white paper

Lightning Induced Transient Susceptibility

A Primer

Guidelines for understanding DO-160, Section 22, and information to assist with the development of a verification and compliance plan to determine the effects of lightning on aircraft systems.

© 2016 Hydra-Electric Company

HydraElectric

Lightning Induced Transient Susceptibility

Contents

Abstract

Background

Transients Caused by High Current

Transients Caused by Electric Fields

Designing and Testing for Lightning Susceptibility

RTCA DO-160, Section 22 (Lightning Induced Transient Susceptibility)

Conclusion

About Hydra-Electric

Abstract

Lightning presents a frequent and inevitable risk to commercial and military aircraft. All electronic or electrical systems in an aircraft must go through a rigorous process to determine if any lightning induced failure may create a risk to the aircraft. The most widely referenced test specification in the military and aerospace industries for determining “Lightning Induced Transient Susceptibility” is RTCA DO-160, Section 22. Understanding the different waveform sets and certification levels is critical to planning how systems will undergo testing in efforts to meet compliance.

© 2016 Hydra-Electric Company

Background

It is estimated that in-flight aircraft are struck by lightning approximately once every 1,000 flight hours. Statistically speaking this means that each commercial aircraft can experience one lightning strike per year. Fortunately, modern aircraft are designed to handle a direct lightning strike. In fact, the last U.S. commercial aircraft to crash as a result of a confirmed lightning strike occurred in 1963 when a direct hit by lightning ignited the fuel tank causing an explosion that caused a catastrophic failure of the wing. As a result of this disaster, the FAA ordered all planes to be equipped with static dischargers. In the decades since then, only two other commercial U.S. airline crashes listed lightning as a contributing factor.

Lightning occurs when regions of positive and negative electrical charges try to achieve equilibrium through charge transfer. These highly charged areas are created as a result of collisions among super cold water and ice particles within clouds. Once the electric potential between the negatively and positively charged regions exceeds the insulation resistance of the surrounding air, a spark or discharge creates the familiar lightning flash. Each lightning strike can carry 20,000 to 30,000 amperes of current at a rate of 1 x 108 meters per second. In addition, the core temperature of the electrically charged plasma can exceed 50,000 degrees Kelvin. It is the rapid expansion of heated air around the lightning bolt that creates a shockwave that is felt as thunder. While cloud to ground lightning is the most understood, it is the intra-cloud (within the cloud) and inter-cloud (cloud-to-cloud) lightning that are more common and can pose the greatest threat to in flight aircraft.

On Dec. 8, 1963 a Pan American World Airways Boeing 707-121 crashed while in a holding pattern awaiting clearance to land in Philadelphia after a flight from Baltimore. Accident investigators determined that the lightning strike had ignited fuel vapors. As a consequence of the ensuing investigation by the U.S. Federal Aviation Agency — a precursor of the Federal Aviation Administration (FAA) — devices known as lightning discharge wicks were ordered to be installed on all commercial jet airliners.

© 2016 Hydra-Electric Company

While the vast majority of lightning strikes are commonly formed within and between clouds without any assistance, it is believed that more than 90% of lightning strikes experienced by an aircraft are actually initiated by the aircraft itself, when it is found in the intense electric field region of a thundercloud (Uman & Rakov, 2003). Damage to an aircraft by a direct lightning strike occurs when high current travels through the metallic portions of the aircraft causing localized heating and sparking. While many aircraft may require repair after such a strike, the resulting damage rarely affects the safety of the aircraft in flight. Fortunately, the occupants of the aircraft are protected from the effects of a lightning strike because the metallic fuselage acts as a Faraday cage. The idea of a Faraday cage was first proposed in the 1800's by Michael Faraday. Any conducting, hollow structure (i.e. aircraft fuselage) protects the occupants from the effects of strong electrical fields by distributing the charge along the outside of the structure while leaving the inside uncharged.

90%

of lightning strikes experienced by an aircraft are actually initiated by the aircraft itself.

Source: Uman & Rakov, 2003

Damage can also be caused by the indirect effects of lightning when electric and magnetic fields are created as a result of high current traveling through the aircraft skin. Transients can also be caused by rapidly changing electrical fields regardless of whether or not the lightning passes through or nearby the aircraft. Transient electrical pulses caused by the various fields can wreak havoc on an aircraft's electrical system by damaging sensitive and unprotected electrical components.

© 2016 Hydra-Electric Company

Transients Caused by High Current

When high current from a lightning strike travels through the aircraft, it creates an induced voltage throughout the metallic portions of the aircraft. The peak voltage is proportional to the current due to resistive coupling or inductive coupling. Resistive coupling typically occurs when the aircraft structure is highly conductive and a voltage gradient develops on the inner surface of the metal structure, whereas, inductive coupling (also known as aperture coupling) occurs when electromagnetic waves enter through windows and other apertures in the aircraft. Inductive coupling is also observed in aircrafts made of composite materials where the electromagnetic fields are more likely to penetrate the aircraft and enter into the electronic systems. In some cases, the induced voltage waveform may be proportional to the rate of change of the current as it interacts with magnetic fields. When this occurs, the peak voltage is proportional to the maximum rate of current change from the lightning pulse.

Transients Caused by Electric Fields

Another source of induced transients occurs when lightning passes through or nearby an aircraft causing it to experience a rapidly changing, highly intense electric field. Wires and cables exposed to this electric field can experience large transient currents that are proportional to the rate of change of the electric field. In addition, electric fields above 2,000 Volts may result in corona discharge along the aircraft edges which produce Radio Frequency emissions that can exacerbate the electric field risk.

© 2016 Hydra-Electric Company

Designing and Testing for Lightning

All electronic or electrical systems in an aircraft must go through a rigorous process to determine if any lightning induced failure may create a risk to the aircraft. First, all systems should be analyzed to classify their failure condition and to assign the appropriate certification level. Any failure condition that is determined to be “Catastrophic” is assigned the Lightning Certification Level A. Failure conditions that are determined to be “Hazardous” or “Major” are assigned Lightning Certification Levels B or C, respectively. Once the Lightning Certification Levels are determined, then the appropriate test levels can be assigned.

RTCA DO-160, Section 22 (Lightning Induced Transient Susceptibility)

The only way to be absolutely sure that your system will handle the effects of a lightning surge is by test. The most widely referenced test specification in the military and aerospace industries for determining “Lightning Induced Transient Susceptibility” is RTCA DO-160, Section 22. The test waveforms and test levels in this specification are designated using six (6) characters. The odd numbered characters (1st, 3rd & 5th) are used to identify the test type/waveform set and the even numbered characters (2nd, 4th & 6th) are used to identify the test level to be performed.

© 2016 Hydra-Electric Company

The various test waveform sets are determined based on the test type and the degree to which the system is exposed to lightning transients. The test types are Pin Injection, Cable Bundle (Single/Multi Stroke) and Cable Bundle (Multiple Burst) and are identified by character designators 1, 3 and 5, respectively. The test waveform sets for each of those test types is then further categorized by the type of coupling (i.e. Aperture vs. Resistance) that the system will see and the type of cabling (i.e. Shielded vs. Unshielded) that is used. Table 1 shows the various test types and their respective test waveform sets. General selection criteria for determining the correct waveform set is also listed. The various Lightning Induced Transient Susceptibility waveforms used for each waveform set are further defined in RTCA DO-160, Section 22 and should be referenced when certifying the system under test. It should be noted that prior to the latest revision (Revision G) of RTCA DO-160 only five (5) characters were used to identify the test requirements. The sixth character was added when an additional test waveform was added to the Multiple Burst test.

What is RTCA?

RTCA is a private, not-for-profit association founded in 1935 as the Radio Technical Commission for Aeronautics. Chartered by the FAA to operate Federal advisory committees, RTCA employs a consensus-driven process to generate minimum performance standards for CNS/ATM (Communications, Navigation, Surveillance / Air Traffic Management) systems and equipment.

© 2016 Hydra-Electric Company

The test levels can range from 1 through 5 and are determined based on the Lightning Certification Level. For instance, a Lightning Certification Level C (Major) will require testing to Level 2 in accordance with RTCA DO-160G, Section 22. In cases where Level C systems may experience severe lightning transients, testing to Level 3 lightning requirements may be required.

Table 1 **RTCA DO-160G, Section 22 Test Waveform Selection Criteria**

Character Designator Location	Test Type	Waveform Set	Test Waveform Selection Criteria
1st	Pin Injection	A	Aperture coupling
		B	Aperture and resistance coupling
3rd	Cable Bundle — Single Stroke	C	Unshielded, Aperture coupling
		D	Unshielded, Aperture and resistance coupling
		E	Shielded, Aperture coupling
		F	Shielded, Aperture and resistance coupling
	Cable Bundle — Single/Multiple Stroke	G	Unshielded, Aperture coupling
		H	Unshielded, Aperture and resistance coupling
		J	Shielded, Aperture coupling
		K	Shielded, Aperture and resistance coupling
5th	Cable Bundle — Multiple Burst	L	Long cables greater than 3 meters in length
		M	Short shielded cables

© 2016 Hydra-Electric Company

Table 2 shows a list of the Lightning Certification levels and some general considerations when selecting the appropriate Lightning Induced Susceptibility test level. Test level considerations for Lightning Certification Level A are a little more involved and require determining failure conditions and malfunctions that can affect Systems as opposed to Displays only. Determining test levels for Lightning Level A displays can use a similar approach as to that used for Level B and Level C Certification Levels.

Table 2 **RTCA DO-160G, Section 22 Test Level Considerations**

Lightning Certification Level	Failure Condition	RTCA DO-160, Section 22 Test Level Considerations
A	Catastrophic	For Level A Systems: Requires a more rigorous, detailed analysis to determine transient levels.
		For Level A Displays: See Table 3 for Test Levels
B	Hazardous	Level 3 for most systems
		Levels 4 or 5 in areas with more severe lightning transients*
C	Major	Level 2 for most systems
		Levels 3 in areas with more severe lightning transients*

** These areas may be external to the fuselage, in poorly shielded composite structures and other exposed areas.*

© 2016 Hydra-Electric Company

Table 3 lists design level considerations that can be used to determine the appropriate Lightning Induced Transient Susceptibility test levels for Level A Display only. Level A Systems (i.e. control systems) require a much more rigorous and detailed analysis for determining Lightning Induced Transient Susceptibility compliance and are beyond the scope of this paper.

Table 3 **Design Level Consideration for Level A Displays**

Level	Design Level Considerations for Level A Displays
1	Used when cable bundles and components are in “well protected” areas of the aircraft. Areas that are “electromagnetically” enclosed would meet this criteria.
2	Used when cable bundles and components are in “partially protected” areas of the aircraft. Examples of this are within a metallic aircraft structure or in a well shielded composite aircraft structure.
3	Used when cable bundles and components are susceptible to “moderate” lightning transients. Systems located in the cockpit or near a large window or aperture that has no EMI protection would fall into this category.
4	Used when cable bundles and components are susceptible to “severe” lightning transients. Systems outside of the fuselage would fall into this category.
5	Used when cable bundles and components are susceptible to “very severe” lightning transients. Examples of this are in areas where there is little or no shielding and areas where there is no likelihood of electrical bonding to the aircraft. This level is typically selected when the equipment is located within composite materials where shielding is very ineffective.

© 2016 Hydra-Electric Company

Conclusion

Navigating through the various specifications and requirements for determining an aircraft's susceptibility to lightning can be a confusing and daunting task. Developing a verification and compliance plan for aircraft systems requires a thorough knowledge of the lightning environment, the location of the system within the aircraft and the level of shielding provided to the affected electrical systems. This paper is designed to provide a brief overview of lightning induced transient susceptibility and to assist engineers in developing an initial assessment of their verification and compliance plan. Further detailed analysis is required to determine the exact lightning test levels and their effects on sensitive electrical equipment.

Protection of sensitive electronic and electrical systems is key to reducing the risk associated with lightning induce transient voltages in aircraft systems. Research has shown that proper lightning protection has significantly reduced the number of electrical failures caused by lightning strikes. Through careful design and rigorous testing, Hydra-Electric has developed proprietary technology that protects its sensors and transducers from some of the highest levels of lightning induced transients and EMI required by the aerospace industry.

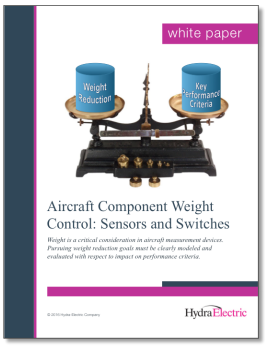
© 2016 Hydra-Electric Company

MORE
Recently Published White Papers

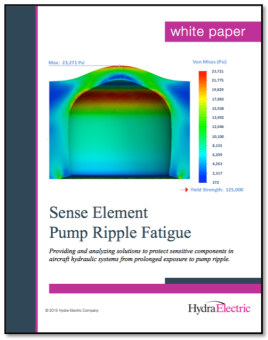
Available for download from our Knowledge Center

www.hydraelectric.com/knowledge-center

Aircraft Component Weight Control



Sense Element Pump Ripple Fatigue



About Hydra-Electric

Hydra-Electric is a provider of breakthrough technology in sensors and switches for the aerospace industry. Its suite of solutions includes pressure, temperature and multi-function sensors; and pressure, temperature and liquid flow switches. Hydra's high performance sensing technology is able to address problems which were previously thought to be unsolvable, including pressure spike damage, pump ripple, high speed impulses, burst diaphragms, broken wire bonds and more.

The company has been an innovator in the industry since 1948 when it introduced the snap action sensing of pressure by means of the negative rate disk spring, a design that remains the standard today for most aerospace pressure switches. Hydra-Electric's products have been used across hundreds of military and commercial applications, including fixed wing and rotary aircraft, missiles, rockets, ships, submarines, tanks and UCAVs.

CONTACT

818.843.6211

www.hydraelectric.com

info@hydraelectric.com

Follow us at twitter.com/hydraelectric

© 2016 Hydra-Electric Company