Multiple Stroke Testing

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INTRODUCTION

Multiple stroke induced lightning testing involves some of the most stringent test waveforms to which subsystem level equipment is subjected. It also involves some of the most difficult waveforms to generate. Multiple stroke tests are becoming increasingly more commonplace because the latest revisions of aircraft test specifications now require testing to this electromagnetic environment. Previously, testing had been performed on a single stroke basis only. This is not, however, indicative of the true lightning strike environment.

Multiple stroke lightning tests are becoming increasingly commonplace.

LIGHTNING GENERATION

The multiple stroke phenomenon comes from what is witnessed as a single lightning strike. What is actually taking place is a series of strikes in rapid succession. To fully understand the multiple stroke phenomenon, formation of the lightning strike must be considered.

As a cumulonimbus cloud builds, charge separation occurs in the cloud and various pockets of charge form. The bottom of the cloud becomes electron rich, gaining in negatively charged ions. This in turn pushes electrons away from the surface of the earth, over which the cloud is passing. The net result is that of a positive charge building up on the earth's surface.

As the charge continues to build, a stepped leader composed of negatively charged ions winds its way down from the cloud to the ground, finding the path of least resistance. As it approaches the ground, a positively charged leader is drawn up from the ground. When they meet, a conductive channel is opened and an extremely high current pulse is formed. This is known as the initial return stroke.

For most lightning strikes, however, this is not the end of the process. The conductive path is kept open by an intermediate current and a continuing current. This is where most of the actual charge transfer takes place. The charge pockets within the cloud are fed into the conductive channel, resulting in restrikes. These restrikes occur on the order of tens to hundreds of milliseconds and can last for up to two seconds. They are joined by the continuing current which keeps the conductive channel open. It is the effects of the initial return stroke and the restrikes that are tested for in multiple stroke induced lightning tests.

WAVEFORM DEFINITION

The initial return stroke yields currents up to 200 kA with an action integral of 2×10^6 A^2s. The restrikes yield peak currents of 100 kA with an action integral of 0.25×10^6 A^2s. The time between restrikes varies from 10 ms to 200 ms. Figure 1 shows these waveforms with a single restrike linked by the continuing and intermediate currents.

When lightning strikes an aircraft, or when an aircraft flies into a lightning channel, the lightning current flows through the skin of the aircraft. Transients are induced onto conductive structures on the inside of the aircraft. These transients exhibit waveform pa-

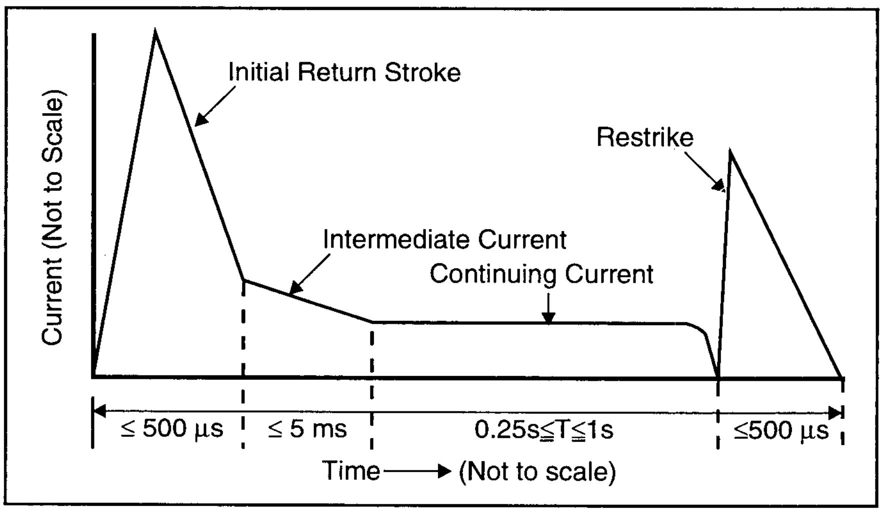

Figure 1. *Current Waveforms.*

rameters which are dependent on the conductive structure onto which they are induced.

On the internal structure, the reference for most electrical equipment, a double exponential transient current flows that is representative of the lightning waveform and has the following typical parameters. The 0 - 100% rise time is 6.4 µs. The half-peak duration time is 70 µs. When this waveform is inductively coupled onto interior conductive elements such as cabling, a double exponential derivative waveform results. The 0 - 100% rise time is less than 100 ns. The zero-crossing duration is 6.4 µs.

Cabling also tends to "ring" when electrically shocked. One origin of this response is arcing in the aircraft. This ringing is exhibited as a damped sinusoidal waveform. For most aircraft, the resonant ringing frequency falls in the 1 MHz to 50 MHz range. These waveforms are shown in Figure 2.

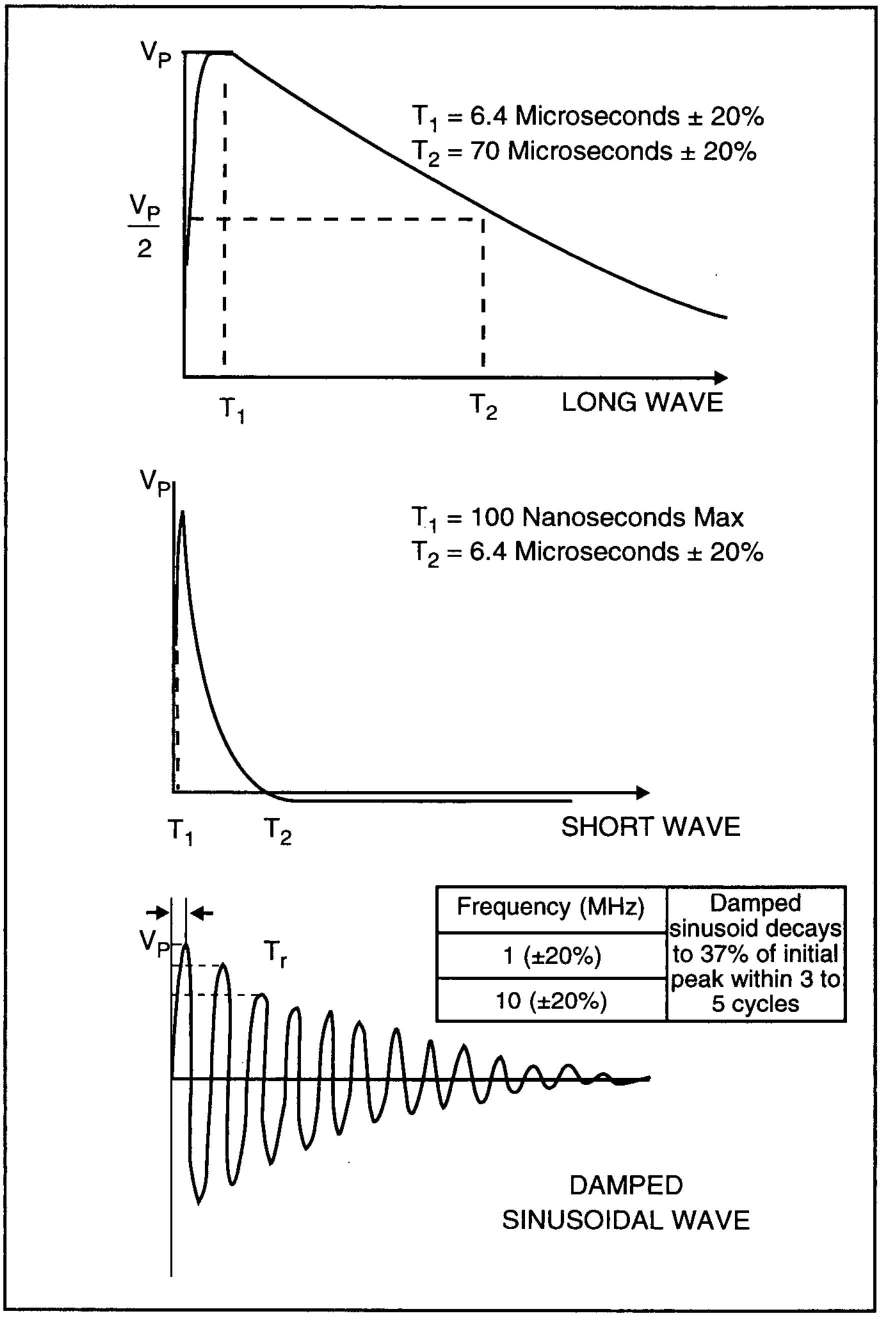

Figure 2. *Voltage Waveforms.*

TEST SPECIFICATIONS

SAE AE4L Committee Report: AE4L-87-3, Revision B (the Orange Book), "Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning" identifies these waveforms as induced waveforms. (FAA Advisory Circular AC 20-136 is essentially an identical document.) Various voltage and current levels are defined which are dependent on equipment location within the aircraft. Locations range from well-protected environments to severe electromagnetic environments.

For the most part these levels are carried over in RTCA/DO-160C, "Environmental Conditions and Test Procedures for Airborne Equipment," Section 22, "Lightning Induced Transient Susceptibility." The December 4, 1989, issue contains procedures for single stroke testing only. This is not indicative of the actual lightning induced environment. The December 1991 draft issue of DO-160, Section 22, does not specifically call out for multiple stroke testing, but does state that performance may be necessary to achieve system certification.

Boeing Specification D200Z001, Revision C, requires multiple stroke testing for equipment deemed critical and single stroke testing for essential equipment. Boeing Document No. D6-16050-3 contains multiple stroke tests, but leaves it to the individual equipment specifications to require multiple or single stroke applications of the waveforms.

In these documents each multiple stroke application of the various induced waveforms is as follows. A single transient of full amplitude is followed by 23 transients of at least half amplitude. These transients are spaced between 10 and 200 milliseconds

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apart, and must occur within a 2-second period. This is displayed in Figure 3. For test repeatability and additional assurance, the equipment under test is subjected to ten sets of the multiple stroke transients within a 2-minute period. The polarity of the waveform is reversed and the test is repeated. Although most lightning is of the same polarity, the equipment on the aircraft may experience either positive or negative polarity transients depending on where the lightning enters and exits the aircraft and the equipment placement within the aircraft.

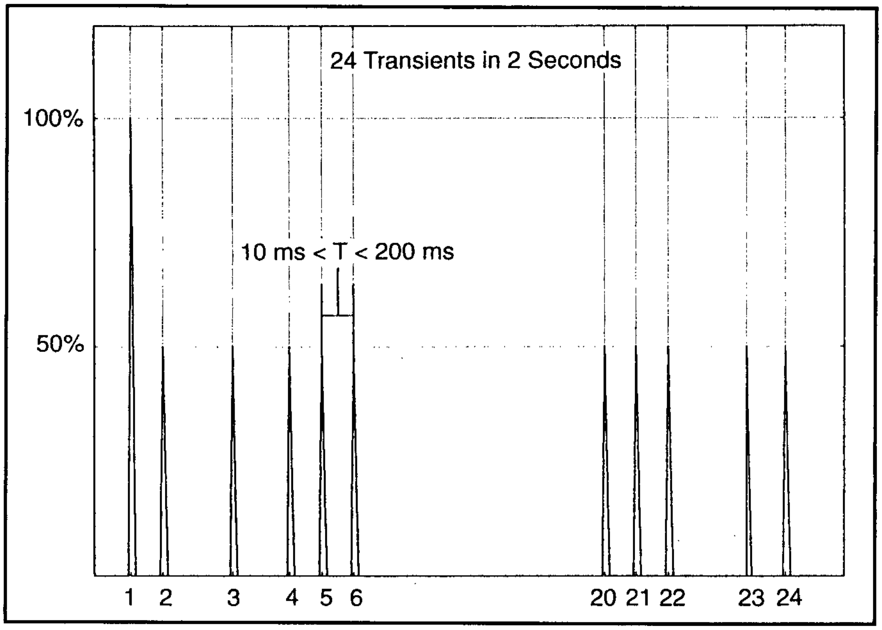

Figure 3. *Multiple Stroke Definition.*

TEST PERFORMANCE

Now that multiple stroke testing is required, it must be performed. There are several paths by which a manufacturer can perform these tests. If an in-house EMI laboratory is already present, construction of generators is one possibility.

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These generators incorporate many different areas of expertise. The tank circuit to produce the individual waveforms requires RF knowledge. This circuit needs to meet the levels required, which means that high voltage is also involved. In order to produce the multiple stroke set of transients, solid state control is required. The 6.4 x 70 µs waveform requires a fairly large capacitor to produce the required waveform. Charging this capacitor in time to fire at the multiple stroke rate may require a special power supply design. Unless the correct resources and personnel are available, the design and construction of generators necessary to meet the requirements could easily turn into an expensive and seemingly never-ending process.

The most effective way to have these tests performed is to either buy the necessary test equipment or hire an independent test lab with the necessary multiple stroke capabilities. If an in-house lab already exists and the testing needs are frequent, then purchasing the test generators may be the most cost-effective way of performing the tests. Most labs already have the necessary support equipment (storage oscilloscopes, current probes, voltage probes, etc.).

If the testing need is infrequent or an in-house laboratory does not exist, then the best way to perform the multiple stroke tests is by hiring an independent test lab with the appropriate capabilities. If moving the equipment under test is not an appealing proposition, the test performance equipment is portable enough that tests can be done on-site.

CONCLUSION

The multiple stroke lightning environment is an actual electromagnetic environment that an aircraft may encounter. Critical equipment aboard all aircraft should be tested to multiple stroke lightning requirements in order to assure flight safety. Specialized equipment is necessary for testing. This equipment is readily available, either through purchase of the equipment itself or through the test services of an independent laboratory.

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