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Analysis of fire spread between two vertical bulkheads on the ship

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The paper focuses on fire safety problems on board. It characterises engine room as a place of fire occurrence. It gives some information about fire spread, it's modelling and methods of fire prevention and protection methods on ship. The paper presents alternative design method – dislocation of risk objects, accepted in July 2002 (SOLAS). It describes a simplified method of risk objects location calculations.

1. Introduction

The water covers more than two thirds of the Earth surface. Therefore to be more accurate, we could name our planet not the Earth but the Ocean. Having such a great treasure as water, it is not surprising that mankind has been trying to find ways of exploring oceans for many years. It has always looked for ways to build craft for seaborne transportation. Tree trunks, hollowed or tied together, and plant fibres or animal skins were used to sail across rivers, lakes and calm seas. One of the results of this process was a construction named the ship. Sea-going vessels, made to navigate in open seas, were developed by Egyptians, Greeks and Romans. Researchers claim that the history of shipbuilding and navigation can be dated about eight thousand years ago (boat found in the inlet Firth of Forth, Scotland) [1].

Throughout the centuries there have been a vast number of inventions to improve vessels. From ordinary rafts up to the first rowing boat thousands of years have passed. Rapid development in shipbuilding was stimulated by people's curiosity of the world and their persistence. Additionally, vessels played a very important role in the trade too. Therefore their evolution is still in progress. We still expect to find solutions, which would let the ship to be not only a great technical event but also a safety vessel. Fire safety problems have always been of the most important ones on the ships.

When people learnt how to build ships capable of crossing the oceans far and wide, they also became aware of possible damages caused by fire. By reason of the very limited fire fighting equipment available, they had to pay close attention to fire prevention. Consequently, a number of serious fires on ships stimulated the study of various methods of fire prevention and protection on ship.

Safety of ship is a very complex problem connected with navigation, fire safety, proper work of mechanisms, human behaviour and other factors. We must be aware that ship is a very specific object with multiplicity of various factors (combustible materials and sources of ignition) whose presence could result in fire. Fire protection methods are concentrated on two groups: passive methods, based on the construction of ship (they determine restricted use of combustible materials, separation of spaces with fire resisting bulkheads and decks; they are also connected with protection of evacuation routes and division of ship into main vertical zones) and active ones which focus on fire-fighting.

The paper reviews the relevant approaches enabling to avoid fires on ships, describes the spread of fire between two vertical bulkheads, which represents bulkheads on board separating engine room casing and accommodation spaces. An examples of fire on ship is described too. This paper also presents dislocation, one of so-called alternative design methods, which aim is to stop fire spread between risk objects like an engine room, accommodation spaces and other ones [2, 3, 4, 5].

2. Identification of fire safety problems on ship

Although the ages passed from first ships, fires are still one of main reasons of ship damages and loss. Figure 1 presents different causes of accidents on ships. Fires and explosions are located on the first position.

Ship is a very specific object. Sometimes it is hard to find similarity between it and any land object. Multiplicity of various factors whose presence could result in fire can easily be found at ships. Combustible materials present at ships are fuels, oils, combustible cargoes, paints, solvents etc. Sources of ignition are hot surfaces, ignitions, sparks, static electricity, set on fire etc. Oxidiser is usually oxygen. Summarising, the causes of fires could be presented as below [7]. As it can be seen main reason of fire occurrence, almost 50% is fuel oil.

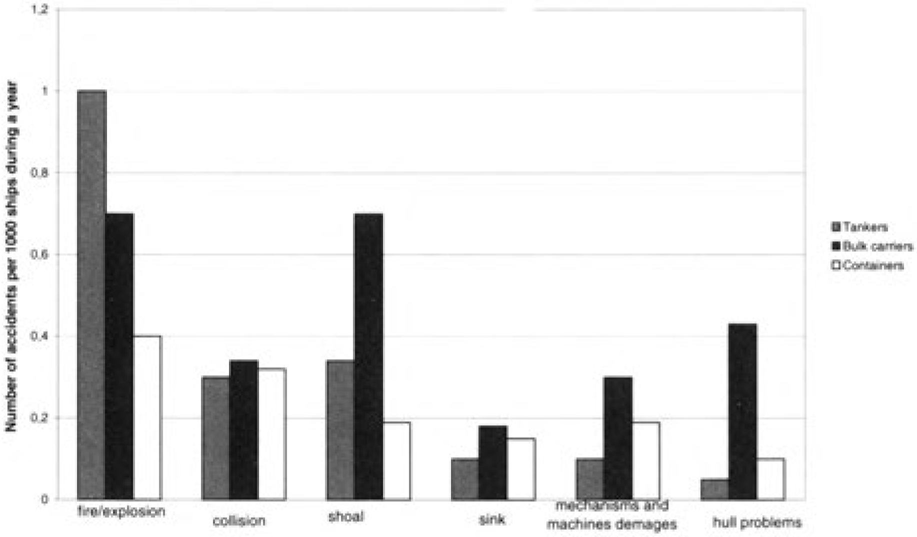


FIGURE 1. Causes of incidents on ships [6].

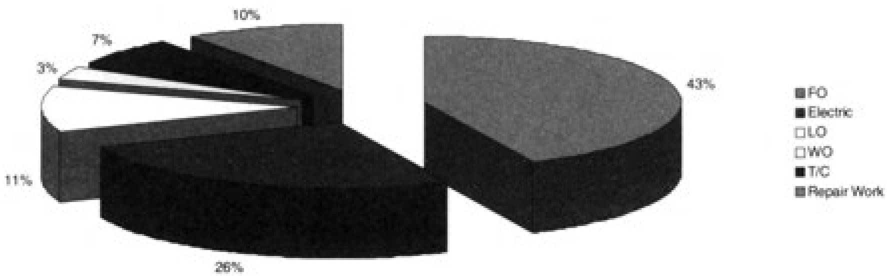
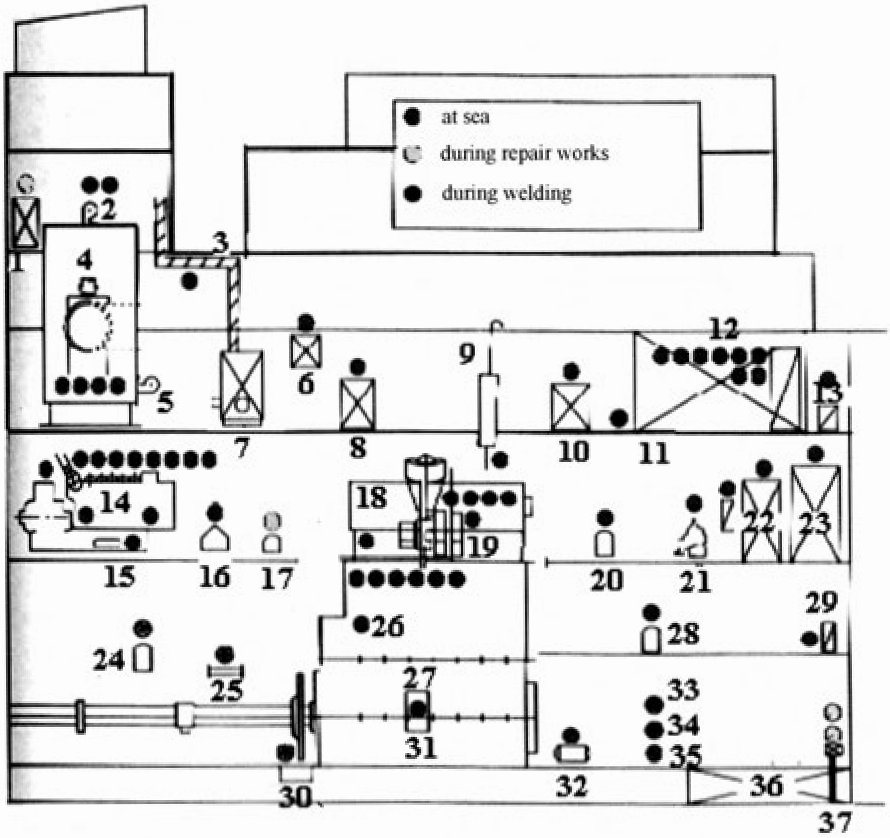


FIGURE 2. Causes of fire at ship [7]: fuel oil (FO), electric, lubrication oil (LO), waste oil (WO), turbocharger (T/C), repair work.

2.1. Engine room as a place of fires occurrence

Experience has shown that the engine room is the place where most of fires occur. There are three dangerous factors: flammable material, source of ignition and oxidiser. There are also many ways of spreading fire such as ventilation casings, opened doors, cable tracts, bulkheads etc.

Figure 3 presents possible sources of fire in engine room during different conditions of exploitation. Most of fires occur at sea. Places like a turbocharger, switchboard, generator engine, were pointed as most dangerous.



1. Waist oil tank
2. Burner
3. Exhaust gas pipe
4. Boiler
5. Burner
6. Diesel oil tank
7. Incinerator
8. Boiler fuel oil
9. Fuel oil mixing column
10. Lubrication oil tank
11. Purifier starter
12. Switchboard
13. Transformer
14. Generator engine
15. Generator engine lubrication cooler
16. T/G (turbogenerator)
17. Strainer
18. Rocker arm lubrication oil
19. Turbocharger
20. Turbocharger strainer
21. Purifier
22. Diesel oil tank
23. Fuel oil tank
24. Oil bilge separator
25. Thermal oil pipe
26. Exhaust valve lubrication oil
27. Main engine
28. Lubrication oil 2nd strainer
29. Cargo ref starter
30. Bilge well
31. Crank case door
32. Fuel oil elect. heater
33. Fuel oil booster pump
34. Ballast pump
35. Mail cool. pump
36. Fuel oil tank
37. Short sounding pipe

FIGURE 3. The sources of fire in engine room [7].

3. Computer modelling

Fire is described as an uncontrolled in time and area burning process which results in material damages or even human health or life loss. Physical and chemical parameters which assist fire in a defined thermodynamic scheme and the spread of fire are complicated problems. The analysis of the fire temperature, area, linear fire spread speed, mass burning intensity, intensity of gases exchange, etc give a simplified picture of those phenomena. Radiation, convection and conduction are the three mechanisms which determine heat transfer between the gas layers and the walls, bulkheads during the fire. The radiation is an important mechanism for heat exchange.

Proper choice and formulation of equations describing the phenomenon of fire and finding a method of their solution provided an opportunity to create mathematical-computer models describing fire in time and space. In recent years, a great effort has been put in developing mathematical models to predict various aspects of fire behaviour, its growth and spread.

Two basic approaches to mathematical modelling of fires are known: probabilistic modelling and deterministic one. Probabilistic models describe fire development as a sequence of events as ignition, flame spread, flashover, etc., and predict the transition from one event to another by probabilities. Such models are based on experience with fire but do not rely much on the fundamental chemistry and physics involved in fires. On the other hand, in deterministic models the problem and the configuration are prescribed, and the laws of physics and chemistry dictate the evolution of the fire. Both probabilistic and deterministic models consist of a set of mathematical equations that must be solved simultaneously.

Deterministic models are subdivided into field models and zone models. In the field modelling, the conditions at every point of space, at any moment, are given by the solutions of a complex set of partial differential equations. Generally, field models require large computers. In zone models the fire compartment is divided into a group of zones and interactions (mass and heat transfer) between the zones are modelled. A lot of models are known, e.g., MARK V, JASMINE, PHOENICS, KAMELON, SMARTFIRE, SOFIE, CFAST, FARSITE and others. They are very helpful in the analysis of fire propagation and spread [8-12].

4. Scenario of fire at ship

More than 60 percent of ship fires have similar scenario: source is in engine room, they spread over the engine room and through the casing to the superstructure where accommodation spaces are located. The ways of fire spread are cables lines, ventilation ducts, bulkheads, opened door, and pipes with inappropriate insulation.

Hot gases and flames outgoing from engine room could heat the bulkheads to a temperature in which fire goes through the bulkheads, especially when they have not good enough insulation. When the casing is separated from superstructure the risk is much lower. The Society Nippon Kaiji Kyokai (NKK) published result of their research. It was shown that 14% of engine room fires spread to the superstructure when it has a traditional construction (engine room casing surrounded by accommodation spaces). No such type of fire spread to accommodation spaces was observed in the construction when the casing is separated [2].

The superstructure is also a place of fire appearance. There are a lot of different types of places such as cabins, kitchens, restaurants, magazines etc. However, the most intricate problem creates unexpected behaviour of humans faced with fire. Superstructure fire spreads through the corridors, steps, cable lines, opened doors, ventilation ducts, under ceiling space, and bulkheads [13, 14, 15].

5. Fire fighting and fire protection methods on ship

Most regulations pertaining to the fire safety are derived from International Convention for Safety of Life at Sea, 1974 (SOLAS). There are eight basic principles listed in SOLAS, which form the basic philosophy of fire protection:

- division of ship into main vertical zones by thermal and structural boundaries,
- separation of accommodation spaces from the remainder of the ship by thermal and structural boundaries,
- restricted use of combustible materials,
- detection of any fire in the zone of origin,
- containment and extinction of any fire in the space of origin,
- protection of means of escape or access for fire fighting,
- ready availability of fire- extinguishing appliances,
- minimisation of possibility of ignition of flammable cargo vapour [16].

Generally, active and passive methods are distinguished. Active methods of fire protection are fire extinguished appliances and media which may be used by crew during the fire to extinguish it. Passive methods are connected with construction of ship. They determine restricted use of combustible materials, separation of spaces with fire resisting bulkheads and decks. They are also connected with the protection of evacuation routes and division of ship into main vertical zones.

Additionally crew and passengers should be adequately trained and act with proper procedures in case of fire (usually called a human factor). A balance of the three mentioned methods of fire protection (active, passive and human factor) assures highest safety in specific conditions. One of the passive methods is dislocation.

6. Dislocation of risk objects

The dislocation could be defined as a location of risk objects which assures the highest safety level. The aim of such a solution is to stop the fire spread. It is one of so-called alternative design methods. In July 2002 new rules, describing alternative methods, were accepted by the international society connected with safety at sea. It has given the designers and builders an opportunity to use the dislocation methods.

The methodology for an alternative design for fire safety is presented in new edition of SOLAS. Engineering analysis should include elements such as the identification of fire and explosion hazards, ignition sources, fire growth potential, smoke and toxic effluent generation. The other necessary elements of analysis are connected with performance criteria which provide the degree of safety, not smaller than that achieved by using the prescriptive requirements. Performance criteria should be quantifiable and measurable. There should be included technical justification demonstrating that the alternative design meet required fire safety performance criteria [16]. Figure 4 presents potential possibilities of fire spread with the source in the engine room on the ship where the casing is separated from the superstructure by air.

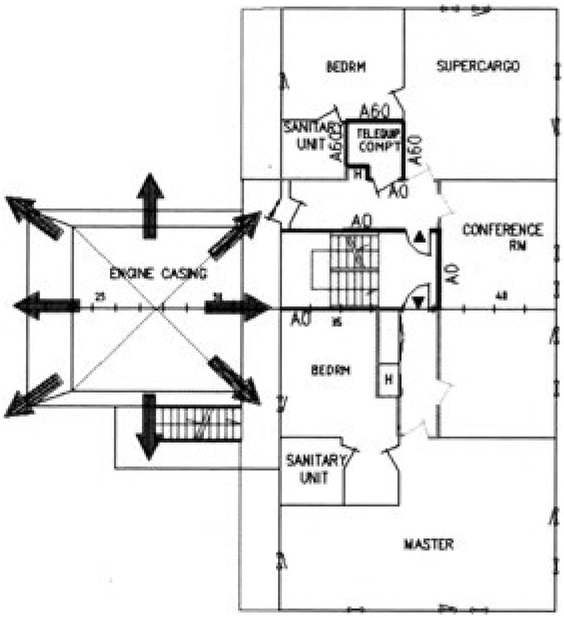


FIGURE 4. The dislocation of casing and possibilities of fire spread.

Engine room casing position could be an example of the dislocation on ship. Historically engine rooms casings were located inside the superstructure. The safety of crew was in danger because of the possibility of fire spread from the engine room. It was also uncomfortable because of noise and vibration. The main reason to separate casing and superstructure were these phenomena. Currently most of engine room casings are situated at a distance from superstructure. Such a construction is connected with the economical, exploitation, and safety aspects [2-5].

The structure presented in Fig. 4 is typical for nowadays ships. It is seen that the accommodation spaces are not in close neighbourhood of the casing. There is a distance between them. It makes cabins and corridors safer. The spreading fire meets a barrier constituted by the air gap bounded in two steal bulkheads. To make the level of safety higher we could think of different solutions, e.g. water curtains between the casing and superstructure as well as other solutions.

Due to the use of dislocation and other modern prevention methods it is noticeable that in recent years fewer and fewer engine room fires, initiated in engine rooms, spread to the superstructures. It is thus obvious that the dislocation of casing is an effective method of fire spread elimination, that should be employed on ships. The only problem is that this method is used as a fire safety mean on the basis of the "best practice". It still needs mathematical description supported by computer modelling.

7. The algorithm of fire spread between two vertical bulkheads

To start the analysis of dislocation as an alternative method of fire spread prevention the theoretical and mathematical description is needed. The use of the dislocation is determined by the distance between risk objects, material, time of fire spread and geometry of objects. An evaluation algorithm should describe factors such as the identification of fire source, characteristics of bulkheads, parameters, heat transfer, and the calculation of safety distance between bulkheads.

One of necessary steps in the analysis using the dislocation method is the formulation of the algorithm that analyses dependencies between the time of spread between risk objects, distance between them, material used to produce bulkhead and time of spread. The economical analysis of this mathod could be made too.

The algorithm is based on the following steps:

- identification of fire source, e.g. the engine room,
- characteristics of bulkheads, e.g. A-60 class,

- description of fire parameters, e.g. temperature,
- description of the heat transfer, e.g. radiation,
- identification of safety distance between objects due to different criteria, e.g. minimal mass of the bulkhead.

The identification of fire source could result in the description of the temperature distribution in the bulkhead. In the next steps the intensity of the radiation of the bulkhead to the next bulkhead could be described. As a result an answer to the question about the possibility of ignition of the second bulkhead or spread to the room protected by this bulkhead is given.

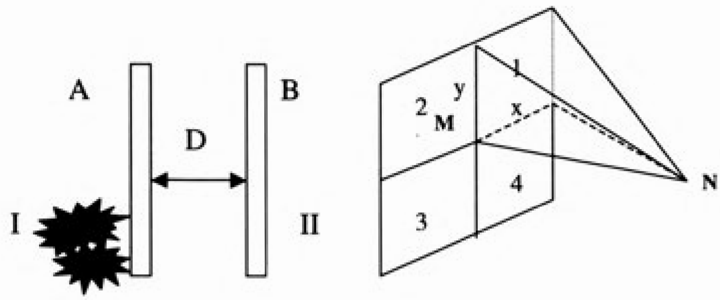


FIGURE 5. Schema of simplified valuation of dependence between bulkheads during fire [17]; I, II – rooms; A, B – bulkheads, D – distance between bulkheads; x, y – rectangles dimensions; 1, 2, 3, 4 – parts of bulkheads; M – common vertex of rectangles 1-4; N – point on the plane of bulkhead B.

Figure 5 presents fire with the source in the cabin I bounded by the bulkhead A and his influence on the cabin II through the bulkhead B. In this case the intensity of the radiation could be defined as the sum of partial intensities emitted by rectangles 1-4:

$$i = 5.71 \left(\frac{T}{1000}\right)^4 \sum Fj \quad [\mathrm{W/cm^2}], \tag{7.1}$$

where i is the radiation intensity at different points of the plane B, j is the the number of parts, T is the absolute temperature [K]. The function F is given by [17]:

$$F = f(a, S), \tag{7.2}$$

where

$$a = \frac{xy}{D^2}, \tag{7.3}$$

$$S = \frac{y}{x}. \tag{7.4}$$

Here the values of a and S should be read off from the diagrams presented by Linder and Strus [17].

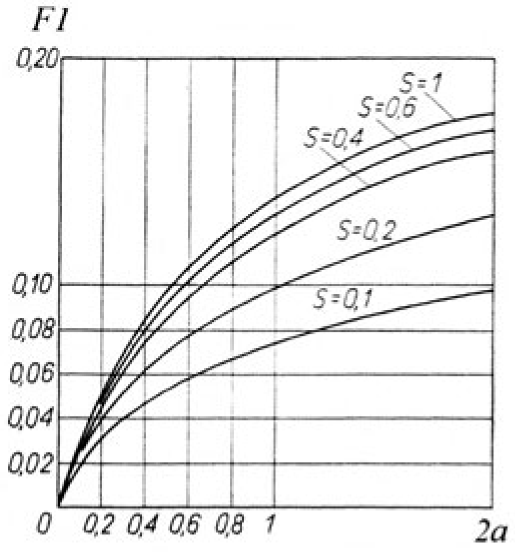


FIGURE 6. Value of the function F1 for average values of a [17].

Knowing the value of i we can find on the diagram presented below the time after which the bulkhead B will burn, depending on the radiation and type of material.

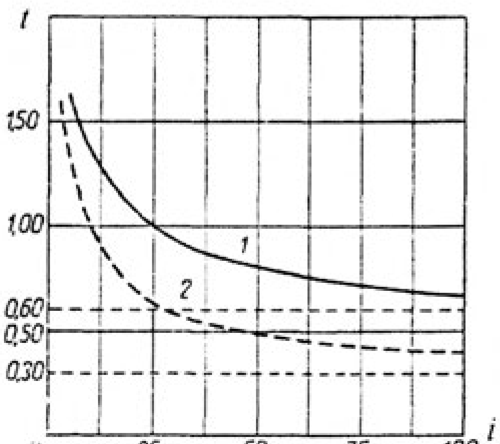


FIGURE 7. Dependence of time of ignition and intensity heat radiation [17]; 1 – self ignition; 2 – ignition with the help of initiator flame.

Changing the distance in model (7.3), let us in a simple way find the safety distance that guarantee that the bulkhead will not burn. A simplified algorithm should be modified by taking into account the real character of fire and the heat transfer between bulkheads.

The algorithm could be helpful in taking the decision and making the process of location of risk objects as an engine room casing / superstructure, engine room / superstructure, superstructure / lifeboat, window of superstructure / lifeboat, etc. It could be used also as a help to design engine room equipment, location of helicopter landing fields in relation to superstructure on ships and platforms and many others.

It is necessary to establish different scenarios of fires to find parameters of fire.

The example could be as follows:
21st of February 1993, "Powstaniec Listopadowy", fire with a source in engine room, reason: spray of oil from fuel filter of working diesel engine generating set on insulated part of a frame of turbocharger, probably by deaerete of filter in result of loosen and undo nut, ignition of sprayed fuel on hot surface of turbine and next on the floor. Fire has spread in engine room and by hot gases and flames was spreading up through the casing what made the rise of temperatures of accommodation spaces bulkheads [18].

8. Conclusion

International legislation connected with fire safety at ship changed in July 2002. New philosophy brought new possibilities. So called alternative design methods have been accepted. It resulted in need of development in construction of tools used in mathematical modelling and evaluation dependencies describing various aspects of fire safety, fire spread etc.

Algorithm presented in this paper could be helpful in decision making process of risk objects location. In future research simplified algorithm should be developed by adding dependencies describing the real fire character and heat transfer between bulkheads.

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