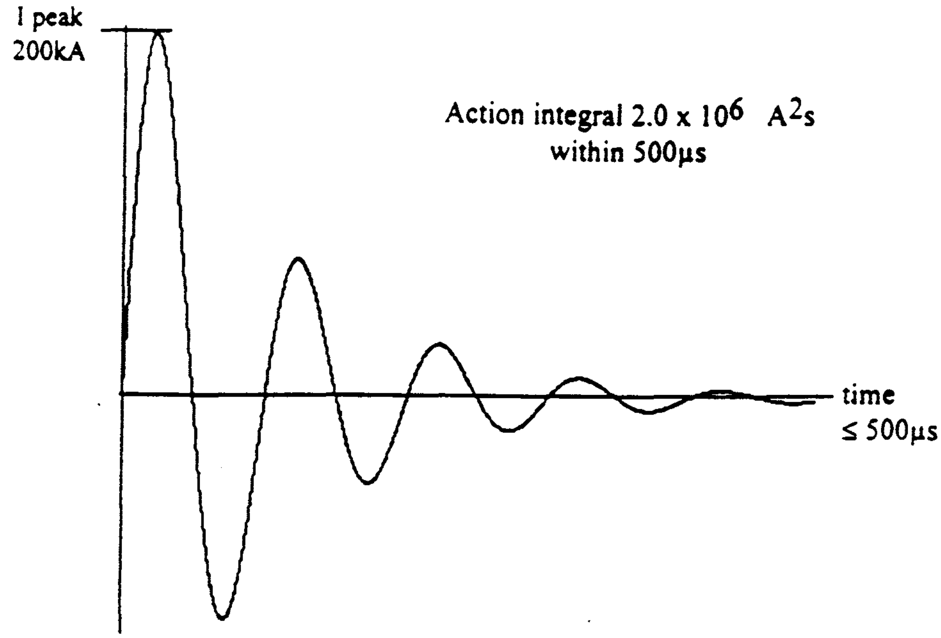


Figure 9-7(a). Damped sinusoidal current.

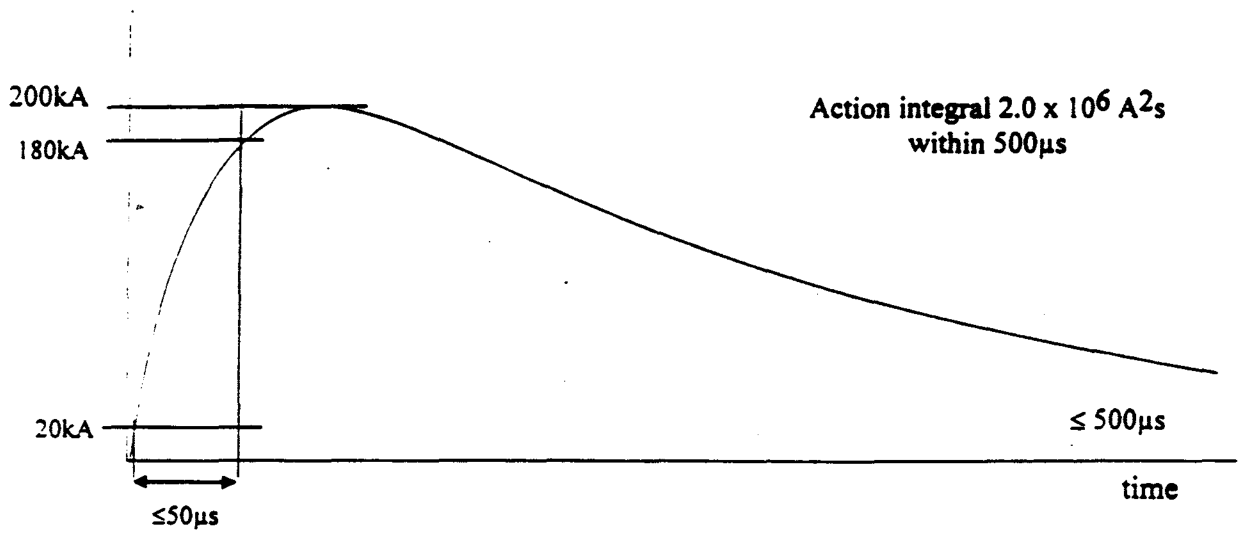


Figure 9-7(b). Unipolar current.

9.3.2 Current component A_h - transition zone first return stroke

The amplitude and waveform of the first return strokes, which might hit an aircraft, depend on the flight altitude. In general, lower amplitudes and action integrals can be expected at higher altitudes.

For analysis purposes a double exponential as shown in Figure 9-8(a) shall be applied. This waveform is applicable in the transition Zone 1C and represents the estimated shape of the first return stroke (Component A) at higher altitudes.

This waveform is defined mathematically by the following double exponential function:

$$i(t) = I_0\left(e^{-\alpha t} - e^{-\beta t}\right)$$

where:

I_0 = 164,903 A
α = 16,065 s^{-1}
β = 858,888 s^{-1}
t is time (s)

For direct effects testing, component A_h can be simulated by an oscillatory or unidirectional waveform as shown in Figures 9-8(b) and 9-8(c). The current must have an amplitude of 150kA (± 10%) with a rise time of up to 37.5µs (the time between 10% and 90% peak amplitude). The action integral has to be 0.8 x $10^6 A^2s$ (± 20%), and the total time for the current to decay to 1% of peak value shall not exceed 500µs.

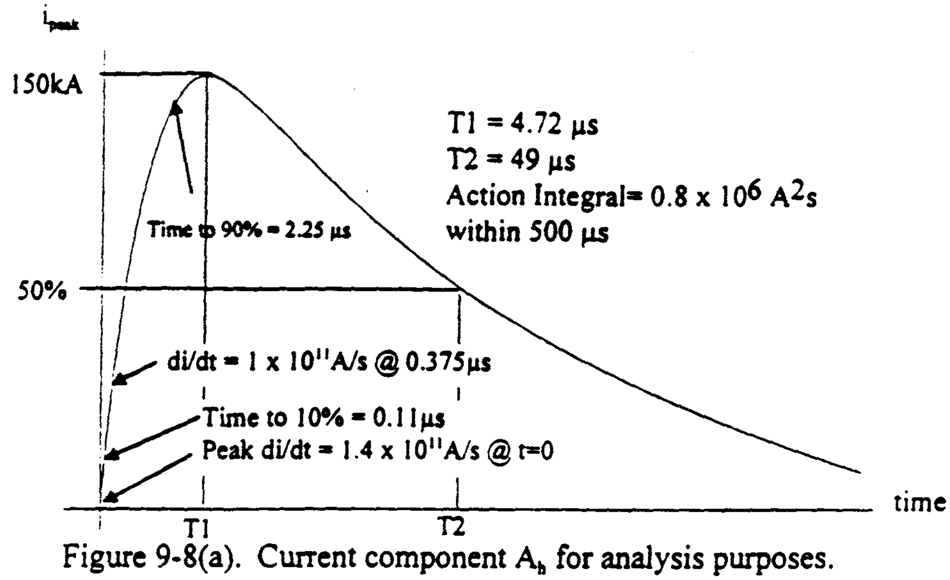


Figure 9-8(a). Current component A_h for analysis purposes.

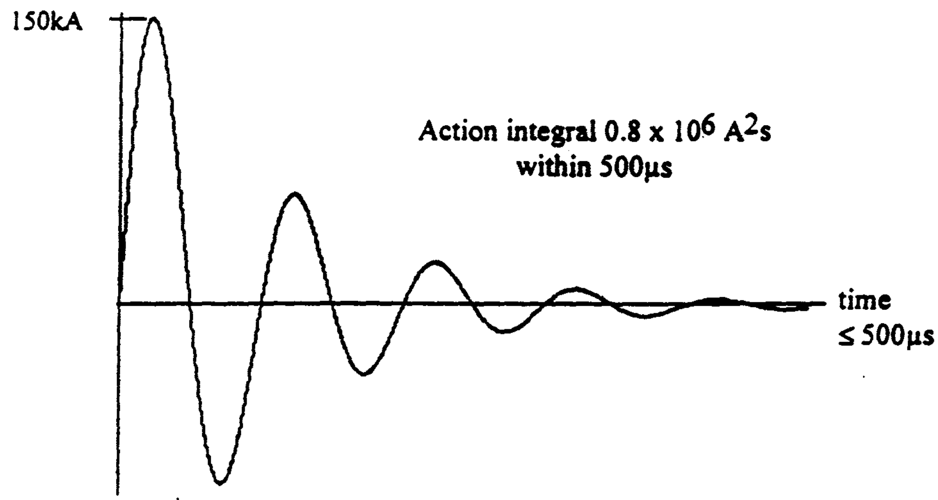


Figure 9-8(b). Example of current component A_h for direct effects, damped sinusoidal current.

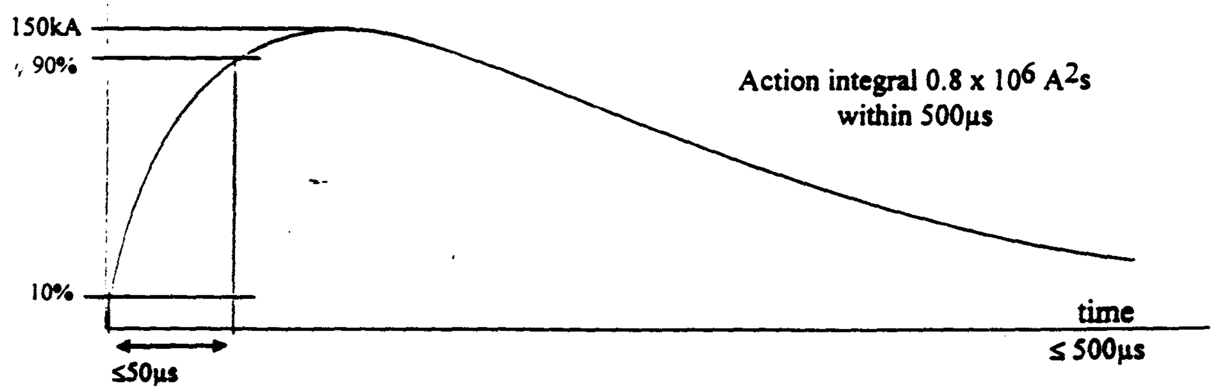


Figure 9-8(c). Example for current component A_h for direct effects, unipolar current.

9.3.3 Current component B- intermediate current

This component represents mainly the intermediate currents following some of the negative initial return strokes and/or restrikes (see Figure 7-2).

For analysis purposes a double exponential current waveform could be used as presented in Figure 9-9(a). This waveform is described mathematically by the following expression:

$$i(t) = I_0\left(e^{-\alpha t} - e^{-\beta t}\right)$$

where:

$I_0 = 11{,}300$ A
$\alpha = 700\ s^{-1}$
$\beta = 2{,}000\ s^{-1}$
t is time (s)

For direct effects testing, this component should be unidirectional, e.g. rectangular, exponential, or linearly decaying as shown in Figures. 9-9(b) and 9-9(c). The average amplitude must be 2kA (± 20%) flowing for a duration of 5 milliseconds (± 10%) with a charge transfer of 10 coulombs (± 10%).

9.3.4 Current component C - continuing current

This current component represents the lightning environment that might be caused by the long duration currents which may follow some restrikes of the negative cloud to ground lightning strikes and also the return stroke of the positive cloud to ground lightning flashes.

For analysis purposes, a square waveform of 400A for a period of 0.5s should be utilized (Figure 9-10(a)).

For direct effects testing, the Component C should have a current amplitude between 200 and 800A, a time duration between 0.25 and 1.0s and transfer charge of 200 coulombs (± 20%). This waveform should be unidirectional; e.g. rectangular, exponential or linearly decaying. Some examples are presented in the Figures 9-10(b) and 9-10(c).

9.3.5 Component C* - modified component C

This component represents the portion of component C which flows into an attachment point in Zone 1A or 2A if the dwell time at that point exceeds 5ms. Component C* is primarily used for evaluating melt through of metal skins. Component C* is a current averaging not less than 400A for a period equal to the dwell time minus the 5ms duration of the component B. An example of component C* for test applications is shown in Fig 9-11.

The combination of components A or D, B and C*, therefore represent the dwell time, which may range from 1 to 50ms. For aircraft surfaces finished with conventional primers and paints dwell times of 20ms will normally be sufficient. Other surfaces may experience shorter or longer dwell times. For example, dwell times of 1 to 5ms are typical of lightning attachments to unpainted metal surfaces when only components A or D, and B would be applied. Dwell times on surfaces covered with especially thick or high dielectric strength coatings may range from 20 to 50 ms.

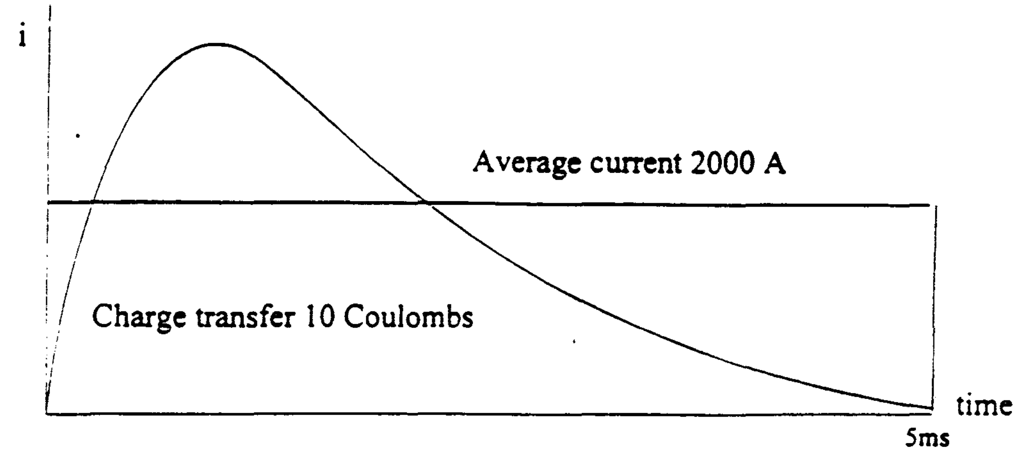


Figure 9-9(a). Current component B for testing and analysis purposes.

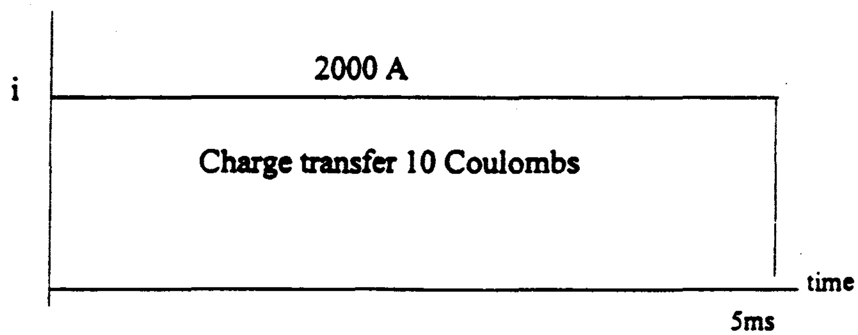


Figure 9-9(b). Example of current component B for direct effects testing.

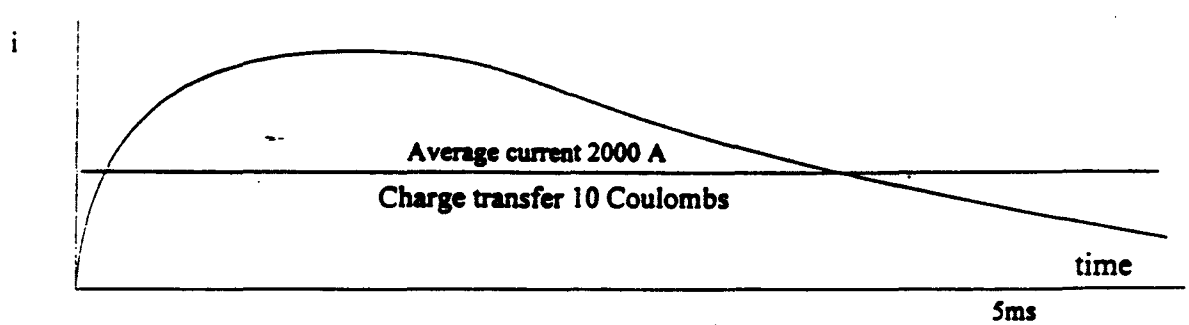


Figure 9-9(c). Example of current component B for direct effects testing.

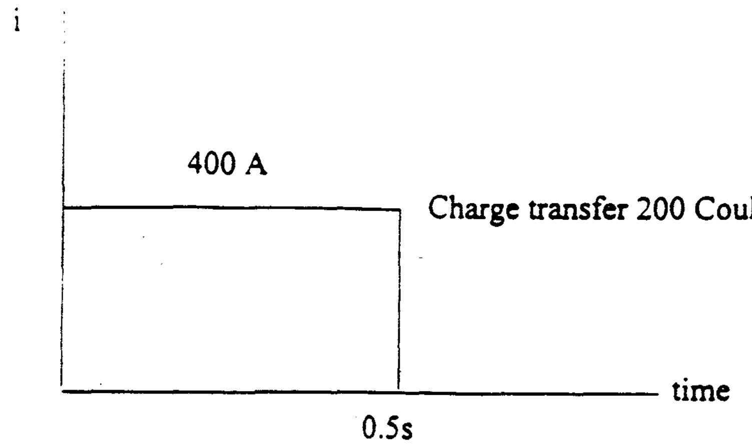


Figure 9-10(a). Current component C for analysis purpose.

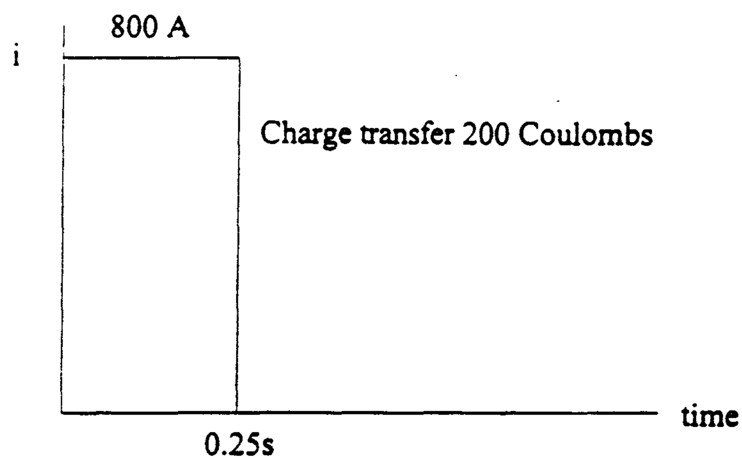


Figure 9-10(b). Example of current component C for direct effects testing.

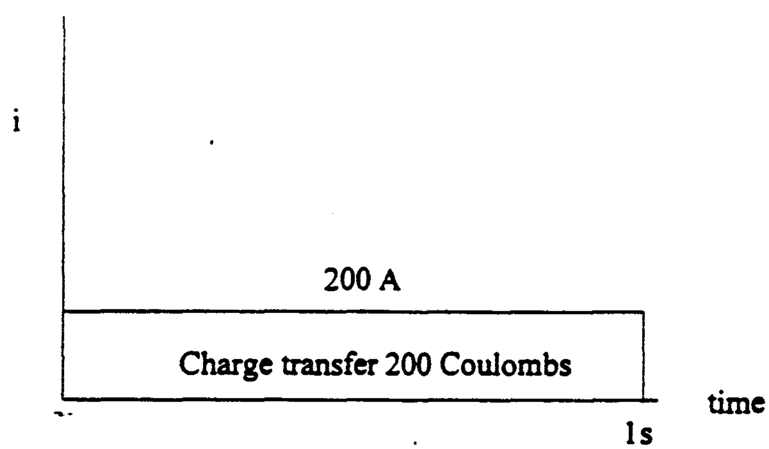


Figure 9-10(c). Example of current component C for direct effects testing.

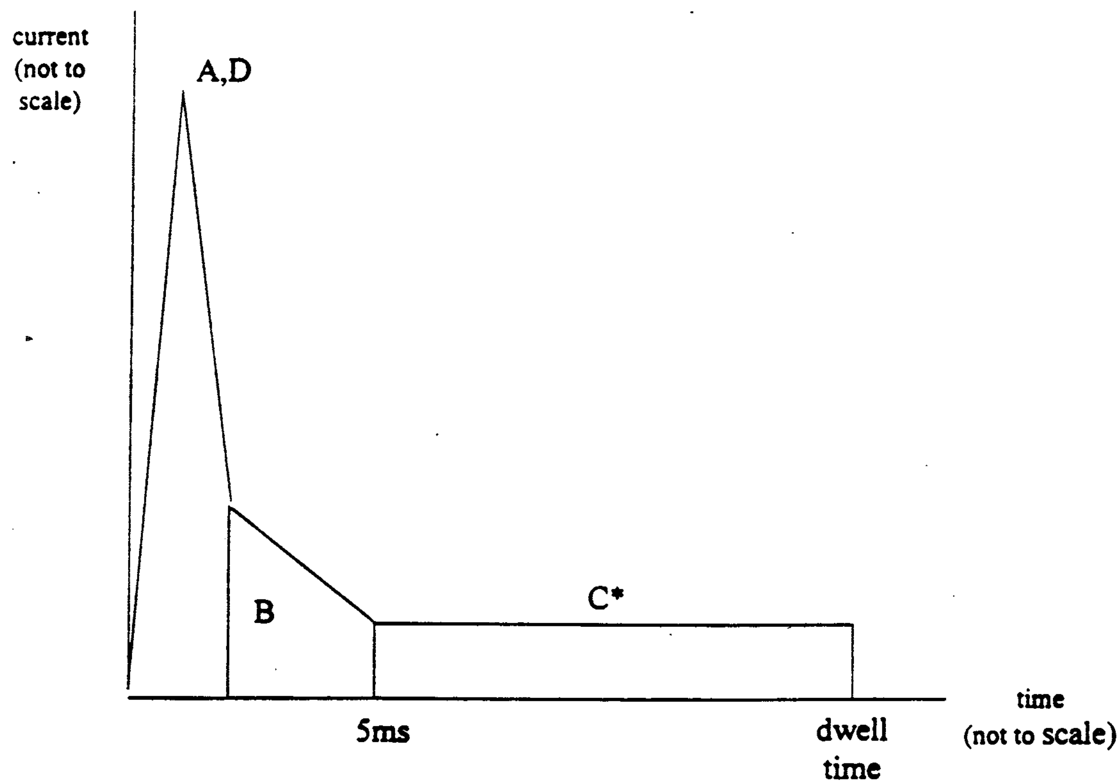


Figure 9-11. Application of current component C*.

9.3.6 Current component D - subsequent stroke current

Current Component D has two applications.

For direct effects assessments current component D represents a subsequent stroke. (Figure 9-5).

For direct effects testing, component D can be simulated by either oscillatory or unidirectional waveforms (Figures 9-13(a) and 9-13(b)) with a total time duration to 1% peak value of 500μs. The amplitude shall be 100kA (± 10%), the rise time shall not exceed 25μs (time between 10% and 90% of the amplitude). The action integral is 0.25 x $10^6 A^2s$ (± 20%).

For indirect effects investigations and analysis purposes, the double exponential current waveform presented in Figure 9-12(a) should be used. This waveform represents the initial stroke in the Multiple Stroke waveform set (Fig. 9-14).

The waveform is defined mathematically by the double exponential expression shown below:

$$i(t) = I_0\left(e^{-\alpha t} - e^{-\beta t}\right)$$

where:

I_0 = 109,405 A
α = 22,708 s^{-1}
β = 1,294,530 s^{-1}
t is time (s).

The frequency content of component D is given on Figure 9-12(b).

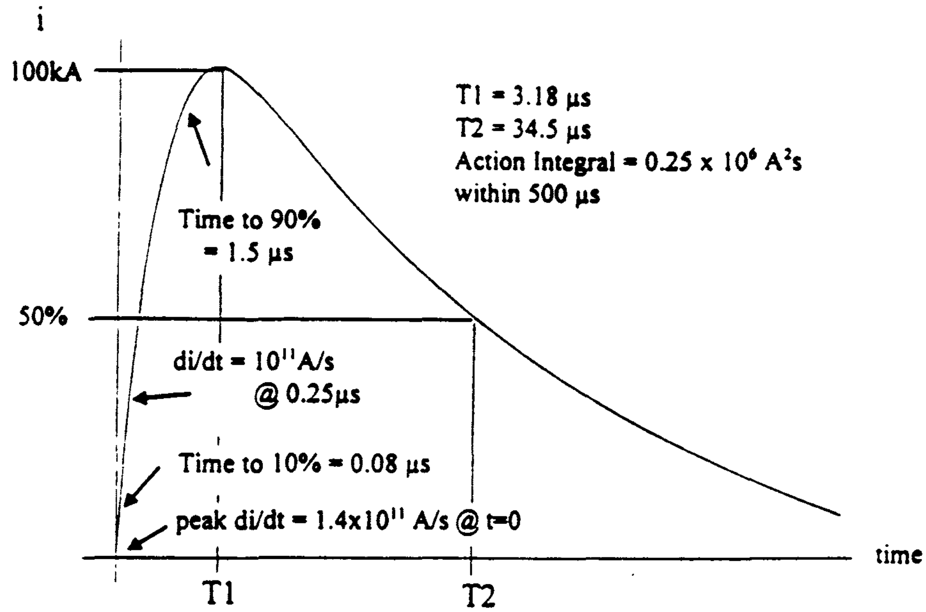


Figure 9-12(a). Current component D for analysis purpose and indirect effects test purposes.

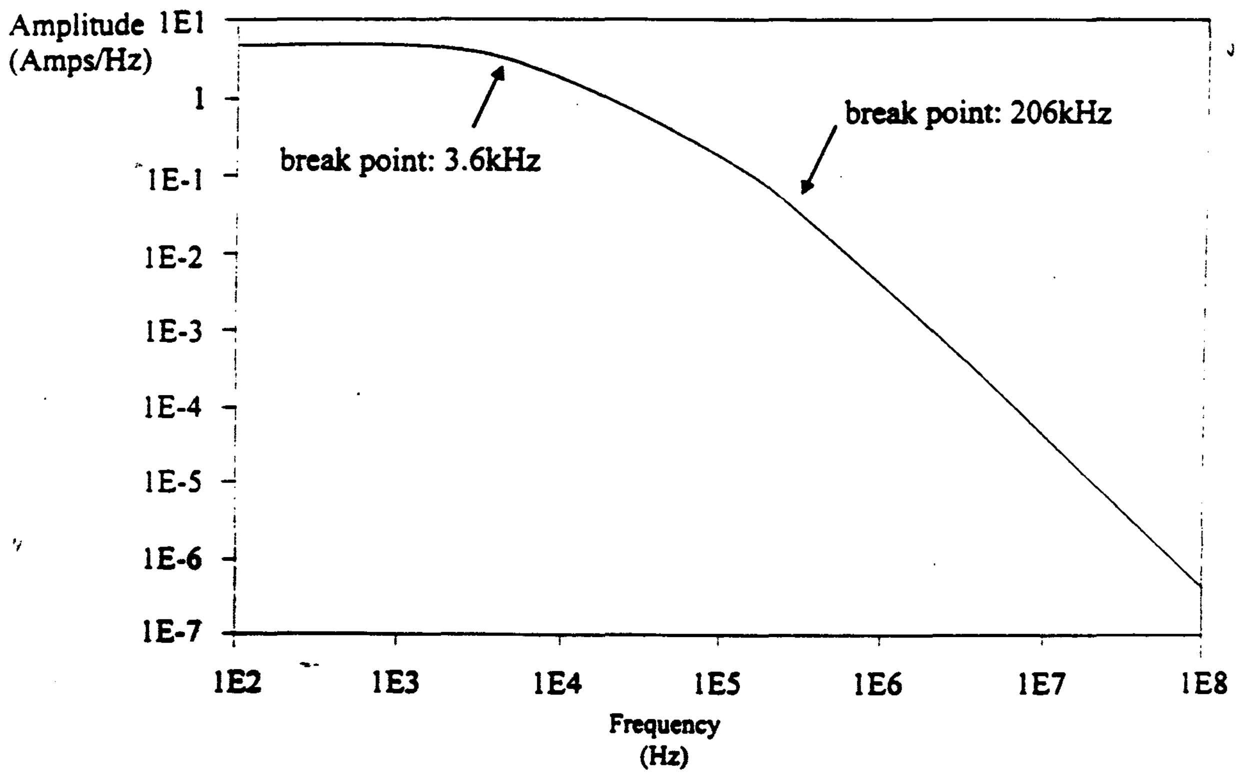


Figure 9-12(b). Frequency content (amplitude spectrum) of component D.

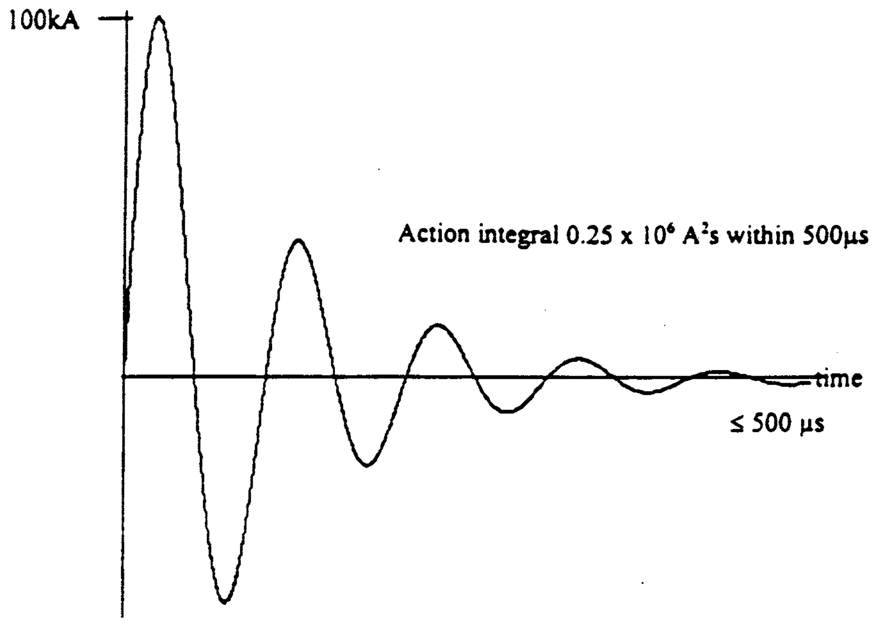


Figure 9-13(a). Damped sinusoidal current.

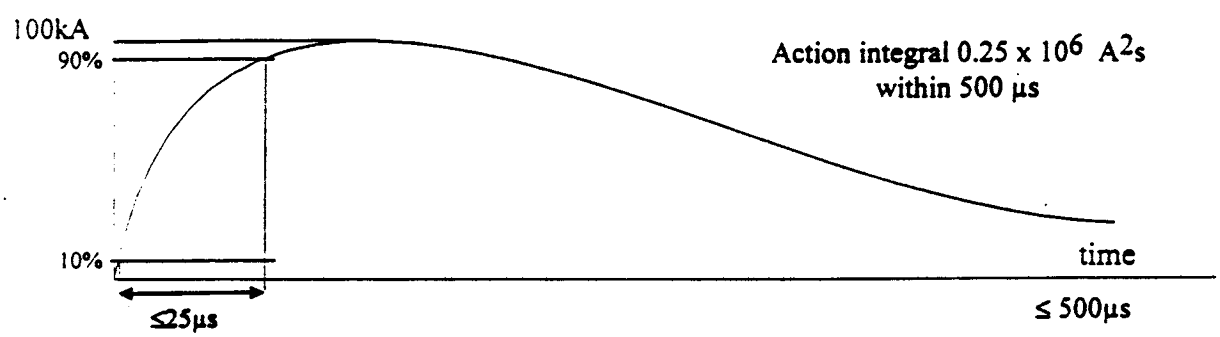


Figure 9-13(b). Unipolar pulse.

9.3.7 Multiple Stroke Waveform set

In many cases up to 14 randomly spaced strokes have been observed in negative cloud to ground flashes. Also several pulses of approximately 30kA can occur in a random sequence in an intra-cloud event as illustrated in Figure 7-3.

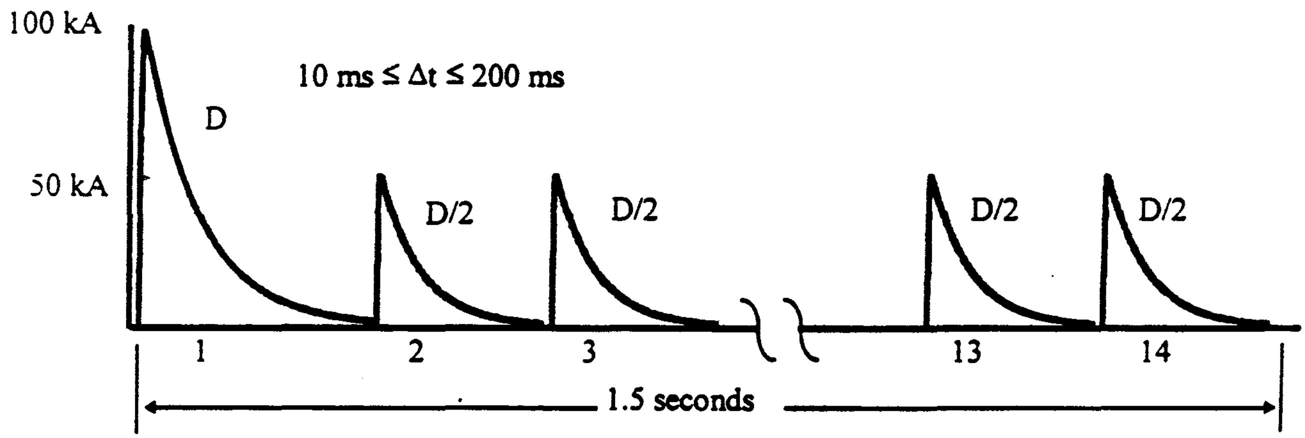
The synthesized Multiple Stroke Waveform set is defined as a current component D followed by 13 components D/2 as shown in Figure 9-14. The components D/2 are distributed randomly over a period of up to 1.5 seconds according to the following constraints:

- the minimum time between components is 10 ms,
- the maximum time between components is 200 ms

The D/2 Waveform parameters are identical to the current component D parameters with the exception that I_0 = 54,703 A.

The primary purpose of the Multiple Stroke Waveform set is to evaluate system functional upset of systems that may be susceptible to effects of multiple induced transients. It is not necessary that this Waveform set be applied at the defined levels in a test. Instead, the internal environment due to a single component may be determined by analysis or test and the Multiple Stroke combination of induced transients applied to the system/equipment.

The Multiple Stroke Waveform set is used only for indirect effects evaluation.



One current component D followed by thirteen current component D/2s distributed over a period of up to 1.5 seconds.

Figure 9-14. Multiple Stroke Waveform set.

9.3.8 Multiple Burst Waveform set

The Multiple Burst Waveform set is comprised of component H waveforms. Component H represents a high rate-of-rise current pulse whose amplitude and time duration are much less than those of a return stroke. Such pulses have been found to occur in groups at the initiation of a lightning strike to an aircraft and randomly throughout the lightning flash duration, together with the other current components (Figure 7-3). While not likely to cause physical damage to the aircraft, the random and repetitive nature of these pulses may cause interference or upset to certain systems. The recommended waveform set comprises repetitive component H waveforms in three bursts of 20 pulses each as shown in Figure 9-15. The minimum time between induced Component H pulses within a burst is 50μs and the maximum is 1,000μs.

The 3 bursts are distributed according to the following constraints:

- the minimum time between bursts is 30 ms,
- the maximum time between bursts is 300 ms.

If the maximum times between individual pulses and bursts were assumed, the Multiple Burst Waveform set would occupy 0.62 seconds.

Waveform H can be mathematically described by using the following formula:

$$i = I_0\left(e^{-\alpha t} - e^{-\beta t}\right)$$

where:

$I_0 = 10{,}572$ A
$\alpha = 187{,}191\ s^{-1}$
$\beta = 19{,}105{,}100\ s^{-1}$
t is time (s)

Component H is presented in Figure 9-16(a).

The frequency content of component H is given on Figure 9-16(b).

> The primary purpose of the Multiple Burst Waveform set is to evaluate system functional upset of systems that may be susceptible to effects of multiple induced transients. It is not necessary that this waveform set be applied at the defined levels in a test. Instead, the internal environment due to a single component H Waveform may be determined by analysis or test and the Multiple Burst combination of induced transients applied to the system/equipment.

The Multiple Burst Waveform set is used only for indirect effects evaluation.

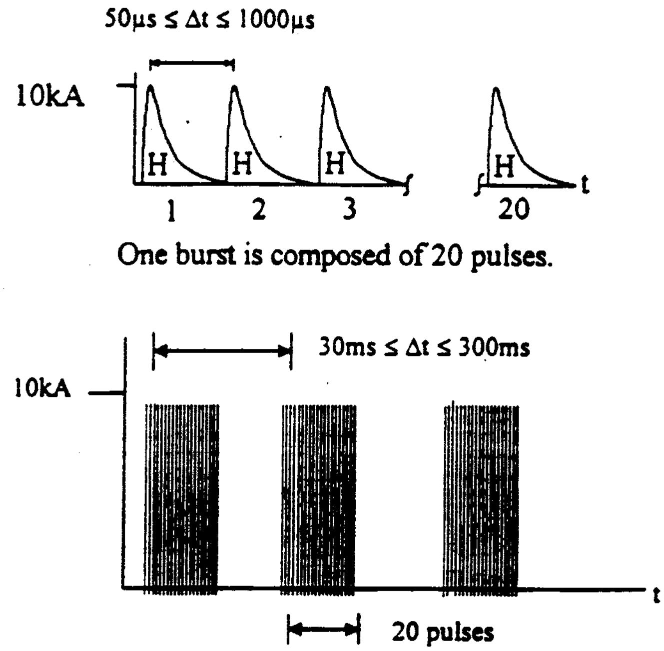


Figure 9-15. Multiple Burst Waveform set.

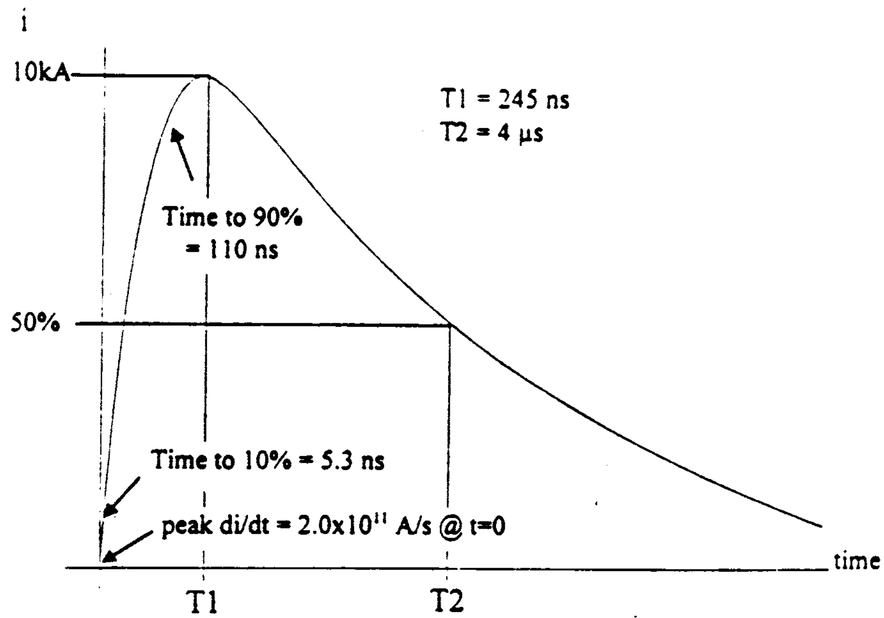


Figure 9-16(a). Current component H for analysis purposes and indirect effects. test purposes

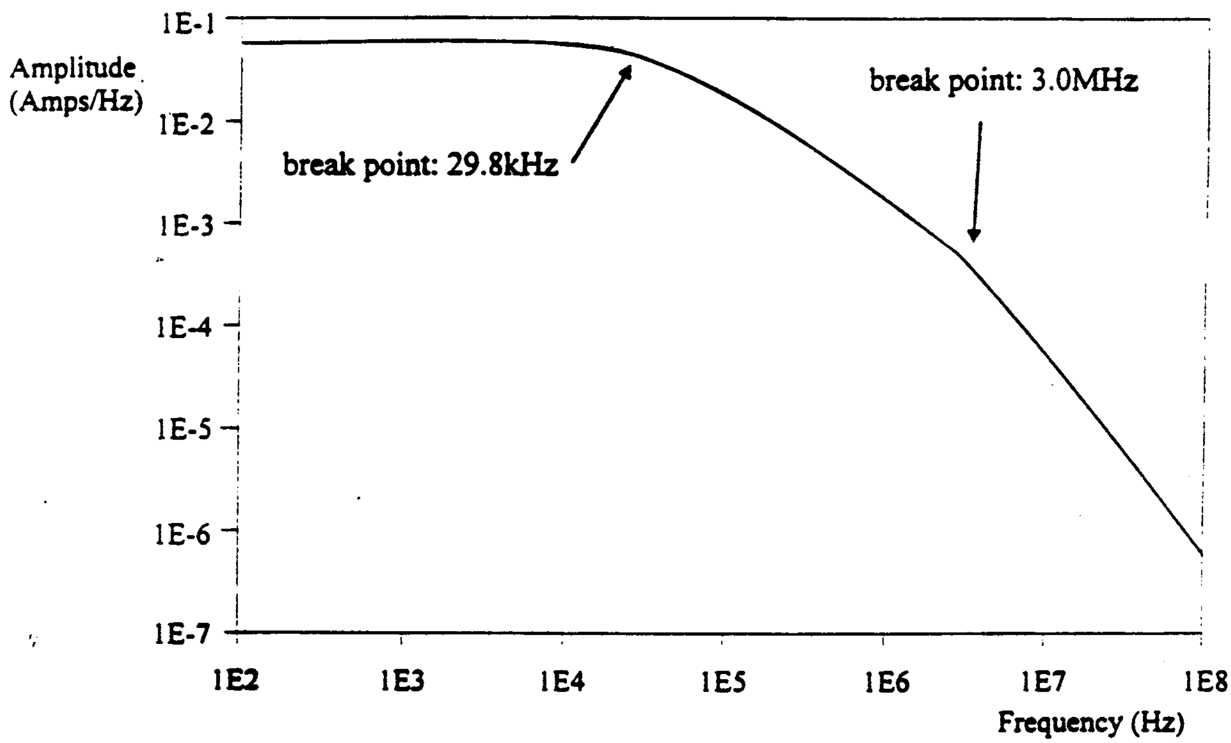


Figure 9-16(b). Frequency content (amplitude spectrum) of current component H

9.4 Application of the Idealized External Environment Waveforms/Components to Aircraft Testing

The application of the lightning environment waveforms and components to specific zones as described in reference 4.1 is shown in Table 9-1.

Table 9-1: Application of Lightning Environment to Aircraft Zones

Aircraft Zone	Voltage Waveforms(s)	Current Component(s)
1A	A, B, D	A, B, C*, H
1B	A. B. D	A. B, C, D. H
1C	A	A_h, B, C*, D, H
2A	A	D, B, C*, H
2B	A	D, B, C, H
3		A, B, C, D, H
Lightning Strike Model Tests	C	

Subsets of these waveforms are to be used for direct and indirect effect evaluation. Waveforms appropriate for direct effects include voltage Waveforms A, B, C, D, and current Components A, A_h, B, C, and D.

Waveforms appropriate for indirect effects evaluation include current components A, D, and H which are individual components of the single stroke, MS and MB Waveform sets.

Since most of an airframe is located within Zone 3, the single stoke, MS and MB Waveform sets are nearly always applicable. However, there may be special cases in Zone 2 where the aircraft system or subsystem and its wiring are isolated from the effects of the initial A current component and current component D is more applicable for single stroke evaluation. In addition there may be situations where a system (i.e. equipment and associated wiring) is located solely within one area of the aircraft (e.g. a nose equipment bay), this system may not be exposed to all of the strokes of the magnitude at those defined by the MS waveform set.

The uses of these waveforms are described in detail in References 4.2, 4.4 and 4.7.

10.0 IDEALIZED STANDARD INDUCED TRANSIENT WAVEFORMS

10.1 General

The idealized transient waveforms presented in this section are intended for design and verification of adequate lightning indirect effects protection of systems and equipment by analysis and/or test.

The external lightning environment will interact with an aircraft to induce voltage and current transients in conductors such as wiring inside the aircraft.

The high amplitudes and rates of change of Components A, D, and H (paragraphs. 9.3.1, 9.3.6, and 9.3.8, respectively) produce the major induced transients in aircraft wiring. Components B and C do not induce significant transients.

There are several mechanisms by which the external environment induces transients. These can be broadly divided into aperture coupling and resistive coupling. Most actual induced transients are complex waveforms that result from combinations of both coupling mechanisms. For design and verification purposes it has proved most practical to separate them and define a set of simpler waveforms described below. Typical TCLs or ETDLs associated with these waveforms are provided in Section 10.6.

10.2 Aperture Coupling

Magnetic fields penetrating through apertures will induce:

i. Current(s) whose waveshape is that of the driving external environment Waveform A (Waveform 1, Figure 10-1) in conductors or shields terminated to structure through low impedance's at each end.

ii. Voltage whose waveshape is that of the derivative of the driving external environment Waveform A (Waveform 2, Figure 10-2) in loops existing between cables and the structure.

Electric and/or magnetic fields penetrating through apertures will drive or excite resonance's on cables producing oscillatory currents and voltages which have the form of damped sinusoids (Waveform 3, Figure 10-3). The frequency will be dependent on the structure length, and/or cable length and terminating components. Frequencies often range between 1 MHz and 10 MHz; other frequencies outside this range have also sometimes been observed.

10.3 Structural IR Voltage and Diffusion Flux Coupling

These mechanisms will produce voltages in loops existing between cables and the structure, which are the sum of the structural IR voltage between the end points of the cables and the voltage resulting from fields diffused through the structural materials. These voltages may have the shape of the external environment Waveform A for resistive structures or slower double exponential waveshapes for highly conductive structures.

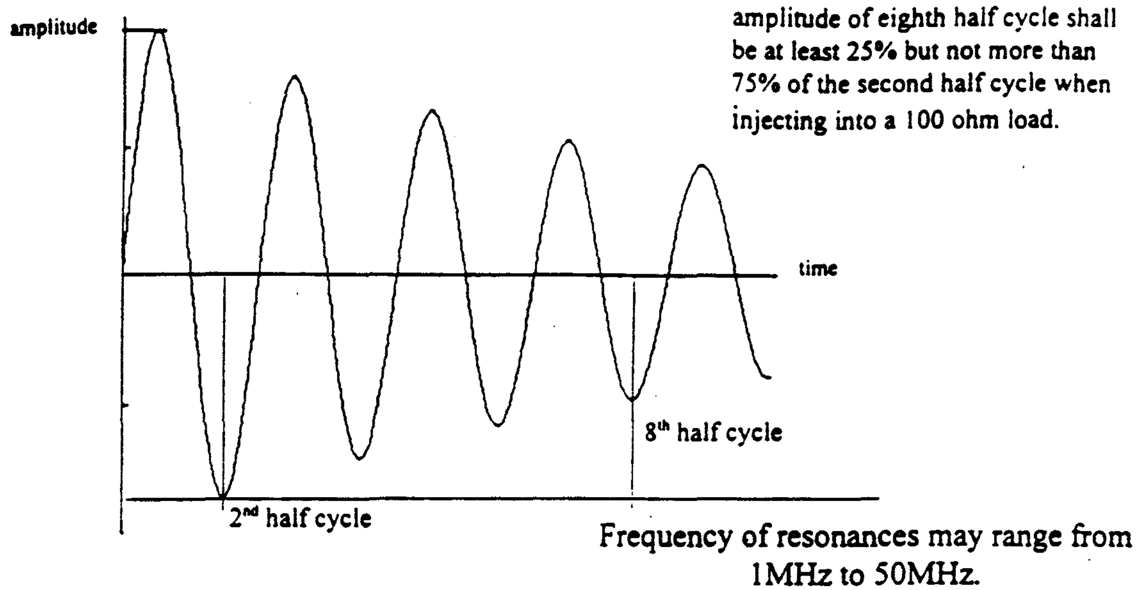


Figure 10-3. Damped sinusoidal voltage/current Waveform 3.

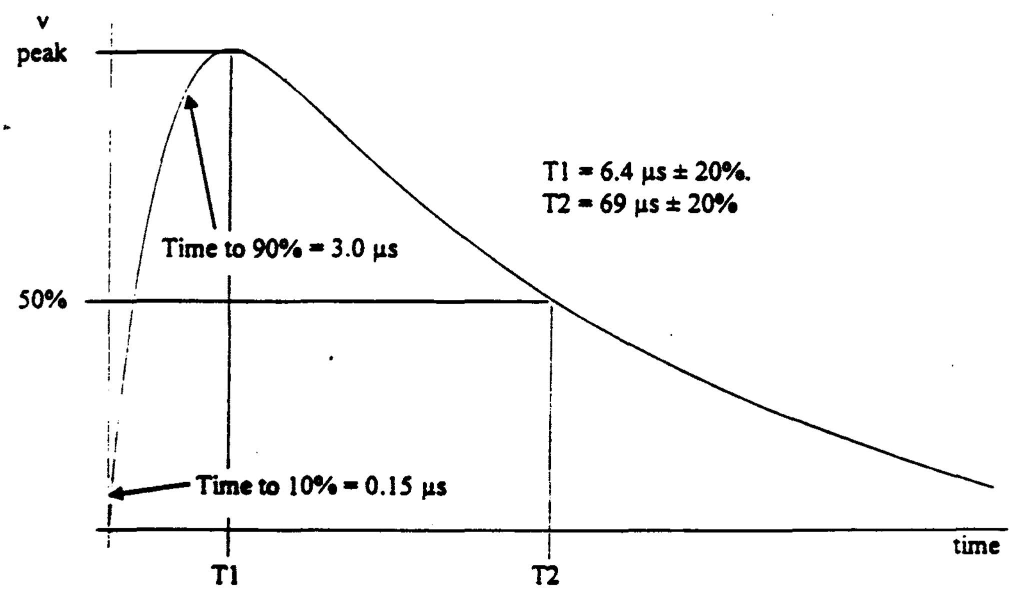


Figure 10-4. Double exponential voltage Waveform 4.

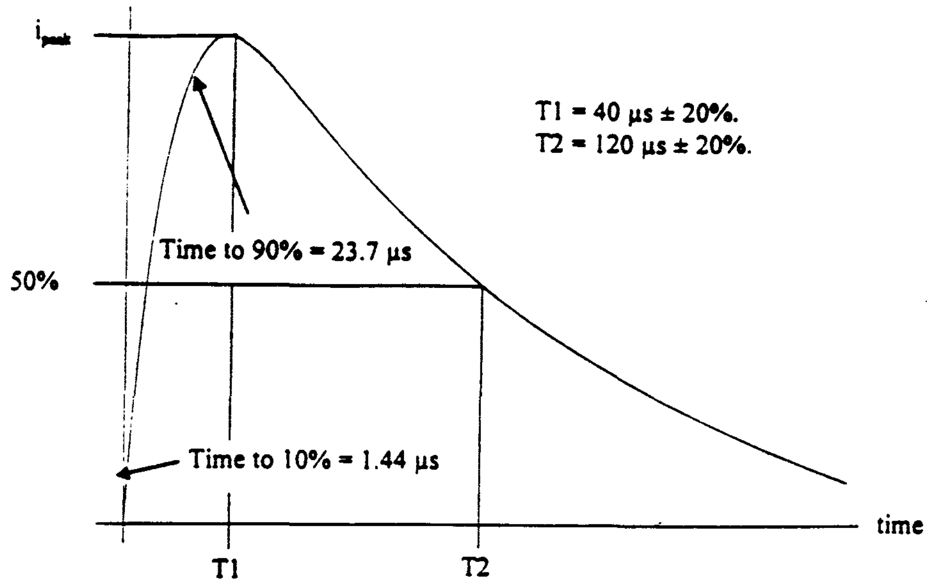


Figure 10-5. Double exponential current Waveform 5A.

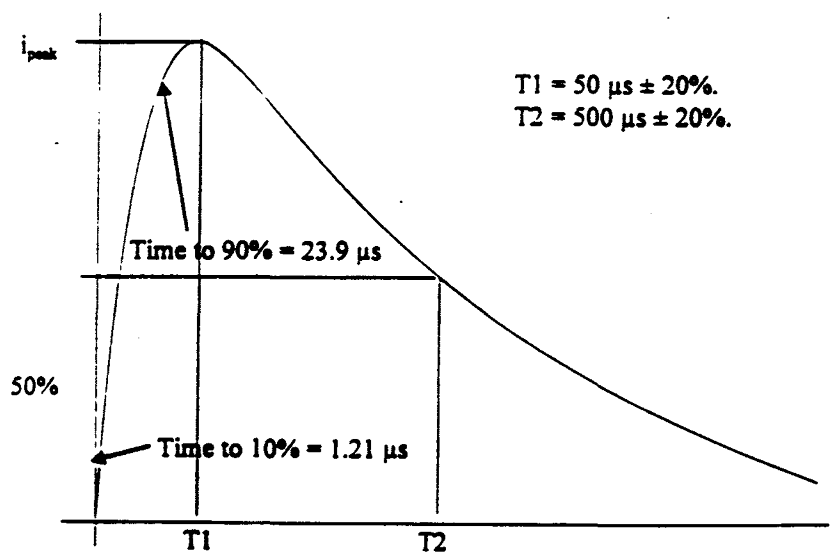


Figure 10-6. Double exponential current Waveform 5B.

10.5 Multiple Burst

Transient responses arising from component H of the Multiple burst Waveform set will also occur in the Multiple Burst sequence. The predominant waveform responses are voltage Waveform 3_H in a frequency range between 1 MHz and 10 MHz or a current waveform (Waveform 6_H) which has the same shape as the external environment component H. In this latter case, for test purposes, the component H rise time can be effectively produced with a current Waveform 3_H at a frequency of 5 MHz or higher. Equipment and system test levels for voltage Waveform 3_H typically have an amplitude of 60 percent of the component A Waveform 3 voltage response. Current Waveform 3_H typically has an amplitude of 1/20th of the component A Waveform 3 current response. Equipment and systems test levels for Waveform 6_H would typically have a maximum level of 1/20th of the component A Waveform 1 response.

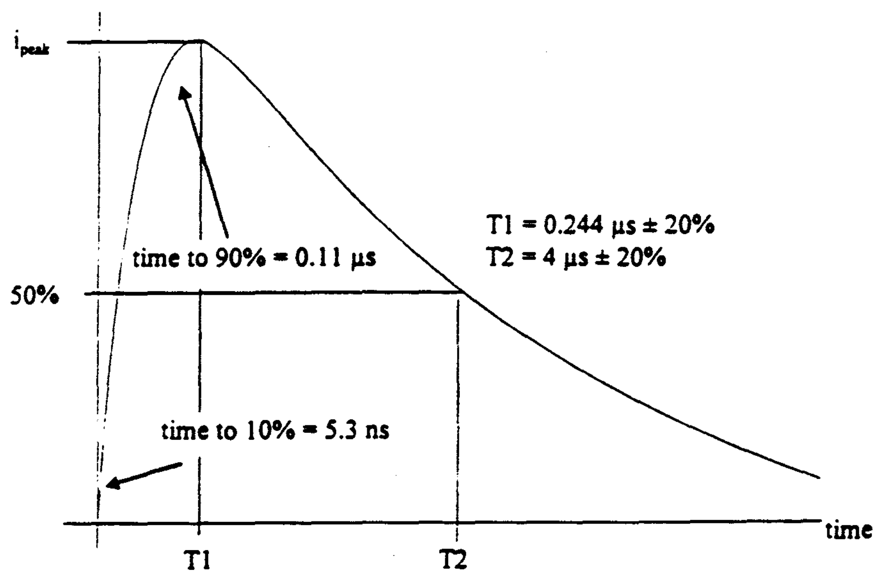


Figure 10-7. Double exponential current Waveform 6.

10.6 Typical Transient Amplitudes

The amplitudes of induced voltages in individual conductors and cable bundles encountered in a wide variety of aircraft installations have ranged from less than 50 volts to 3200 volts. The amplitudes of typical induced currents have ranged from less than 20 amperes to 1600 amperes in individual conductors and from less than 20 amperes to 5000 amperes in typical cable bundles.

This broad range has been subdivided into five narrower ranges that correspond roughly to aircraft electromagnetic regions that have been or can be achieved through design measures. Since the various transient waveforms arise from different coupling mechanisms, it follows that regions in an airframe designed to meet a particular level for one waveform will not necessarily meet the same level for the other transient waveforms.

Descriptions of five voltage and current amplitude levels and the aircraft areas with which they can be associated are provided in References 4.3 and 4.5. These levels are shown in Table 10-2 for individual conductors and Table 10-3 for cable bundle single and Multiple Stroke amplitudes, and Table 10-4 for cable Multiple Burst amplitudes.

Table 10-2.: Individual Conductor TCL, ETDL or Test Levels due to Current component A.

Level	Waveforms		
	3	4	5
	V/I	V/I	V/I
1	100/4	50/10	50/50
2	250/10	125/25	125/125
3	600/24	300/60	300/300
4	1500/60	750/150	750/750
5	3200/128	1600/320	1600/1600

Table 10-3.: Cable Bundle TCL, ETDL or Test Levels due to Current component A.

Level	Waveforms				
	1	2	3	4	5
	V/I	V/I	V/I	V/I	V/I
1	50/100	50/100	100/20	50/100	50/150
2	125/250	125/250	250/50	125/250	125/400
3	300/600	300/600	600/120	300/600	300/1000
4	750/1500	750/1500	1500/300	750/1500	750/2000
5	1600/3200	1600/3200	3200/640	1600/3200	1600/5000

Table 10-4. Cable Bundle TCL, ETDL or MB Test Levels due to Current Component H.

Level	Waveforms	
	3_H	6_H
	V/I	I
1	60/1	5
2	150/2.5	12.5
3	360/6	30
4	900/15	75
5	1920/32	160

11.0 SUMMARY OF WAVEFORMS/WAVEFORM SETS

A summary of the characteristics of the external lightning current components and the parameters necessary for their double exponential descriptions is presented in Table 11-1.

A summary of the characteristics of the induced transient waveforms and the parameters necessary for their double exponential descriptions is presented in Table 11-2.

Table 11-1. Summary of idealized external lightning current component parameters.

Parameter	Current component						
	A	A_h	B	C	D	D/2[1]	H[2]
I_0 (A)	218,810	164,903	11,300	400	109,405	54,703	10,572
$\alpha(s^{-1})$	11,354	16,065	700	N/A	22,708	22,708	187,191
$\beta(s^{-1})$	647,265	858,888	2,000	N/A	1,294,530	1,294,530	19,105,100
ipeak (A)	200,000	150,000	4,173	400	100,000	50,000	10,000
di/dt_{max} (A/s) (t=0+ s)	1.4×10^{11}	1.4×10^{11}	N/A	N/A	1.4×10^{11}	0.7×10^{11}	2.0×10^{11}
di/dt (A/s)	1.0×10^{11} (t=0.5 μs)	1.0×10^{11} (t=0.375 μs)	N/A	N/A.	1.0×10^{11} (t=0.25 μs)	0.50×10^{11} (t=0.25 μs)	N/A
action integral (A^2s)	2.0×10^6	0.8×10^6	N/A	N/A	0.25×10^6	0.0625×10^6	N/A

1) Applicable for the Multiple Stroke

2) Applicable for the Multiple Burst

Table 11-2. Summary of induced transient Waveform parameters.

PARAMETER	WAVEFORM							
	1	2	3	4	5A	5B	3H	6H
Pin tests	V/I	V/I	V/I	V/I	V/I	V/I	V/I	I
Level 1 V_0/I_0	N/A	N/A	100/4	50/10	50/50	50/50	N/A	N/A
Level 2 V_0/I_0	N/A	N/A	250/10	125/25	125/125	125/125	N/A	N/A
Level 3 V_0/I_0	N/A	N/A	600/24	300/60	300/300	300/300	N/A	N/A
Level 4 V_0/I_0	N/A	N/A	1500/60	750/150	750/750	750/750	N/A	N/A
Level 5 V_0/I_0	N/A	N/A	3200/128	1600/320	1600/1600	1600/1600	N/A	N/A
Cable tests								
Level 1 V_0/I_0	50/100	50/100	100/20	50/100	50/150	50/150	60/1	5
Level 2 V_0/I_0	125/250	125/250	250/50	125/250	125/400	125/400	150/2.5	12.5
Level 3 V_0/I_0	300/600	300/600	600/120	300/600	300/1000	300/1000	360/6	30
Level 4 V_0/I_0	750/1500	750/1500	1500/300	750/1500	750/2000	750/2000	900/15	75
Level 5 V_0/I_0	1600/3200	1600/3200	3200/640	1600/3200	1600/5000	1600/5000	1920/32	160
α (s^{-1})	11,354	11,354	0.231f4)	11,354	12,632	1585	0.231f4)	187,191
β (s^{-1})	647,265	647,265	N/A	647,265	43,605	80,022	N/A	19,105,100
ω ($Rad.s^{-1}$)	N/A	N/A	2πf4)	N/A	N/A	N/A	2πf4)	N/A
Equation	DE1)	Deriv2)	DS3)	DE1)	DE1)	DE1)	DS3)	DE1)
Peak Multiplier5)	1.094	1.00	1.059	1.094	2.334	1.104	1.059	1.057

Notes:

1) DE: Double exponential of the form $v_t = V_0\ (e^{-\beta t} - e^{-\alpha t})$ or $i_t = I_0\ (e^{-\beta t} - e^{-\alpha t})$
2) Deriv: Derivative of a double exponential of the form $v_t = \beta e^{-\beta t} - \alpha e^{-\alpha t}$ or $i_t = \beta e^{-\beta t} - \alpha e^{-\alpha t}$
3) DS: Damped sinusoid of the form $v_t = V_0 \sin(\omega t)\ e^{-\alpha t}$ or $i_t = I_0 \sin(\omega t)\ e^{-\alpha t}$
4) f: Frequency in Hertz
5) The value of the peak multiplier is that which when multiplied by the peak threat level given above provides a value for V_0 or I_0

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

14 CFR Parts 23, 25, 27, and 29

[Docket No. FAA–2010–0224; Amendment Nos. 23–61, 25–134, 27–46, and 29–53]

RIN 2120–AJ57

Airworthiness Standards; Electrical and Electronic System Lightning Protection

AGENCY: Federal Aviation Administration (FAA), DOT.

ACTION: Final rule.

SUMMARY: The Federal Aviation Administration (FAA) amends the lightning protection airworthiness standards by establishing new lightning protection regulations for electrical and electronic systems installed on aircraft certificated under parts 23, 27, and 29, and revises lightning protection regulations for electrical and electronic systems installed on airplanes certificated under part 25. This rule establishes two levels of lightning protection for aircraft systems based on consequences of system function failure: Catastrophic consequences which would prevent continued safe flight and landing; and hazardous or major consequences which would reduce the capability of the aircraft or the ability of the flightcrew to respond to an adverse operating condition. This rule also establishes lightning protection for aircraft systems according to the aircraft's potential for lightning exposure. The airworthiness standards establish consistent lightning protection requirements for aircraft electrical and electronic systems.

DATES: These amendments become effective August 8, 2011.

FOR FURTHER INFORMATION CONTACT: Lee Nguyen, AIR–130, Federal Aviation Administration, Suite 4102, 470 L'Enfant Plaza, Washington, DC 20591; telephone (202) 385–4676; facsimile (202) 385–4651, e-mail *lee.nguyen@faa.gov.*

SUPPLEMENTARY INFORMATION:

Authority for This Rulemaking

The FAA's authority to issue rules on aviation safety is found in Title 49 of the United States Code. Subtitle I, Section 106 describes the authority of the FAA Administrator. Subtitle VII, Aviation Programs, describes in more detail the scope of the agency's authority.

This rulemaking is promulgated under the authority described in Subtitle VII, Part A, Subpart III, Section 44701(a)(1). Under that section, the FAA is charged with prescribing regulations to promote safe flight of civil aircraft in air commerce by prescribing minimum standards in the interest of safety for appliances and for the design, material, construction, quality of work, and performance of aircraft, aircraft engines, and propellers. This regulation is within the scope of that authority by prescribing standards to protect aircraft electrical and electronic systems from the effects of lightning.

I. Background and History

Existing regulations for the lightning protection of electrical and electronic systems installed on aircraft certificated under parts 23, 27 and 29 of Title 14, Code of Federal Regulations (14 CFR) require the type certification applicant only to "consider" the effects of lightning. Unlike system lightning protection regulations for part 25 airplanes, these regulations have not been significantly amended since they were first adopted, and do not reflect current advances in technology. Adopted in the 1960s, these regulations require that the aircraft be protected against catastrophic effects of lightning, but do not have specific requirements for electrical and electronic system lightning protection. At the time, most aircraft contained mechanical systems, or simple electrical and electronic systems. Airframe components were made from aluminum materials, with high electrical conductivity, and offered good protection against lightning.

The early 1980s ushered in part 25 transport airplane designs that routinely included more complex electrical and electronic systems. In addition, there has been a trend for increased use of composite aircraft materials with less inherent lightning protection than aluminum. As electrical and electronic systems became more common on part 25 airplanes, the FAA issued § 25.1316 on April 28, 1994 (59 FR 22112), specifically requiring protection for electrical and electronic systems on part 25 transport category airplanes.

A. Summary of the Notice of Proposed Rulemaking (NPRM)

The NPRM, Notice No. 10–05, published in the **Federal Register** on April 2, 2010 (75 FR 16676), is the basis for this final rule. In the NPRM, the FAA proposed to establish type certification standards for lightning protection of electrical and electronic systems for aircraft certificated under parts 23, 27 and 29, equivalent to those found in part 25. At the same time, the NPRM proposed to revise § 25.1316 for transport category airplanes to be consistent in format with the proposed regulatory text for parts 23, 27 and 29. Overall, the NPRM proposed to establish lightning protection standards for aircraft systems according to the consequences of the failure of the functions they provide, and according to the aircraft's potential for lightning exposure.

The NPRM proposed the establishment of consistent performance standards for lightning protection of aircraft electrical and electronic systems against the catastrophic, hazardous or major failures of the functions these systems provide. The standards for protection against catastrophic failure would require an applicant to show that the function that the system performs would not be adversely affected during or after the time the aircraft is exposed to lightning, and that the system that was affected would automatically recover normal operation of that function in a timely manner after the aircraft is exposed to lightning. The standards for protection against hazardous or major failure would require the applicant to show that the affected function would recover normal operation in a timely manner after the aircraft is exposed to lightning.

The performance standards would also be imposed according to the aircraft's potential for exposure to lightning. The standards for all aircraft operated under instrument flight rules would meet more stringent requirements than aircraft certificated to part 23 and part 27 standards approved solely for operations under visual flight rules. This proposal ensured that protection would be applied to aircraft according to their potential for exposure to lightning.

The comment period for the NPRM ended on July 1, 2010.

B. Summary of the Final Rule

The final rule adopts all the standards proposed in the NPRM, with one exception. We chose not to adopt proposed paragraph (b)(1) to §§ 23.1306, 25.1316, 27.1316 and 29.1316, which required that the system must not be damaged after exposure to lightning for systems with hazardous or major failure conditions. We discuss the reasons for this decision later in this document.

C. Summary of Comments

The FAA received 17 comments from 8 commenters, including manufacturers, international aviation standards associations, and the European Aviation Safety Agency. All the commenters generally supported the proposed changes to parts 23, 25, 27 and 29. We discuss the comments in more detail below.

II. Discussion of the Final Rule

The FAA received comments on the following general areas of the proposal:

- Requirement that "the system must not be damaged" for systems with hazardous or major failure conditions;
- "Indirect" and "direct" effects of lightning;
- Requirement for automatic system recovery of the function with catastrophic failure conditions;
- Automatic system recovery of the function with hazardous failure conditions;
- Provide more guidance on "in a timely manner";
- Resolve conflict regarding systems providing multiple functions;
- Guidance on acceptable means of compliance;
- Definition of "catastrophic", "hazardous", and "major failure conditions".

Below is a more detailed discussion of the rule, as it relates to the substantive comments the FAA received to the NPRM.

Requirement That "The System Must Not be Damaged" for Systems With Hazardous or Major Failure Conditions

The FAA proposed for §§ 23.1306, 25.1316, 27.1316 and 29.1316, in paragraph (b)(1), that each electrical and electronic system that performs a function, for which failure would reduce the capability of the aircraft or the ability of the flightcrew to respond to an adverse operating condition, must be designed and installed so that the system is not damaged after the aircraft is exposed to lightning.

The SAE International AE–2 Lightning Committee, Cessna Aircraft Company, Garmin International, and an individual commenter asked that the FAA delete paragraph (b)(1). The SAE AE–2 Lightning Committee and Cessna expressed concern that the proposal would not reflect a codification of current industry practices as characterized by the FAA. The SAE AE–2 Committee and the individual commenter also expressed concern that the proposal would: (1) Have a significant economic impact on the production of aircraft that use multiple redundant antennas for radio systems performing functions required to comply with paragraph (b)(1); and (2) reflect a significant change to the existing system lightning protection regulations.

The commenters explained that although lightning commonly attaches to antennas, these systems use redundant, spatially separated antennas so that a single lightning strike will not damage more than a single antenna and its associated radio system. If paragraph (b)(1) were adopted, significant changes would be required for radio and antenna installation design. Specifically, aircraft designers and installers would have to install external sensors (e.g., antennas, air data probes) that will not be damaged by lightning strikes, and thus enable the system to remain recoverable after the lightning event. Such sensors are generally heavier, more complex, and more costly than current sensor systems. The commenters stated that such sensors are unnecessary, since using redundant and spatially separated antennas for radio systems provide effective lightning protection for these systems. The SAE AE–2 Committee pointed out that the FAA did not properly consider the economic impact of paragraph (b)(1) in its analysis.

After careful consideration of the points raised by the commenters, we have concluded that proposed paragraph (b)(1) should not be adopted. When we originally developed paragraph (b)(1), we did so in response to a recommendation from the Electromagnetic Effects Harmonization Working Group (EEHWG) of the Transport Airplane and Engines Issues Group under the Aviation Rulemaking Advisory Committee, which assumed that a lightning strike to these systems would cause damage resulting in the unrecoverable loss of the function, even if the system included redundant elements to maintain system integrity and availability. Under this assumption, the systems could no longer perform their intended functions, which would reduce the capability of the aircraft or the ability of the flightcrew to respond to an adverse operating condition.

The commenters showed that the EEHWG incorrectly assumed that loss of a function (caused by lightning damage) performed by a system equipped with external sensors such as radio antennas and air data probes—which are occasionally damaged by lightning—would be unrecoverable. If the proposed rule had been adopted, designers and manufacturers would no longer be able to use sensor separation as a means of compliance. Thus the rule change would have eliminated a means of compliance that is acceptable under the current regulatory scheme.

Garmin further commented that, if adopted, the proposed paragraph (b)(1) would have the unintended effect of requiring excessive lightning protection. Garmin explained that systems performing functions with hazardous or major failure consequences may include systems that perform other functions for which the failure would have minor consequences or even no safety effect. Garmin suggested that the proposed standard should be required for only those functions having hazardous or major failure consequences similar to that provided in proposed paragraph (b)(2), which requires each electrical and electronic system that performs a function, for which failure would reduce the capability of the aircraft or the ability of the flightcrew to respond to an adverse operating condition, be designed and installed so that the function recovers normal operation in a timely manner after the aircraft is exposed to lightning. The FAA acknowledges Garmin's point that paragraph (b)(1) may be subject to this kind of unintended interpretation.

For these reasons, we have determined that the proposed paragraph (b)(1) would not serve the purpose that we had intended and should not be adopted. Further, this requirement would limit the approaches that aircraft system designers may use to show that the design and installation meets the requirements of paragraph (b)(2). As proposed, this provision will have no impact on safety because paragraph (b)(2) will require that the "function" must recover in a timely manner after lightning exposure. Garmin's concern over unintended interpretations, as well as the individual commenter's concern for additional cost impact are resolved by our decision not to adopt this proposal.

Finally, Cessna recommended that the FAA revise the proposed requirement of "system must not be damaged after the airplane is exposed to lightning" to "system is installed such that damage to the system is minimized as a result of the airplane being exposed to lightning."

The FAA disagrees. The term "minimized" would require a subjective evaluation of the damage, and defeat our purpose to provide an objective measure of system lightning protection effectiveness.

Indirect Effects and Direct Effects of Lightning

The SAE AE–2 Lightning Committee commented that the proposed regulatory text did not use the phrase "indirect effects of lightning," although the phrase is used in current § 23.1309(e) and AC 20–136A, "Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning." The commenter stated that this omission may cause confusion when considering regulations such as § 27.610, which is intended to address the "direct effects of lightning."

The FAA acknowledges the commenter's point that the terms "indirect" and "direct" were not used in the regulatory text, although they are often used to classify the specific effects of lightning. The phrases "direct effects of lightning" and "indirect effects of lightning" generally refer to the mechanism in which lightning affects electrical and electronic systems or functions. Direct effects are typically associated with the actual lightning attachment to the airframe or electrical and electronic system external sensors which can cause damage in the form of burning, blasting, or deformation. Conversely, indirect effects are those caused by lightning energy that is electrically coupled into electrical and electronic equipment and its associated wiring. The performance standards address protection of aircraft electrical and electronic systems when exposed to lightning based on the consequences of failure of the functions that the systems perform. The regulations, as adopted, are not intended to differentiate between how the effects of lightning are caused, but are instead directed at the continued performance of the system or function.

The commenter also asserted that the performance standards do not reflect current industry practices or regulatory requirements. The FAA disagrees; these performance standards are consistent with the existing §§ 23.1309(e), 25.1316, 27.1309(d), and 29.1309(h). These regulations refer to the effects of lightning in general, not to "indirect effects" of lightning exclusively. The existing § 23.1309(e), specifically states that both direct and indirect effects of lightning must be considered. Section 25.1316 addresses protection of the electrical and electronic systems against lightning. Sections 27.1309(d) and 29.1309(h) require that the effects of lightning strikes on the rotorcraft must be considered. Accordingly, the performance standards established by this rulemaking are consistent with existing regulations and industry practice.

The commenter also stated that the proposed rules should specify that the requirement refers to "indirect effects of lightning" to be consistent with AC 20–136A. In fact, the AC addresses both indirect and direct effects of lightning. The AC does not, however, describe the methods for showing compliance if an electrical or electronic system is subject to direct lightning attachment (direct effects). It refers to other documents, such as SAE Aerospace Recommended Practice (ARP) 5416, *Aircraft Lightning Test Methods,* for methods to show compliance for direct effects. Nonetheless, the AC does speak to the need for the applicant to address the direct effects of lightning on electrical and electronic systems.

Finally, the commenter stated that the proposed rules would require a change in approach if they apply to the direct effects of lightning, as the proposed rules stated that essential systems must not be damaged after the aircraft is exposed to lightning. As discussed previously, the FAA has decided not to adopt the proposed requirement of paragraph (b)(1). This decision resolves this commenter's concern.

Requirement for Automatic System Recovery of the Function With Catastrophic Failure Conditions

In the NPRM, the FAA proposed paragraph (a)(2), which required that each electrical and electronic system that performs a function for which failure would prevent the continued safe flight and landing of the aircraft must be designed and installed so that the system automatically recovers normal operation of that function in a timely manner after the aircraft is exposed to lightning. In part, this proposal was based on EEHWG recommendation submitted to the FAA. That recommendation also contained a relieving clause which allowed the requirement for "automatic and timely recovery" to be disregarded if the automatic and timely recover would interfere with continued performance of other operational or functional requirements of the system.

We omitted the relieving clause in the proposal published in the NPRM, which in effect made automatic and timely recovery compulsory. After careful review of the EEHWG's recommendation for an exception to the "automatic and timely recovery" requirement, we could not justify its inclusion because we could not find any real-world example where this provision would apply. Also, the phrase "unless this conflicts with other operational or functional requirements of that system" provides no objective definition of operational or functional requirements for the system. Finally, we were unable to develop standards that would ensure an equivalent level of safety should the exception be adopted.

The SAE AE–2 Lightning Committee commented on the FAA's decision to eliminate the relieving clause. It stated that (1) this clause would not decrease safety as long as the function is maintained, and (2) some systems do exist that, due to other functional or operational requirements, cannot recover automatically without flightcrew action: Such as attitude and heading reference systems, fly-by-wire flight controls, and brake-by-wire systems. The committee submitted, as an example of a system mode change that requires flightcrew action, the Falcon 7X fly-by-wire control system for which the flightcrew has to trigger normal mode recovery from a backup mode after the aircraft is exposed to lightning.

The FAA has considered the reasons and examples provided and has concluded that they do not present scenarios that adequately justify the need for including the recommended exception. Paragraph (a)(1) requires that functions with catastrophic failure conditions are "not adversely affected" by lightning. A system mode change caused by lightning, that requires flightcrew action, would be evaluated according to existing guidance and practices to determine whether it is an adverse effect. As such, the examples provided would be evaluated to determine if the function was "adversely effected" under paragraph (a)(1), and do not justify an exception clause to paragraph (a)(2).

Further, the commenters did not suggest any objective standard for what should occur in the event of an exception, should we adopt the exception clause. Therefore, we will not change the regulatory text based on the comment.

Automatic System Recovery of the Function With Hazardous Failure Conditions

In the NPRM, the FAA proposed to require that systems having the potential for hazardous failure consequences must recover normal operation of the function in a timely manner after the aircraft is exposed to lightning.

Airbus commented that the FAA should require the higher standard of automatic recovery for hazardous failure conditions because it would help to avoid situations where the pilot has to manually recover from multiple failures with hazardous classification.

After consideration, the FAA has decided against the Airbus suggestion. The standard gives certification applicants the flexibility to choose automatic or pilot-initiated recovery for functions with hazardous failure conditions. This standard is consistent with the existing § 25.1316(b) and with prior special conditions, both of which have provided a satisfactory level of safety.

Guidance on "In a Timely Manner"

Garmin asked that the FAA provide more guidance on what constitutes "in a timely manner." It suggested the following paragraph should have been inserted into the NPRM preamble:

"The term 'in a timely manner,' when used for recovery of catastrophic, hazardous, and major functions, is referring to the length of time the function(s) may be lost before it would be considered catastrophic, hazardous, or major. For major and hazardous functions, crew interaction is allowed in the recovery of the function. The FAA would determine what constitutes 'timely' automatic recovery on a case-by-case evaluation for failure of any specific function and its failure effect on the aircraft, pilot workload, and safety margins."

The FAA has determined that the phrase "in a timely manner" does not lend itself to a generic description since it is dependent upon various factors such as the function performed by the system being evaluated, the specific system design, interaction between systems, and interaction between the system and the flight crew. The FAA agrees that we will determine what constitutes "timely recovery" on a case-by-case evaluation based on engineering and flight crew assessment of the specific function and its failure effects. Should consideration of additional factors be appropriate, the FAA would consider those as well. Since the Garmin's comment addresses the preamble to the NPRM, no change to the final regulations is required.

Resolve Conflict Regarding Systems Providing Multiple Functions

Garmin commented that there is a conflict between the two following paragraphs in the NPRM preamble:

"For systems that provide one or more functions, the proposal would require the system to automatically recover normal operations of those functions for which failure could be catastrophic. Other functions would not be required to return to normal operation* * *" and "The proposed requirements for protection against hazardous or major failure would require the applicant to show that the system would not be damaged, and the function would recover normal operation in a timely manner after the aircraft is exposed to lightning."

The FAA agrees with Garmin, and clarifies that the other functions would not be required to "automatically" return to normal operation.

Guidance on Acceptable Means of Compliance

Garmin, in their comment, was concerned with the means of compliance for these proposed regulations. Garmin proposed that the following paragraph should be added to the preamble of the NPRM:

"The term 'after the airplane is exposed to lightning' is not intended to mean that all systems regardless of criticality are required to meet the transient levels resulting from the most severe lightning strike to the aircraft (200kA). When the rule or text in the preamble refers to systems or functions needing to meet requirements 'after the airplane is exposed to lightning,' the development of the transient levels at the system/equipment interfaces can take into account the criticality of the system/equipment. Further guidance is provided in AC 20–136A."

Since this comment addresses the preamble of the NPRM, there is no need for a change in the regulatory text. However, the NPRM preamble wording cited by Garmin is not about lightning induced transient characteristics, but focuses on lightning protection requirements for systems and functions. These regulations do not define a specific means of compliance. AC 20–136A provides guidance on an acceptable means of compliance for lightning induced transient characteristics at the system interfaces, which addresses Garmin's concerns.

Definitions of Catastrophic, Hazardous, and Major Failure Conditions

The European Aviation Safety Agency (EASA) generally concurred with the FAA's proposed requirements, but suggested new wording that combined existing EASA regulation requirements for electrical and electronic system lightning protection with the FAA's wording.

The FAA has decided not to adopt EASA's proposed revision because the FAA's regulatory text more clearly emphasizes that lightning protection must ensure the continued performance of the system functions. Adopting the regulatory text proposed by EASA would not further the FAA's intent to place the emphasis on protecting the function. In addition, the FAA's adopted regulatory text is consistent with that used in the High-Intensity Radio Frequency regulations (§§ 23.1307, 25.1317, 27.1317, and 29.1317), which clearly emphasizes the need to protect the functions performed by the systems more than the systems themselves.

Miscellaneous Issues

The SAE AE–2 Committee commented that in the proposed § 29.1316(b), the term "airplane" should be "rotorcraft". The FAA agrees and adopts this change.

One individual recommended that the FAA mandate the calibration of precision tools that are used to return an aircraft to service, because it is important to ensure that a positive crimp, torque or connection is made. This comment does not address any requirements that were proposed in the NPRM and is outside the scope of the proposed rules. Therefore, we do not make any regulatory changes based on the comment.

III. Regulatory Notices and Analysis

Paperwork Reduction Act

The Paperwork Reduction Act of 1995 (44 U.S.C. 3507(d)) requires that the FAA consider the impact of paperwork and other information collection burdens imposed on the public. The FAA has determined that there is no new requirement for information collection associated with this final rule.

International Compatibility

In keeping with U.S. obligations under the Convention on International Civil Aviation, it is FAA policy to conform to International Civil Aviation Organization (ICAO) Standards and Recommended Practices to the maximum extent practicable. The FAA has determined that there are no ICAO Standards and Recommended Practices that correspond to these regulations.

Regulatory Evaluation, Regulatory Flexibility Determination, International Trade Impact Assessment, and Unfunded Mandates Assessment

Changes to Federal regulations must undergo several economic analyses. First, Executive Order 12866 directs that each Federal agency shall propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs. Second, the Regulatory Flexibility Act of 1980 (Pub. L. 96–354) requires agencies to analyze the economic impact of regulatory changes on small entities. Third, the Trade Agreements Act (Pub. L. 96–39) prohibits agencies from setting standards that create unnecessary obstacles to the foreign commerce of the United States. In developing U.S. standards, this Trade Act requires agencies to consider international standards and, where appropriate, that they be the basis of U.S. standards. Fourth, the Unfunded Mandates Reform Act of 1995 (Pub. L. 104–4) requires agencies to prepare a written assessment of the costs, benefits, and other effects of proposed or final rules that include a Federal mandate likely to result in the expenditure by State, local, or tribal governments, in the aggregate, or by the private sector, of $100 million or more annually (adjusted for inflation with base year of 1995). This portion of the preamble summarizes the FAA's analysis of the economic impact of the final rule.

Department of Transportation Order DOT 2100.5 prescribes policies and procedures for simplification, analysis, and review of regulations. If the expected cost impact is so minimal that a proposed or final rule does not warrant a full evaluation, this order permits that a statement to that effect and the basis for it be included in the preamble. Such a determination has been made for this final rule.

The reasoning for this determination follows: In a cost survey of industry conducted by the FAA, six of the seven replying firms reported no incremental cost from the provisions included in this final rule. One firm reported "little or no cost." The reason for little or no incremental cost is that these firms (six out of seven) reported usage of Advisory Circular AC 20–136A, "Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning," as guidance for complying with lightning requirements. Consequently, these firms are already in compliance with the final rule as it represents a codification of current practices. For manufacturers of Part 25 airplanes, cost changes should be minimal in any case, as the changes in the final rule are clarifying only. Moreover, four of the seven respondents reported at least some expected benefits from the provisions included in this final rule (See "Benefits" section below). We did receive comments that one requirement would raise costs. The FAA removed this requirement. The FAA therefore has determined that this final rule will have minimal costs with positive net benefits and does not warrant a full regulatory evaluation. Our analysis follows below.

The FAA has also determined that this final rule is not a "significant regulatory action" as defined in section 3(f) of Executive Order 12866, and is not "significant" as defined in DOT's Regulatory Policies and Procedures.

Total Costs and Benefits of This Rulemaking

As noted above, there are little or no expected costs for this final rule and some benefits. The benefits result in increased safety. The benefits therefore justify the costs. See details in the separate costs and benefits sections below.

Who is potentially affected by this rulemaking?

Manufacturers of parts 23, 25, 27, and 29 aircraft and manufacturers of electrical and electronic systems for those aircraft.

Assumptions and Sources of Information

- We use a ten-year period of analysis, 2009–2018.
- Data on costs of compliance and benefits of this rule were obtained from an FAA survey of industry.
- Firms are defined as "small" or "large" using Small Business Administration (SBA) size standards (U.S. SBA. Table of Small Business Size Standards Matched to North American Industry Classification System Codes, July 21, 2006).

Costs of This Rulemaking

On February 9, 2009, we sent a detailed cost survey to six manufacturers of Parts 23, 25, 27, and 29 aircraft and three manufacturers of electrical and electronic systems for those aircraft. In addition to several detailed cost questions, the survey also asked one question about potential benefits from the provisions included in this final rule. We received four responses to this initial survey. On March 17, 2009, we resurveyed the five non-respondents and, after additional follow-up requests, received three additional replies, although the last response came only on August 8, 2009. The seven responses we received were from manufacturers ranging from a small aircraft manufacturer (less than 1,500 employees) to the largest U.S. aircraft manufacturer. Despite repeated requests, we received no survey responses from the two part 27/part 29 manufacturers to whom we sent questionnaires, one never replying and the other eventually replying that management had "decided not to respond."

We did receive comments that the proposed paragraph (b)(1) would create costs. The FAA agrees and removes this requirement.

As shown in the table below, the respondents indicated little or no cost from the provisions included in this final rule.

SUMMARY OF COST SURVEY RESULTS

Firm	Type	Products certified to	Costs	Benefits
A	Airplane manufacturer	Part 23	No cost	"The certification process will be less ambiguous and slightly streamlined by writing some of the AC 20–136A requirements directly into the regulations."
B	Airplane manufacturer	Parts 23 & 25	No cost	"The commonality between parts and the ability to use the same substantiation across product lines is a very large benefit."
C	Airplane manufacturer	Parts 23 & 25	No cost	"Harmonization of Part 23 and Part 25 rules will simplify our certification process as our internal procedures benefit from any similarity of the two Parts."
D	Airplane manufacturer	Part 25	Little or no cost	No response to benefits question.
E	Electrical/electronic systems mfr	Parts 23 & 25	No cost	"NA."
F	Electrical/electronic systems mfr	Parts 23, 25, 27, & 29	No cost	"None."
G	Electrical/electronic systems mfr	Parts 23, 25, 27, & 29	No cost	

Benefits of This Rulemaking

As supported by the responses to the benefits question, shown in the table, the final rule and the standardization of rule language across parts will reduce firm costs by simplifying and clarifying the certification process.

Regulatory Flexibility Determination

The Regulatory Flexibility Act of 1980 (Pub. L. 96–354) (RFA) establishes "as a principle of regulatory issuance that agencies shall endeavor, consistent with the objectives of the rule and of applicable statutes, to fit regulatory and informational requirements to the scale of the businesses, organizations, and governmental jurisdictions subject to regulation. To achieve this principle, agencies are required to solicit and consider flexible regulatory proposals and to explain the rationale for their actions to assure that such proposals are given serious consideration." The RFA covers a wide-range of small entities, including small businesses, not-for-profit organizations, and small governmental jurisdictions.

Agencies must perform a review to determine whether a rule will have a significant economic impact on a substantial number of small entities. If the agency determines that it will, the agency must prepare a regulatory flexibility analysis as described in the RFA. However, if an agency determines that a rule is not expected to have a significant economic impact on a substantial number of small entities, section 605(b) of the RFA provides that the head of the agency may so certify and a regulatory flexibility analysis is not required. The certification must include a statement providing the factual basis for this determination, and the reasoning should be clear.

As noted above, in a cost survey of industry, the FAA found little or no expected costs from this final rule. The reason for this finding is that all but one respondent reported usage of AC 20–136A, "Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning," as guidance for complying with system lightning requirements. We agree that the requirements of proposed paragraph (b)(1) would have an unintended effect and raise costs. The FAA removed this paragraph. Accordingly, this final rule represents current practice and imposes no more requirements than those previously voluntarily adopted by industry by following AC 20–136A. Consequently, these firms are already in compliance with the final rule as it represents a codification of AC 20–136A. For manufacturers of Part 25 airplanes, cost changes should, in any case, be minimal as the changes in the final rule are clarifying only. Therefore as the FAA Administrator, I certify that this rule will not have a significant economic impact on a substantial number of small entities.

International Trade Impact Assessment

The Trade Agreements Act of 1979 (Pub. L. 96–39) prohibits Federal agencies from establishing any standards or engaging in related activities that create unnecessary obstacles to the foreign commerce of the United States. Legitimate domestic objectives, such as safety, are not considered unnecessary obstacles. The statute also requires consideration of international standards and, where appropriate, that they be the basis for U.S. standards. The FAA has reviewed the potential effect of this final rule and determined that the standards adopted by this rulemaking are based on internationally harmonized recommended regulations and compliance means and, thus, they do not create an obstacle to foreign commerce. For this reason, the FAA has determined that the standards adopted by this final rulemaking will comply with the Trade Agreements Act.

Unfunded Mandates Assessment

Title II of the Unfunded Mandates Reform Act of 1995 (Pub. L. 104–4) requires each Federal agency to prepare a written statement assessing the effects of any Federal mandate in a proposed or final agency rule that may result in an expenditure of $100 million or more (adjusted annually for inflation with the base year 1995) in any one year by State, local, and tribal governments, in the aggregate, or by the private sector; such a mandate is deemed to be a "significant regulatory action." The FAA currently uses an inflation-adjusted value of $140.8 million.

This final rule does not contain such a mandate. The requirements of Title II do not apply.

Executive Order 13132, Federalism

The FAA has analyzed this final rule under the principles and criteria of Executive Order 13132, Federalism. We determined that this action will not have a substantial direct effect on the States, or the relationship between the Federal Government and the States, or on the distribution of power and responsibilities among the various levels of government, and, therefore, does not have federalism implications.

Regulations Affecting Intrastate Aviation in Alaska

Section 1205 of the FAA Reauthorization Act of 1996 (110 Stat. 3213) requires the FAA, when modifying its regulations in a manner affecting intrastate aviation in Alaska, to consider the extent to which Alaska is not served by transportation modes other than aviation, and to establish appropriate regulatory distinctions. In the NPRM, we requested comments on whether the proposed rule should apply differently to intrastate operations in Alaska. We did not receive any comments, and we have determined, based on the administrative record of this rulemaking, that there is no need to make any regulatory distinctions applicable to intrastate aviation in Alaska.

Environmental Analysis

FAA Order 1050.1E identifies FAA actions that are categorically excluded from preparation of an environmental assessment or environmental impact statement under the National Environmental Policy Act in the absence of extraordinary circumstances. The FAA has determined this rulemaking action qualifies for the categorical exclusion identified in paragraph 308 (c)(1) and involves no extraordinary circumstances.

Regulations That Significantly Affect Energy Supply, Distribution, or Use

The FAA analyzed this final rule under Executive Order 13211, Actions Concerning Regulations that Significantly Affect Energy Supply, Distribution, or Use (May 18, 2001). We have determined that it is not a "significant energy action" under the executive order and it is not likely to have a significant adverse effect on the supply, distribution, or use of energy.

Availability of Rulemaking Documents

You can get an electronic copy of rulemaking documents using the Internet by—

1. Searching the Federal eRulemaking Portal (*http://www.regulations.gov*);
2. Visiting the FAA's Regulations and Policies Web page at *http://www.faa.gov/regulations_policies/*or
3. Accessing the Government Printing Office's Web page at *http://www.gpoaccess.gov/fr/index.html.*

You can also get a copy by sending a request to the Federal Aviation Administration, Office of Rulemaking, ARM–1, 800 Independence Avenue SW., Washington, DC 20591, or by calling (202) 267–9680. Make sure to identify the amendment or docket number of this rulemaking.

Anyone is able to search the electronic form of all comments received into any of our dockets by the name of the individual submitting the comment (or signing the comment, if submitted on behalf of an association, business, labor union, etc.). You may review DOT's complete Privacy Act statement in the **Federal Register** published on April 11, 2000 (Volume 65, Number 70; Pages 19477–78) or you may visit *http://DocketsInfo.dot.gov.*

Small Business Regulatory Enforcement Fairness Act

The Small Business Regulatory Enforcement Fairness Act (SBREFA) of 1996 requires FAA to comply with small entity requests for information or advice about compliance with statutes and regulations within its jurisdiction. If you are a small entity and you have a question regarding this document, you may contact your local FAA official, or the person listed under the **FOR FURTHER INFORMATION CONTACT** heading at the beginning of the preamble. You can find out more about SBREFA on the Internet at *http://www.faa.gov/regulations_policies/rulemaking/sbre_act/.*

List of Subjects

14 CFR Part 23

Aircraft, Aviation safety, Signs and symbols.

14 CFR Part 25

Aircraft, Aviation safety, Reporting and recordkeeping requirements.

14 CFR Part 27

Aircraft, Aviation safety.

14 CFR Part 29

Aircraft, Aviation safety.

The Amendments

In consideration of the foregoing, the Federal Aviation Administration amends parts 23, 25, 27, and 29 of Title 14, Code of Federal Regulations, as follows:

PART 23—AIRWORTHINESS STANDARDS: NORMAL, UTILITY, ACROBATIC, AND COMMUTER CATEGORY AIRPLANES

■ 1. The authority citation for part 23 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701, 44702, 44704.

■ 2. Add new § 23.1306 to read as follows:

§ 23.1306 Electrical and electronic system lightning protection.

(a) Each electrical and electronic system that performs a function, for which failure would prevent the continued safe flight and landing of the airplane, must be designed and installed so that—

(1) The function is not adversely affected during and after the time the airplane is exposed to lightning; and

(2) The system automatically recovers normal operation of that function in a timely manner after the airplane is exposed to lightning.

(b) For airplanes approved for instrument flight rules operation, each electrical and electronic system that performs a function, for which failure would reduce the capability of the airplane or the ability of the flightcrew to respond to an adverse operating condition, must be designed and installed so that the function recovers normal operation in a timely manner after the airplane is exposed to lightning.

PART 25—AIRWORTHINESS STANDARDS: TRANSPORT CATEGORY AIRPLANES

■ 3. The authority citation for part 25 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701, 44702, 44704.

■ 4. Revise § 25.1316 to read as follows:

§ 25.1316 Electrical and electronic system lightning protection.

(a) Each electrical and electronic system that performs a function, for which failure would prevent the continued safe flight and landing of the airplane, must be designed and installed so that—

(1) The function is not adversely affected during and after the time the airplane is exposed to lightning; and

(2) The system automatically recovers normal operation of that function in a timely manner after the airplane is exposed to lightning.

(b) Each electrical and electronic system that performs a function, for which failure would reduce the capability of the airplane or the ability of the flightcrew to respond to an adverse operating condition, must be designed and installed so that the function recovers normal operation in a timely manner after the airplane is exposed to lightning.

PART 27—AIRWORTHINESS STANDARDS: NORMAL CATEGORY ROTORCRAFT

■ 5. The authority citation for part 27 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701, 44702, 44704.

■ 6. Amend § 27.610 by revising paragraph (d)(4) to read as follows:

§ 27.610 Lightning and static electricity protection.

* * * * *

(d) * * *

(4) Reduce to an acceptable level the effects of static electricity on the functioning of essential electrical and electronic equipment.

§ 27.1309 [Amended]

■ 7. Amend § 27.1309 by removing paragraph (d).

■ 8. Add a new § 27.1316 to read as follows:

§ 27.1316 Electrical and electronic system lightning protection.

(a) Each electrical and electronic system that performs a function, for which failure would prevent the continued safe flight and landing of the rotorcraft, must be designed and installed so that—

(1) The function is not adversely affected during and after the time the rotorcraft is exposed to lightning; and

(2) The system automatically recovers normal operation of that function in a timely manner after the rotorcraft is exposed to lightning.

(b) For rotorcraft approved for instrument flight rules operation, each electrical and electronic system that performs a function, for which failure would reduce the capability of the rotorcraft or the ability of the flightcrew to respond to an adverse operating condition, must be designed and installed so that the function recovers normal operation in a timely manner after the rotorcraft is exposed to lightning.

■ 9. Add paragraph X. to Appendix B of part 27 to read as follows:

Appendix B to Part 27—Airworthiness Criteria for Helicopter Instrument Flight

* * * * *

X. Electrical and electronic system lightning protection. For regulations concerning lightning protection for electrical and electronic systems, see § 27.1316.

PART 29—AIRWORTHINESS STANDARDS: TRANSPORT CATEGORY ROTORCRAFT

■ 10. The authority citation for part 29 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701, 44702, 44704.

■ 11. Amend § 29.610 by revising paragraph (d)(4) to read as follows:

§ 29.610 Lightning and static electricity protection.

(d) * * *

(4) Reduce to an acceptable level the effects of static electricity on the functioning of essential electrical and electronic equipment.

§ 29.1309 [Amended]

■ 12. Amend § 29.1309 by removing paragraph (h).

■ 13. Add new § 29.1316 to read as follows:

§ 29.1316 Electrical and electronic system lightning protection.

(a) Each electrical and electronic system that performs a function, for which failure would prevent the continued safe flight and landing of the rotorcraft, must be designed and installed so that—

(1) The function is not adversely affected during and after the time the rotorcraft is exposed to lightning; and

(2) The system automatically recovers normal operation of that function in a timely manner after the rotorcraft is exposed to lightning.

(b) Each electrical and electronic system that performs a function, for which failure would reduce the capability of the rotorcraft or the ability of the flightcrew to respond to an adverse operating condition, must be designed and installed so that the function recovers normal operation in a timely manner after the rotorcraft is exposed to lightning.

Issued in Washington, DC, on May 20, 2011.

J. Randolph Babbitt,

Administrator.

[FR Doc. 2011–14142 Filed 6–7–11; 8:45 am]

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DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

14 CFR Part 95

[Docket No. 30787; Amdt. No. 494]

IFR Altitudes; Miscellaneous Amendments

AGENCY: Federal Aviation Administration (FAA), DOT.

ACTION: Final rule.

SUMMARY: This amendment adopts miscellaneous amendments to the required IFR (instrument flight rules) altitudes and changeover points for certain Federal airways, jet routes, or direct routes for which a minimum or maximum en route authorized IFR altitude is prescribed. This regulatory action is needed because of changes occurring in the National Airspace System. These changes are designed to provide for the safe and efficient use of the navigable airspace under instrument conditions in the affected areas.

DATES: *Effective Date:* 0901 UTC, June 30, 2011.

FOR FURTHER INFORMATION CONTACT: Harry Hodges, Flight Procedure Standards Branch (AMCAFS–420), Flight Technologies and Programs Division, Flight Standards Service, Federal Aviation Administration, Mike Monroney Aeronautical Center, 6500 South MacArthur Blvd. Oklahoma City, OK 73169 (Mail Address: P.O. Box 25082 Oklahoma City, OK 73125) *telephone:* (405) 954–4164.

SUPPLEMENTARY INFORMATION: This amendment to part 95 of the Federal Aviation Regulations (14 CFR part 95) amends, suspends, or revokes IFR altitudes governing the operation of all aircraft in flight over a specified route or any portion of that route, as well as the changeover points (COPs) for Federal airways, jet routes, or direct routes as prescribed in part 95.

The Rule

The specified IFR altitudes, when used in conjunction with the prescribed changeover points for those routes, ensure navigation aid coverage that is adequate for safe flight operations and free of frequency interference. The reasons and circumstances that create the need for this amendment involve matters of flight safety and operational efficiency in the National Airspace System, are related to published aeronautical charts that are essential to the user, and provide for the safe and efficient use of the navigable airspace. In addition, those various reasons or circumstances require making this amendment effective before the next scheduled charting and publication date of the flight information to assure its timely availability to the user. The effective date of this amendment reflects those considerations. In view of the close and immediate relationship between these regulatory changes and safety in air commerce, I find that notice and public procedure before adopting this amendment are impracticable and contrary to the public interest and that good cause exists for making the amendment effective in less than 30 days.

Conclusion

The FAA has determined that this regulation only involves an established body of technical regulations for which frequent and routine amendments are necessary to keep them operationally current. It, therefore—(1) Is not a “significant regulatory action” under Executive Order 12866; (2) is not a “significant rule” under DOT Regulatory Policies and Procedures (44 FR 11034; February 26, 1979); and (3) does not warrant preparation of a regulatory evaluation as the anticipated impact is so minimal. For the same reason, the FAA certifies that this amendment will not have a significant economic impact on a substantial number of small entities under the criteria of the Regulatory Flexibility Act.

List of Subjects in 14 CFR Part 95

Airspace, Navigation (air).

Issued in Washington, DC, on May 27, 2011.

John M. Allen,

Director, Flight Standards Service.

Adoption of the Amendment

Accordingly, pursuant to the authority delegated to me by the Administrator, part 95 of the Federal Aviation Regulations (14 CFR part 95) is amended as follows effective at 0901 UTC, June 30, 2011.

PART 95 [AMENDED]

■ 1. The authority citation for part 95 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40103, 40106, 40113, 40114, 40120, 44502, 44514, 44719, 44721.

■ 2. Part 95 is amended to read as follows: