



AEROSPACE RECOMMENDED PRACTICE

ARP5412™

REV. C

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Superseding ARP5412B

Aircraft Lightning Environment and Related Test Waveforms

RATIONALE

This revision ensures consistency between SAE Aerospace Recommended Practices (ARPs) regarding Zone 3 direct attachment, updates the waveform 3 figure, corrects a value in Table 10, corrects a typo regarding lightning components in Table 3, updates Figure 1, and makes editorial changes.

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1. SCOPE

The environment and test waveforms defined in this SAE Aerospace Recommended Practice (ARP) account for the best lightning data and analysis currently available. The quantified environment and levels herein represent the minimum currently required by certifying authorities, which is consistent with the approach applied in related lightning documents.

Lightning, like other weather phenomenon, is probabilistic in nature. Levels and waveforms vary considerably from one flash to the next. Within this document, standardized voltage and current waveforms have been derived to represent the lightning environment external to an aircraft. These standardized waveforms are used to assess the effects of lightning on aircraft. The standardized external current waveforms have, in turn, been used to derive standardized transient voltage and current test waveforms that can be expected to appear on cable bundles and at equipment interfaces within an aircraft. When deriving these latter internal induced test waveforms, considerations such as testability and important waveform characteristics that can demonstrate lightning design effectiveness have been taken into account.

The parameters of the standardized waveforms, both external and derived internal induced 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. These standardized waveforms are thus referred to as idealized standard lightning environment waveforms, idealized standard waveforms, or just idealized waveforms within this document. The waveforms associated with the external environment are termed the idealized standard external lightning environment. The waveforms associated with the internal induced environment are termed the idealized standard induced transient waveforms.

In every case, more severe versions of each of the individual characteristics of the idealized standard external lightning environment waveforms have been recorded in natural lightning flashes. The more severe individual characteristics of the idealized standard external lightning environment waveforms have never been recorded together within a single lightning flash. Therefore, the parameters combined in the idealized standard lightning environment waveforms provided in this document represent a very severe environment.

The waveforms provided in this ARP 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 (refer to ARP5414) and test methods (refer to ARP5416) and applicable FAA and EASA advisory and interpretive material.

1.1 Purpose

This ARP is one of the set of three documents covering the whole spectrum of aircraft interaction with lightning. The purpose of this ARP 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 information on aircraft lightning zoning (refer to ARP5414) and aircraft lightning testing (refer to ARP5416). The relationship between the environment, zoning, and testing, along with the associated document number, is depicted in Figure 1.

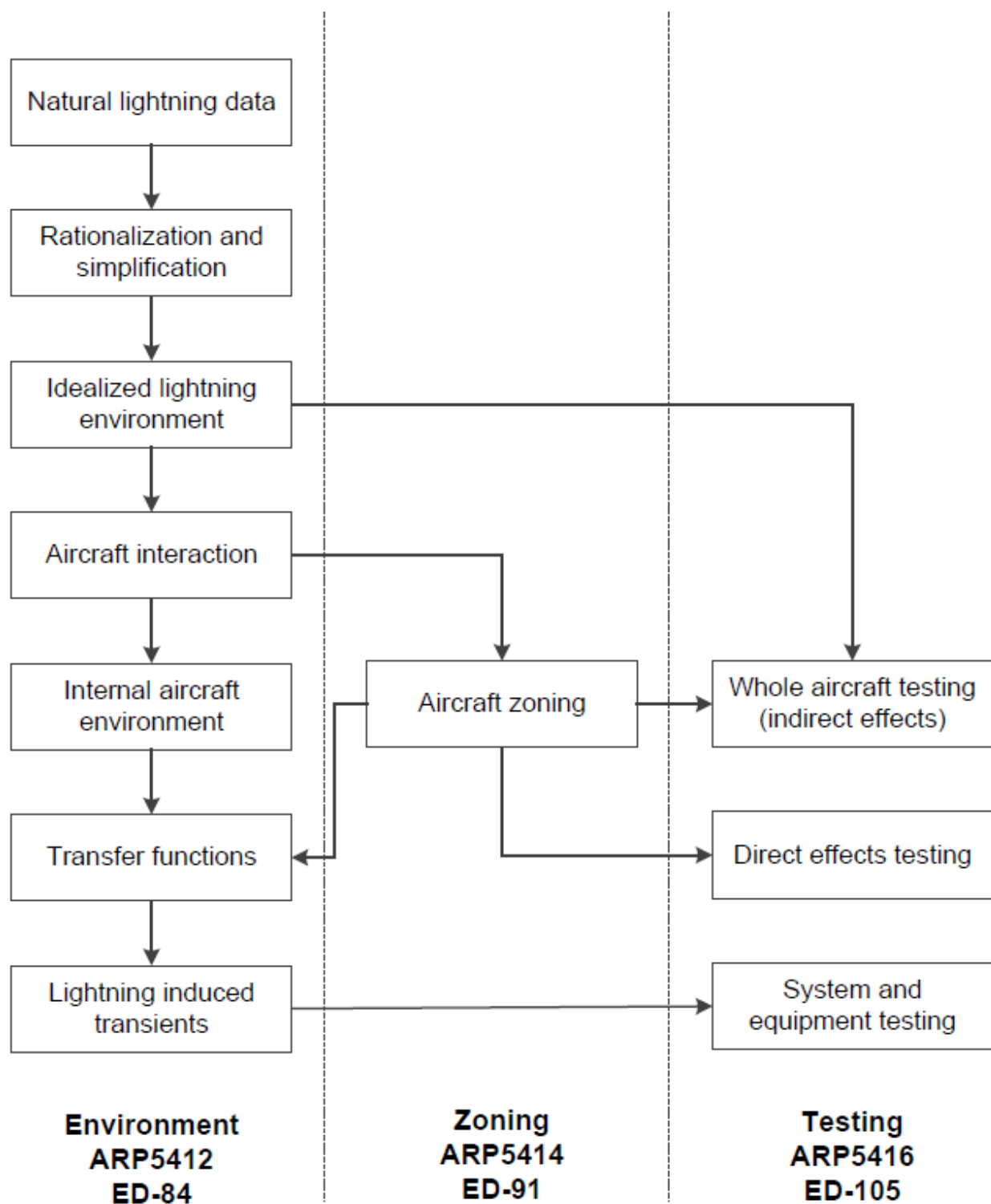


Figure 1 - Relationship between aircraft environment, zoning, and testing

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE and EUROCAE publications shall apply.

The latest issue of other applicable documents as of the publish date of this document are specified below. The applicable issue of these publications may be but may not necessarily be the latest issue. The user should determine the applicable issue, considering the nature of the referenced documents and the context of the guidance.

In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

ARP5414 Aircraft Lightning Zoning (technically equivalent to ED-91)

ARP5415 User's Manual for Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning (technically equivalent to ED-158)

ARP5416 Aircraft Lightning Test Methods (technically equivalent to ED-105)

2.1.2 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

AC 20-136B Aircraft Electrical and Electronic System Lightning Protection

2.1.3 EUROCAE Publications

Available from EUROCAE Secretariat, 9-23 Rue Paul Lafargue, 93200 Saint-Denis, France, Tel: +33 1 40 92 79 30, <https://www.eurocae.net/>.

ED-14 Environmental Conditions and Test Procedures for Airborne Equipment (technically equivalent to RTCA DO-160)

ED-91 Aircraft Lightning Zoning (technically equivalent to ARP5414)

2.1.4 Other Publications

Cianos, N. and Pierce, E.T. (1972). *A ground-lightning environment for engineering usage*. Stanford Research Institute.

Malan, D.J. and Schonland, B.F.J. (1951). The distribution of electricity in thunderclouds. *Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences*, 209(1097), 158-177.

Rakov, V.A. and Uman, M.A. (2003). *Lightning: Physics and effects*. Cambridge University Press.

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

ARP5577 Aircraft Lightning Direct Effects Certification (technically equivalent to ED-113)

ARP6205 Transport Airplane Fuel System Lightning Protection (technically equivalent to ED-303)

2.2.2 U.S. Regulations

Available from United States Government Publishing Office, 732 North Capitol Street, NW, Washington, DC 20401, Tel: 202-512-1800, www.gpo.gov.

Federal Aviation Regulations 14 CFR Parts 23.867, 23.954, 23.1306, 23.1309(a)(1), 23.2335, 23.2515, 25.581, 25.954, 25.981, 25.1316, 27.610, 27.954, 27.1316, 29.610, 29.954, 29.1316, and 33.28(d).

2.2.3 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

AC 20-53C Protection of Airplane Fuel Systems Against Fuel Vapor Ignition Due to Lightning

AC 20-155A SAE Documents to Support Aircraft Lightning Protection Certification

AC 21-16G RTCA Document DO-160 versions D, E, F, and G, Environmental Conditions and Test Procedures for Airborne Equipment

AC 23.1309-1E System Safety Analysis and Assessment for Part 23 Airplanes

AC 25.1309-1A System Design and Analysis

AC 25.954-1 Transport Airplane Fuel System Lightning Protection

AC 27-1B Certification of Normal Category Rotorcraft

AC 29-2C Certification of Transport Category Rotorcraft

2.2.4 EUROCAE Publications

Available from EUROCAE Secretariat, 9-23 Rue Paul Lafargue, 93200 Saint-Denis, France, Tel: +33 1 40 92 79 30, <https://www.eurocae.net/>.

ED-84 Aircraft Lightning Environment and Related Test Waveforms (technically equivalent to this ARP)

ED-105 Aircraft Lightning Test Methods (technically equivalent to ARP5416)

ED-113 Aircraft Lightning Direct Effects Certification (technically equivalent to ARP5577)

ED-158 User's Manual for Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning (technically equivalent to ARP5415)

ED-303 User's Guide for Lightning Protection of Fuel Tank Structures and Systems (technically equivalent to ARP6205)

2.2.5 European Union Regulations

Available from European Union Aviation Safety Agency, Konrad-Adenauer-Ufer 3, D-50668 Cologne, Germany, Tel: +49 221 8999 000, www.easa.europa.eu.

Certification Specifications 23.867, 23.954, 23.1309(e), 23.1316, 23.2335, 23.2515, 25.581, 25.899, 25.954, 23.1309(a)(1), 27.610, 27.954, 27.1309(d), 27.1316, 29.610, 29.954, 29.1309(h), 29.1316, and E.170.

2.2.6 EASA Publications

Available from European Union Aviation Safety Agency, Konrad-Adenauer-Ufer 3, D-50668 Cologne, Germany, Tel: +49 221 8999 000, www.easa.europa.eu.

AMC 20-136A Aircraft Electrical and Electronic System Lightning Protection

AMC 25.1309 System Design and Analysis

AMC 25.899 Electrical Bonding and Protection Against Lightning and Static Electricity

AMC 25.581 Lightning Protection

2.2.7 RTCA Publications

Available from RTCA, Inc., 1150 18th Street, NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

DO-160G Environmental Conditions and Test Procedures for Airborne Equipment (technically equivalent to ED-14)

2.2.8 Other Publications

Mazur, V. and Moreau, J.P. (1992). Aircraft-triggered lightning: Process following strike ignition that affect aircraft. *Journal of Aircraft*, 29(4), 575-580.

Moreau, J.P. and Alliot, J.C. (1986, June 24-26). *Analysis of the first milliseconds of aircraft lightning attachments* [Conference presentation]. 11th International Aerospace and Ground Conference on Lightning and Static Electricity, Dayton, OH, USA.

Pitts, F.L., Perala, R.A., Rudolph, T.H., and Dee, L. (1987). *New methods and results for quantification of lightning-aircraft electrostatics* (Report No. 2737). NASA.

Reaser, J.S., Serrano, A.V., Walko, L.C., and Burket, H.D. (1987). Analysis of correlated electromagnetic fields and current pulses during airborne lightning attachments. *Electromagnetics*, 7(3-4), 509-539.

Uman, M.A. (2001). *The lightning discharge*. Academic Press.

2.3 Definitions, Abbreviations, and Acronyms

2.3.1 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 (A²s).

ACTUAL TRANSIENT LEVEL: The level of transient voltage and/or current that appears at the equipment interfaces as a result of the external lightning environment.

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 x s).

CONTINUING CURRENT: A low-level, long-duration lightning current that occurs between or after the high current strokes.

DART LEADER: A leader that 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.

EQUIPMENT TRANSIENT DESIGN LEVEL: The peak amplitude of transients to which the equipment is qualified.

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.

FULL WIDTH HALF MAXIMUM: The time interval between 50% amplitudes of a pulse.

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.

INTERMEDIATE CURRENT: A low-level current of a few kiloamperes, following a return stroke, that persists for several milliseconds.

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 (refer to ARP5414).

LINE REPLACEABLE UNIT: An element of a system that may be removed and replaced by a line maintenance crew while the aircraft is in operational status

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). 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 a time-dependent function. Given the time-dependent function, $i(t)$, the peak rate-of-rise may be expressed as:

$$\text{Peak rate-of-rise} = \text{maximum of } di(t)/dt \quad (\text{Eq. 1})$$

RECOIL STREAMER: Miniature return strokes associated with intercloud or intracloud lightning thought to be a consequence of the leader encountering a pocket of opposite charge.

SHIELD: A conductor that 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-resistance path between equipment so connected.

STEPPED LEADER: The intermittent low-luminosity, low current precursor of a lightning return stroke accompanied by an intense electric field and usually associated with a negative first return stroke.

STRUCTURAL IR VOLTAGE: 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.

SUBSEQUENT STROKE: 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.

SWEPT CHANNEL: The lightning channel relative to the aircraft that 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.

TRANSIENT CONTROL LEVEL: The maximum allowable level of transients appearing at the equipment interfaces as a result of the defined external lightning environment.

UPSET: See System Functional Upset.

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.

2.3.2 Abbreviations

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

2.3.3 Acronyms

AC	advisory circular
AMJ	advisory material joint
ATL	actual transient level
CFC	carbon fiber composite
DLTW	downward lightning measured on towers
ETDL	equipment transient design level
FWHM	full width half maximum
HC	high current
HV	high voltage
IR	current x resistance
LRU	line replaceable unit

MB	multiple burst
MS	multiple stroke
N/A	not applicable
RTLT	rocket-triggered lightning
TCL	transient control level
ULTW	upward lightning measured on towers

3. BACKGROUND

This standard defines the idealized standard lightning environment waveforms appropriate for aircraft lightning protection. It gives a brief discussion of the mechanisms for transforming the external lightning environment into an internal environment and the resulting transients on cable bundles and at equipment interfaces.

4. NATURAL LIGHTNING DESCRIPTION

4.1 General

Lightning flashes usually originate from charge centers in a cloud, particularly the cumulonimbus cloud, although lightning can occur in other atmospheric conditions. The charges in clouds are produced by complex processes of freezing and melting and by collisions and splintering resulting from movements of raindrops and ice crystals. 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 2 depicted by Malan and Schonland (1951), who extensively studied thunderstorms in South Africa.

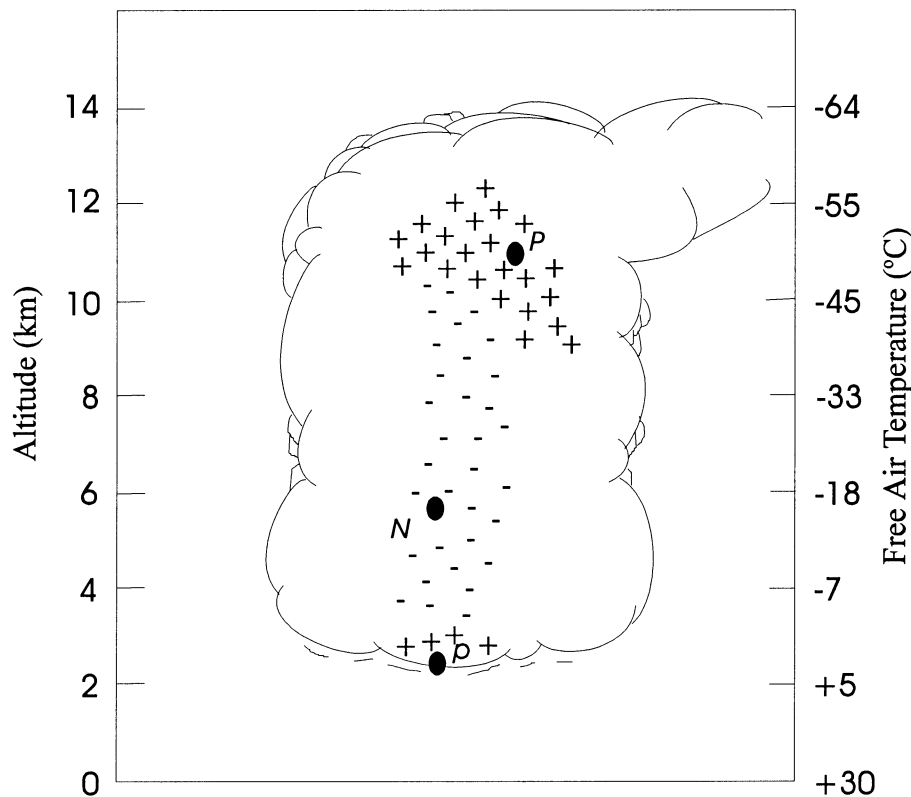


Figure 2 - Generalized diagram showing distribution of electrical charge in typical cumulonimbus cloud



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

- a. Flashes from cloud-to-ground and from ground-to-cloud of either polarity.
- b. Flashes between regions of opposite polarity in different clouds (intercloud discharges).
- c. Flashes between regions of opposite polarity within a cloud (intracloud discharges).

Over 50% of all flashes are intracloud discharges.

4.2 Cloud-to-Ground Flashes

4.2.1 The Discharge Process

A negative flash lowers negative charge to earth, while a positive flash lowers positive 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 (first return strokes and subsequent return 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 900 kV/m for water droplets or 500 kV/m for ice crystals. For a negative discharge to earth, the column advances in zigzag steps (hence the name stepped leader), each about 50-m long and separated by pauses of 20 to 100 μ s.

Return stroke modeling indicates that there is a decrease in the value of the return stroke current as altitude increases (see 5.2 and 6.3.9). 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 aircraft that forms part of the lightning path.

4.2.2 The Negative Flash to Ground

An example of the return stroke current in a severe negative flash is sketched in Figure 3A. The number of strokes in a negative flash is usually between one and 11, the mean value being three; the maximum number observed is up to 26. The total duration is between about 20 ms and 1 second, with a mean value of 0.2 second. The time interval between the strokes is typically about 60 ms. There is some correlation among these parameters; the flashes with the most strokes tend also to be the longest duration. The rise time of the first stroke is about 2 μ s, with a decay time (to half the peak amplitude) of 40 μ s. Subsequent strokes in the flash tend to have a higher rate-of-rise with lower peak amplitudes than the initial stroke and 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 kiloamperes persisting for several milliseconds, known as an “intermediate current component” as shown in Figure 3A. After some strokes, a “continuing current” of 100 to 400 A flows with a duration of 100 to 800 ms, so 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 subsequent stroke can occur the continuing current must cease, as illustrated after stroke five in Figure 3A.

4.2.3 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% of positive flashes to ground. Positive flashes are usually initiated by upward moving leaders and more commonly occur over mountains than over flat terrain. Positive flashes usually consist of one stroke only. Positive strokes have slower rise times with higher peak current and charge transfer than negative strokes. The duration of a positive stroke is longer than a single stroke of a negative flash but usually shorter than a complete negative flash. The positive stroke may be followed by a continuous current.

An example of the current in a positive flash is shown in Figure 3B. Typically, the rise time of a positive flash is 20 μ s and the total duration is 0.1 second. 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.

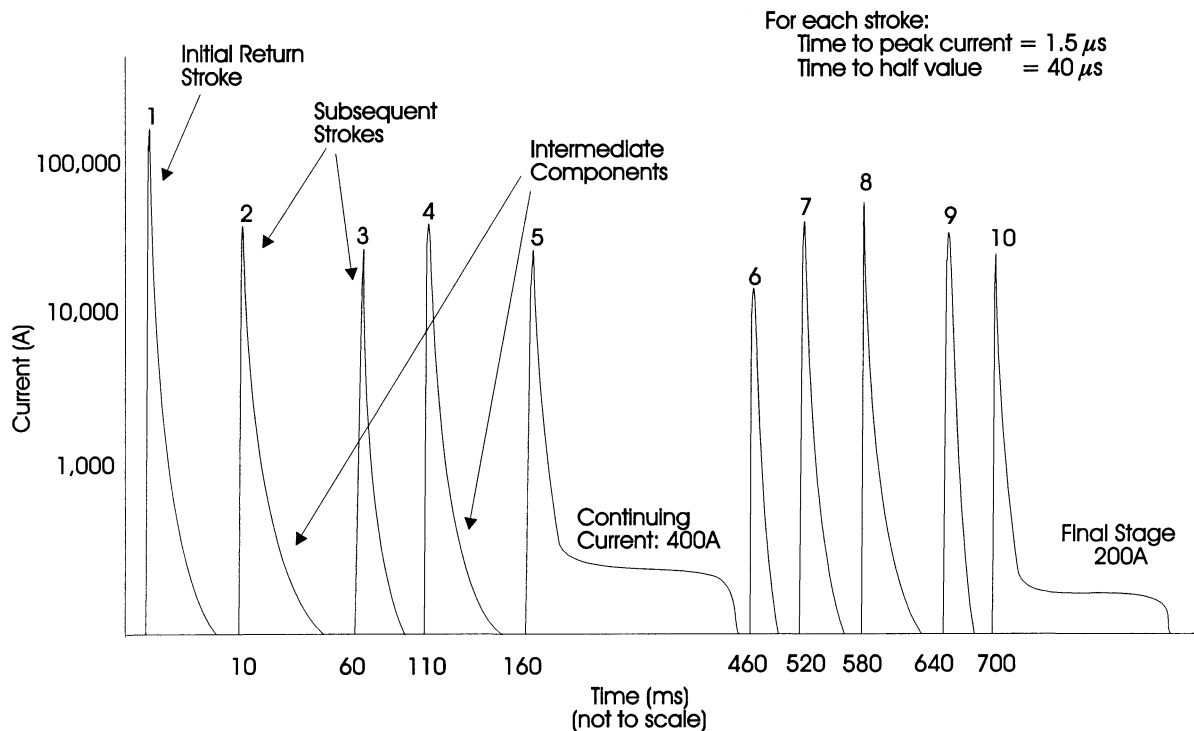


Figure 3A - Model of a severe negative lightning flash current waveform

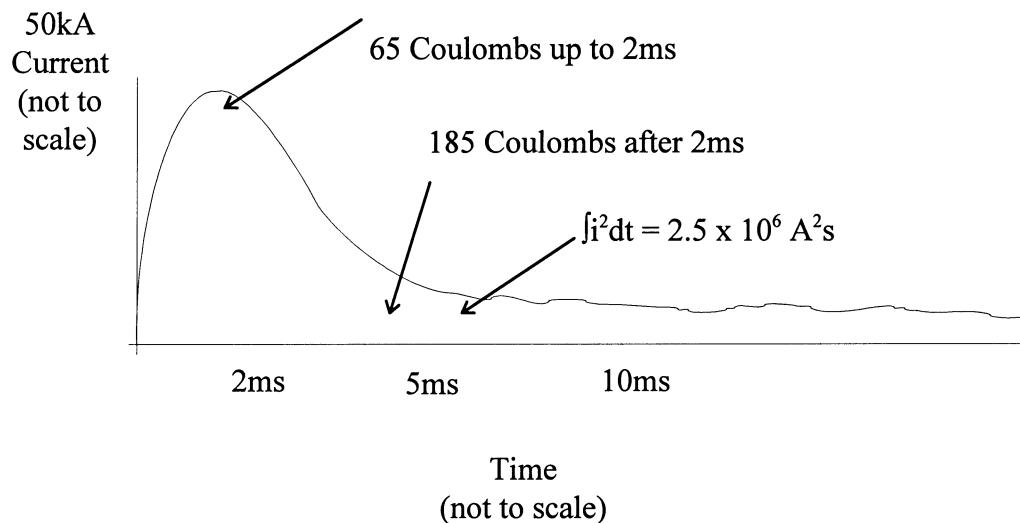


Figure 3B - Model of a moderate positive lightning flash current waveform

4.3 Intercloud and Intracloud 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 the U.S. 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 0.4 μ s) 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 intracloud flashes. Similar pulses due to charge redistribution in a cloud have been observed between return strokes in flashes to ground.

For intracloud discharges, recoil streamers of up to 60 kA peak current have been recorded but are more typically 20 to 30 kA (see 4.4). A typical intracloud lightning flash is presented in Figure 4. The pulses occurring during the initial attachment phase might also occur in negative cloud-to-ground flashes.

4.4 Flash Parameters

Most of the available statistical data are from cloud-to-ground and ground-to-cloud lightning flashes measured on instrumented towers or by artificially (rocket) triggered lightning experiments. The relevant parameter values for negative flashes are presented in Table 1 and for positive flashes in Table 2. Measured lightning data from which the parameter values were derived are provided in Appendix A. The tables include statistical values for the lightning currents and all related parameters of interest for the definition of the idealized standard external lightning 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 intercloud and intracloud lightning flashes (see 4.3). 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 (see 4.3). Similar pulses with fast rates of change have also been reported in cloud-to-ground flashes, which transport 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 3000 kV/m, with rates-of-rise of up to 1000 kV/m/ μ s.

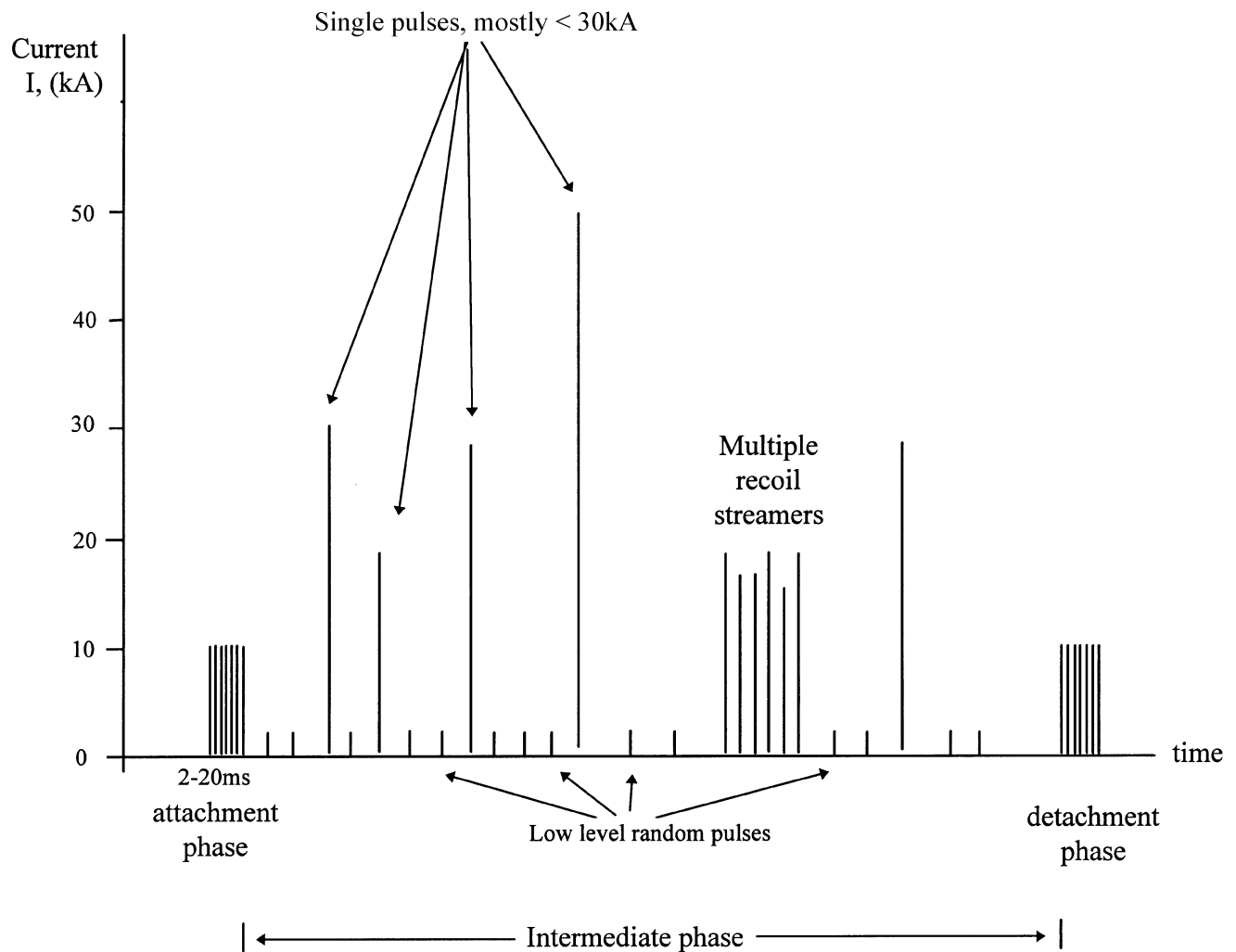


Figure 4 - Typical intracloud lightning flash to an aircraft

Table 1 - Parameters for negative lightning flashes measured at ground

Parameters	Unit	Lightning Parameters 95%	Lightning Parameters 50%	Lightning Parameters 5%
Negative Flashes:				
Number of strokes		1-2	3-4	12
Time intervals between strokes	ms	12	47	180
Flash duration	ms	37	240	910
Charge in flash	C	1.4	16	98
Negative First Stroke:				
Peak current	kA	14	30	80
Peak rate-of-rise	kA/μs	5.5	12	32
Front duration ⁽¹⁾	μs	1.8	5.5	18
Stroke duration ⁽²⁾	μs	30	75	200
Total charge ⁽³⁾	C	1.1	5.2	24
Impulse charge	C	1.1	4.5	20
Action integral	A ² s	6 x 10 ³	5.5 x 10 ⁴	5.5 x 10 ⁵
Negative Subsequent Strokes:				
Peak current	kA	4.6	11	30
Peak rate-of-rise	kA/μs	20	37	200
Front duration ⁽¹⁾	μs	0.20	0.90	3.2
Stroke duration ⁽²⁾	μs	8.3	31	110
Total charge ⁽³⁾	C	0.30	1.6	12
Impulse charge	C	0.23	0.73	3.6
Action integral	A ² s	4.8 x 10 ²	3.1 x 10 ³	3.5 x 10 ⁴
Continuing Current ⁽⁴⁾ :				
Amplitude	A	48	140	427
Duration	s	0.077	0.16	0.344
Charge	C	8	26	85

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.

⁽¹⁾ 2 kA to peak.

⁽²⁾ 2 kA to half peak (50%) value on tail.

⁽³⁾ Includes continuing current.

⁽⁴⁾ The values for 5% and 95% are interpolated from data in Reference A.4.1 (Cianos and Pierce, 1972).

Table 2 - Parameters for positive lightning flashes measured at ground

Parameters	Unit	Lightning Parameters 95%	Lightning Parameters 50%	Lightning Parameters 5%
Positive Flashes:				
Flash duration	ms	14	85	500
Total charge ⁽³⁾	C	20	80	350
Positive Stroke:				
Peak current	kA	4.6	35	250
Peak rate-of-rise	kA/μs	0.2	2.4	32
Front duration ⁽¹⁾	μs	3.5	22	200
Stroke duration ⁽²⁾	μs	25	230	2000
Impulse charge	C	2	16	150
Action integral	A ² s	2.5×10^4	6.5×10^5	1.5×10^7

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.

⁽¹⁾ 2 kA to peak.

⁽²⁾ 2 kA to half peak (50%) value on tail.

⁽³⁾ Includes continuing current.

5. 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 an encounter with a naturally occurring leader that originated elsewhere.

5.1 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, etc.). 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 10000 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 1000 flight hours. Therefore, the average probability of a lightning strike to a given aircraft will likely fall somewhere between one strike per 1000 and 20000 flight hours.

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

5.2 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: intercloud, intracloud, and cloud-to-ground.

As noted, most intracloud 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 toward the vehicle.

5.3 Aircraft Triggered Lightning

Aircraft may also trigger lightning 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 (see 2.1.7) produced lightning strikes that were probably triggered by the aircraft.