Establishing Computational Simulation Capability for Aircraft Lightning Certification
항공기 낙뢰 해석 및 인증 기술

26th (2:00-5:00PM) November, 2013

R. S. Myong
Dept. of Aerospace and System Engineering
Aerospace Computational Modeling Lab; *http://acml.gnu.ac.kr*
Gyeongsang National University, South Korea
myong@gnu.ac.kr

Presented at KAI

Acknowledgement of

Dr. Sangwook Lee (Boeing)
R. Ranjith (GNU; Graduate Student)

and

financial support through the Brain Pool program.

Subjects

- **Introduction of lightning**
  - Lightning research communities and references
  - Aircraft lightning and its importance
- **Lightning certification**
  - Certification process and standards
  - Current waveforms
  - Lightning zoning
  - Steps in protection design and certification
- **Computational lightning simulation**
  - Role of computational simulation and applications
  - Numerical codes
  - Mechanical-thermal-electrical physical modeling
  - Validation of computational codes

Subjects (Continued)

- **Sample calculations**
  - Integrated wet fuel tank
  - EM simulation supporting lightning protection design
- **Recent research trend**
  - New zoning method
  - Digital photographic technique
  - Conductivity in composites and scaling issues
  - Lightning research using UAV
- **Summary**
  - Major computational capabilities and issues
- **Q & A**

Research Communities and References

- *ICOLSE* International Conference on Lightning and Static Electricity (Seattle 2013; www.icolse.us, 2007)
- Aircraft lightning requirements, components testing, aircraft testing, and certification (*University of Kansas Course*, 2012); introduction, EMI EMC, certification, environment, aircraft lightning attachment phenomena, lightning effects on aircraft, direct effect, indirect effect, design to minimize indirect effects, fuel systems, aircraft wiring
- Lightning hazards of aircraft and launchers, *Journal Aerospace Lab* (12 articles, Issue 5, December 2012)
- Other journal articles

Lightning - Importance

- Lightning is an atmospheric electrical phenomenon which deserves adequate protection design of aircraft.
- Though the probability of the lightning strike is very low (10^{-9} events per hour), the effects might be quite considerable. (small-size solid-state components, sensitive devices, reinforced polymers, complex systemization → Lightning protection must be considered from the start. Cf. Embedded de-icing systems)



Lightning – Importance (Korea)

한반도 늘어난 낙뢰에 공군 전투기도 '몸살'

한반도 기상이변으로 낙뢰 발생 빈도가 증가하면서 전투기도 실제 벼락을 맞아 피해를 입은 사례가 있는 것으로 나타났다.

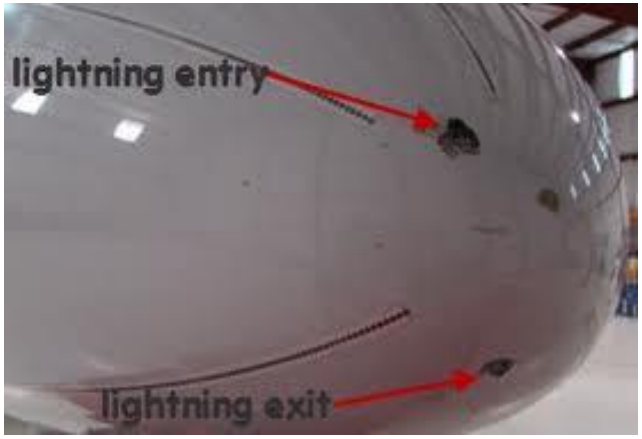
5일 한국국방연구원(KIDA)의 국방정책 전문연구 자료인 '국가안보 차원에서 본 기후변화와 한국의 대응'에 따르면 2009년 3월26일 공군 한 비행단의 F-16C 전투기가 낙뢰 사고를 당했다.

이날 기지를 이륙한 F-16C는 임무 완료 후 지상 진입 관제레이더(PAR)를 통해 기지로 접근하던 중 상공에서 낙뢰를 맞았다.

이 사고로 전투기 꼬리 날개의 수직 안정판에 지름 5~6㎝의 구멍이 뚫리고 레이더 안테나 덮개 등 24개 부위에 손상을 입어 비상 착륙했다.

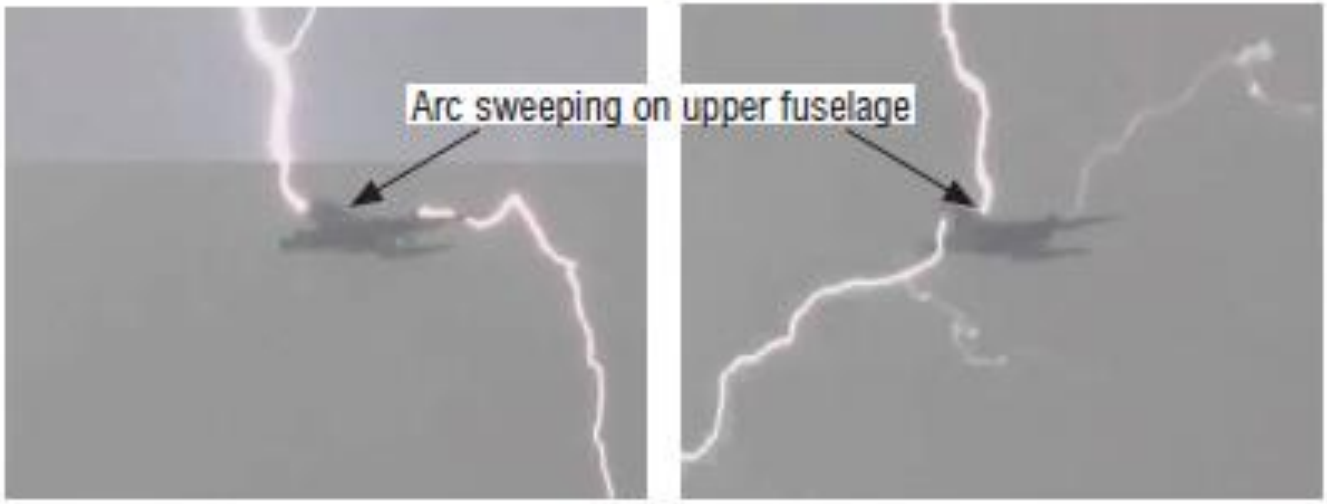
Lightning – Effects

- The effects of lightning are classified into two as direct and indirect effects.
- Direct effects include the structural damage, fuel ignition, etc., whereas indirect effects are interference to the navigation equipment.
- The worst case would be the loss of the aircraft and the lives in it.



Lightning – Mean Rate

- Pan Am Boeing 707 in 1963: induced EM effects in the fuel tank
- Iran Air Boeing 747 in 1976: arcing in the fuel tank by a direct lightning strike
- TW800 in 1996: central fuel tank explosion (wear and tear on bonding braids and sparking at chafed wiring)
- Mean rate of one event per year

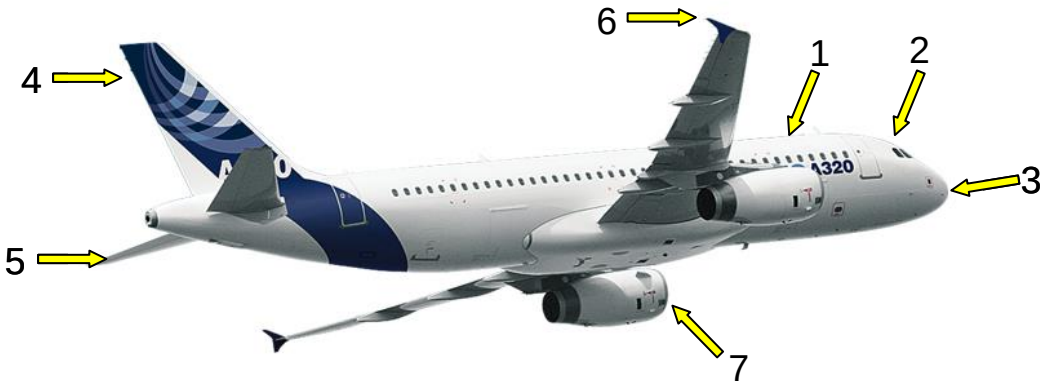


A380 1st stroke

A380 subsequent stroke

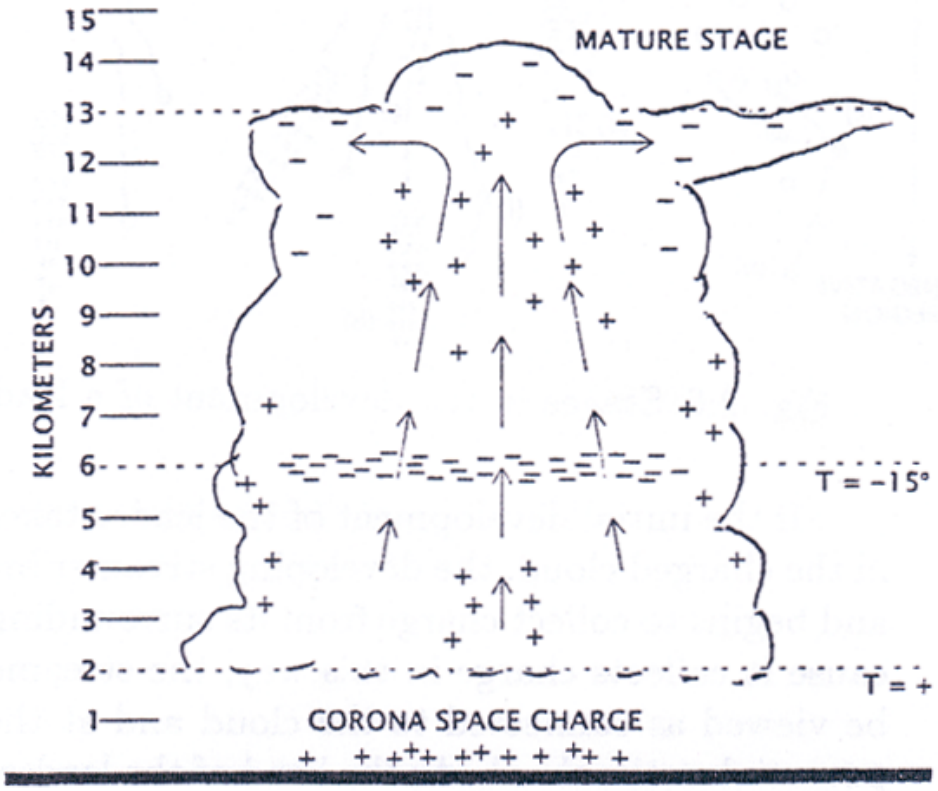
Lightning – Air France Case

- Strikes take place during: approach, cruise, take-off
- Damage locations



- Damage effects:
  - 68% minor
  - 24% moderate
  - 8% major (flight control planes)
- Air France:
  - 0.7 events/AC/year
  - 205 hrs delay, 11 flights cancelled
- Use of ILDAS (In-flight Lightning Strike Damage Assessment System) could result in more efficient maintenance procedures.

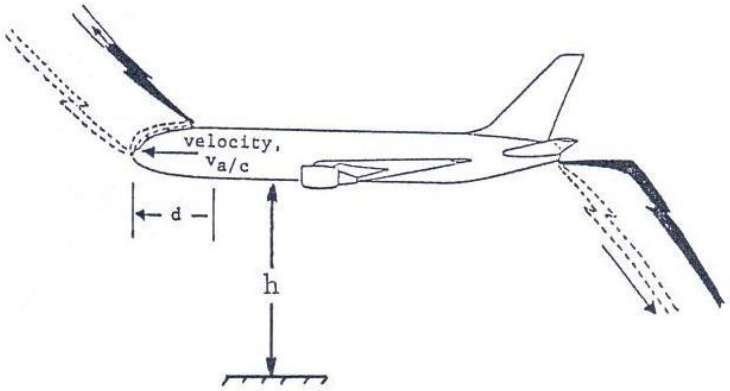
Lightning – Phenomenon

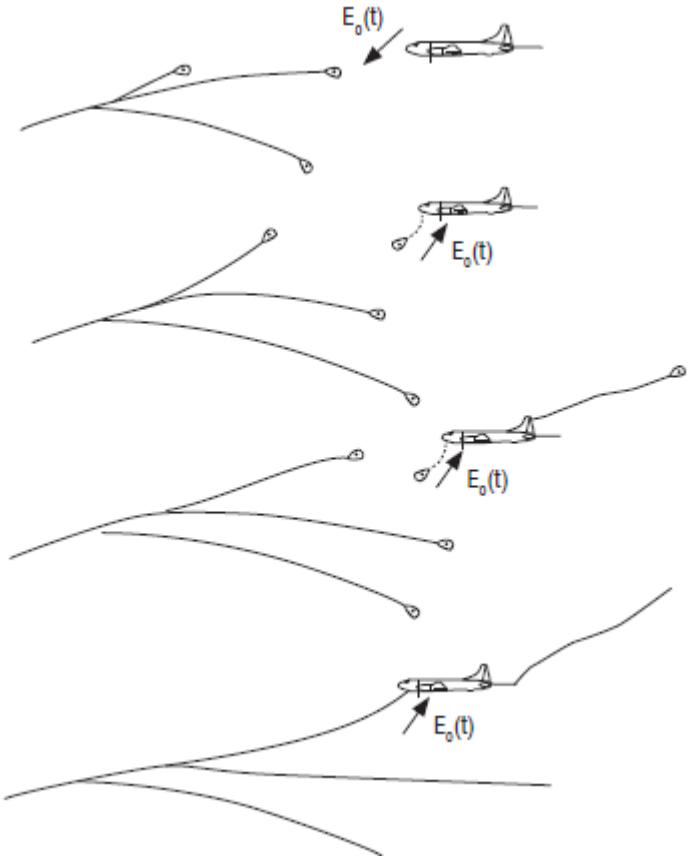


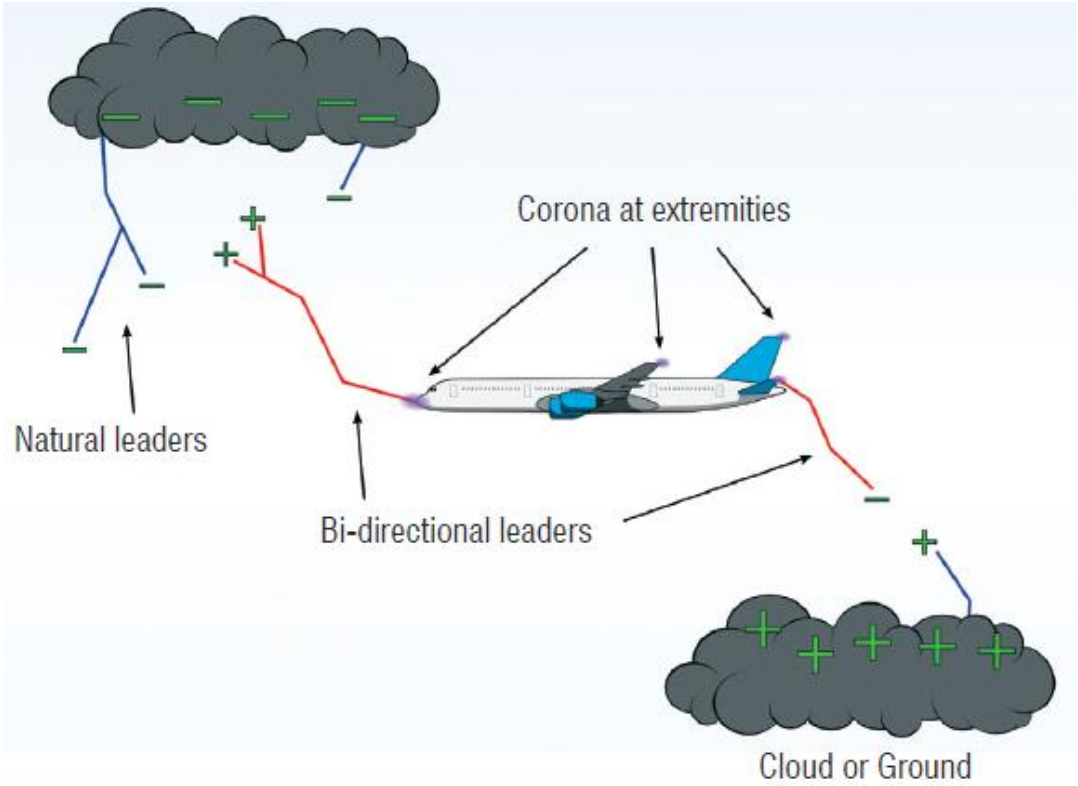
Generalized diagram showing distribution of air currents and electrical charge in a typical cumulonimbus cloud

Lightning - Triggering/Interception

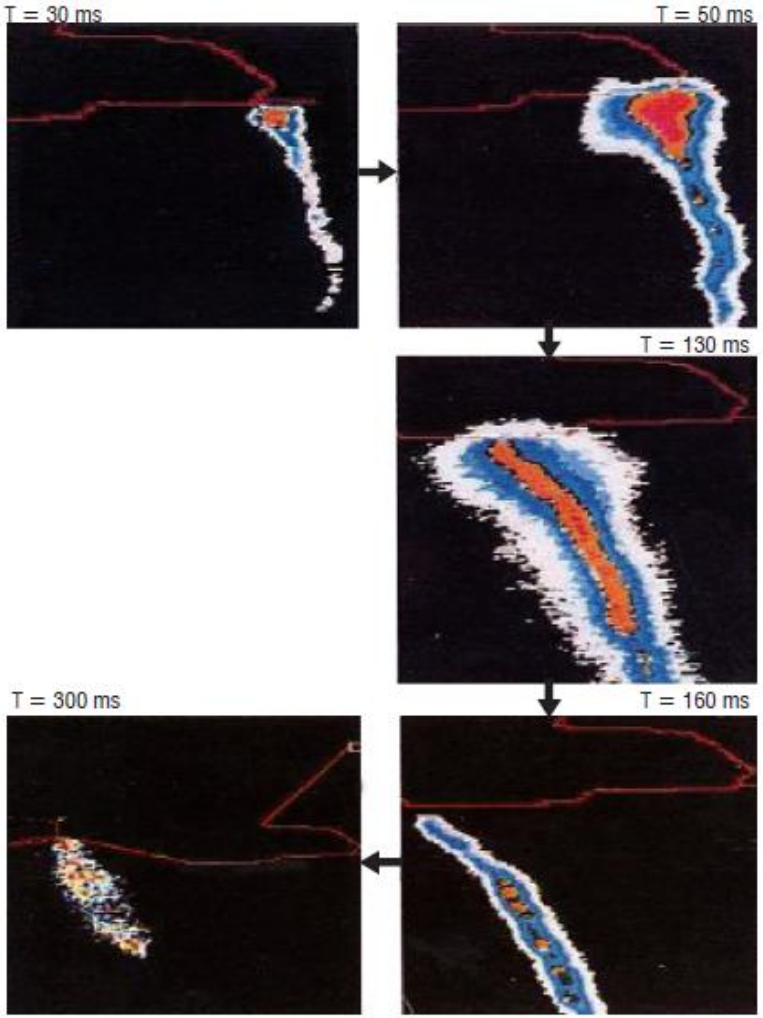
- Transall C160 research aircraft (1980s)

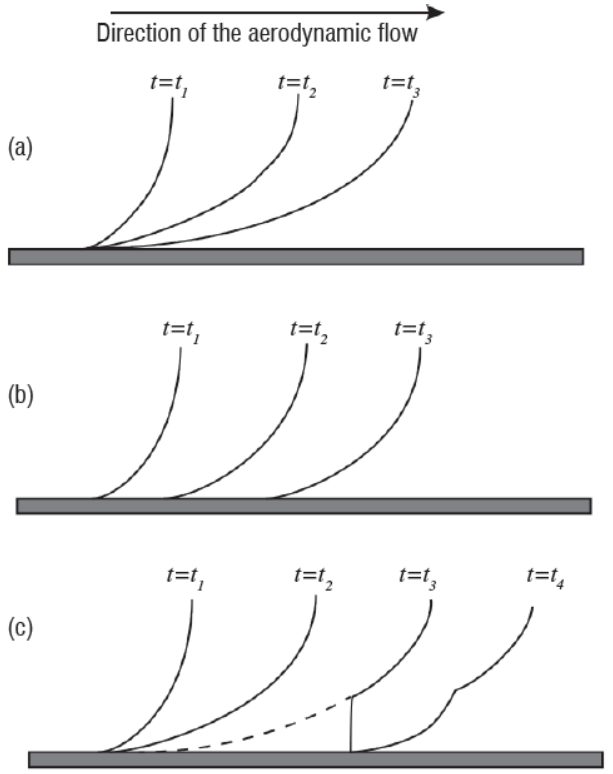


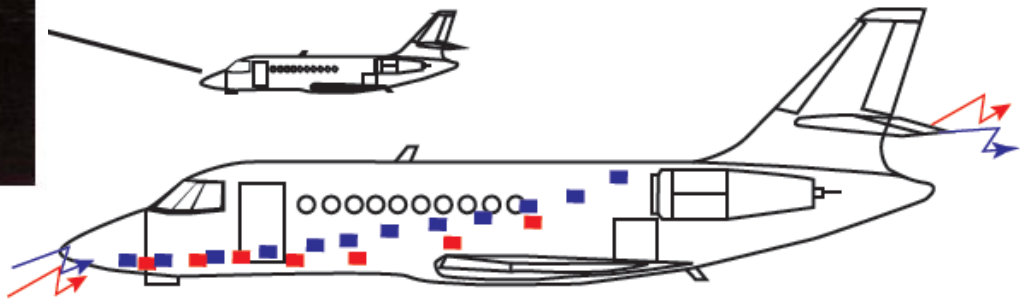




Lightning - Triggering/Interception/Sweeping

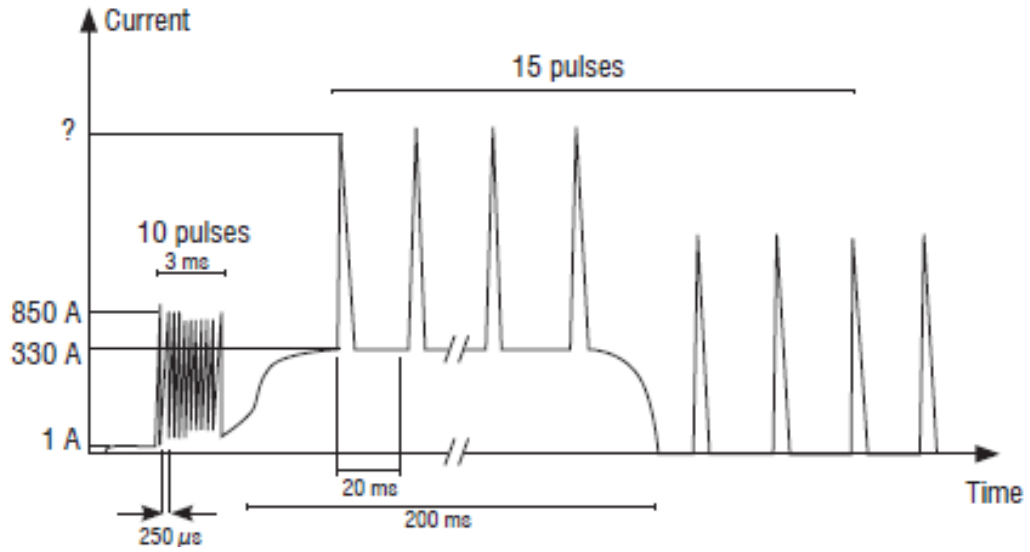




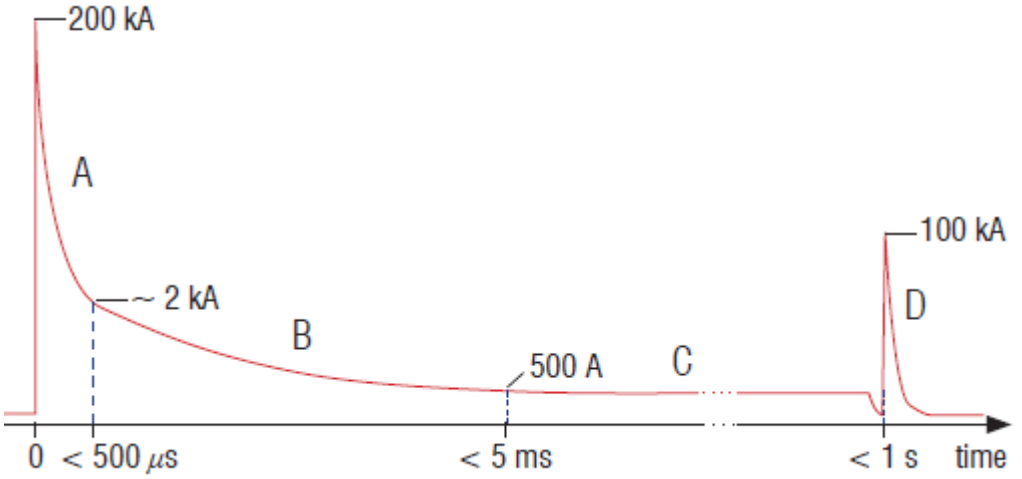


Lightning – Typical Current Waveform

C160 research aircraft



Idealized high current waveforms



Lightning - Certification

- Fundamental goal:
  - To prevent catastrophic accidents, and to enable the aircraft to continue flying safely and be able to land at a suitable airport.
- The lightning protection requirements have been included in the collection of Federal Aviation Regulations (CFRs) and Advisory Circulars (ACs).
- A certification plan needs to be submitted earlier in the certification process. It includes
  - Description of the system
  - Description of the protection
  - Pass/Fail criteria

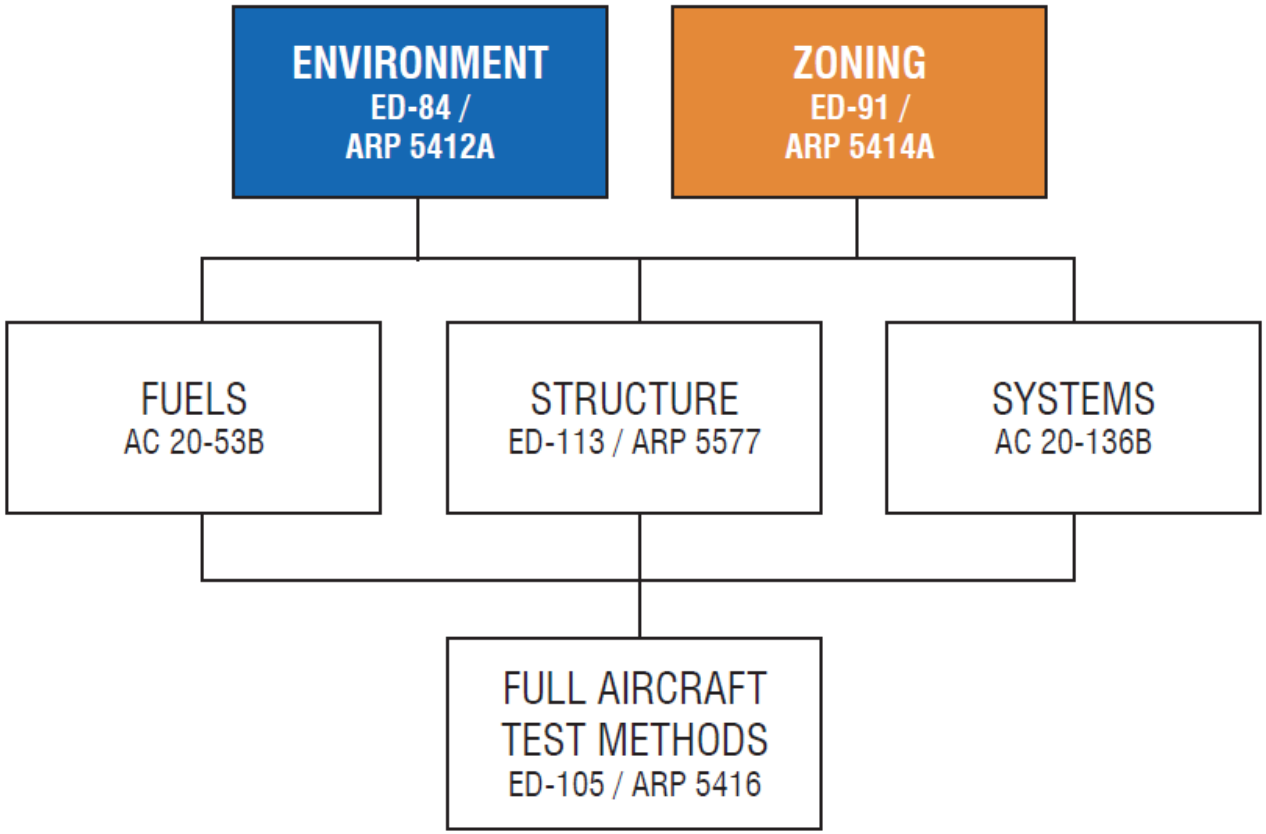
Lightning - Certification

CFRs Pertaining to Lightning Protection

Vehicle Type and Regulations				
	Aircraft		Rotorcraft	
	General Aviation	Transport	Normal	Transport
Airframe	23.867	25.581	27.610	29.610
Fuel System	23.954	25.954	27.954	29.954
Other System	23.1306	25.1316	27.1316	29.1316

Lightning - Certification

Guidance Documents: EUROCAE & SAE

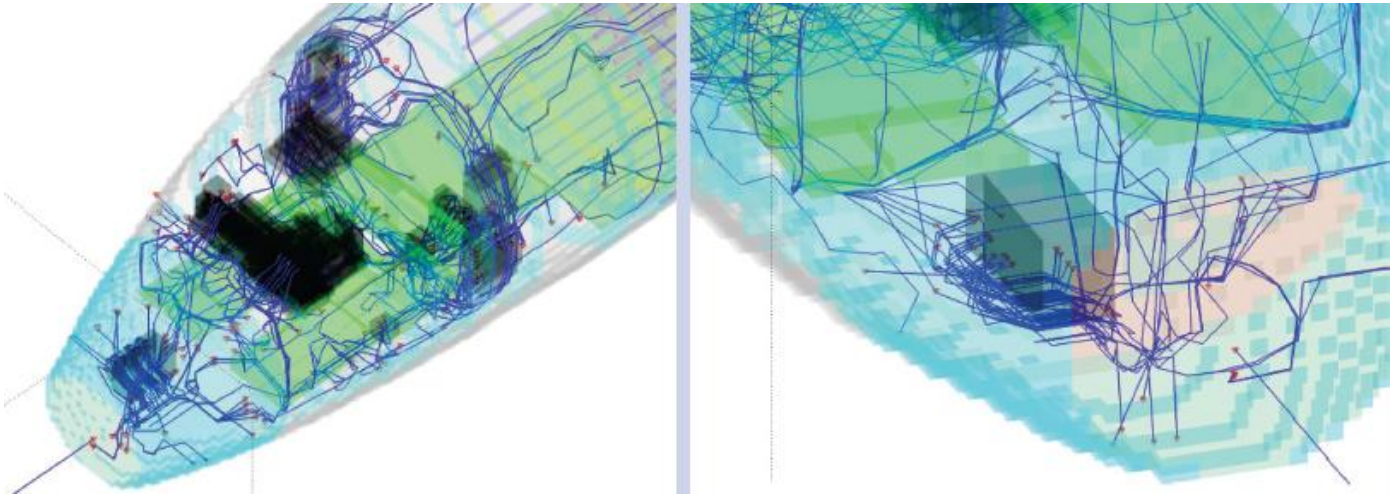


Lightning - Certification

- Aerospace Recommended Practice (ARP) edited by the SAE international group: ARP 5412A (Waveforms), ARP 5414A (Zoning), etc.
- **SAE 'Blue Book'** "*Lightning Test Waveforms and Techniques for Aerospace Vehicles and Hardware*." The US standard for aircraft protection design and certification testing, of both civil and military aircraft. Foreign certifying agencies accepted this standard via bilateral agreements

Lightning - Certification

- **SAE 'Orange book'** "*Protection of Aircraft Electrical/ Electronic Systems Against the Indirect Effects of Lightning*." In wide use as a de facto standard for certification of flight critical or essential systems aboard transport category aircraft.



Lightning – Certification (Continued)

- AC 20-53 dealt exclusively with lightning protection of airplane fuel systems.
- The Federal Aviation Regulation Part 23.945, fuel system lightning protection reads:

The fuel system must be designed and arranged to prevent the ignition of fuel vapor within the system by

(a) Direct lightning strikes to areas having a high probability of stroke attachment;

(b) Swept lightning strokes on areas where swept strokes are highly probable; and

(c) Corona or streamering at fuel vent outlets.

Certification Steps

- Determine the lightning strike zones
- Establish the lightning environment
- Identify flight critical/essential components
- Establish protection criteria: determine system/ components protected and establish pass-fail criteria
- Design lightning protection
- Verify protection adequacy by similarity with previously proven designs, by simulated lightning tests or by acceptable analysis. When analysis is utilized, appropriate margins may be required to account for uncertainties in the analytical techniques

Design Protection

- Direct effects: the basic structural material and manufacturing techniques, the addition of treatments or devices to improve electrical conductivity, arc or spark suppression, finishes, sealants and gaskets, application of lightning diverters, insulating structures and electrical bonding provisions and relocation of equipment
- Indirect effects: application of electromagnetic shielding, provision of low impedance grounding surfaces, incorporation of surge suppressors and proper design of input and output circuits of electronic equipment

Test Plans

- Purpose of the test
- Production or test article to be utilized
- Article configuration and test drawing
- Method of installation that simulates the production installation
- Applicable lightning zone(s)
- Lightning simulation method; test voltage or current waveforms
- Diagnostic methods
- Pass/fail criteria
- Appropriate schedule and location of proposed test

Test Procedural Steps

- Obtain FAA concurrence that the test plan is adequate.
- Obtain FAA concurrence on details of part conformity of the test article and installation conformity of the test setup.
- Schedule FAA witnessing of the test(s).
- Conduct testing.
- Submit a final test report describing all results.
- Obtain FAA approval of the report.

Concluding Remarks

- Need of further activities in lightning study
- Major computational capabilities required for future program
  - Zoning
  - EM simulation of transient lightning physics
  - Mechanical-thermal-electrical coupled simulation

Concluding Remarks (Continued)

- Main issues in computational simulation for structure

  - Global/local current distribution

  - Current distribution in fasteners (found randomness-oscillation or focusing of current on one fastener)

  - Damage effects in materials

  - Sparking conditions/threshold

  - Lightning protection of radomes (electro-static approach is common; what shape beneath the skin is the key factor)

Q & A