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RESEARCH ARTICLE OPEN ACCESS

# LIGHTNING PROTECTION ON NON-CONVENTION VESSELS IN DYNAMIC CONDITIONS

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**SUMMARY**
The vessels at sea are exposed to transverse and longitudinal movements, and the existing standardized protection carried out according to technical norms on Non-Convention vessels, i.e., sailboats, is considered insufficient. As Non-Convention vessels may be considered vessels such as entertainment, military and fishing boats and those of obsolete build. In terms of equipment, this is determined by the recommendations of the Convention on the Protection of Vessels at Sea (Safety of Life at Sea, SOLAS).
It is assumed that the existing standardized protection on Non-Convention vessels is insufficient, as evidenced by the simulation models of protection against lightning strikes.
It is expected that the proposed methodology for lightning protection on Non-Convention vessels should provide essential improvement of protection, and to some extent contribute to the development of early detection of the risk of lightning strikes on vessels.
**Keywords:** standardized model protection, lightning protection, Non- Convention vessels, dynamic conditions

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## I. VESSELS AND THUNDERBOLT

Atmospheric electrical outbreak or discharge is the electric discharge from the clouds, which does not reach the ground. Lightning or thunder is atmospheric outbreak that occurs between
electrically charged clouds and the earth [13].

Due to friction in the storm clouds electric charges are polarized which leads to an increase in electric potential between certain parts, and resulting in electric discharge, which may occur within a cloud, between two clouds or between clouds and the ground. The marine industry is interested in this last case, i.e. short circuit between the sky and lightning rods on the boat, and the surge drain in the sea [14].

For the purpose of this study the properties of the sea [10] are considered; salinity [$S_m$], the chemical composition of [ks], the density [ρ] and temperature [$t_m$]. In addition to static electricity, the danger of lightning at sea ($O_{PG}$) as a function of the conditions that are held essential for the formation of thunder:

$$O_{PG} = f(S_m, ks, \rho, t_m) \quad (2.1.)$$

Furthermore, it is particularly important to look at the speed and direction of propagation of the waves. For the purpose of perceiving the important properties of the sea link changes with changes in the air and the humidity and temperature. Wind direction and speed can also affect the properties of air and sea.

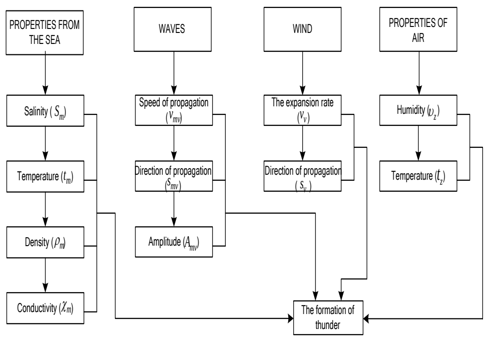



**Figure 1.** The properties of the sea and the formation of thunder
Source: [1]

International regulations pertaining to the protection and safety of the lightning [10] does not regulate issues related to the dynamic conditions. This paper proposes a new model of detecting a lightning strike, which suggests a dynamic approach to solving, project planning and the prevention of danger from lightning.

## II. VESSELS' MOVEMENT AND PRESENT LIGHTNING STRIKE

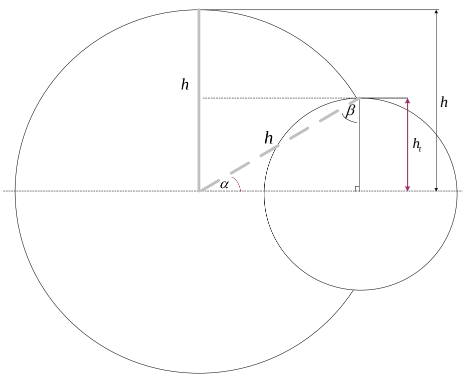
***Protection***

Risk of lightning strikes on ships is present every day. Summer is, on the contrary to the commonly held view, the most dangerous part of the year [12]. So, if one takes into account that in the summer there is a greater risk of lightning strikes, it can be concluded that there is a larger number of potentially vulnerable people at sea than it is the case in other seasons. Of the total number of non-convention vessels about 20% are sailboats - cruisers, and the rest are motor boats with no protection from lightning [6, 7, 8]. Analysis of statistical data shows that ~ 10% of deaths on the cruise are the result of lightning strikes [11].

Thomson [11, 12] raises questions of what to do if lightning is approaching and what happens to the boat when lightning strucks and he is seeking answers, especially to improve the protection in a way that lightning protection system on the boat diverts current to dissipate in the sea without any damage to the hull, personal injury or damage to the electronics.

The protection of vessels is set in a manner of the buildings' protection, which means in static conditions.

The vessel is exposed to translational and rotary movement [1, 3, 4, 14]. Translational relating to: reliance (Sway), plunge (Heave), retention, jumping the gun (Surge). Rotary relating to: the staggering (Pitch), yawing (Yaw) and swing (Roll). The movements of the vessel caused by the decrease of the lightning rod height above the waterline, i.e. reducing the surface of the base of the cone and move the center of protection - circle cone (Figure 2).




h - the height of the mast
α - the angle of inclination of the mast to the sea level
$h_t$ – mast altitude in at an angle α

**Figure 2**. Models of moving the center to protect the vessels from lightning at the height of 7 m
Source: [1]

It is believed that the area of protection against lightning strikes on vessels is greater the greater the height of the lightning rod. Figure 2 shows the area to protect the vessel from lightning at the height of seven meters under static conditions and reducing lightning protection area in accordance with the tilting of the vessel to the angle α. The model showed that during the rolling of the vessel the protection cone area is reduced. Starting from this fact all the mathematical models can be described by the following equations:

$$h_t = h \cdot \sin\alpha \quad (2.1.)$$

$$b = 0.5 \cdot a \cdot tg\alpha \quad (2.2.)$$

$$P = h^2 \cdot \pi \quad (2.3.)$$

$$P_t = h_t^2 \cdot \pi \quad (2.4.)$$

$$l = \sqrt{h^2 - h_t^2} \quad (2.5.)$$

$$z = l + 0.5 \cdot a \quad (2.6.)$$

Where is: a - beam
b - changes the height of the wing due to rolling depending on the angle of inclination α
h - the height of the mast
α - the angle of inclination of the mast to the sea level (30° left or right relative to sea level)
$h_t$ - mast altitude depending on the angle α
P - size of the protected area
$P_t$ - change (decrease) in the surface of the protected area, depending on the angle of inclination
l - the change in length buffer zones
z - necessary bandwidth protection

It is believed that the Protection Zone of sailboats against lightning in the layout area of the base of the cone, which is equal to the radius of the base of the mast. The angle of inclination has a range of at least 30° to the left and right of the initial position of balance for which the metacentric height is calculated. A boat in a storm is more exposed to rolling, resulting in Protection Zone changes (Figure 3). The simulation proved that the sides of the boat's out of the protection zone. So, during the race, if a person is on the side of the sailing boat, is directly exposed to risk [1].

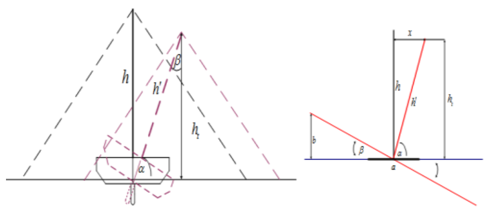



Figure 3. Changing the protection zones sailboats
Source: [1]

During rolling the protective zone of the vessel is reduced, i.e. the mast height changes respectively to the water surface in dependence on the angle of inclination:

(2.1.) $h_t = h \cdot \mathrm{si}$

The mathematical model, shown in Figure 4, shows the inadequacy of protection against lightning strikes when the boat is in dynamic conditions, what can be expected in navigation.

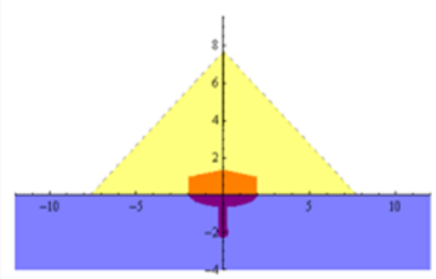



Figure 4. Mathematical model of rolling boat in dynamic conditions (α = 0°)
Source: [1]

Mathematically expressed simulation model[1] demonstrates the inadequacy of protection against sailboats lightning strikes (Figure 4a).
It is concluded that, given the results of the simulation, the side of the stern is the first to be exposed out of the protection zone. In addition to endangering human lives lightning strike causes the destruction of vessels and damage to the vessel and/or equipment. This phenomenon is particularly noticeable in the sailboat when sailing.
So, if a sailor falls outside the protection, he is potentially threatened. When rolling the protective zone of the vessel is reduced, i.e., changing the height of the mast depending on the angle of inclination which is in the range of 30° to the left or right of the starting position of the mast (static conditions).

[1] Simulation models have been developed in the mathematical program Wolfram Mathematica 7.0. The simulation model allows the simulation of the movement of vessels and more critical for each type of vessel [1]. This approach holds that it is crucial because it allows the simulation of different parameters of movement of different types of vessels. The movements of the vessel caused by decrease of the lightning rod, that is, reduces the area of the base of the cone, moves the center of protection and reduces the volume of a cone of protection.

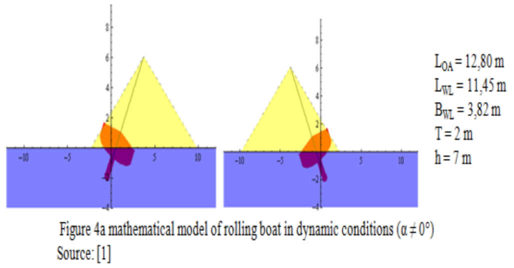



**Figure 4a** mathematical model of rolling boat in dynamic conditions (α ≠ 0°)
Source: [1]

There is another problem, the stern of the ship. The mast is located at a distance of ~ 3/5 from the stern, and 2/5 from the bow [5]. The engine is no longer in the protective zone of the cone, which can be observed in case of pitching (Figure 5), and the angle of inclination is in the range of 30° to the left or to the right relative to the initial position of the mast static conditions.

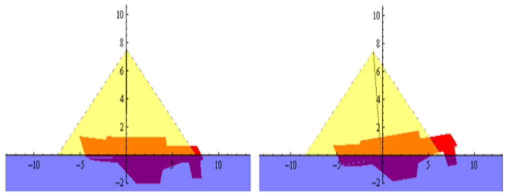


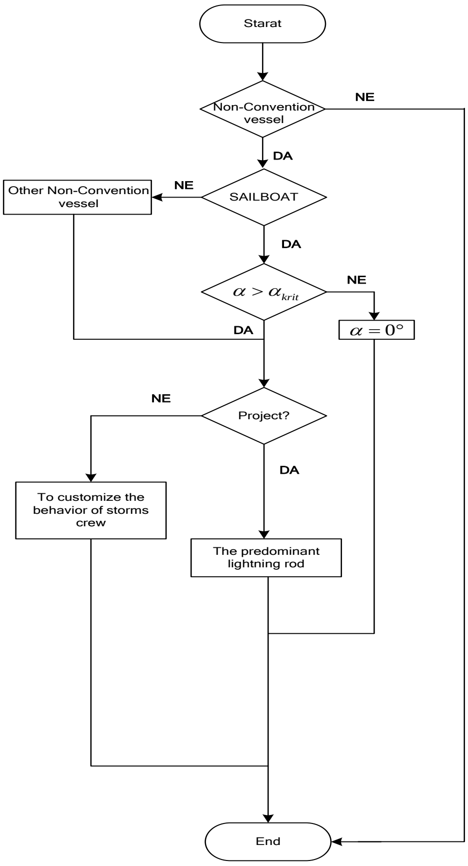
**Figure 5.** The mathematical model pitching boat in dynamic conditions
Source: [1]

According to mathematical models, it is evident that the present lightning protection does not meet the expectations and regulations for protection against lightning strikes in real terms. Mathematical model for Non-Conventional vessels in the case of sailboats proves a direct threat from lightning strikes due to transverse movement.

***A New Approach***

Sailing the convention vessels with lightning protection also set to question the safety of thevessel by lightning in dynamic conditions. The angle of inclination to the waterline is considered to be 30°, however for the sport sailing boat is higher. Most vessels of this type on the stern harbor the fuel tanks, which represents an additional danger.
According to the model in Figure 5. the engine is never in the protection zone. When using outboard engines it can be concluded that the area around the motors is directly affected by lightning. The sailors usually take position at the side of the sail boat, so the average height person's upper body is outside the protection cone and directly exposed to the danger of lightning.

The resarch results show that the increase in the height of the lightning rods, as a result, yields the increase in the lightning protection field. The height of the protection cone is decreased by a dynamic tilting movement. However, the height can be retrieved by either increasing the height of the lightning rods or new constructing solution (Figure 7).




*CRS Rules for technical supervision of ships - Part 12 - Electrical Equipment

**Figure 6.** Model for early detection of the risk of lightning strikes on vessels
Source: [1]

The authors propose a new working title for lightning rods – the opposing direction lightning rod. The arm with a rotating coupling is fixed perpendicularly to the top of the mast.

$$n = \frac{180°}{\beta} \quad (3.1.)$$

Where is: n - the number of degrees of horizontal scrolling branches per unit inclinations of the mast
β - the angle of inclination of the vessel

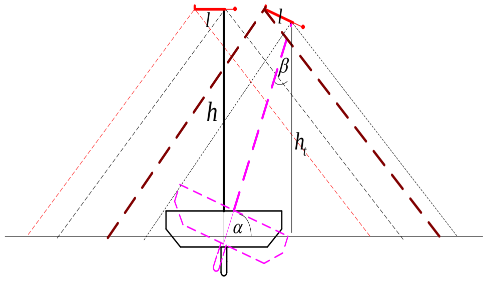



**Figure 7.** The new design solution to increase the height of lightning rod
Source: [1]

Boom length perpendicular to the mast can be determined according to the relations:

$$h_t = h \cdot \sin\alpha \quad (2.1.)$$

$$b = 0.5 \cdot a \cdot tg\alpha \quad (2.2.)$$

$$P = h^2 \cdot \pi \quad (2.3.)$$

$$P_t = h_t^2 \cdot \pi \quad (2.4.)$$

$$l = a - b \quad (3.2.)$$

Where is: a - beam
b - change of the the height of the wing due to rolling depending on the angle of inclination
h - the height of lightning rod
α - the angle of inclination of the mast (30° left or right above the sea level)
$h_t$ - elevation height, mast altitude depending on the angle of inclination
P - size of the protected area
$P_t$ - change (decrease) in the surface of the protected area, depending on the angle of inclination
l - length of arm firmly attached perpendicular to the mast at a maximum angle (α = 30°)

Figure 7 shows that the static central lightning rod meets the requirements of protection, the opposition direct lightning rod meets the protection standards in terms of the length of the ship. Due to the prevailing rolling motion lightning rod follows the movement of the ship, and the slope exceeds the height of the central conductor and improves the protection of vessels of lightning. An engineering approach is necessary to solve the lightning strike current dissipation problem without additional and unwanted resistance (R) in a slipping rotating coupling.
A special feature of this construction is evident in the movements of the vessel. Lightning rod counterweight is always placed on the opposite side to the force of pitching or heaving of the vessel. By

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changing the length of the arms, the height ofthe lightning rods is also changed in comparison to solid installation. Thus, the lightning protection zone is increased.
The mathematical model, shown in Figure 8, demonstrates better results.

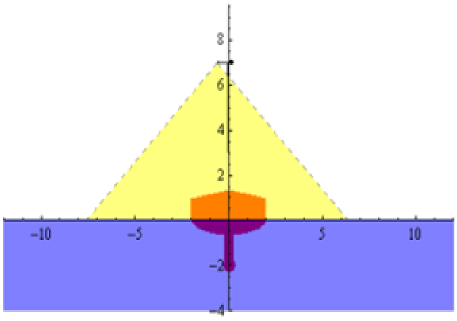


**Figure 8**. The simulation results of the rolling in extreme conditions with the prevailing lightning rod (α = 0°)
Source: [1]

It is suggested that the predominant branch of lightning rods is made of light materials.[2] For lightning rod it is proposed to use scattering lightning rod.[3] In the design, construction and maintenance of lightning protection, technical measures contained in the technical regulations on lightning rods should apply.[4]

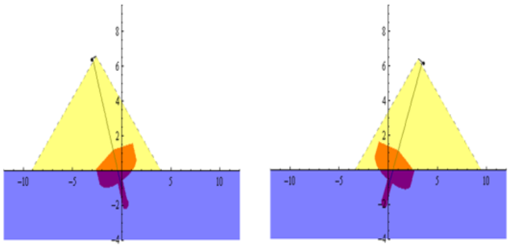

**Figure 8a** mathematical model sailboats in dynamic conditions with prevailing lightning rod (α ≠ 0°)
Source: [1]

Furthermore, it is necessary to pay attention to the air resistance, the weight of the lightning rods and the risks of the wind blasts, and to a way of dissipating the strike current. The common approach to the dissipation of the strike current can be maintained, because the body in the rotation does not change the properties of the current drainage.

### 3.1. The complex model of the application in two floating objects and more

While the sailboats are at berth, they are relatively close to each other. Due to the movement, masts may intersect. Model shows the change of the surface of protection zones depending on the direction of movement. The simulation in Figure 9 indicates the movement of the boats in accordance with the last in the series exposed to the increased risk of lightning strikes. If only a single boat is moving, that one it is exposed to changes. (Figure 9a)

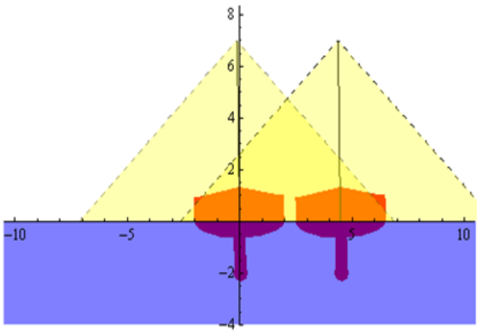


**Figure 9**. The mathematical model of two boats in dynamic conditions (α = 0 °)
Source: [1]

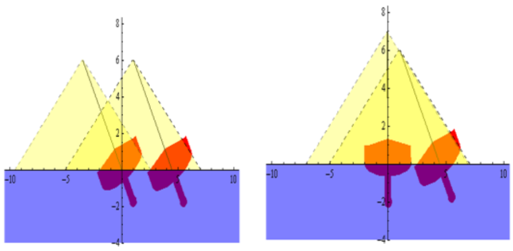

**Figure 9a** mathematical model of two boats in dynamic conditions (α ≠ 0 °)
Source: [1]

If the boats are moving towards each other, the zone of protection is increased because one boat enters the territory of the other, thus increasing the protection zone of the cone. (Figure 10a) However, in such a movement masts can be crossed (Figure 10b), cables may be intertwined, which poses a new problem. If, however, sailboats move from one another, the zone of protection between the boats is reduced, and they are exposed to the risk of lightning strike. (Figure 10c)

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[2] To create branches of predominant lightning rods it is proposed to use epoxy resins because they have excellent mechanical properties and are resistant to vibration, especially if the paper is added.
[3] Bursting lightning rod: installation of lightning rods that rejects electricity to the atmosphere without the need for grounding
[4] The application of implemented regulations is established in Article 53 of the Law on Standardization (NN, Nos. 55/96.)

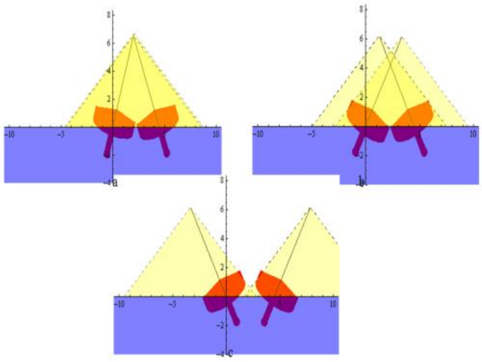

**Figure 10**. Simulation results rolling in extreme conditions (α ≠ 0 °)
Source: [1]

The conclusion is that the area of protection can be increased by new engineering solution comprising elevated lightning rods height (Figure 7).

## III. CONCLUSION

The lightning protection equipment is installed aboard all vessels, according to the Registry regulations. The current protection standard do not provide sufficient safety. The current regulations [13] for the design of lightning protection for vessels do not recognize the environmental conditions to which the vessel is exposed in navigation (rolling, pitching, swinging). It is believed that the vessel should be placed in the real conditions of navigation during the design process. It is proposed that a new approach should be considered as for the design of lightning protection.

According to the mathematical and simulation models it is evident that the present lightning protection does not meet the expectations of protection against lightning strikes in real conditions.

In case that the proposed lightning strike warning system is developed, the crew could be alerted in real time. According to the model of the lightning strikes early detection on vessels, it could be possible to predict the risks of lightning strikes to the certain extent. A software package, that would alert the crew of the dangerous area of movement, the probability of lightning strikes, and the distance from clouds to the likely impact, should be installed on the central computer on the bridge.

The conclusion is that no particular technology is not good enough; it could always be improved. [5] It is difficult to assess the real implications, because the technology is constantly changing [4]. Therefore, on the basis of the research, the authors propose the creation of the draft of the new approach standards for the vessels protection against lightning. After drafting the standard norms, the draft should be submitted to the International Maritime Organization, so that they can harmonize and eventually adopt the norms on which the authors are still working.

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