Lightening Protection Of Launch Facilities At Kennedy Space Center

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ABSTRACT

The location of the Apollo Launch Complex in a region of high lightning incidence necessitated that protective measures be incorporated in the design of the complex and its associated control facilities to prevent damage or interference with launch operations. Hazards to personnel, fuel and electrical or electronic systems were of particular concern. General Electric's High Voltage Laboratory, under contract to NASA, designed protective measures which were incorporated in the complex. These included control of lightning attachment points on the complex and provision of safe conduction paths to ground, control of lightning-induced voltages in umbilical systems by application of shielding and circuit routing criteria, and protection of above and below ground instrument and power cable runs by appropriate shielding and grounding techniques. As a result of these measures being incorporated in the launch complex design, very few incidents of lightning related interference or damage have been recorded. The few that have occurred are associated with incomplete application of the protective criteria.

INTRODUCTION

The launch facilities for the Apollo vehicles, being located on a flat plain in a region of high thunderstorm incidence, were early recognized as prime targets for lightning flashes. In 1962 there was formed a lightning study team composed of representatives from the various NASA branches with the aim of assessing the hazards that lightning would present to the launch facilities and to the flight vehicle and to study how these hazards might be reduced or eliminated. In early 1963 a contract was signed with the General Electric Company's High Voltage Laboratory so that its expertise in the field of lightning and lightning protection could be brought to bear on the problems. The purpose of this paper is to give a review of the hazards that lightning presented, to discuss how lightning protection facilities were incorporated into the design of the launch facilities and to review the performance of these protective features.

There were three major categories of possible effects that lightning might produce. The first was the potentially catastrophic accident if lightning were to ignite the great quantities of propellants in the vicinity, either by a direct flash to a fueled vehicle or by a flash to the fuel storage facilities. The second category of problems dealt with the remote though more personal hazards of electrocution of people working on the ground on the launch towers. The third category dealt with the more subtle hazards of damage to electrical control and guidance equipment. One can visualize a scenario in which lightning burns out one relay or transistor, and because the damage remained hidden, causes loss of an entire mission. Such a possibility was remote because of the redundant designs and automated checkout facilities. The possibility of a mission hold or scrub because of such burnout was however very real.

NUMBER OF LIGHTNING INCIDENTS TO BE EXPECTED

As a rough rule of thumb one might expect 0.25-0.50 lightning flashes to each square mile of flat terrain for each thunderstorm day. Since the isokeraunic level, or the number of days during the year when thunder is heard, is about 75 at KSC one would expect 19-38 lightning flashes per year for each square mile or 7-15 flashes per square kilometer. Within the confines of the launch pad one would expect 4 to 8 lightning flashes per year. The great majority of such flashes land in places remote from anything connected with the launch facilities and would be no cause for concern. disc of the tall structure or hydrogen dewars, however, would intercept most lightning flashes that would otherwise terminate on the ground over a diameter several times the height of the structure. From geometrical considerations and past experience one could then predict that the number of flashes intercepted by structures would vary with their height as shown of Figure 1. Thus, one might expect the umbilical tower to be struck 3 times per year, the VAB to be struck 4-5 times and the hydrogen dewar to be struck perhaps once every two years. Most of the flashes would occur during the summer months since historically 70 percent of the thunderstorm days occur during the months of June-September. Rather than refine the statistics further for this paper suffice it to say that the probability of being struck was sufficiently large that lightning could not be ignored.

PROTECTION OF TOWERS AND VEHICLE AT LAUNCH SITE

Interception of the Lightning Flash

The choices open to the lightning protection team were either to prevent lightning from occurring, to
divert it away from places where it might cause damage or to make all structures immune to a direct lightning flash. There were several concepts whereby electrification might be eliminated and whereby lightning might be diverted away from the launch pad. A number of schemes were considered whereby lightning might be diverted away from the launch pad. The most practical of these was to erect one or two guyed towers alongside the launch pad. Two towers each about 550 feet (165 meters) high would have provided the best protection. All the evidence indicated that such towers would indeed keep lightning flashes from hitting the vehicle or umbilical tower while located on the launch pad. Such towers however could not have protected the vehicle while it was being transported from the VAB to the launch pad unless they were near the vehicle on their own mobile transporters. This would have entailed a prohibitive expense. Also considered were guyed balloons, which in principle at least could be flown from trucks driving alongside the vehicle while in transit or parked permanently on the launch pad. These, too were unattractive because of their cost and because of the operational difficulties of keeping the balloons in their desired positions, regardless of the direction of the wind.

The most practical type of protection seemed to be to use the umbilical tower itself to intercept the lightning flash and insure that no flash would strike the vehicle directly. This was feasible since the umbilical tower was sufficiently massive that no conceivable lightning flash would damage the tower itself.

The criterion used to determine whether a flash would terminate on an object or be diverted to an adjacent higher structure was the same honored cone of protection concept. This concept, proven by experience since Franklin's day, is illustrated on Figure 2. It simply states that an object of height, h, will attract to itself lightning flashes and prevent nearby and lower objects from being hit if they lie within a cone centered on the taller object and having a base radius equal to the height of the taller object. This concept assumes the protecting object is a good conductor and not a poor conductor like a tree. An object just outside such a cone however is not completely exposed to lightning. The protective range of a given object extends for a radius several times its height, with the degree of protection decreasing as the further one is away from the protecting object. Substantial protection is still provided for objects inside a cone having a base radius twice the height of the protecting object. Accordingly an extension of the cone of protection concept was developed as shown on Figure 3. This stated that protection equivalent to a 1:1 cone would be provided an object covered by overlapping 2:1 cones produced by two protecting objects.

When the concept of a 1:1 cone was applied to the original designs of the vehicle and the umbilical tower it was found that the escape rocket and a portion of the command module were not within a 1:1 cone when the service structure was rolled away from the pad and the vehicle was ready for firing. Such a configuration would occur when the vehicle was fully fueled and probably manned. This would be the period when a flash to the vehicle would cause the greatest concern. While the probability of the vehicle being struck was low it could be reduced even further by increasing the height of the umbilical tower. This was most easily done by putting a 90 foot tower atop the crane on the umbilical tower. Figure 4 shows the protected regions with and without the tower. Incidentally this tower had to be hinged at the base so it could be lowered when the umbilical tower was taken inside the VAB.

When the mobile service structure was parked adjacent to the umbilical tower the vehicle was shielded even more completely.

Conduction of Current to Ground

Assuming the umbilical tower to be struck by a lightning flash the surge currents of 20,000 - 200,000 amperes had to be conducted to ground and dissipated in the earth. In principle one could use an insulated conductor from the top of the tower in an attempt to keep the lightning currents out of the umbilical tower or the vehicle. In practice this cannot successfully be done since it would require a conductor insulated sufficiently that it could withstand several million volts, insulation equivalent 15-30 feet of air. While such insulation could be provided the flow of current along an insulated lightning conductor would still induce large currents in the adjacent umbilical tower. Accordingly the lightning mast atop the umbilical tower was solidly connected to the crane body and the lightning current permitted to flow down the legs of the umbilical tower.

Not all the current however flows down the tower. Since the umbilical arms provide electrical paths between the tower and the vehicle a portion of the lightning current will flow to ground through the skin of the vehicle. The manner in which the current divides has been studied both by means of tests on small scale geometric models and by means of equivalent circuits. A typical pattern is shown on Figure 5. The significant point to observe is that currents of tens of thousands of amperes may flow across the umbilical arms onto the vehicle. While these currents appear large, they are, by virtue of short duration, easily carried by very small conductors. The legs of the umbilical tower or the structural members of the umbilical arms can carry any conceivable lightning current with impunity. Accordingly there was no necessity for copper lightning conductors running the length of the umbilical tower and none, in fact, were used.

The lightning current thus flowed down the legs of
the umbilical tower onto the umbilical tower platform and from there onto the support pedestals and into the ground grid.

Grounding

An extensive ground grid was provided around the launch pad. This was formed through the use of buried conductors or counterpoise connected to driven ground rods. In general, the ground rods were driven sufficiently deep to achieve a one ohm ground resistance. Figure 6 shows some of the locations where ground rods and counterpoise were originally planned. During construction numerous extra ground rods were driven so that the grounding grid was even more extensive than shown here.

CONTROL OF TRANSIENT VOLTAGES

The changing electromagnetic fields associated with the flow of lightning current can induce dangerous transient voltages on control wiring if the wiring is routed incorrectly or if improper shielding and grounding practices are used. The fundamental problem is shown on Figure 7. The flow of current across the umbilical arm (I1) or down the legs of the tower (I2) produce changing magnetic fields (dB and d2) in the regions surrounding the control wires. By Lenz's law these changing magnetic fields produce voltages

\[ V_{total} = \frac{dB}{dt} + \frac{d2}{dt} \]

between the wires and the structural steel. These voltages divide inversely according to the circuit impedances at the ends of the wire, appearing in this case as the two line-to-ground voltages \( V_1 \) and \( V_2 \). These could easily have amplitudes of thousands of volts. These voltages were controlled by providing shields on all control wiring. These shields took two forms:

1. All wiring exposed to the magnetic fields of lightning was carried in cables having an overall braided shield.

2. This overall shield was grounded, at each end, to the structural steel framework of the umbilical tower onto the side of the vehicle. This shield was not grounded to any sort of insulated or low noise or single point ground.

3. Cables running up the umbilical tower were contained in shielded cable trays.

On some previous launch towers these trays were placed along the outside of the tower. In such a location the trays themselves would carry a substantial part of the total lightning current and were also in a region where the magnetic fields produced by the tower current were greatest. On Complex 39 the cable trays were deliberately located within the tower where the magnetic fields produced by current flowing down the tower were lowest.

MISCELLANEOUS LIGHTNING PROTECTION PROBLEMS

Grounding of the Crawler while in Transit

During the time the vehicle was being moved from the VAB to the launch pad it was as much a target for lightning as it was at the launch pad. The vehicle itself was shielded by the umbilical tower and so the problems of interception of the flash while in transit were no different than when mounted at the pad. Grounding however is difficult to achieve. Consideration was given to various types of sliding contacts between the transporter and buried rails or buried cables. None of these proved to be necessary since if the lightning flash could jump several thousand feet through the air to the umbilical tower it could easily jump another few feet between the crawler tracks and the low resistance soil underlying the crushed rock upon which the crawler treads rested. Such an arcing contact to ground required that the crawler, the umbilical tower, the vehicle and all the checkout equipment contained in the mobile launcher be elevated during a strike to several hundred thousand volts above the potential of the surrounding ground. This however presented no hazards since none of the electronic equipment in either the vehicle or the launcher was connected to points remote from the local ground. All of the electrical equipment in the launcher would remain at the potential of the launcher, regardless of what that potential was relative to the potential of the nearby soil into which the lightning flash is discharging. Thus, as long as there were no circuit connections from the vehicle or launcher to remote points the voltages on the electrical equipment within the vehicle and the launcher would be the same regardless of how well or poorly the launcher itself was connected to earth. Sparking from the treads of the transporter was then not, per se, harmful.

Uncontrolled sparking however was not desired, mostly because there was a remote possibility of sparking between the transporter and a cable tray system that was originally planned to be built immediately adjacent to the crawler way. In order to provide a controlled sparkover path to ground there was provided a continuous counterpoise wire buried just under the ground in the center of the crawler way. Over this was then dragged a chain fastened to the crawler. In the event of a lightning flash to the umbilical tower any discharge from the crawler would take place from the chain to the counterpoise wire just below the surface of the ground. The purpose of the chain then was not to provide a low resistance ground for the crawler, but only to provide a controlled sparkover path from the crawler to the ground.

Protection of Cross Country Cable Systems

A lightning flash, if it struck directly on a cable, could burn through the shield and inject high currents and voltages onto the internal signal conductors. To prevent this all above ground cable trays were shielded by an overhead ground wire as shown on Figure 8. The supporting post for the
ground wire was insulated from the cable trays so that the lightning current was carried directly to ground. This minimized the current flow through the cable trays.

Buried cable ducts were protected with either one or two bare copper ground cables buried about a foot above the cable ducts.

PERFORMANCE OF THE LIGHTNING PROTECTION SYSTEM

There have been a number of lightning flashes to the launch facilities at KSC, ranging from a stroke while the first test vehicle was being transferred from the VAB to the pad to five flashes while Apollo 15 was on the pad. None of the flashes terminated on the vehicle; all of them terminated on either the umbilical tower or the service structure. There were of course the two flashes to Apollo 12, but these occurred after the vehicle was in flight. There have been no instances of fire or physical damage and no personnel injuries caused by any of the lightning flashes. There were several cases of damage to electronic equipment caused by the flashes associated with Apollo 15. This damage however all seemed to be associated with systems in which cable shields were not properly made. As mentioned earlier it is of prime importance that all cables exposed to the electromagnetic fields be fitted with overall shields that are continuous and are grounded at each end. On those systems that were damaged either the continuity of the overall shield had been broken by omission of jumpers in terminal boxes or the overall shield had not been grounded to the structural steel at each end. Equipment consoles identical to those damaged, but connected to properly made cable systems were not damaged, even though they were exposed to the same lightning strokes.

ILLUSTRATIONS

Figure 1 - Expected Flash Rate as a Function of Height.
Figure 2 - A 1:1 Cone of Protection.
Figure 3 - Two Overlapping 2:1 Cones of Protection.
Figure 4 - Shielded Regions with and without the Added Lightning Mast.
Figure 5 - Manner in which Stroke Current Divides.
Figure 6 - Launch Area Ground Rod Locations.
Figure 7 - Voltages Induced by Electromagnetic Fields.
Figure 8 - Lightning Protection of Cable Trays.
FIG. 1 - EXPECTED FLASH RATE AS A FUNCTION OF HEIGHT

FIG. 2 A 1:1 CONE OF PROTECTION

FIG. 3 TWO OVERLAPPING 2:1 CONES OF PROTECTION

FIG. 4 SHIELDED REGIONS WITH AND WITHOUT THE ADDED LIGHTNING MAST
L STROKE

LOX LINE

13.2 KV CABLE

DATA LINK AND HP GAS GROUND SYSTEM

2/0 AWG COPPER

CABLE TRAY GROUND SYSTEM

VEHICLE CENTER CONNECT TO FLAME DEFLECTOR TRACKS

CRAWLER ROADSWAY GROUND SYSTEM

NOTE: GROUND ROD DRIVEN DEEP ENOUGH TO ACHIEVE A 1 OHM RESISTANCE

FIG. 6 - LAUNCH AREA GROUND ROD LOCATIONS

100%

14% 14% 14% 14% 14%

28% 14% 6% 14% 6%

34% 4% 4% 4% 4%

38% 5% 5% 5% 5%

43% 2% 2% 2% 2%

45% 1% 1% 1% 1%

46% 0 0 0 100%

46% 54 54 54 54

FIG. 5 MANNER IN WHICH STROKE CURRENT DIVIDES

FIG. 7 VOLTAGES INDUCED BY ELECTROMAGNETIC FIELDS

FIG. 8 LIGHTNING PROTECTION OF CABLE TRAYS