OVERVIEW – LIGHTNING PROTECTION OF AIRCRAFT AND AVIONICS

ROB MAJKNER

TOPICS

- Environment
- Interaction with Aircraft
- Requirements
- Protection
- Design Verification

LIGHTNING ENVIRONMENT

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NATURAL LIGHTNING PHENOMENOLOGY

- **CLOUD ELECTRIFICATION AND LIGHTNING FORMATION**

  CHARGES PRODUCED BY COMPLEX PROCESSES OF FREEZING AND MELTING AND MOVEMENTS OF RAINDROPS/ICE CRYSTALS INVOLVING COLLISION AND SPLINTERING

- **LIGHTNING ORIGINATES FROM CHARGE CENTERS IN A CLOUD**

  CUMULONIMBUS PARTICULARLY BUT CAN OCCUR IN OTHER ATMOSPHERIC CONDITIONS

  VERTICAL EXTENSION OF 3 KM CAN PRODUCE LIGHTNING

- **INTRA-CLOUD FLASHES - BETWEEN REGIONS OF OPPOSITE POLARITY WITHIN A CLOUD**

- **INTER-CLOUD FLASHES - BETWEEN REGIONS OF OPPOSITE POLARITY IN DIFFERENT CLOUDS**

- **CLOUD-TO-GROUND FLASHES**

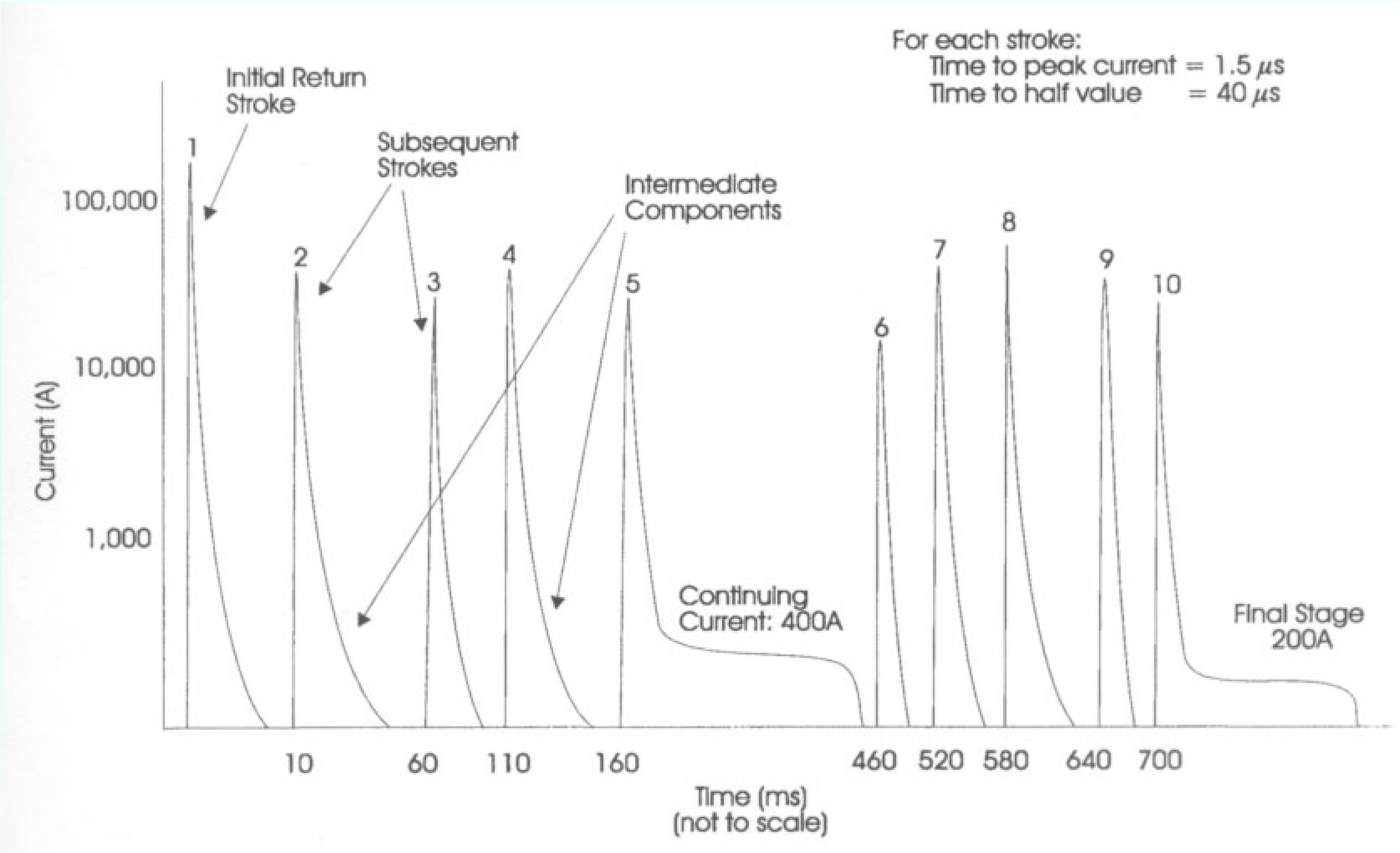
LIGHTNING CHARACTERISTICS (CLOUD-TO-GROUND)

- **HIGH ELECTRICAL FIELD - SEVERAL THOUSAND V/M**
- **PROTRUDING POINTS ON GROUND CONCENTRATE POTENTIAL GRADIENT**
  - EXCEED 30 KV/CM (BREAKDOWN POTENTIAL OF AIR)
  - CORONA DISCHARGE (ST. ELMO'S FIRE)
- **LEADER DEVELOPMENT - HIGH ELECTRIC FIELD (500-900 KV/M)**
  - **PILOT STREAMER - 30-50 M**
  - **STEPPED LEADER**
    - ZIG-ZAG PATTERN, ≈50 M LONG, ≈50 ms PAUSES
    - DIAMETER 1-10 M, CURRENT ≈100A
    - 1-2 X 10^5 M/S PROPOGATION
  - **STREAMERS**
    - ORIGINATE AT GROUND (≈VOLTAGE GRADIENT 5.5 KV/M)
    - TRAVEL UPWARD TO MEET APPROACHING LEADER

LIGHTNING CHARACTERISTICS (CLOUD-TO-GROUND)

- **INITIAL RETURN STROKE**
  - **LOW IMPEDANCE PATH FORMED**
  - **INTENSE FLASH NORMALLY ASSOCIATED WITH LIGHTNING STROKE**
  - **CURRENT LEVELS UPWARDS OF 200 KA**
- **SUBSEQUENT RETURN STROKES**
  - **ADDITIONAL CHARGE CENTERS TAPPED**
  - **CURRENT LEVELS UP TO 100 KA**
  - **UP TO 15 RESTRIKES IN LIGHTNING STRIKE**
- **LIGHTNING CHARACTERISTICS (INTRA/INTER CLOUD)**
  - **LESS SEVERE THAN CLOUD-TO-GROUND STRIKES**
  - **HIGHER RATE-OF-RISE**
  - **SHORT, NUMEROUS, FAST RATE-OF-RISE PULSES**

TYPICAL CLOUD-TO-GROUND FLASH NEGATIVE POLARITY



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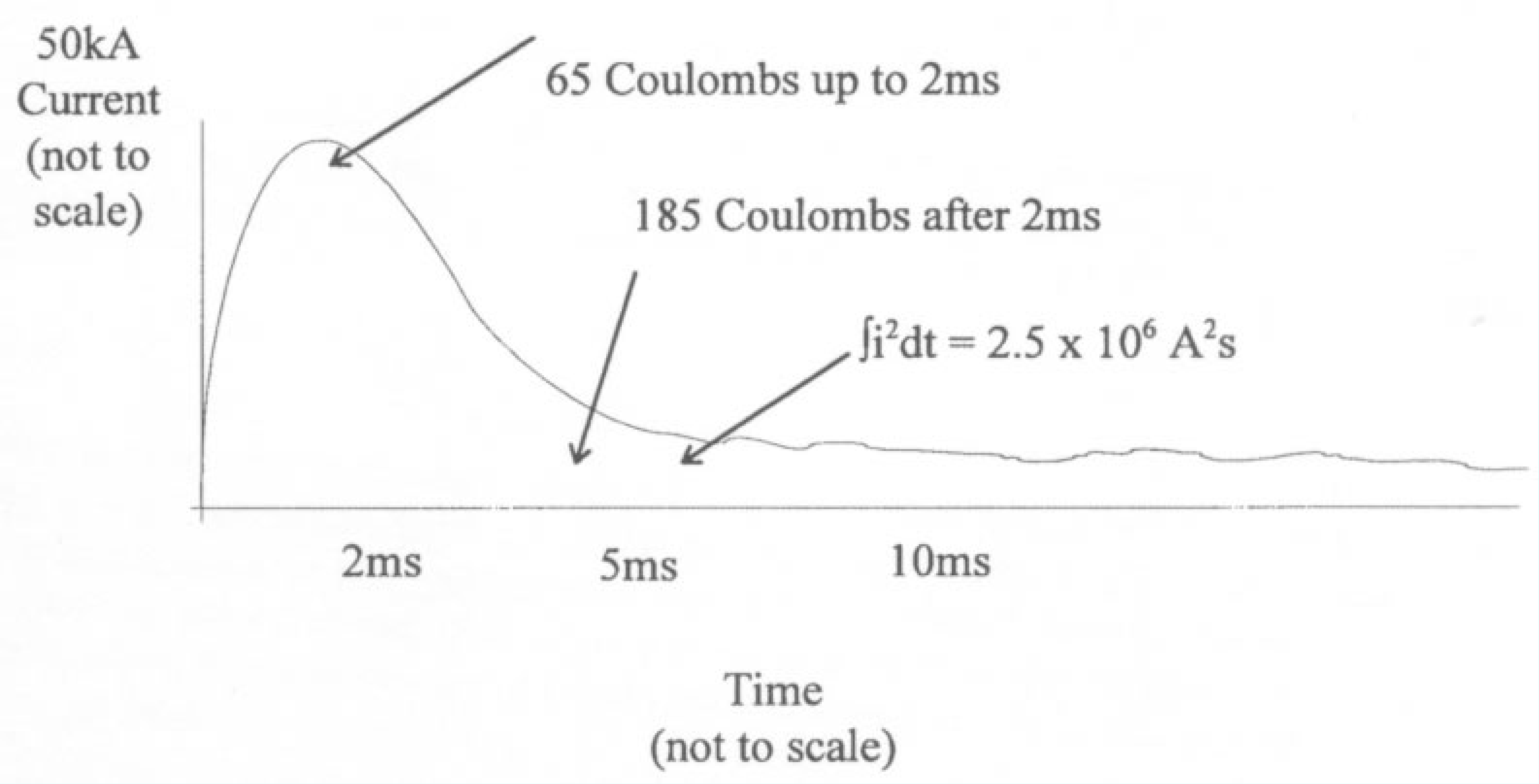
TYPICAL CLOUD-TO-GROUND FLASH POSITIVE POLARITY



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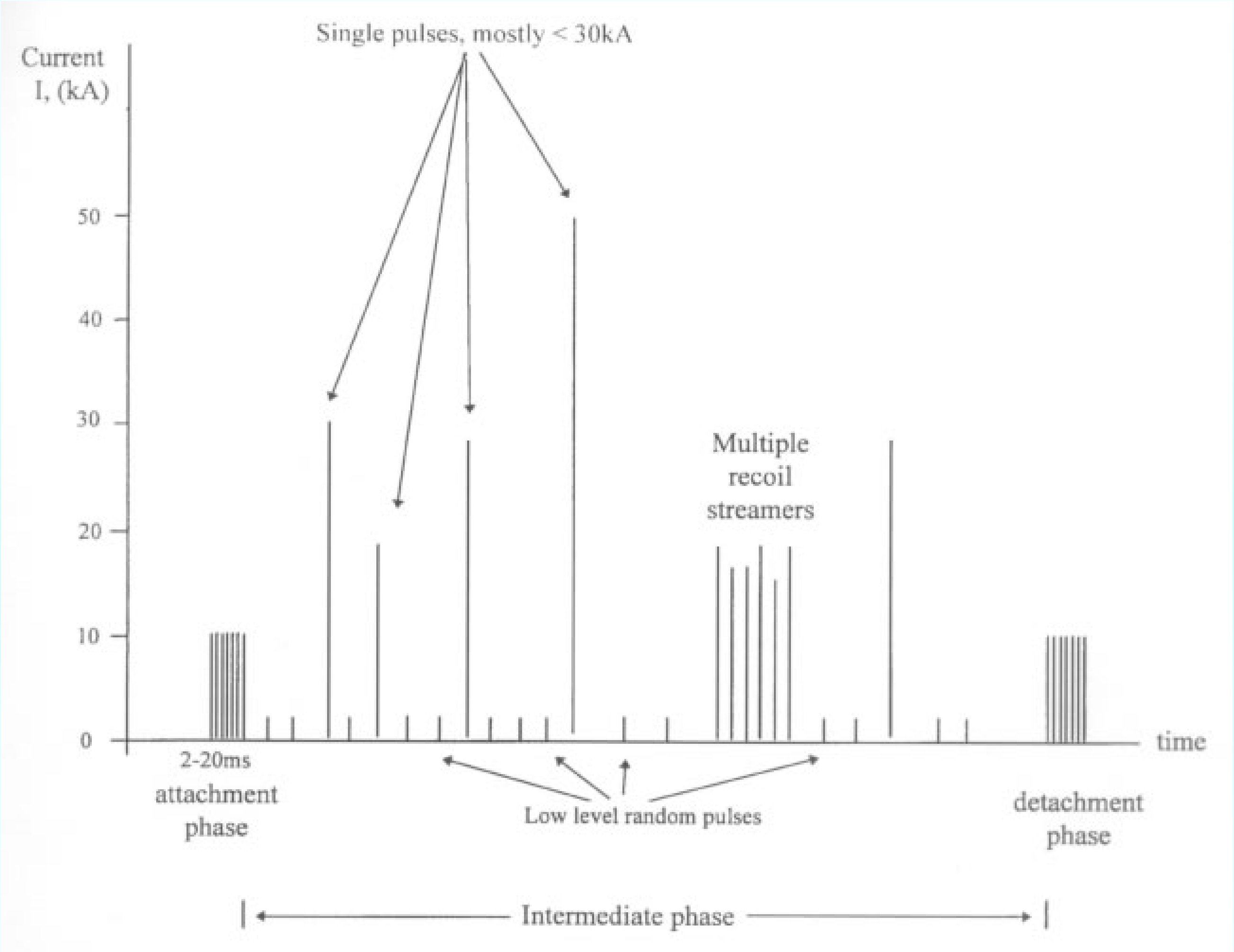
TYPICAL INTRA/INTER CLOUD FLASH



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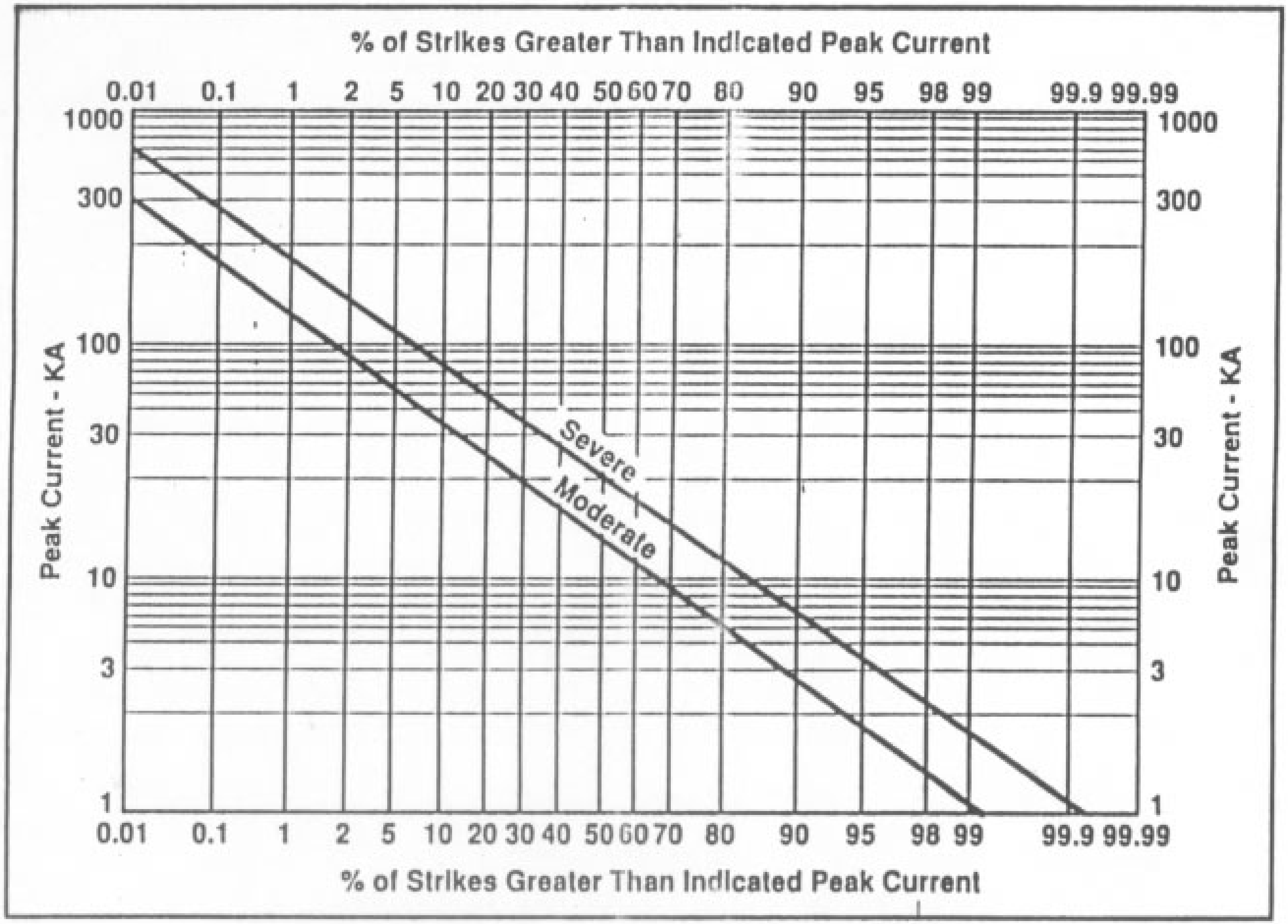
LIGHTNING THREAT LEVELS (CLOUD-TO-GROUND DATA)



Cianos and Pierce Lightning Probabilities Chart.

NEGATIVE VS. POSITIVE PROBABILITIES

The parameters of a negative, 2% probability (98% of all negative flashes will not exceed these parameters), flash, and a negative, 20% probability (80% of all negative flashes will not exceed these parameters), flash are:

Parameter	2% Probability Level	20% Probability Level
Peak Current	140 kA	50 kA
Impulse Charge	22 Coulombs	5 Coulombs
Total Charge	200 Coulombs	50 Coulombs
Action Integral	0.7×10^6 A^{2}s	0.08×10^6 A^{2}s

The parameters of a positive, 8% probability (92% of all positive flashes will not exceed these parameters), flash, and a positive, 38% probability (62% of all positive flashes will not exceed these parameters), flash are:

Parameter	8% Probability Level	38% Probability Level
Peak Current	200 kA	40 kA
Impulse Charge	120 Coulombs	24 Coulombs
Total Charge	350 Coulombs	100 Coulombs
Action Integral	11×10^6 A^{2}s	0.9×10^6 A^{2}s

LIGHTNING INTERACTION WITH AIRCRAFT

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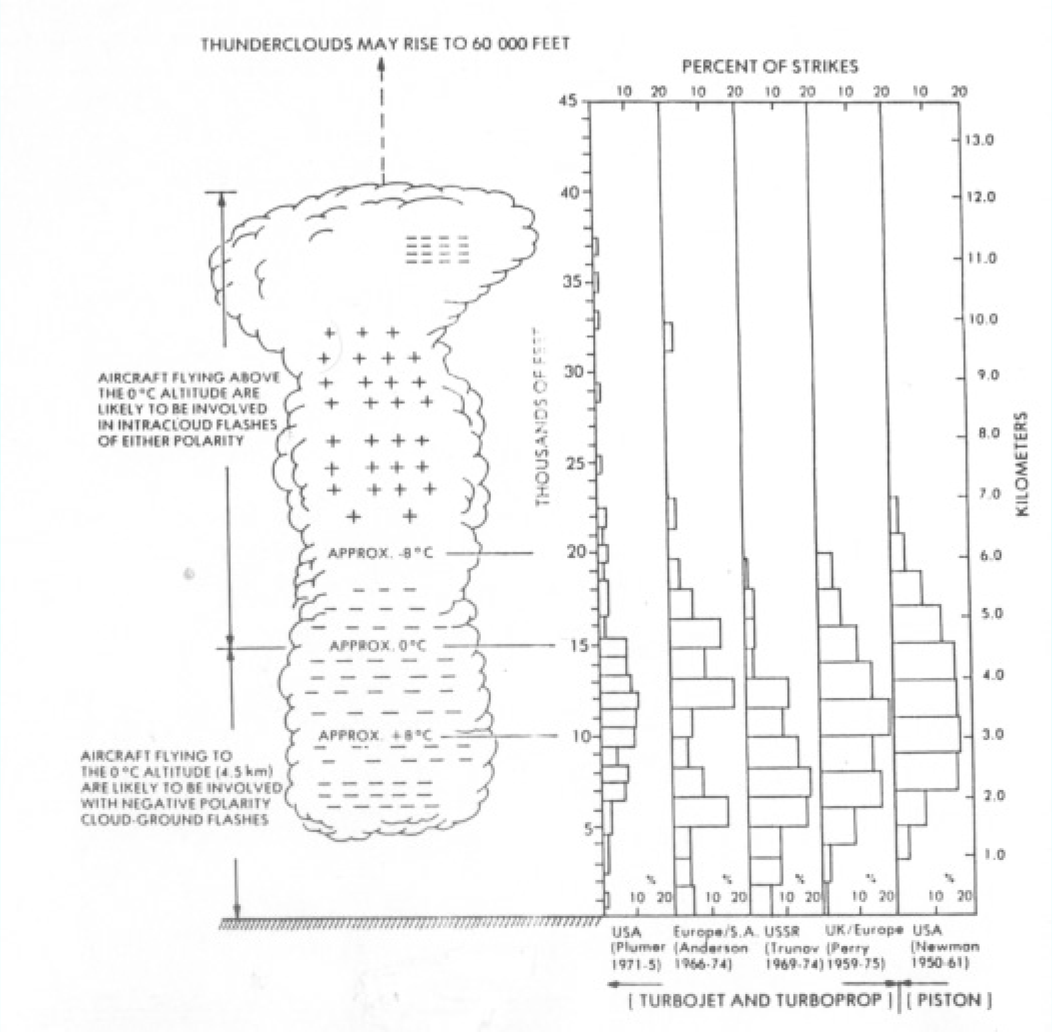
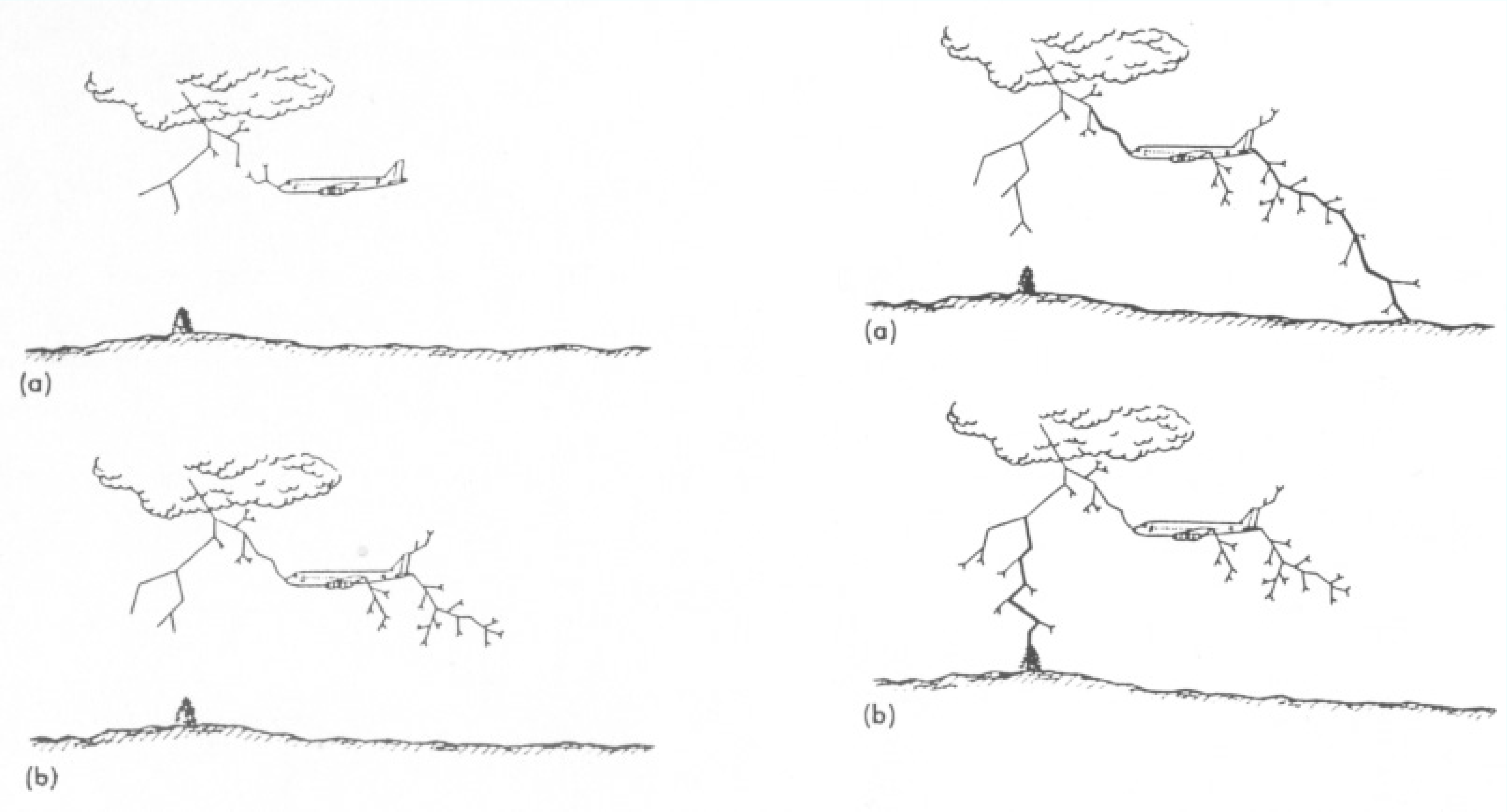
LIGHTNING INTERACTION WITH AIRCRAFT

- **STRIKE OCCURRENCE**
  - **TRANSPORT AIRCRAFT - ≈1 PER 2500 FLIGHT HOURS (≈ ONE STRIKE/PLANE/YEAR) (ARP5412 between 1 per 1000 and 1 per 20,000 FHs)**
  - **S-61N FLEET, NORWAY - ≈1 PER 15000 FLIGHT HOURS (13 STRIKES IN 8 YEARS)**
- **AIRCRAFT INTERCEPTED LIGHTNING - basically the wrong place at the wrong time**
- **AIRCRAFT TRIGGERED LIGHTNING - flashes would not have occurred at that place /time w/o the aircraft present**

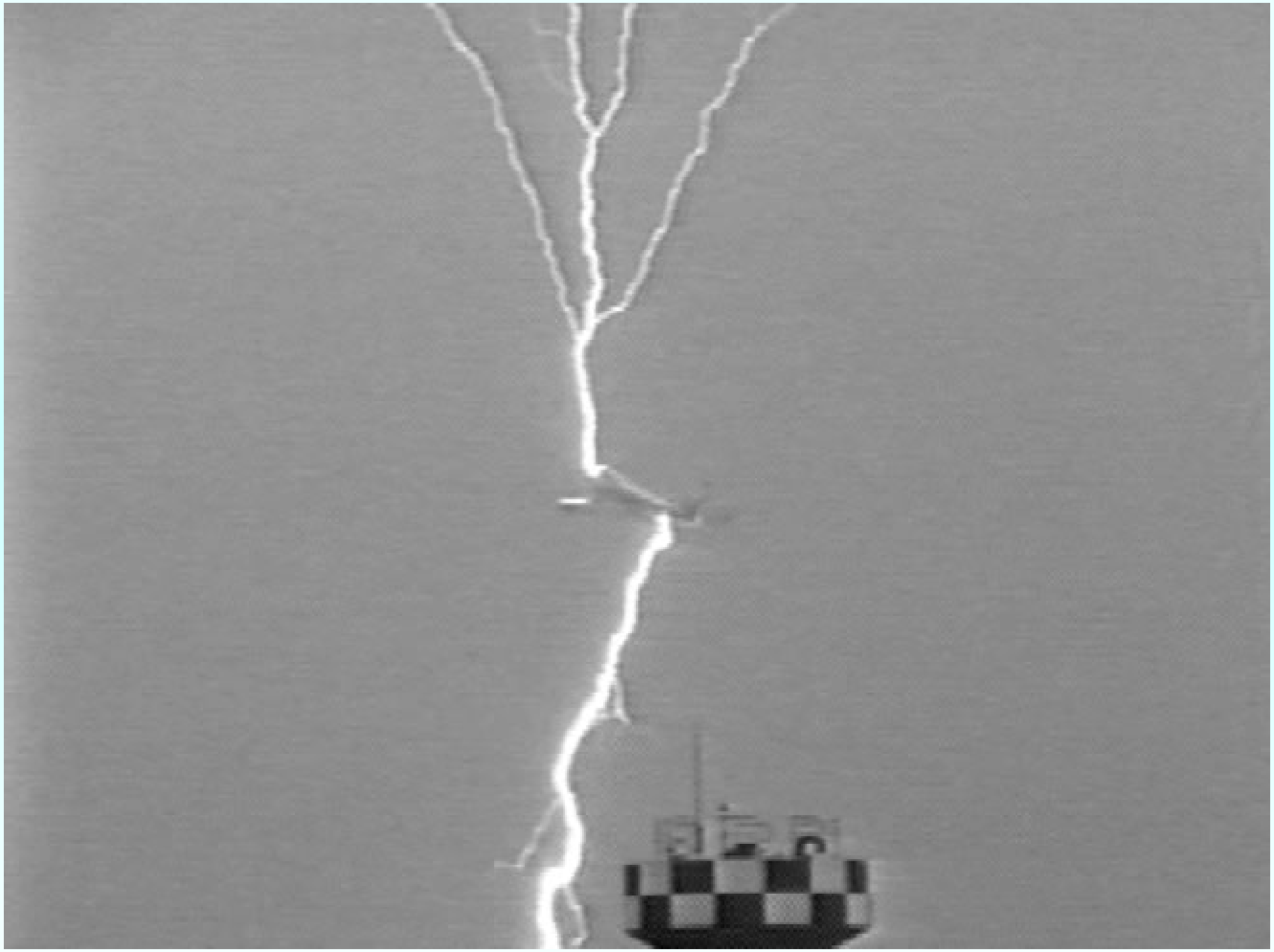
AIRCRAFT LIGHTNING STRIKE INCIDENTS VS ALTITUDE



LIGHTNING ATTACHMENT PROCESS



Plane struck by lightning in Japan,
Colorado Lightning Resource Center, Hodanish_files
(http://www.crh.noaa.gov/pub/ltg.shtml)



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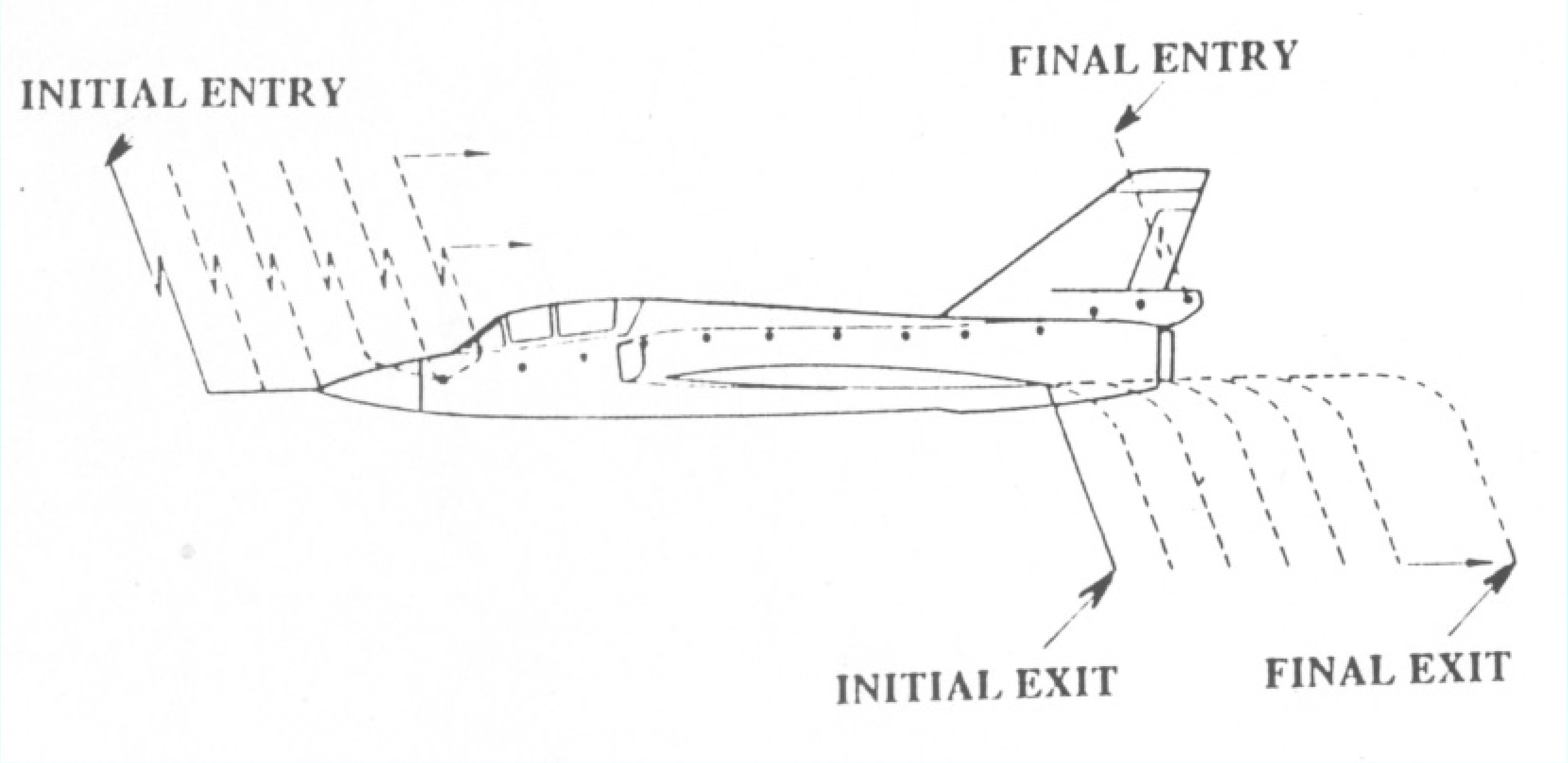
SWEPT STROKE EFFECT



LIGHTNING EFFECTS ON AIRCRAFT

- **DIRECT EFFECTS**
  - **PHYSICAL DAMAGE TO THE AIRCRAFT AND/OR EQUIPMENT DUE TO THE DIRECT ATTACHMENT OF THE LIGHTNING CHANNEL AND/OR CONDUCTION OF THE CURRENT**
    - **DIELECTRIC PUNCTURE**
    - **BLASTING, BENDING, MELTING, BURNING, PITTING AND/OR VAPORIZATION OF AIRCRAFT STRUCTURE OR COMPONENTS**
    - **MAGNETIC PINCHING**
    - **SHOCK WAVE AND OVERPRESSURE**
    - **EXPLOSION OF FUEL VAPORS**
    - **ELECTRIC SHOCK AND FLASHBLINDNESS**
    - **RESIDUAL MAGNETISM**
  - **ALSO INCLUDES DIRECTLY INJECTED VOLTAGES AND CURRENTS IN ASSOCIATED WIRING AND PLUMBING**

LIGHTNING EFFECTS ON AIRCRAFT

- **INDIRECT EFFECTS**
  - **ELECTRICAL TRANSIENTS INDUCED BY LIGHTNING IN ELECTRICAL/AVIONIC WIRING/SYSTEMS**
    - **APERTURE COUPLING - MAGNETIC FLUX GENERATED AS A RESULT OF THE RAPID CURRENT CHANGE**
    - **STRUCTURAL IR VOLTAGES - RESISTIVE VOLTAGE RISES ALONG STRUCTURE DUE TO LIGHTNING CURRENT FLOW THROUGH IT**
      - **PREVALENT IN COMPOSITE STRUCTURE**
      - **RESISTIVE JOINTS/HINGES**
  - **CANNOT DEPEND ON REDUNDANCY FOR PROTECTION**

LIGHTNING REQUIREMENTS

FAA CERTIFICATION REQUIREMENTS ROTORCRAFT

29.610 - Lightning protection. This is the basic airframe lightning protection regulation, which requires that the rotorcraft be able to sustain a lightning strike without catastrophic damage.

29.954 - Fuel System Lightning Protection. This regulation requires that fuel tanks and systems be free of ignition sources such as electrical arcs and sparks due to direct or swept lightning strikes and corona at exposed fuel vent outlets. Protection against indirect ignition sources such as fuel tank wiring is also applicable.

29.1309 - Equipment, Systems, and Installations. This regulation requires that flight-critical and essential systems, equipment, and functions be designed and installed to continue to perform their intended functions under any foreseeable operating condition, and requires, specifically, that the direct and indirect effects of lightning be considered in complying with this regulation.

FAA ADVISORY CIRCULARS

AC 20-53A - Lightning Protection of Fuel Systems. This AC presents a method of showing compliance with FAR 29.954 and includes a set of procedural steps including location of lightning strike zones, identification of potential lightning hazards, and verification of protection adequacy. This AC also defines the lightning environment for design and certification requirements. Because this is the only AC that pertains to lightning direct effects, the elements of compliance described in it are frequently followed in a general way for substantiation of other aspects of protection against direct lightning effects on skins, structures, and flight-control surfaces.

AC 20-136 - Protection of Flight Critical and Essential Electrical and Electronic Systems Against the Indirect Effects of Lightning. This AC provides a means of compliance with regulations (FAR 29.1309) and special conditions (xx-x) that address protection of avionics against lightning indirect effects, and a definition of the lightning environment for this purpose. It is the most recent AC issued by the FAA regarding lightning protection.

JAA REQUIREMENTS

The JARs basically parallel the FARs with the following exceptions:

29.610 - Lightning and Static Electricity Protection. Same as FAR 29.610 except added emphasis on protection against problems associated with static electricity, including danger of electrical shock, fuel vapor ignition, and interference with essential equipment.

29.1309(h) - Equipment, Systems, and Installations: Effects of Lightning. This section also imposes additional requirements and means of compliance above the requirements of FAR 29.1309. Specifically, an expansion of the requirements for flight critical and essential systems is provided as follows:

- (i) Each system whose failure to function properly would prevent the continued safe flight and landing of the rotorcraft should be designed and installed to ensure that it can perform its intended function during and after exposure to lightning; and
- (ii) Each system whose failure to function properly would reduce the capability of the rotorcraft or the ability of the flight crew to cope with adverse operating conditions should be designed and installed to ensure that it can perform its intended function after exposure to lightning.

ADDITIONAL DATA

- **FAA REPORT DOT/FAA/CT-89/22, LIGHTNING PROTECTION HANDBOOK**

- **SAE ARPs**
  - 5412 – Aircraft Lightning Environment and Related Test Waveforms
  - 5413 – Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning (5415 – Associated User's Manual)
  - 5414 – Aircraft Lightning Zoning
  - 5416 – Aircraft Lightning Test Methods (Draft)

MIL-STD-464A

5.4 Lightning. The system shall meet its operational performance requirements for both direct and indirect effects of lightning. Ordnance shall meet its operational performance requirements after experiencing a near strike in an exposed condition and a direct strike in a stored condition. Ordnance shall remain safe during and after experiencing a direct strike in an exposed condition. Figure 1 provides aspects of the lightning environment that are relevant for protection against direct effects. Figure 2 and Table 2A provide aspects of the lightning environment associated with a direct strike that are relevant for protecting the platform from indirect effects. Table 2B shall be used for the near lightning strike environment. Compliance shall be verified by system, subsystem, equipment, and component (such as structural coupons and radomes) level tests, analysis, or a combination thereof.

TABLE 2A. Lightning indirect effects waveform parameters

Current Component	Description	$i(t) = I_0 (\varepsilon^{-\alpha t} - \varepsilon^{-\beta t})$ t is time in seconds (s)		
		I_0 (Amperes)	α (s^{-1})	β (s^{-1})
A	Severe stroke	218,810	11,354	647,265
B	Intermediate current	11,300	700	2,000
C	Continuing current	400 for 0.5 s	Not applicable	Not applicable
D	Restrike	109,405	22,708	1,294,530
D/2	Multiple stroke	54,703	22,708	1,294,530
H	Multiple burst	10,572	187,191	19,105,100

TABLE 2B. Electromagnetic fields from near strike lightning (cloud-to-ground)

Magnetic field rate of change @ 10 meters	2.2×10^9 A/m/s
Electric field rate of change @ 10 meters	6.8×10^{11} V/m/s

ADS-37A PRF

<u>Lightning Protection</u>. The aircraft shall survive the direct and indirect effects of a 200,000 ampere lightning strike, which either directly attaches to the aircraft or occurs nearby. Specifically, the aircraft and its subsystems shall:

(a) prevent hazardous temporary upset and permanent damage to flight-critical electrical and electronic subsystems;

(b) prevent lightning ignition of fuel and ordnance;

(c) prevent catastrophic structural damage to the aircraft and associated flight-critical equipment, which would preclude safe return and landing; and

(d) prevent upset and permanent damage to mission-critical equipment, which would preclude safe return and landing.

The voltage and current waveforms of the lightning attachment are described in DO-160C and AC20-136.

CERTIFICATION REQUIREMENTS

A – CERTIFICATION STEPS (AIRCRAFT)

1- Define applicable FARs and ACs
2- Determine lightning strike zones
3- Establish the external lightning environment
4- Identify flight critical/essential airframe
5- Establish protection criteria
6- Design lightning protection
7- Verify protection adequacy

B – CERTIFICATION STEPS (FUEL SYSTEM)

1- Determine lightning strike zones
2- Establish the lightning environment
3- Identify possible ignition sources
4- Establish protection criteria
5- Verify protection adequacy

CERTIFICATION REQUIREMENTS

C – CERTIFICATION STEPS (ELECTRICAL AND AVIONICS EQUIPMENT)

1- Determine lightning strike zones

2- Establish the internal lightning environment

3- Identify flight critical/essential systems/equipment

4- Establish TCLs and ETDLs

5- Verify design adequacy

D – CERTIFICATION DATA

1- Lightning Certification Plan

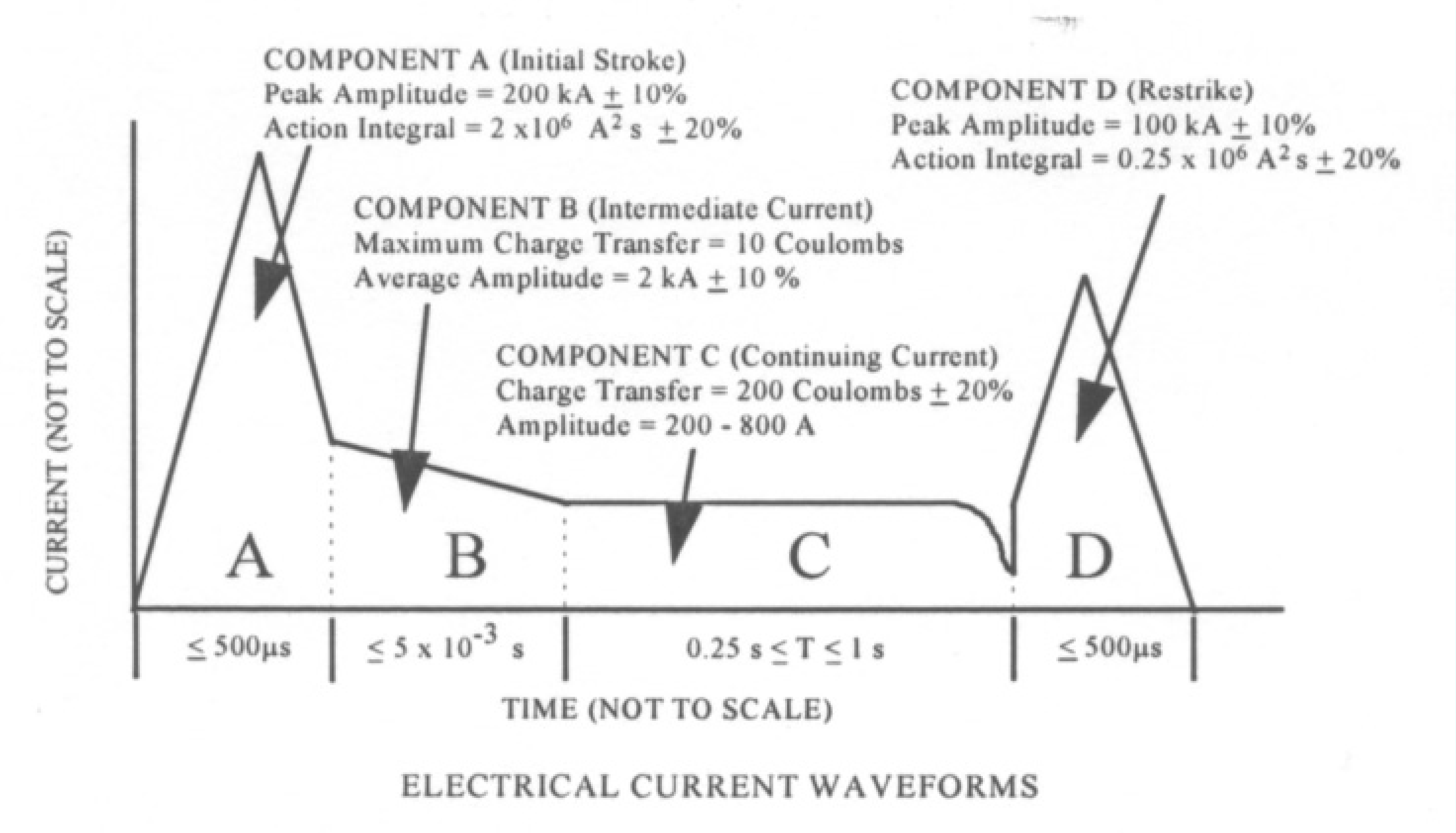
2- Lightning Verification Test Plans (Includes Vendor Tests)

3- Lightning Verification Test Reports (Includes Vendor Tests)

4- Lightning Certification Report

LIGHTNING PROTECTION

IDEALIZED CURRENT WAVEFORM



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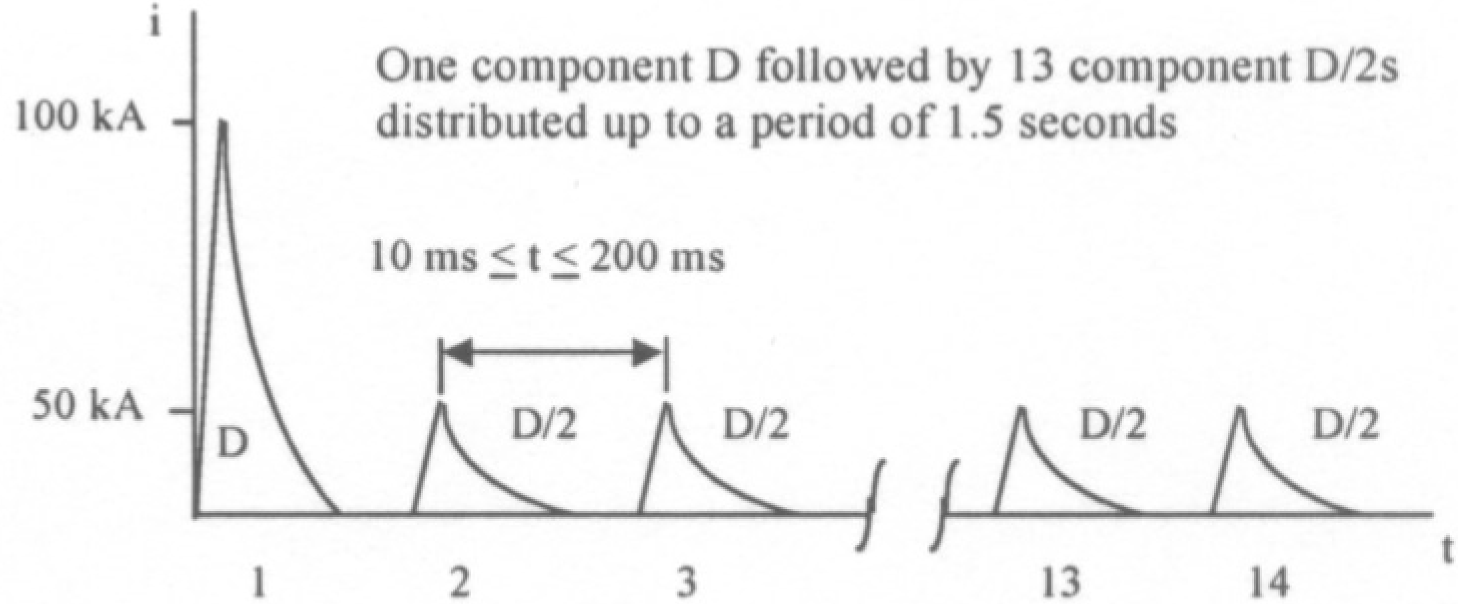
MULTIPLE STROKE WAVEFORM



Multiple Stroke Flash

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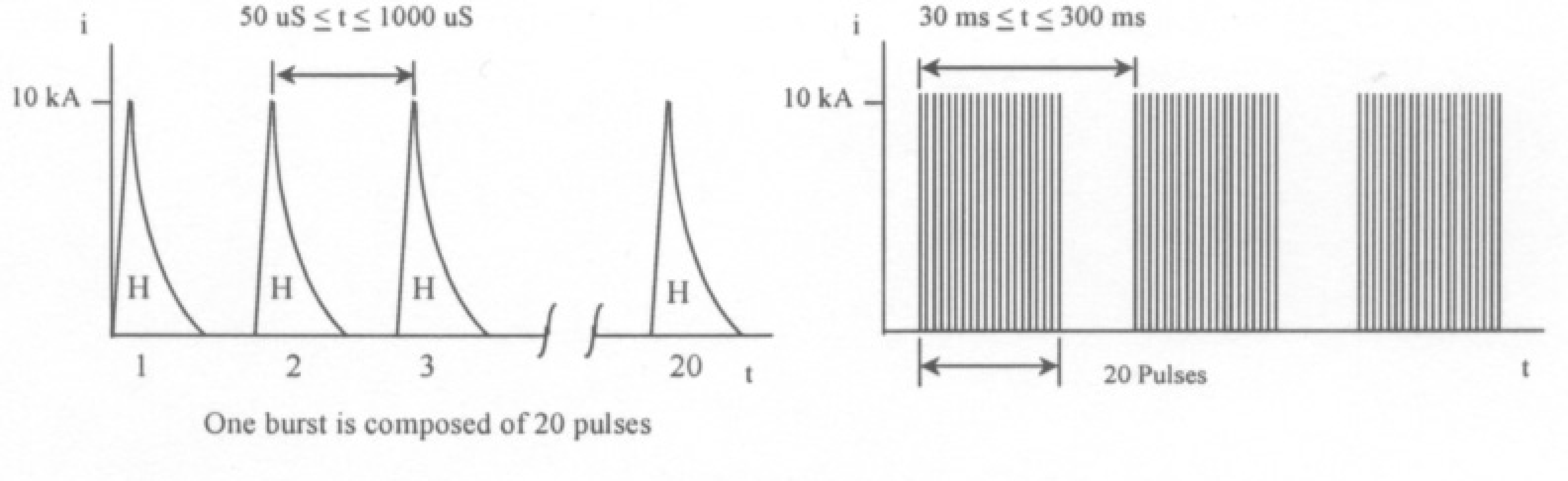
MULTIPLE BURST WAVEFORM



Multiple Burst Waveform

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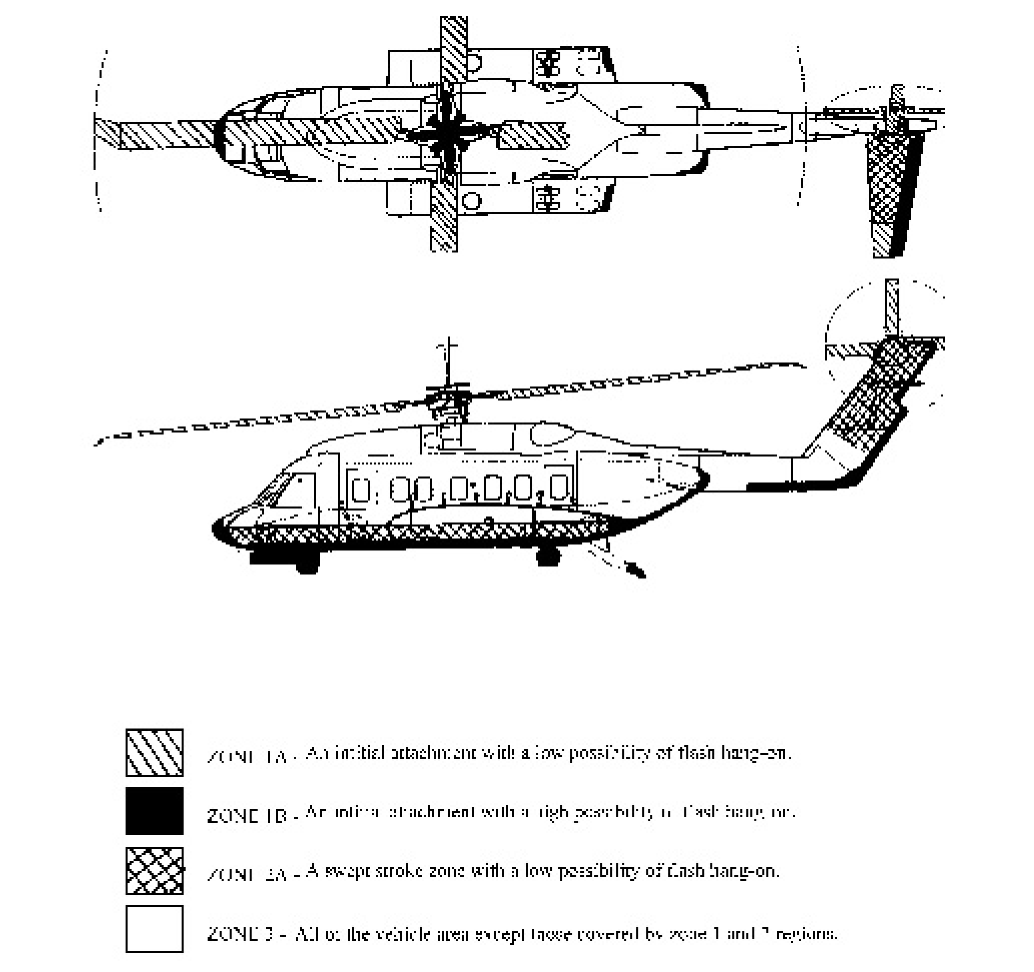
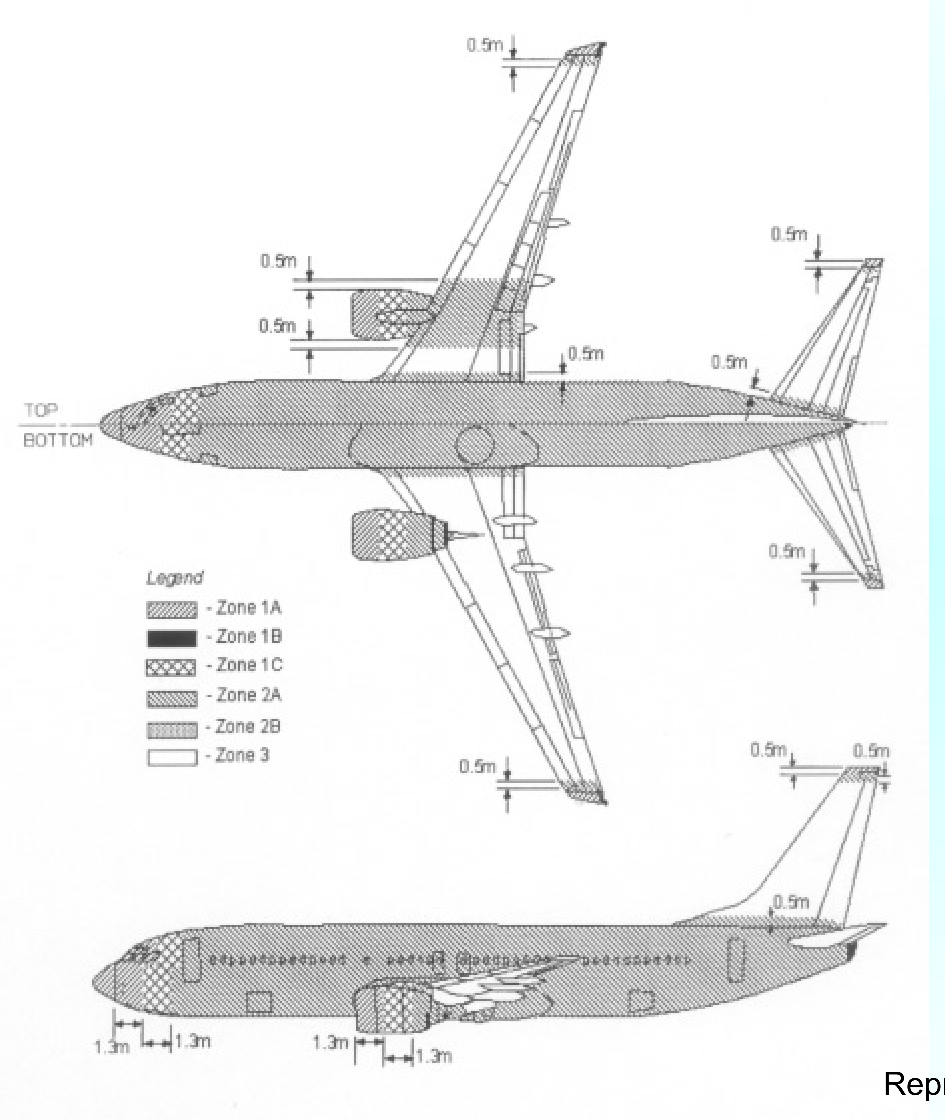
S-92 LIGHTNING STRIKE ZONES



LIGHTNING ZONES – TYPICAL TRANSPORT AIRCRAFT



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LIGHTNING ZONE DEFINITIONS

- **ZONE 1A – FIRST RETURN STROKE ZONE**
- **ZONE 1B – FIRST RETURN STROKE ZONE WITH LONG HANG ON**
- **ZONE 1C – TRANSITION ZONE FOR THE FIRST RETURN STROKE**
- **ZONE 2A – SWEPT STROKE ZONE**
- **ZONE 2B – SWEPT STROKE ZONE WITH LONG HANG ON**
- **ZONE 3 – CONDUCTED CURRENT ZONE**

SCALE MODEL HIGH VOLTAGE TEST

Lightning Technologies, Inc Photo

LIGHTNING TEST CURRENT ZONAL APPLICATION

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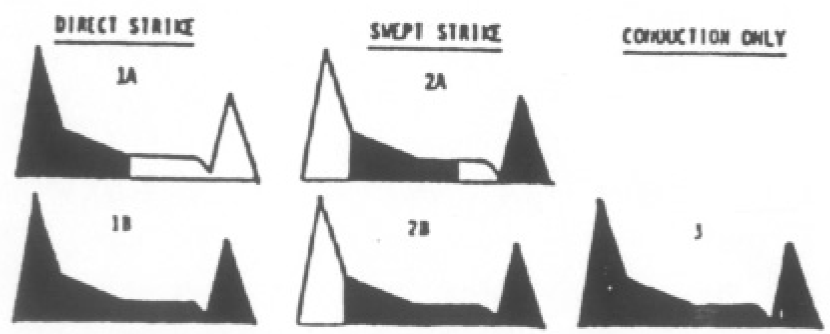
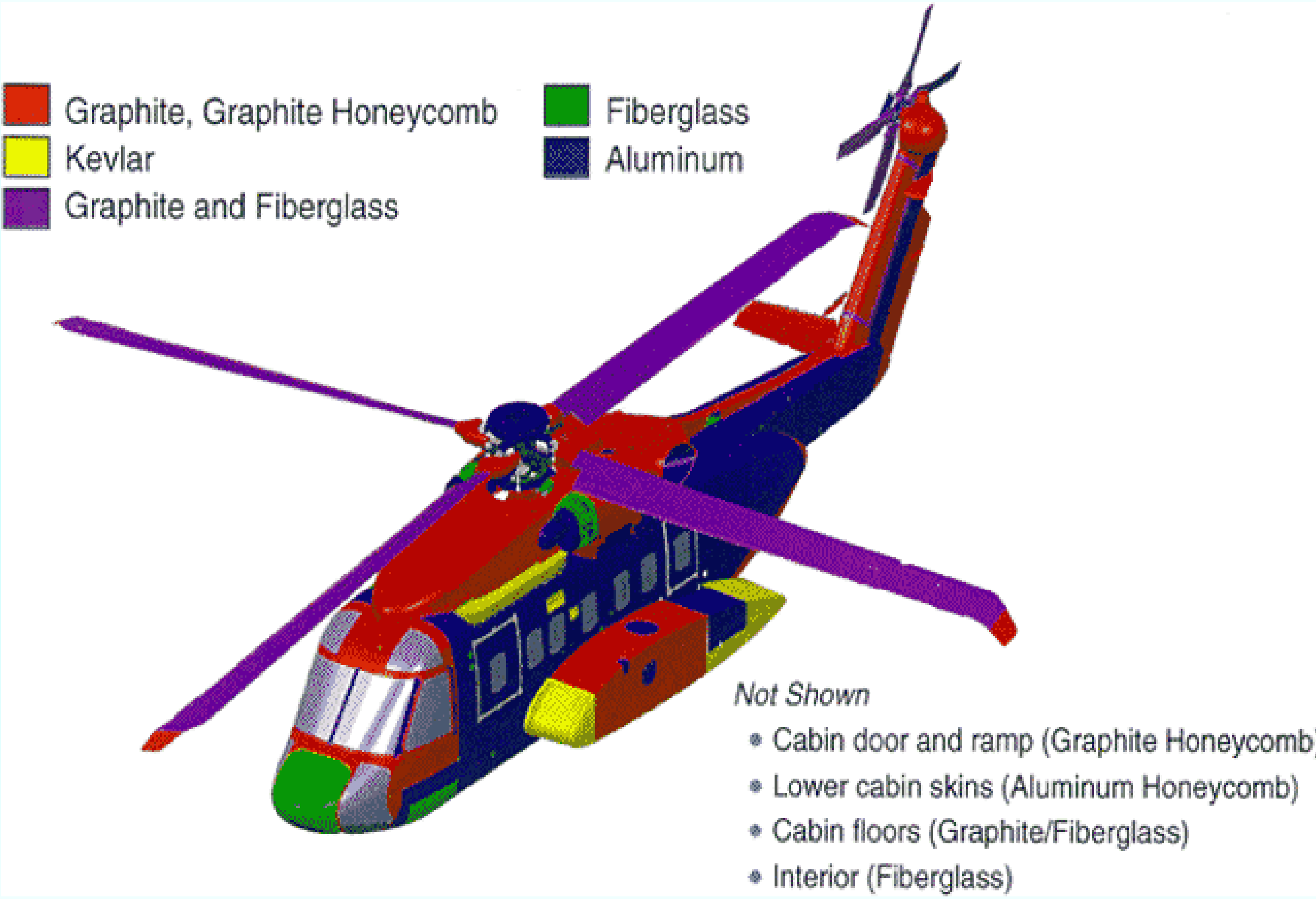


- Lightning Current Components Expected in Each Zone.

TABLE 3 - 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	

S-92 MATERIAL USAGE



MATERIAL USAGE/PROPERTIES

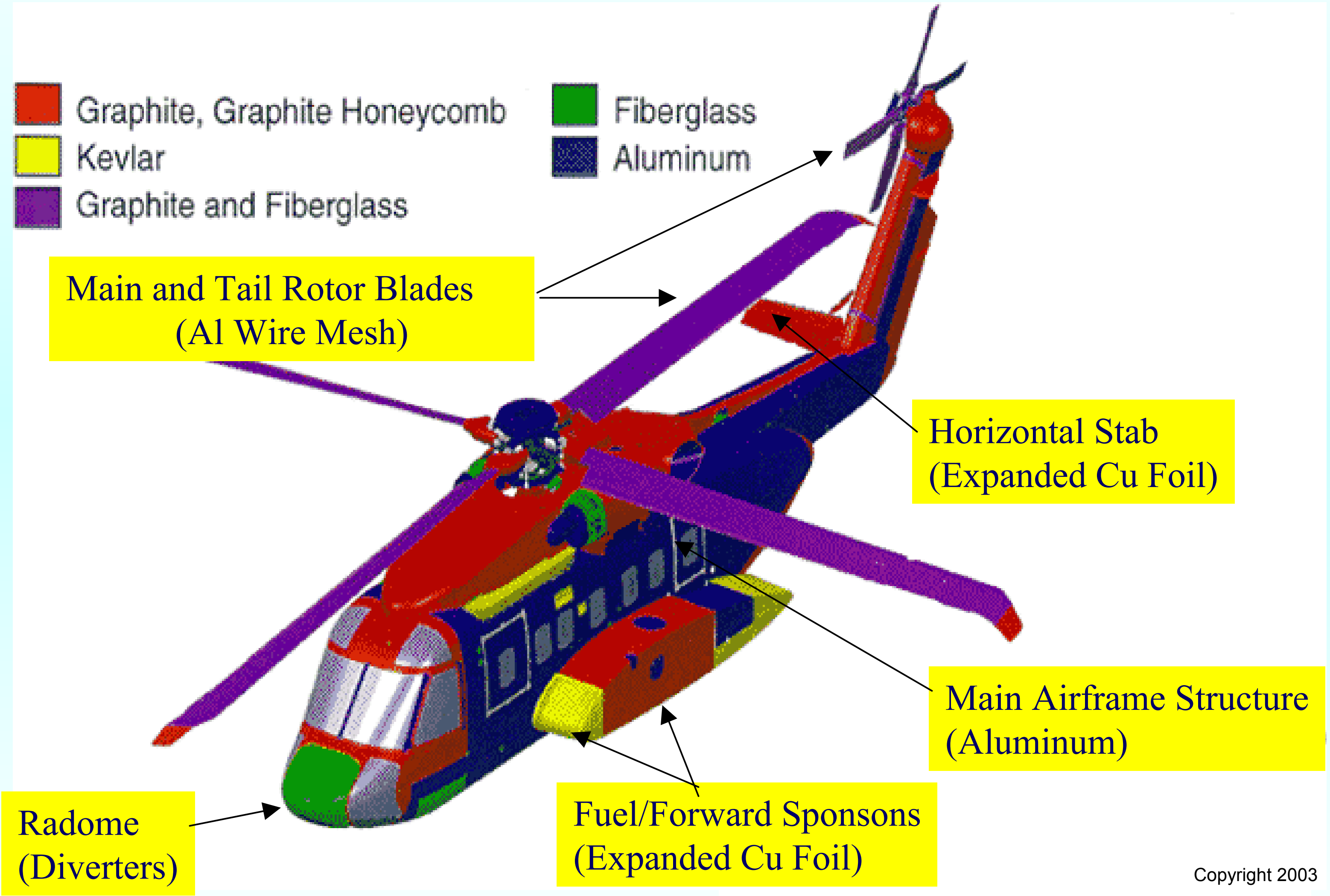
- **KEVLAR/FIBERGLASS - NON-CONDUCTOR**
  - **TRANSPARENT TO LIGHTNING**
  - **REQUIRES PROTECTION IN ARC ATTACHMENT AREAS**
- **GRAPHITE - CONDUCTOR, ALTHOUGH A POOR ONE**
  - **ARC ATTACHMENT PROCESS IS SAME AS METAL**
  - **SUBJECT TO PYROLYSIS OF RESIN AT ARC ATTACHMENT AREA AND IN HIGH CURRENT CONCENTRATION AREAS (JOINTS)**
  - **SUBJECT TO FRACTURE DUE TO SHOCK WAVES**
  - **≈ 1000X MORE RESISTIVE THAN ALUMINUM**
  - **LARGE VOLTAGE RISES ASSOCIATED WITH CURRENT FLOW**
- **TITANIUM/STAINLESS STEEL - CONDUCTOR**
  - **≈ 10-30X MORE RESISTIVE THAN ALUMINUM**
  - **COMPATIBLE WITH GRAPHITE**
- **ALUMINUM - EXCELLENT CONDUCTOR**
  - **NOT COMPATIBLE WITH GRAPHITE (ALUMINIM ANODIC)**

LIGHTNING PROTECTION

DESIGN APPROACH

- DIRECT EFFECTS
  - Prevent hazardous damage at arc attachment points
  - Provide adequate lightning current paths to preclude damage to joints/bonds between attachment points
  - Prevent ignition of fuel vapors
- INDIRECT EFFECTS
  - Preclude damage/upset of flight critical avionic/electrical sub-systems
  - Preclude damage to flight essential/mission critical systems

S-92 LIGHTNING PROTECTION FEATURES



LIGHTNING PROTECTION

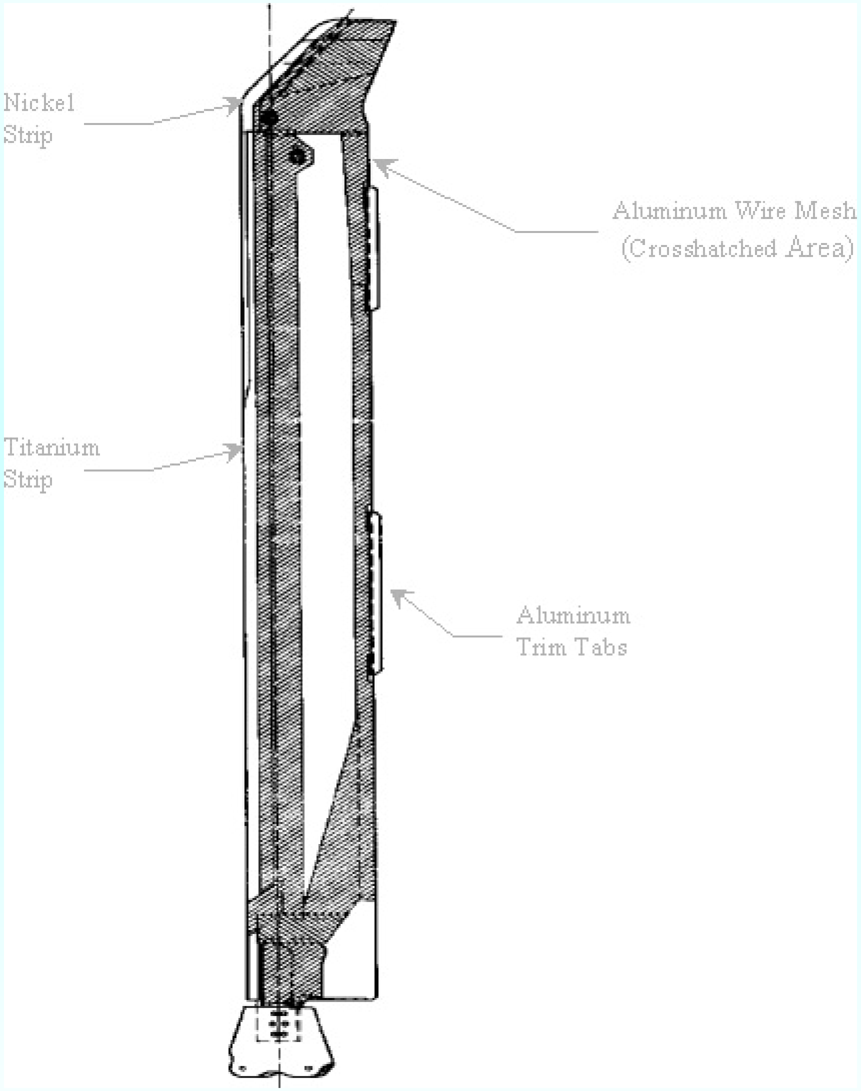
DIRECT EFFECTS DESIGN

- DEFINE THE LIGHTNING STRIKE ZONES TO ESTABLISH THE EXTERNAL LIGHTNING ENVIRONMENT
- EXPANDED COPPER FOIL/ALUMINUM MESH
  - Utilized to minimize damage at arc attachment points
  - Selectively used at arc attachment areas (i.e., fuel sponson, fairings, horizontal stab, main and tail rotor blades)
  - Metalization techniques proven on the S-92, RAH-66 and H-60 aircraft
- LIGHTNING DIVERTER STRIPS USED ON RADOMES
- ELECTRICAL BONDING
  - Joints/contact areas (mating surfaces)
  - Jumpers/straps (as necessary)

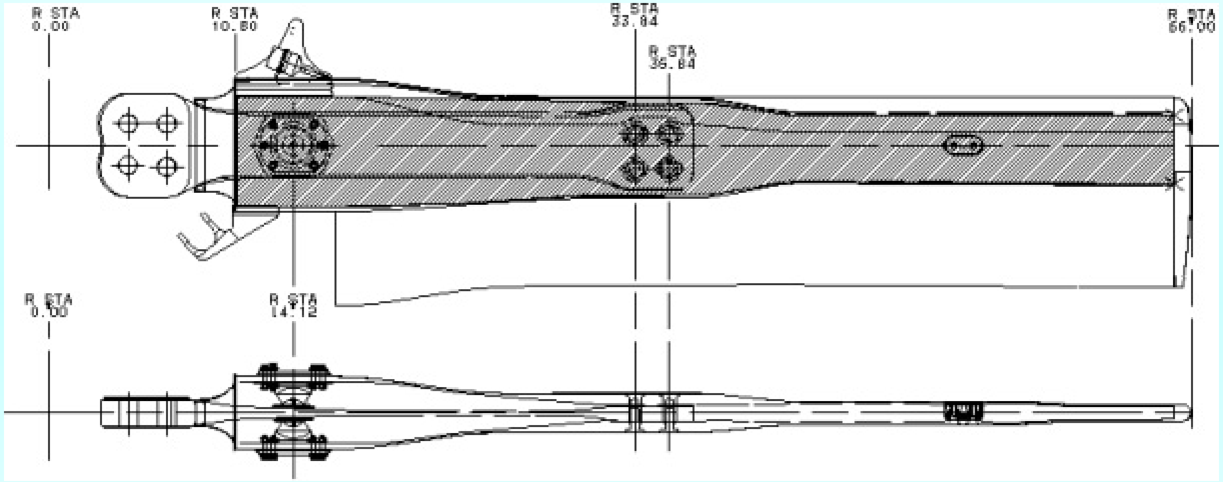
FUEL SYSTEM DESIGN

- CONTAINMENT – DESIGN FUEL VESSEL TO CONTAIN RESULTING OVERPRESSURE
- INERTING – CONTROLLING ATMOSPHERE IN THE FUEL SYSTEM SO COMBUSTION IS NOT SUPPORTED (I.E., OBIGGS)
- FOAMING – PREVENT PROPAGATION OF FLAME
- ELIMINATE IGNITION SOURCES
    - FLUSH/RECESSED VENTS/DRAINS OR LOCATE OUTSIDE DIRECT STRIKE ZONES
    - SINGLE POINT ELECTRICALLY BOND PLUMBING/HARNESSES AT POINT OF ENTRY INTO THE TANKS (NO INTERNAL CURRENT LOOPS) - USE DIELECTRIC ISOLATORS IF NECESSARY
    - PREVENT SPARKING AT ACCESS DOORS/FASTENERS
    - PREVENT ARC PENETRATION, HOT SPOT FORMATION, OR BURN-THROUGH
    - NEED TO CONSIDER STATIC CHARGES IN DESIGN

S92 MAIN BLADE LIGHTNING PROTECTION



S92 TAIL BLADE LIGHTNING PROTECTION



INDIRECT EFFECTS DESIGN

- **TRANSLATE THE EXTERNAL ENVIRONMENT INTO THE INTERNAL ENVIRONMENT**
  - **ANALYSIS OR TEST**
  - **DIFFERENCES BETWEEN FIXED WING AND ROTORCRAFT**

- **HAZARD ANALYSIS - CRITICALITY OF EQUIPMENT /FUNCTIONS**

- **UTILIZE INHERENT PROTECTION AFFORDED BY THE AIRCRAFT**

- **ASSIGN PROTECTION IN TIERS**
  - **AIRCRAFT**
    - **Equipment locations**
    - **Wire routing**
  - **HARNESS TREATMENT**
    - **Gross/individual shields**
    - **360° peripheral shield terminations**
  - **BOX LEVEL PROTECTION**
    - **Circuit design**
    - **Terminal Protection Devices**
  - **SYSTEM/SOFTWARE COORDINATION FOR UPSET**
    - **Limit/Rate checks**
    - **Use last good value or synthesized parameter**

1st Order Principles

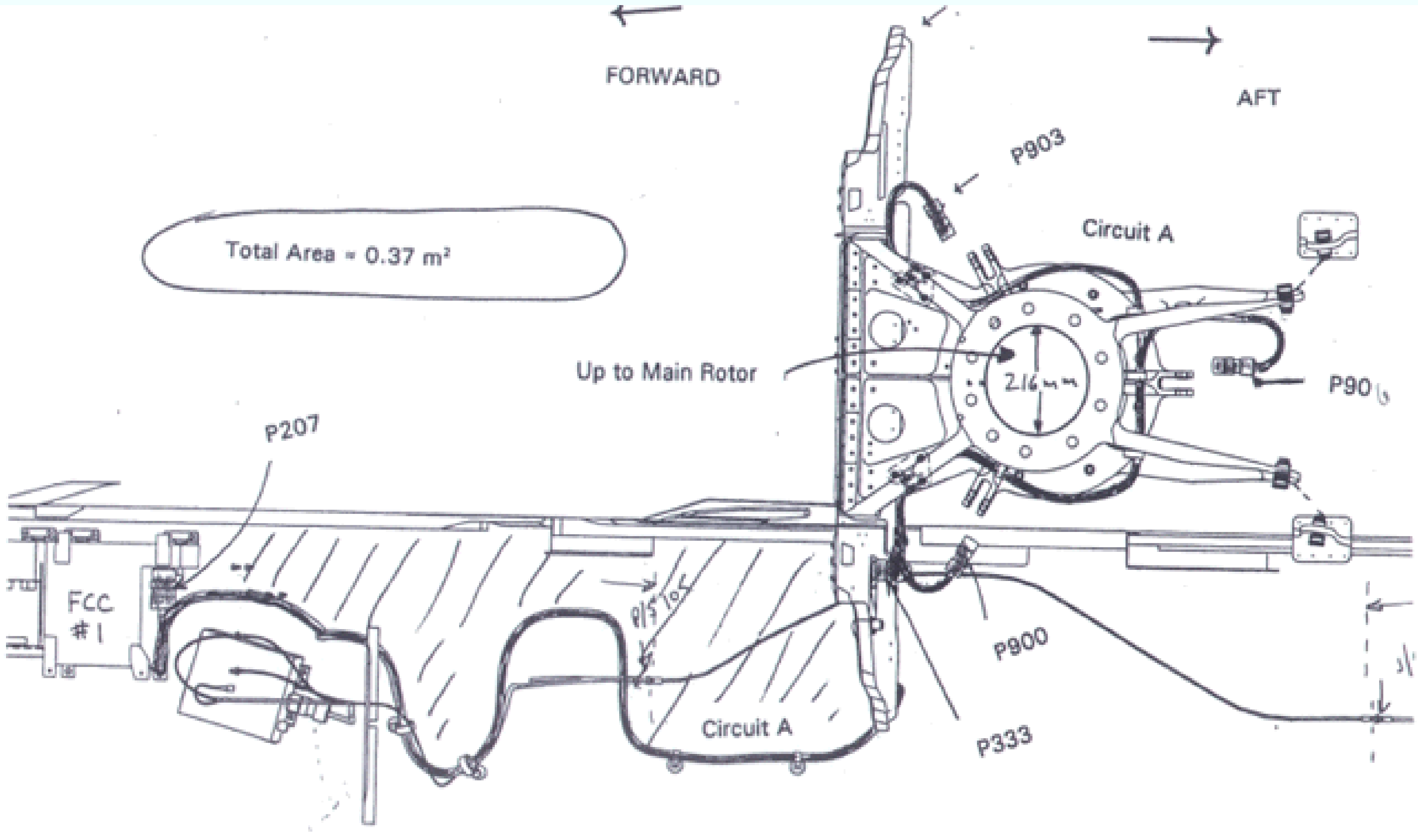
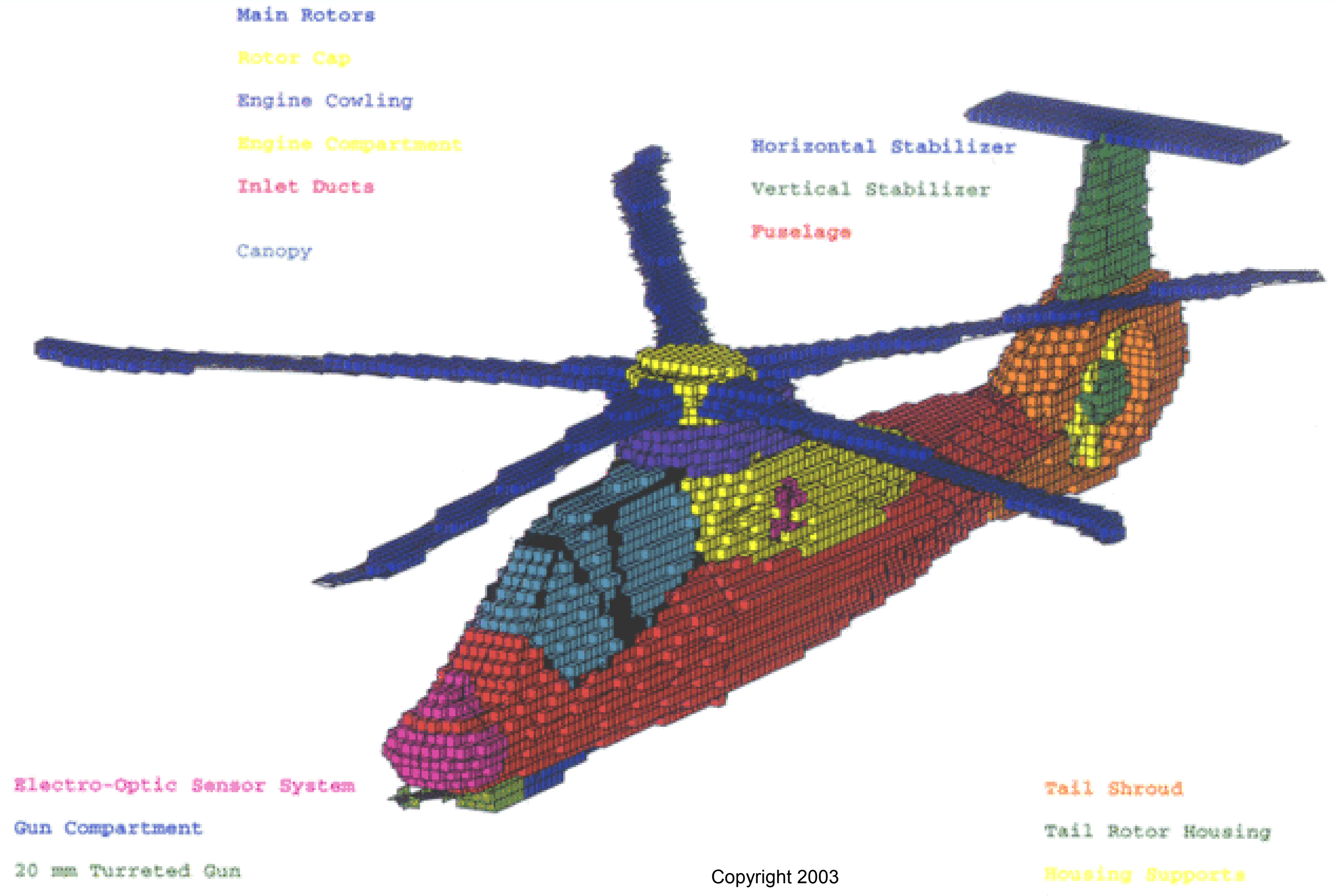
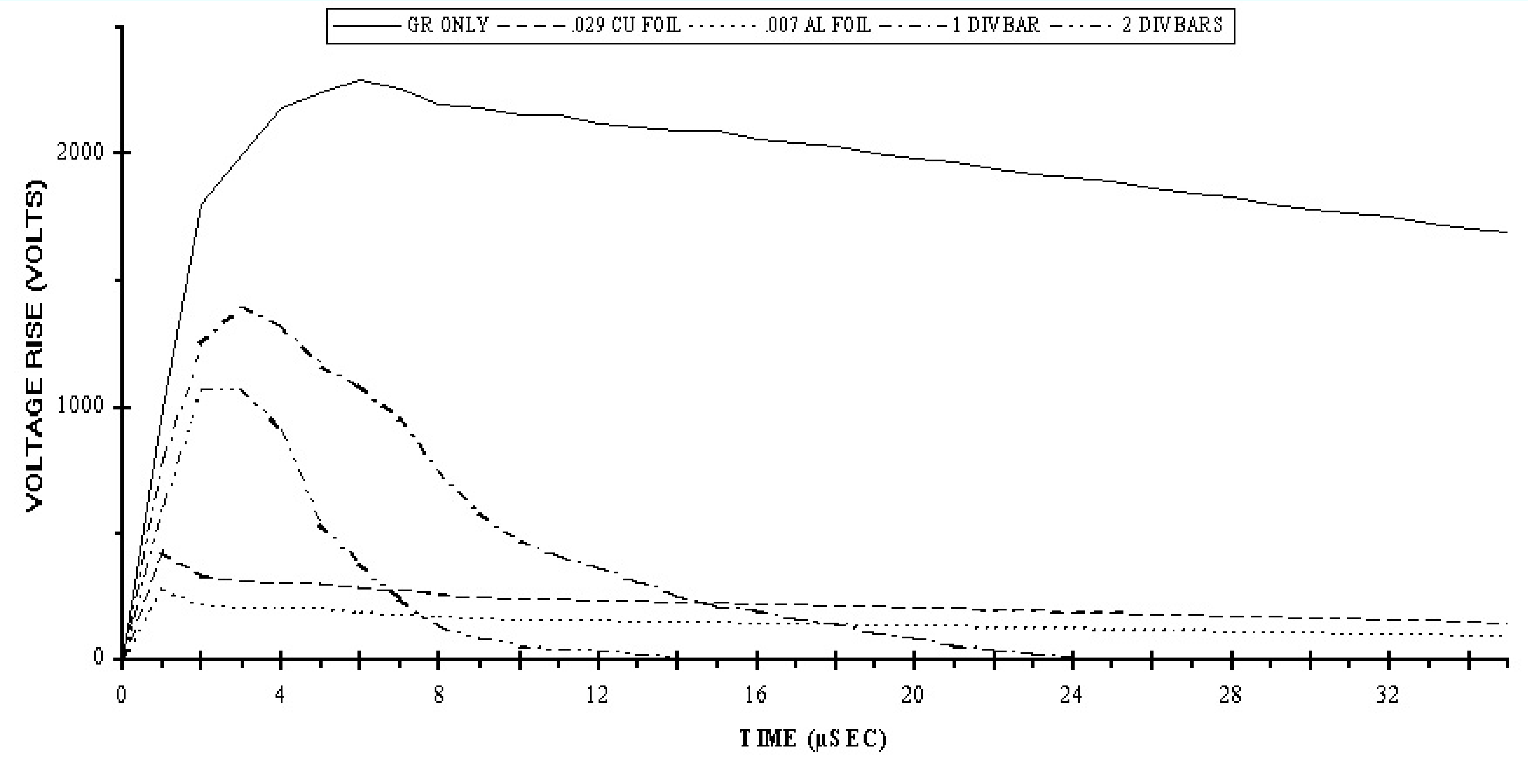


Figure 2 - Routing of Conductors for Circuit A (continued)

Computational Analysis



STRUCTURAL (IR) VOLTAGE RISE



FHA/SSA CRITICALITY LEVELS

FAILURE CONDITION CLASSIFICATION (AC 23.1309-1C, AC 25.1309-1A and ARP4754)	SYSTEM DEVELOPMENT ASSURANCE LEVEL (ARP4754)
No Effect	Level E
Minor	Level D
Major	Level C
Severe Major/Hazardous	Level B
Catastrophic	Level A

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EQUIPMENT TRANSIENT DESIGN LEVEL CRITERIA

- An Equipment Transient Design Level (ETDL) should be established for each LRU/sub-system. This ETDL depends in large part on the criticality and location of the equipment.

- The following general criteria may be assigned to sub-systems based on their criticality :

Equipment/ Function	Damage Tolerance(1)	System Upset(2)	Not Installation Dependent(3)	Installation Dependent(4)
Critical (Level A)	X	X		X
Essential (Level B/C)	X		X	

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EQUIPMENT TRANSIENT DESIGN LEVEL CRITERIA

- (1) Damage tolerance verification may consist of pin injection tests and/or cable injection tests, applied in a single stroke or multiple stroke format. Extent and type of test is dependent upon criticality and location of the equipment and associated wiring runs on the aircraft. Equipment performing Level A or B functions should be tested to the categories and levels identified in DO-160C, Section 22, Change Notice 2 (or higher). Equipment performing Level C functions may be tested to the default categories and levels identified in DO-160C, Section 22, Interim Procedure or Change Notice 2 (or higher).

- (2) Upset of critical equipment/functions shall be tested using the multiple stroke and multiple burst waveforms defined in AC20-136 or DO-160D, Change Notice 3. Multiple burst tests may have been conducted in accordance with the "old" requirement of 24 bursts of 20 pulses each burst or the current requirement of 3 bursts of 20 pulses each burst, dependent on when and how the testing was performed.

- (3) Essential equipment/functions may be tested to DO-160C default levels based on equipment location (and the location of associated wiring runs) on the aircraft. Verification, via an aircraft level test, is not required.

- (4) Critical equipment/functions shall be tested to DO-160C/D levels, whose adequacy shall be verified by an aircraft level test or a test of a suitable mock-up. A minimum 6 dB safety margin should be shown for critical control functions.

TYPICAL PIN TEST LEVELS

TABLE 5 - Individual Conductor TCL, ETDL or Test Levels Due to Current Component A

Level	Waveform 3 V/I	Waveform 4 V/I	Waveform 5 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

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TYPICAL BULK CABLE TEST LEVELS

TABLE 6 - Cable Bundle TCL, ETDL or Test Levels
Due to Current Component A

Level	Waveform 1 V/I	Waveform 2 V/I	Waveform 3 V/I	Waveform 4 V/I	Waveform 5 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

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TYPICAL BULK CABLE TEST LEVELS

TABLE 7 - Cable Bundle TCL, ETDL or MB Test Levels Due to Current Component H

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

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DESIGN VERIFICATION

TYPICAL ROTORCRAFT LIGHTNING CERTIFICATION TESTS

FULL SCALE COMPONENT TESTS

- MAIN AND TAIL ROTOR BLADES
- FUEL SPONSON
- NOSE DOOR RADOME

LOW LEVEL INDUCED AIRCRAFT LEVEL TEST

EQUIPMENT SUB-SYSTEM TESTS (IAW DO-160C/D)

- PIN INJECTION DAMAGE TOLERANCE TESTS
- CABLE INJECTION DAMAGE TOLERANCE TESTS
- CABLE INJECTION SYSTEM UPSET TESTS (FLT CRITICAL EQUIPMENT ONLY)

LIGHTNING DIRECT EFFECTS TEST CRITERIA

MAIN ROTOR BLADE – ZONE 1A+

- **High Voltage, Long Arc Attachment Tests**
- **High Current Multiple Component Strikes**
  - Initial Strike Amplitude – 200 kA
  - Action Integral – 2 x 10^6 A^2S
  - Charge Transfer – 50 Coulombs
  - Entire S-92 blade, including inboard spar area was conservatively tested to most severe region (i.e., Zone 1A plus continuing current) vs. present day zoning standards for blades (Zone 1A outboard 0.5 m, remainder Zone 2A).

LIGHTNING TEST CRITERIA (cont.)

MAIN ROTOR BLADE CUFF – Zone 1B

- **High Current Multiple Component Strikes**
  - **Initial Strike Amplitude – 200 kA**
  - **Initial Action Integral – 2 x 10^6 A^2S**
  - **Charge Transfer – 200 Coulombs**
  - **Restrike Amplitude – 100 kA**
  - **Restrike Action Integral – 0.25 x 10^6 A^2S**

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LIGHTNING TEST CRITERIA (cont.)

TAIL ROTOR BLADE – ZONE 1A+

- High Voltage, Long Arc Attachment Tests
- High Current Multiple Component Strikes
  - Initial Strike Amplitude – 200 kA
  - Action Integral – 2 x 10^6 A^2S
  - Charge Transfer – 20 Coulombs

LIGHTNING TEST CRITERIA (cont.)

FUEL SPONSON and FORWARD SPONSON –

- **Lower Surfaces - Zone 1B**
  - **High Current Multiple Component Strikes**
    - **Initial Strike Amplitude – 200 kA**
    - **Initial Action Integral – 2 x 10^6 A^2S**
    - **Charge Transfer – 200 Coulombs**
    - **Restrike Amplitude – 100 kA**
    - **Restrike Action Integral – 0.25 x 10^6 A^2S**
- **Side Surfaces – Zone 2A**
  - **Restrike Amplitude – 100 kA**
  - **Restrike Action Integral – 0.25 x 10^6 A^2S**

LIGHTNING TEST CRITERIA (cont.)

NOSE DOOR RADOME – Zone 1B

- **High Voltage, Long Arc Attachment Tests**
- **High Current Multiple Component Strikes**
  - **Initial Strike Amplitude – 200 kA**
  - **Initial Action Integral – 2 x 10^6 A^2S**
  - **Charge Transfer – 200 Coulombs**
  - **Restrike Amplitude – 100 kA**
  - **Restrike Action Integral – 0.25 x 10^6 A^2S**

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LIGHTNING TEST CRITERIA (cont.)

AIRCRAFT LEVEL TEST

- **Test To Determine Actual Transient Levels of Cables/Pins**
- **Lightning Transient Analysis (LTA) Technique**
  - 1000 A Injected Current
  - Coaxial Current Return
  - Current Waveform A
  - Measurements
    - Voc/Isc
    - Bulk Cable Currents
    - Magnetic Fields

HIGH VOLTAGE TEST

HIGH CURRENT TEST

AIRCRAFT LEVEL LIGHTNING TEST

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POSSIBLE PIT-FALLS, CERTIFICATION

- **LACK OF COORDINATION BETWEEN APPLICANT AND FAA OR BETWEEN AIRCRAFT OEM AND SUPPLIER**
  - DIFFERENCES BETWEEN REQUIREMENTS (i.e., ARPs vs. ACs)
  - INTERPRETATIONS

- **TSOs AND APPLICABILTY TO CERTIFICATION**
  - LACK OF TESTS
  - NO COORDINATION WITH INTERACTING SYSTEMS

- **SOFTWARE (PRODUCTION vs. TEST)**
  - CHANGES, CONTROL

- **HAZARD ANALYSIS AND MITIGATION - I.E.,**
  - PRIMARY FLIGHT DISPLAYS WITH BACK-UP INSTRUMENTS
  - FADECs

H-60 TAIL BLADE -
HIGH AMPLITUDE - POSITIVE POLARITY STRIKE

PRECIPITATION STATIC (P-STATIC)

- **CHARGE MECHANISM - FRICTIONAL CHARGING DUE TO PARTICLE (IE: DUST, SNOW, HAIL) IMPINGEMENT DURING FLIGHT/HOVER**
- **RESULTANT EFFECT ON AIRCRAFT**
  - **SEVERE NOISE GENERATED IN COMM/NAV FREQUENCY RANGE**
  - **DEGRADATION OF OTHER SENSITIVE AVIONIC/ELECTRICAL SYSTEMS**
- **CHARGE BUILD-UP ON DIELECTRIC SURFACES (IE: TRANSPARENCIES, RADOMES, ACCESS DOORS)**
  - **SURFACE STREAMER DISCHARGE**
  - **PUNCTURE DISCHARGE**

P-STATIC DESIGN OBJECTIVES

- **CONTROL BUILD-UP AND DISCHARGE**
- **PREVENT NOISE TO COMM/NAV SYSTEMS**
- **PREVENT DEGRADATION OF AVIONIC/ELECTRICAL SYSTEMS**
- **PREVENT HAZARD TO PERSONNEL DURING MAINTENANCE, REFUELING**

P-STATIC DESIGN FEATURES

- **ANTI-STATIC PAINT FOR EXTERNAL NON-CONDUCTING PANELS, DOORS, FAIRINGS, ETC...**
- **ELECTRICALLY BOND ALL EXTERIOR CONDUCTING OBJECTS**
- **ELECTRICALLY BOND ALL DOORS, HATCHES, PANELS, AND COVERS**
- **UTILIZE P-STATIC DISCHARGERS AS APPROPRIATE**