TE-4 LIGHTNING PROTECTION

BACKGROUND

This technical information report is intended as a guide for the design, construction, and installation of lightning protection systems on boats. Its primary objective is to decrease the risk to personnel and the risk of fire and sinking. Additional measures may be needed to harden electrical and electronics systems against lightning damage.

The probability of a lightning strike varies with geographic location and the time of the year. When the conditions that create an electrical charge between clouds and the earth exist, there is nothing that can be done to prevent the lightning discharge. A boat can be struck in open water or while tied to the dock.

INTENT

This technical information report applies to powerboats and sailboats if a lightning protection system is installed.

Complete protection from equipment damage or personal injury is not implied.

A lightning protection system offers no protection when the boat is out of water, and is not intended to afford protection if any part of the boat comes in contact with power lines while afloat or ashore.

Protection of persons and small craft from lightning is dependent on a combination of design and maintenance of equipment.. The basic guides contained in this technical information report should be considered and used in designing and installing a lightning protection system. However, in view of the wide variation in structural design of boats, and the unpredictable nature of lightning, specific recommendations cannot be made to cover all cases.

REFERENCED ORGANIZATIONS

ABYC - American Boat and Yacht Council, 613 Third Street, Suite 10, Annapolis, MD 21403 (410)990-4460, Fax: (410)9904466. Website: www.abycinc.org.

NFPA - National Fire Protection Association, 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269-9101. (617) 770-3000. Website: www.nfpa.org.

DEFINITIONS – For the purpose of this technical information report, the following definitions apply.

Air Terminal - a device at the uppermost point of the lightning protection system that attaches a lightning stroke to the lightning ground system.

Lightning Bonding Conductor - a conductor used for potential equalization between metal bodies, and the lightning protection system.

Lightning Grounding Terminal - a device that conducts, the lightning current from the lightning protection system to the water.

Lightning Protective Mast - a conductive structure, or if non-conductive, equipped with a conductive means, and an air terminal.

Primary (Main) Lightning Conductor – a conductor intended to be used to carry lightning current between air terminals and lightning grounding terminals.

Secondary Lightning Conductor - a conductor used to connect conductive fittings, such as the rigging on a sailboat, to the primary lightning conductor, or to the lightning grounding terminal.

Side Flash - any discharge that occurs between the lightning system and any metallic object, or between any on-board conductor and the water.

Striking Distance – the final distance bridged by a lightning stroke when it makes its attachment to a grounded object.

Zone of Protection - an essentially cone shaped space below a grounded air terminal, mast, or overhead ground wire, wherein the risk of a direct lightning strike is substantially reduced. See Figure 1.

GENERAL INFORMATION

Each primary (main) conductor should have a resistance not greater than that of a #4 American Wire Gage (AWG) (21.2mm²) copper conductor of the same length.

Each secondary conductor should have a resistance not greater than that of a #6 AWG (13.3mm^2) copper conductor of the same length.

To provide a conductive path for the adequate discharge of lightning currents, from an air terminal to the water (ground), the system should consist of conductors that are essentially vertical and straight.

Conductors

Conductors should be tinned stranded copper Type II, if #4 AWG (21.2mm²) or smaller conductor, and may be type III stranding for any wire conductor larger than #4 AWG (21.2mm²), and in accordance with ABYC E-11, *AC and DC Electrical Systems on Boats*.

Copper ribbon should not be used as a primary conductor.

Ribbon or strip used in secondary conductor application shall have the same or less resistance than the equivalent wire and shall have a minimum thickness of 1/20 inch (0.8mm).

Copper braid should not be used.

End fittings and connections in stainless steel rigging introduce the possibility of high resistance. The rigging does not provide a reliable path to ground.

An aluminum mast with an area of at least 0.155 in² (100 mm²) would be considered an adequate conductor.

Air Terminal

An air terminal should be a minimum 3/8 inch (9.5mm) diameter copper rod, or 1/2 inch (12.7mm) diameter aluminum solid rod, extending at least six inches above the top of the lightning protective mast, with the end that is exposed to the clouds being rounded.

The means of securing an air terminal shall have a resistance not greater than that of a primary (main) conductor. If threaded, threads shall be fully engaged as per manufacturer's instructions.

Boats with ungrounded or non-conductive objects projecting above the metal masts or superstructure may have these objects protected by a lightning ground conductor terminating in an air terminal above the object.

Whip type radio antennas should not be tied down during a lightning storm if they have been designed as a part of the lightning protection system.

Interconnection

Every metallic shroud and stay should be connected from the chain plate directly to the lightning protection system, with at least a secondary conductor.

Large metal objects such as tanks, engines, electric winches, etc., within six feet (1.8m) of any lightning conductor should be connected to the lightning protection system by means of a secondary lightning conductor.

If the case of electrical equipment is internally connected to the DC negative and the negative cable is #6 AWG or larger this cable may also serve as the secondary lightning conductor.

If the case of the electrical equipment is not internally connected to the DC negative or the connection is less than #6 AWG then a secondary lightning conductor shall be installed.

Additional large metal bodies on boats may include any large masses such as bow and stern pulpits, steering pedestals, horizontal guardrails, handrails on cabin tops, smokestacks from galley stoves, electric winches, davits, metallic hatches, metallic arches, towers, engines, water and fuel tanks, and control rods for steering gear or reversing gear.

It is not intended that small metal objects such as compasses, clocks, galley stoves, medicine chests, and other parts of the boat's hardware be grounded.

The materials used in the lightning protection system should be resistant to corrosion. The use of combinations of metals that form detrimental galvanic couples should be avoided.

In those cases where it is impractical to avoid a junction of dissimilar metals, the corrosion effect can be reduced by the use of suitable plating or special connectors, such as stainless steel connectors used between aluminum and copper alloys. Except for the use of conducting materials that are part of the structure of the boat, such as aluminum masts, only copper should be used as a lightning conductor system. Where copper is used, it should be of the grade ordinarily required for commercial electrical work, generally designated as being of 98 % conductivity when annealed.

Conductive joints should be made and supported in accordance with ABYC E-11, *AC and DC Electrical Systems on Boats*, and should have resistance no greater than that of the conductors used. Solder shall not be used.

No bend of a primary conductor shall form an angle of more than 90 degrees and all bends must have a minimum radius of eight inches.

For illustration purposes see Figure 4.

ZONE OF PROTECTION

A grounded conductor, or lightning protective mast of up to 100 feet (30m), will generally divert to itself a direct strike that might otherwise fall within a cone-shaped space. The apex of this space is the top of the conductor or a lightning protective mast and the base is a circle at the water surface having a radius equal to the height of the top of the conductor or lightning protective mast.

Air terminals should be located so that the zone of protection will cover the entire boat. See Figure 1.

To protect a boat of the size that renders the use of a single air terminal impracticable, additional lightning protective means should be erected to form overlapping zones of protection.

The zone of protection afforded by any configuration of masts, or other elevated, conductive, grounded objects higher than 100 feet (30m), can readily be determined graphically using the 'rolling ball' concept illustrated in Figure 3. Increasing the height of a mast above the length of the striking distance (which is generally assumed to be 100 feet (30m) does not increase the zone of protection. Masts lower than 100 feet (30m) afford a zone of protection shown in Figure 1.

Lightning Protective Mast Alternatives

If the mast is composed of non-metallic material, the associated lightning or grounding conductor should be essentially straight, be securely fastened to the mast, extend at least six inches (150mm) above the mast, terminate in an air terminal, and be led as directly as practicable to the grounding connection. See Figure 4. An outrigger that serves as a lightning protective mast should have conductivity equivalent to or less than the resistance of a primary conductor.

Carbon Fiber

Although partially conductive, carbon fiber materials, and carbon fiber masts, are regarded as non-conductive (non-metallic) for the purpose of this technical information report. For lightning protection, carbon fiber masts require the addition of an air terminal and primary conductor as described elsewhere in this technical information report. If the hull or other structure contains carbon fiber, lightning conductors should be insulated from the laminate.

LIGHTNING GROUNDING TERMINAL

A lightning grounding terminal for a boat should consist of a metal surface (copper, copper alloys, stainless steel, aluminum or lead) which is in contact with the water, having a thickness of at least 3/16 inch (5 mm), and an area of at least 1 square foot (0.1m²). It should be located as nearly as possible directly below the lightning protective mast in order to minimize any horizontal runs in the primary (main) conductor.

The boat's propeller(s), shaft(s), metallic rudder(s), and other metallic surfaces that have the required area can be effectively used as a lighting grounding terminal only where the lightning protective mast is located above the in-water metallic objects to be used as the lightning system ground. The connecting conductor should be at least equivalent to a primary (main) conductor.

Rudders, struts, external ballast keels, or any other metallic fitting with at least one external face may be used for supplemental grounding so long as they meet other requirements in this report, such as the recommendation for the connecting conductor to be at least equivalent to a secondary conductor. If the rudder(s) is used for grounding, the lightning conductor should be connected directly to the rudder shaft or metallic collar.

In order to avoid routing grounding conductors horizontally through the boat, boats that use a lightning ground plate or strip located forward should ground backstays, or other metallic objects aft, to the engine negative terminal, a metallic rudder, or other external ground at the aft end of the boat. These grounds should also be interconnected with the ground plate or strip located forward.

The plate or strip should be located so that it is submerged under all operating conditions. All connections to a strip should be as short and direct as possible. Additional thru-hull bolts may be located along the length of a strip for additional connections.

The aft end of a lightning ground strip should be connected directly to the engine negative terminal. This will provide a path inside the hull for any DC stray currents that might be imposed on the thru-hull bolts and the lightning ground strip.

The spark initiation necessary to dissipate a lightning stroke is more likely to occur at sharp edges and corners than from flat surfaces. The edges of the external ground plate or grounding strip need to be sharp, exposed, and not caulked or faired into the adjoining area.

Any through hull stud connecting a lightning conductor to a grounding terminal shall have conductivity not less than that of the primary (main) conductor.

Seacocks and Thru-Hull Fittings

Seacocks and thru-hull fittings, if connected to the lightning ground system, should not be connected to the main down conductor. They should be connected to the underwater grounding strip, or the lightning ground plate with a minimum of a secondary conductor.

Multihull boats should provide a lightning ground connection in accordance with the General Information section of this document for each hull that has items to be grounded, attached, or fitted to it.

BOATS WITH METAL HULLS

If there is electrical continuity between metal hulls and masts, or other metallic superstructures of adequate height in accordance with the Lightning Protective Mast section of this document, then no further protection against lightning is necessary.

BOATS WITHOUT A PERMANENT MAST

Boats without a permanent mast should be protected by means of a temporary lightning protective mast that may be erected when lightning conditions are observed. It should be as close to the geometric center of the boat as possible, but, if necessary, can be offset, so long as the zone of protection will cover the entire boat when the mast is erected. The location should be such that persons on the boat can avoid physical contact with the mast. If the lightning protective mast has a separate base, the base should extend as high as possible, and provision should be made to plug in the upper section of the lightning mast so that it will not be displaced by the rolling and pitching of the boat in rough water. The temporary lightning protective mast should be all metal or other material if provided with a primary

(main) conductor. The temporary lightning protective mast should be connected to a submerged grounding terminal of at least one square foot (0.1 m^2) in area as described above.

Open Daysailers

As stainless steel rigging may not provide an adequate conductive path for the discharge of lightning currents, protection will depend on the grounding of all rigging as well as the metal masts, or the continuous metallic tracks on nonmetallic masts. These should be connected at the lower ends to a lightning grounding terminal, located directly below the mast. Metallic rudders at the aft end of the boat should not be used as the lightning ground for the mast because of the need for a long horizontal conductor to the aft end of the boat. The tiller, or other connections to metallic rudders that the operator will contact, should be non-conductive materials. Metallic keels or centerboards should be directly connected to the lightning grounding terminal, and may serve as the lightning grounding means if they have the required one square foot (0.1 m^2) area in contact with the water.

PRECAUTIONS FOR PERSONNEL

The basic purpose of protection against lightning is to ensure the safety of personnel. It is therefore appropriate that during a lightning storm the following precautions be taken:

Personnel should remain inside a closed boat, as far as practical.

Arms and legs should NOT be dangled in the water.

Consistent with safe handling and navigation of the boat, personnel should avoid making contact with any items connected to a lightning protection system, and especially in such a way as to form a bridge between these items. For example, it is undesirable that an operator be in contact with reversing gear levers and a spotlight control handle at the same time, or for sailboats hand on a metallic wheel and head near the backstay.

Personnel should NOT be in the water.

Personnel should avoid contact with metal parts of a sailboat's rigging, spars, fittings, and railings.

MAINTENANCE

Lightning protection provisions are likely to receive scant attention after installation. Therefore, their composition and assembly should be strong, and materials used should be highly resistant to corrosion.

Grounding of metallic objects for lightning protection may increase the possibility of harmful galvanic corrosion. See ABYC E-2, *Cathodic Protection of Boats*.

If a boat has been struck by lightning, compasses, electrical, and electronic gear should be checked to determine whether damage or changes in calibration have taken place.

If a boat has been struck by lightning, the lightning protection system should be inspected for physical damage, system integrity, and continuity to ground.

If a boat has been struck by lightning, it should be hauled for inspection of the hull, underwater structures and thru-hull fittings. Lightning can exit from one or numerous locations below the waterline. Subsequent flooding, sinking, or long term hull damage can result from undetected lightning damage.

Protection of Equipment - Wherever possible, electronic equipment should be enclosed in metal cabinets that are connected to the lightning grounding system with a minimum #8 AWG (8.39mm^2) conductor. Surge suppression devices should be installed on all wiring entering or leaving electronic equipment.

The grounding of metal rod type radio antennas provides some protection for boats without masts and spars provided that conductors in the grounding circuit of the antenna have a conductivity equivalent to a primary (main) conductor in accordance with the General section of this document, and the top of the antenna is not more than 100 feet (30m) above the water, and a line drawn from the top of the antenna downward toward the water at an angle of 45 degrees to the vertical does not intercept any part of the boat (see "Lightning Protective Mast"), and the antenna loading coil is provided with a suitable protective device for bypassing the lightning current.

Because a loading coil presents a high impedance to the flow of lightning current, the portion of an antenna above the bottom of a loading coil is not as effective as a lightning protective mast.

Non-conducting antenna masts with spiral wrapped conductors are not considered suitable for lightning protection purposes.

In order to protect the radio transmitter, antenna feed lines should be equipped with a means for grounding during electrical storms, or protected by lightning arresters or lightning protective gaps.

FIGURE 1 – ZONE OF PROTECTION BOAT WITH MAST NOT EXCEEDING 100 FEET (30 M) ABOVE THE WATER

FIGURE 2 - BOAT WITH MAST NOT EXCEEDING 100 FEET (30M) ABOVE THE WATER

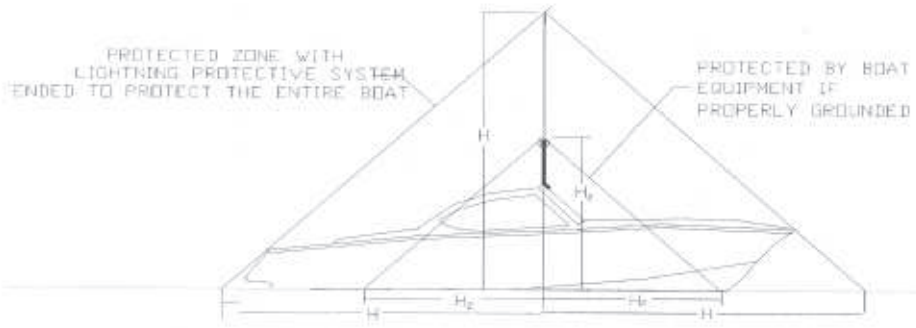


FIGURE 3 - BOAT WITH MASTS IN EXCESS OF 100 FEET (30M) ABOVE THE WATER - PROTECTION BASED ON LIGHTNING STRIKING DISTANCE OF 100 FEET (30M) ("ROLLING BALL")

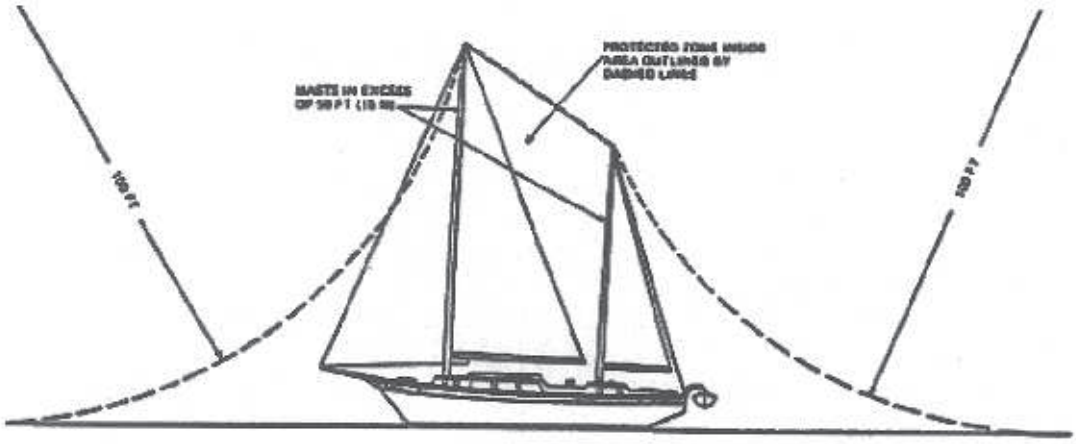
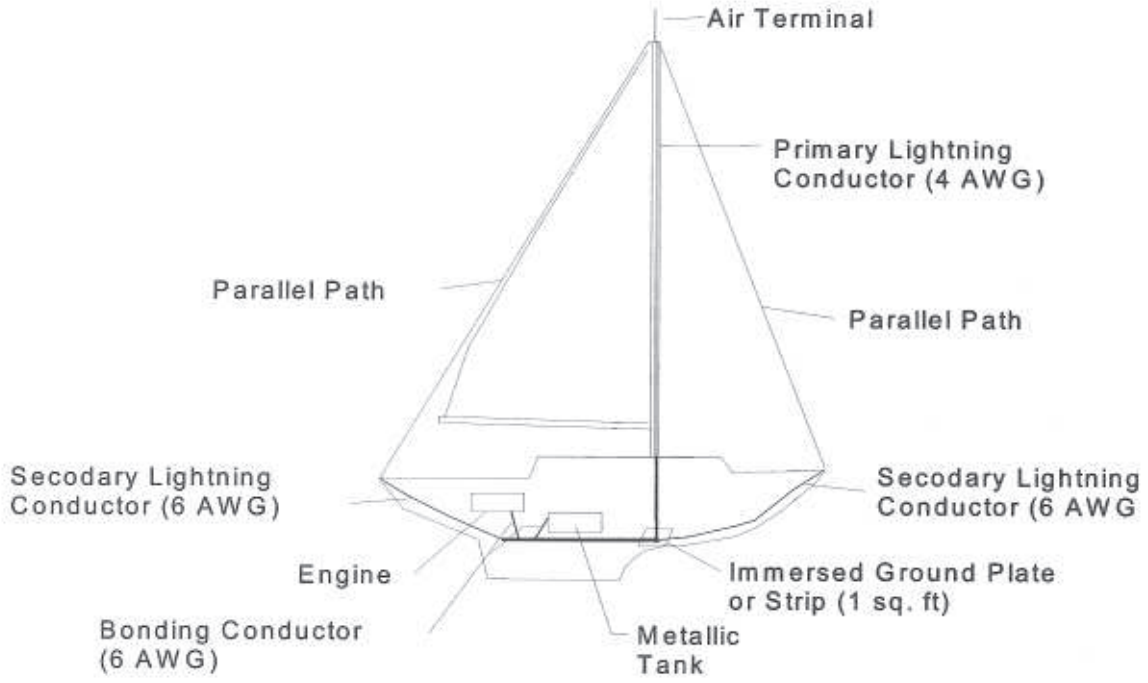


FIGURE 4 - INTERCONNECTION



Notes:

1. The primary conductor is connected directly to the immersed ground plate or strip.

2. All otherwise isolated bare metal objects within six feet (1.8m) of a lightning conductor should be connected to the lightning protection system with a minimum of a secondary bonding conductor.