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A New Concept for Lightning Protection of Boats

Protect a Boat like a Building

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Ewen Thomson is a recognized expert on marine lightning and was instrumental in writing the new NFPA watercraft standard. He is also the founder of Marine Lightning Protection, a company that specializes in lightning protection of boats. This article is being published in the interest of disseminating new information about marine lightning grounding and is not meant to imply endorsement of any product.

"A Critical Assessment of the US Code for Lightning Protection of Boats" was the title of a paper[1] published in 1991 by the Institute of Electrical and Electronic Engineers (IEEE). True to its name, this peer-reviewed journal publication pointed out several key problem areas then existing in standards published by all major authorities concerning lightning protection of boats. Some, such as upgrading the size of a main lightning conductor from 8AWG to 4AWG, required minor editorial changes while others were fundamental issues that had no clear solution. A major issue was the conclusion that "a 1-sq ft ground plate is shown to be hopelessly inadequate to prevent sideflashes in fresh water". In 1991 there was no practical solution for this. Stretching the grounding area into a long strip improves its theoretical performance but is difficult to implement. Another concern, which also gives a hint to the solution, becomes evident when we compare lightning protection techniques used successfully in buildings with those typically applied, with much less success, to watercraft. In buildings the lightning conductors are placed on the outside and terminate in multiple ground rods, also on the outside. On the other hand, the requirement that only one ground plate is called for in a boat usually results in a single down conductor running through the middle of the boat. With 20:20 predictability, internal side flashes frequently form between conductors in the lightning protection system and other conducting fittings. These internal side flashes can be prevented by bonding the fittings to the lightning protection system, as mandated in the standards, but bonding also increases the risk of external side flashes from the fittings to the water.

The obvious organization to address these problems is ABYC, whose marine standards form the basis for NMMA certification. In recognition of the above problems inherent in its Lightning Protection Standard E-4, in its latest rewrite ABYC downgraded E-4 to a Technical Report, TE-4[2]. However, even when the standard E-4 existed, it was not required for NMMA certification. During its latest revision cycle, the National Fire Protection Association (NFPA) has taken on a comprehensive rewrite of their lightning protection standard for watercraft based on the simple concept that the lightning protection system on a boat should resemble that on a building. The NFPA standard is reviewed on a four-yearly cycle by a committee of lightning protection professionals and contains not only code language but also several informational annexes explaining the underlying principles. The result in Chapter 8 of NFPA780-2008[3]is a new watercraft standard that is a major departure from the old. Instead of a single lightning rod (air terminal) at the top of a centrally located mast, many air terminals may be placed around the perimeter. Instead of a single down conductor following the straightest path to the water, an interconnected grid of down conductors are placed externally to fittings, crew and electronics. Instead of a single one-square-foot immersed ground plate, multiple grounding terminals terminate the down conductors, also preferentially externally.

Indeed, there are several instances where observed damage to boats can be related to shortcomings in the existing standard. Let's start with these. Then we can show what changes needed to be made to the marine standard so that a boat protection system looks more like that on a building. Finally we will discuss a system that has been designed in accordance with the new concepts.

Problems with previous standards

While there were a number of problems with the status quo (before NFPA780-2008), the major stumbling block was the mandate for a one square foot ground plate or strip. This was frequently interpreted to mean that that was all that was required and the best way to connect this was by the shortest path possible to a single air terminal on top of a mast. In my 1991 IEEE paper[1] I calculated what typical voltage the lightning protection system would reach if it were connected to a single immersed grounding conductor with a contact area of one square foot. In fresh water this voltage was found to be so large that sideflashes would be inevitable. (A side flash is an uncontrolled spark that carries current to the water and can do extensive damage to hulls and equipment.) This calculation was done to help explain observations of extensive sideflash damage in sailboats even when the mast was grounded to the keel or a ground plate. Cases such as that below from Boat US claim #950447 have necessitated a new term to be added to the glossary of lightning protection - a "supplemental grounding electrode" that conducts lightning current into the water in addition to that conducted by a main grounding electrode (or ground plate). In this case the anchor chain formed sideflashes through the hull causing extensive hull damage.


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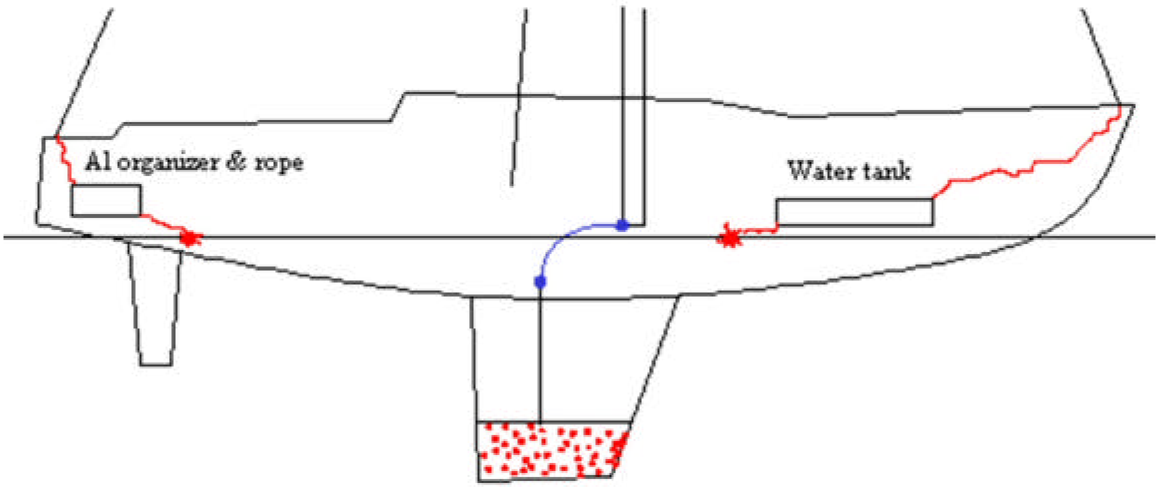
In another case, shown below, a water tank and an aluminum organizer acted as supplemental electrodes. The owner of this sailboat reported not only "thousands of holes" in the lead ballast- indicating that lightning current had indeed flowed out of the intended grounding conductor - but also noted two large holes at about the waterline and outboard of an aluminum organizer aft and a water tank forward. The side flashes that caused these holes originated, respectively, on the backstay and forestay and clearly took much longer and more tortuous paths than the shortest distance to the water. Apparently lightning does not always take the straightest path to the water, but rather has an affinity for the waterline. Note the major role of the two intermediate conductors (the organizer and the water tank) in guiding the side flash on its way to the waterline. It does not take much imagination to appreciate the probable consequences if a crew member had been lying in the V berth between the forestay chain plate and the water tank.



In other cases an aluminum I-beam mast support, a plumbing fixture, gel coat blisters, and moisture in the hull all acted as supplemental grounding electrodes. In fact, in another well-documented case the keel ballast appeared to have carried no current at all, but four large holes at the waterline implicated the lightning down conductors (connected to the keel bolts) as the grounding electrodes, which could hardly be interpreted here as being "supplemental".

When a side flash does occur through a fiberglass hull, carbon atoms are split out of the resin, thereby weakening the laminate, and this residual carbon now forms conducting paths through otherwise insulating fiberglass. So if the boat were to be struck again it is highly likely that the carbon traces would provide attractive current pathways but their high resistances would likely result in overheating. In other words, the risk for serious hull damage is increased if the carbon is not removed during repairs. Thus removal of all carbon tracks should be a high priority during the repair of any fiberglass hull damaged by lightning. Unfortunately, finding and repairing these traces is often problematic, but if there is a side flash exit from the hull, you can be sure there are carbon traces present.

So, theoretically, one square foot is not nearly enough. However, the illustration above shows that even the area of the lead ballast was not enough in this case. Apparently the problem is not so much the size of the grounding area but how it is distributed. Rather than attempting to dissipate the lightning current through just one ground plate, we need multiple exit points. The preferred locations for these, as indicated from observed exit holes, are around the outside of the hull rather than directly below the mast.

The single ground plate is not the only major problem. The short, straight connection from mast base to the ground plate is another. This places the lightning charge right in the middle of the boat, increasing the risk of internal side flashes to intermediate conductors on the boat. In this respect, electrical wiring, water tanks (whether metal or plastic), and crew members are all possible conductors.

NFPA standard: Protect a boat like a building

So what to do now? Well, remember that the standard for buildings has been around for a long time, has undergone many iterations under guidance from a committee of lightning experts, and works very well. The difference is that the building standard places multiple lightning rods, conductors and grounding rods on the *outside* of the building. Maybe we can do something similar for boats?

This one idea is the basis for the new NFPA watercraft standard[3]. When the NFPA committee on lightning protection saw the types of damage sustained by boats and recognized the fundamental causes, they agreed that there were serious issues that needed to be addressed. So we examined the existing standard with the intention of changing the fundamental concepts to be more in line with those applied to buildings. The result is a major departure. The final text is a comprehensive treatment of a whole lightning protection system, that includes details such as how to use existing fittings as part of the system and introduce spark gaps to minimize galvanic corrosion and electrolysis. Three main points stand out in stark contrast to the status quo.

1. Multiple air terminals

First, when determining where air terminals should be placed, any method that is allowable for buildings can now be used for boats. So, instead of having to use just the cone of protection method to establish the protective zone, the rolling sphere method can be used. This allows air terminals to be placed around the perimeter and results in much shorter lightning rods being required. For example, in a powerboat with a T-top, the inverted cone when hung off the T-top gives a zone of protection that usually does not cover the whole foredeck. If instead we use the rolling sphere method, we can add an air terminal on the bow pulpit, such as a metal flag staff, so that the foredeck is now included. As long as the forward air terminal is higher than head height, the theoretical zone of protection now covers anyone working the foredeck. An even better approach is to string a catenary wire between the T-top and the air terminal as an overhead conductor provides far superior protection to a vertical rod.

2. External lightning conductors

Second, consistent with the building standard, lightning conductors (note the plural) are placed preferentially on the outside of the boat. What this does is establish a protective shield, somewhat similar to a Faraday cage, around the interior of the boat. Inside of this shield everything is at about the same voltage as the lightning protection system even if there is no bonding connection. In the new NFPA standard a novel feature is a loop conductor that completely encircles the boat. This serves as a conducting backbone for the conductor network, allowing air terminals and grounding terminals to be interconnected, as well as establishing this protective shield around the interior of the boat.

The loop conductor serves the same function as the equalization bus in the old standard and replaces it. While equalizing potentials through bonding is a good idea, bonding conductors can also initiate side flashes. And the old mandate in Section 8.6.1.3 in the 2004 version of NFPA780 that "The equalization bus shall be connected to the underwater lightning grounding strip at both ends" virtually guaranteed that the bus would be centrally located and well below the waterline, two conditions that increase side flash risk. Instead, the new standard in Section 8.4.3.1 states "A main size loop conductor shall be routed … to form a continuous conducting loop *outboard* of crewed areas, wiring and electronics". Placing the loop conductor well above the waterline, outboard, and with grounding terminals below it retains the advantages of the equalization bus while correcting for its weaknesses.

3. Grounding terminals near waterline & around perimeter

Third, the multiple lightning conductors coming down the outside need to be terminated in multiple grounding terminals, preferably close to the waterline. Distributing the down conductors and grounding terminals uniformly around the hull promotes current flow away from the boat. This minimizes voltage differences in the water below the boat and hence considerably reduces the risk of sideflashes from conducting fittings, even those that are close to the water.

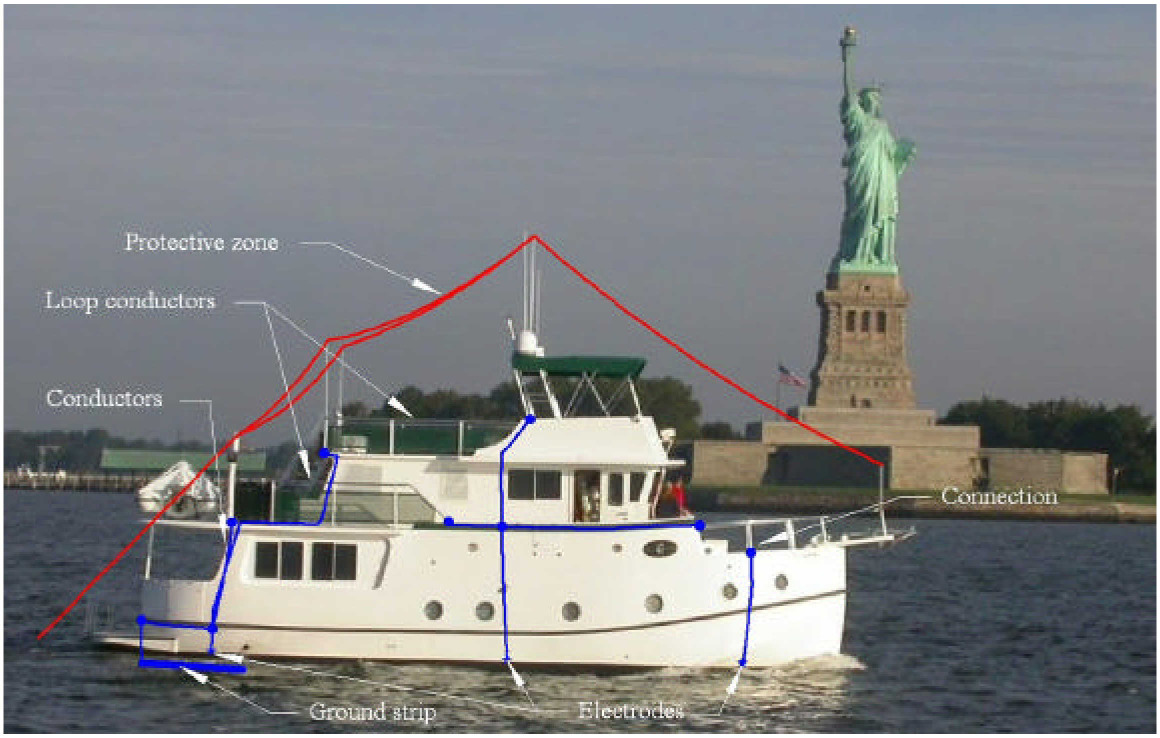
However this poses several practical problems if the only allowable type of grounding terminal is a one square foot immersed ground plate or strip. It is difficult enough to convince someone to bore holes through the hull below the waterline for installing even one immersed ground plate, let alone many. Doing this would appear to increase the risk of sinking after a lightning strike rather than decreasing it. In particular, if there has been any water leakage through these holes a steam-boiler type explosion is distinctly possible. So, if one is a problem, "multiple" compounds this to the point of infeasibility. And what about the old requirement that the ground plate should always be immersed? If a sailboat heels or powerboat comes to a plane the ground plate can become airborne.

So when the new standard mandates multiple grounding electrodes this could cause serious implementation problems. Note that "grounding electrode" is NFPA's new term for a grounding terminal in that it is a conductor through which current is passing at the interface between the lightning protection system and the grounding medium (water here). Fortunately, the damage we showed earlier indicates that lightning does not necessarily share this preference for immersed grounding conductors. In fact, the corners of water tanks, plumbing fixtures, metallic fittings and anchor chains seem to work just as well, and frequently much better. The same is true for immersed conductors such as metallic through hulls and propeller shafts that may have contact areas much less than one square foot. The waterline is a very popular target for sideflashes, and multiple exit points is the norm, especially in fresh water.

Recognizing that onboard fittings frequently act as inadvertent grounding electrodes, we have introduced the idea of a supplemental grounding electrode, one that has a contact area of less than one square foot, including zero. The standard still requires at least one main grounding conductor with an immersed area of at least one square foot, but now smaller additional grounding terminals are also allowed. This makes it feasible to install multiple grounding terminals using existing metallic fittings such as through-hulls, propeller struts, and rudder posts even those with contact areas less than one square foot. Alternatively, smaller fittings specifically designed to act as grounding electrodes can be added, as we have done for John Henry below. Note that ABYC TE-4 also allows that "Rudders, external ballast keels, or any metallic fitting with at least one external face can be used for supplemental grounding so long as they meet other requirements in this bulletin…".

Lightning protection system on *John Henry*

We have applied all of these new concepts in *John Henry*, a Great Harbour 47' passagemaker built by Mirage Manufacturing and displayed in last year's Annapolis powerboat show. The annotated photo below shows the main features. The red lines show the total zone of protection using the rolling sphere method. Any person walking anywhere on the deck is inside this protective zone. In order to achieve this coverage we placed air terminals on the bow pulpit, on top of the fly bridge arch, and on top of the handrails at the rear of the fly bridge deck. We also connected the dinghy davit to the lightning protection system. The blue lines show the additional lightning conductors which were made of 2AWG tinned copper marine battery cable. These were connected to existing conducting fittings - the handrails on both main and fly bridge levels, and the bimini – to form two conducting loops, one around the main deck level and the other around the fly bridge deck. Down conductors connected to these loop conductors were run vertically down the inside of the hull and terminated at Siedarc™ grounding electrodes at six locations symmetrically distributed around the waterline. The patented Siedarc™ electrode is a customized fitting designed specifically for lightning grounding. Each of these was installed just above the black stripe. One square foot of immersed grounding area was provided by a grounding strip placed near the stern of the boat. This placement allowed the down conductor to this strip also to be run down the inside of the hull, external to all conducting fittings and equipment. As an additional precaution, all through bolts for the grounding strip were contained inside a watertight lazarette. The cost of such an installation is around $6000-$7000. *John Henry* has not been struck by lightning yet so that the effectiveness of this system has not been tested. And while *John Henry's* owner may hope the boat is never hit, we would find such a strike would add tremendously to current data.



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Bio

Ewen Thomson is founder of Marine Lightning Protection Inc. (www.marinelightning.com),. His Ph.D. is in Electrical Engineering and he has nearly three decades of experience as a lightning researcher and university instructor, including 20 years at the University of Florida. The main author of the revision that led to NFPA780-2008, he was also involved in the development of ABYC TE-4.