Scientific Journals
of the Maritime University of Szczecin

Zeszyty Naukowe
Akademii Morskiej w Szczecinie

2016, 45 (117), 94–98
ISSN 1733-8670 (Printed)
ISSN 2392-0378 (Online)
DOI: 10.17402/091

Received: *31.08.2015*
Accepted: *07.12.2015*
Published: *25.03.2016*

An analysis of discrepancies in search areas in a diagram of an expanding square search

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Key words: SAR, search area, manoeuvrability characteristics, search patterns, rescue, accident

Abstract

Search patterns and procedures contained in the International Aeronautical and Maritime Search and Rescue Manual for Mobile Facilities meet the requirements of theoretical assumptions about search and rescue operations. But the individual manoeuvrability characteristics of a search vessel cause real search and rescue operations to differ from theoretical patterns. This article analyses the difference between theoretical and actual search regions in a Diagram of an Expanding Square Search. Different variants of parameters of ship manoeuvrability have been considered. Some solutions modifying the Diagram of Expanding Square Search are proposed by the authors.

Introduction

Under the provisions of international law and humanitarian considerations, ship masters are obliged to assist others in distress at sea whenever they can safely do so, as specified in the following international conventions:

- The International Convention on Marine Search and Rescue;
- Regulation V/10 of the International Convention for the safety of Life at Sea, SOLAS 1974.

In 1998, based on the above regulations, the *International Aeronautical and Maritime Search and Rescue Manual for Mobile Facilities* (IAMSAR) was developed (IMO, 2013). All officers must be familiar with its contents and be regularly trained. The manual is intended to be carried on every bridge. It contains the standard methods and procedures for searching, and principles of cooperation and coordination under various circumstances.

Planning a rescue at sea includes a complex set of actions to determine the position or area of the accident, the designation of the search area, and the detection of the desired object (Frost, 1996). Due to the complexity of the issues and the range of interests, the authors of this article decided to focus on the problems faced by the masters of merchant ships during the planning and execution of a search and rescue action.

To achieve its objective, a rescue craft must perform a number of manoeuvres in order to search the body of water using technical and visual observation procedures. The data and recommendations contained in the IAMSAR manual aim to eliminate impulsive actions during an emergency.

At the planning stage of exploration, a ship's master should analyse the conditions determining an appropriate search area, selecting the proper search method based on this analysis. The search should then proceed in accordance with existing standards to ensure an optimal search area is targeted, and that the probability of detecting an object or person quickly is as high as possible. This begs the question of whether recommendations applicable to all vessels are sufficiently clear and take adequate account of the manoeuvrability characteristics of individual vessels (Kasyk & Pleskacz, 2015).

When planning action, the master must account for existing hydro-meteorological conditions and the limitations imposed by the ship's stability and manoeuvrability characteristics.

Because the IAMSAR manual does not take into account the influence of and connection between a ships stability and prevailing hydro-meteorological conditions, the authors focus on the manoeuvrability characteristics of a vessel as the parameter of interest for a search and rescue (SAR) operation.

Influence of manoeuvring on the search and rescue process

Each ship has its own manoeuvrability characteristics. Differences may even occur between sister ships, let alone vessels of different types, sizes, and construction. These differences are caused by such factors as the location of superstructures along the hull, and the consequent reaction pattern of the vessel to side winds. Other important considerations include drive and control issues associated with the types and number of rudders, propellers and thrusters, and whether a ship has a right- or left-handed propeller, which determines handling characteristics when making right or left turns. Finally, the turning radius is dependent on such variables as loading and rudder angle.

According to international regulations contained in resolution A.751(18), 1993, "Interim Standards for Ship Manoeuvrability", each ship with a length of 100 m or more, as well as chemical tankers and LPG tankers built after 1994, must have certain manoeuvrability standards. In practice, manoeuvrability standards are known for all ships, as they are necessary for safe operation (Turner et al., 2008).

From the point of view of course alterations during SAR operations, the two parameters that must be considered are manoeuvring speed and turning ability.

For a ship 200 m in length, the diameter of the acceptable theoretical turning circle is approximately 800–1000 m. In the case of a specific vessel, such as, for example, a type B 517/2, the minimum turning circle diameter is approximately 600 m, corresponding to three ship lengths. It should, however, be noted that this is the diameter of the fixed turning circle, which is measured in a situation when the ship is already moving in a circle. If the ship has to change course by approximately 90 degrees from previous position when moving along a fixed course, this is a very important parameter defined as the *advance* (see Figure 1). The advance describes

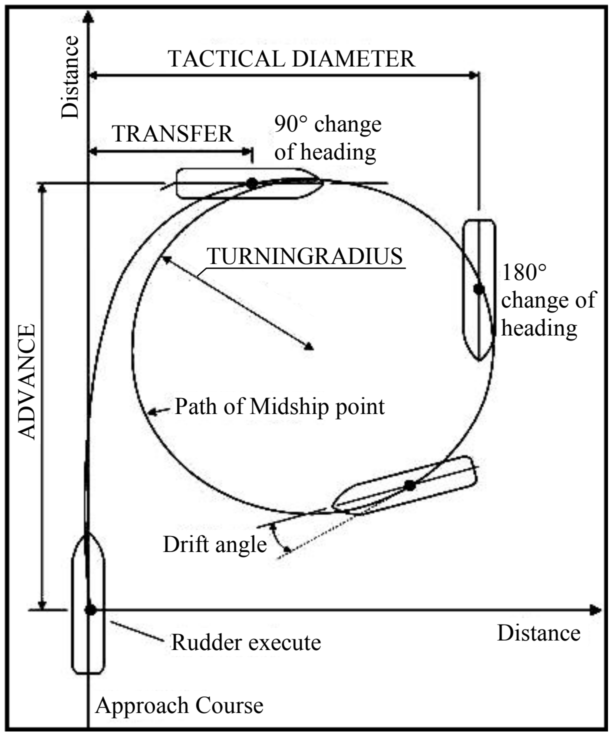

Figure 1. Advance and tactical diameter (American Bureau of Shipping, 2006)

the distance run on the original course until the ship steadies on the new course. Advance is measured from the point where the rudder is first put over. The point of put over is very important, because there is a certain time delay between the command and the placement of the rudder. After the rudder is turned, a ship does not immediately adopt a circular path. Due to the inertia of the vessel, additional way is made after the rudder input to turn in the desired direction.

In practice it is very difficult to perform a complete "hard about" manoeuvre during a rescue. Therefore, the authors focused on a real value of 15 degrees.

Neglecting the manoeuvrability of the ship during a SAR action may lead to two problems, especially during the first sections of the spiral.

The first problem is that the ship will not be physically able to perform the manoeuvre. Such a situation will occur, for example, when the search ship is a container ship with a capacity of 93,000 DWT, whose manoeuvring speed is 14 kn. The way overcome from the start of the manoeuvre until the ship starts to react to the rudder is d = 6.8 cb (at rudder = 15°), entering then a circulation of radius r = 9.2 cb (with the same helm). According to the American Bureau of Shipping handbook (American Bureau of Shipping, 2006), if the search object is a 5-metre boat with a visibility of 3 Nm, the distance S between the arms of the expanding square

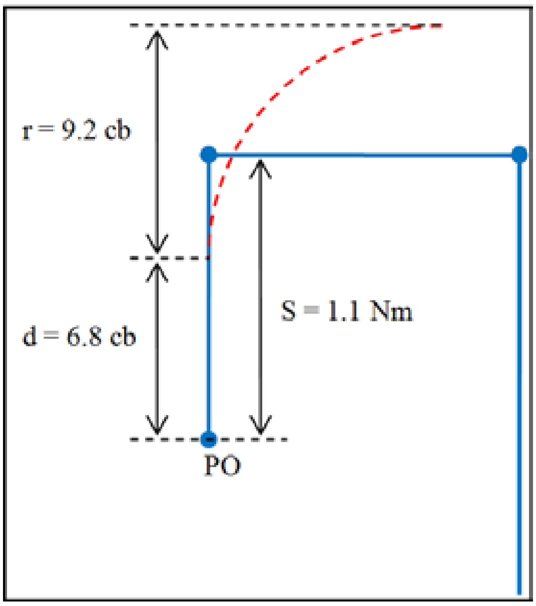

Figure 2. Situation when the first course alteration is not possible

search should be 1.1 Nm. This is also the length of the first two arms of the diagram. As shown in Figure 2, a navigator starting a manoeuvre in reference position (PO) is not able to follow the second leg of the diagram.

A similar situation also occurs when visibility is 5 Nm, for which S is 1.4 Nm. For such vessels as a container ship of 20,000 DWT, d = 4.9 cb, and r = 6.3 cb, the manoeuvrability characteristics will not allow this manoeuvre to be executed.

Another problem arises when manoeuvrability characteristics are such that the first arm of the manoeuvre can be executed, but the calculated way equal to the length of the second arm is too short to perform the next two returns (Figure 3).

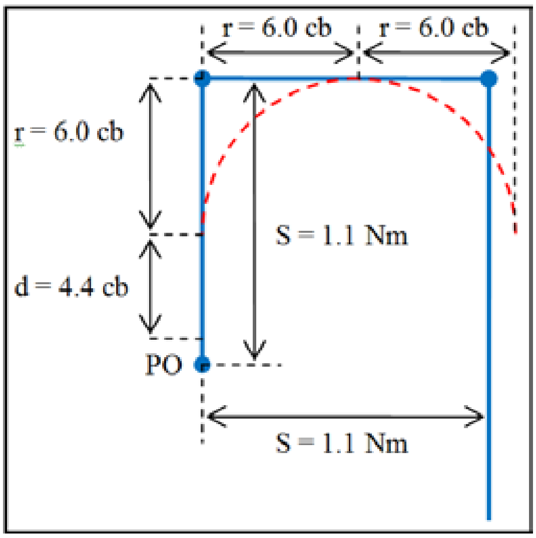

Figure 3. Scenario in which two successive course alterations are impossible

This is because the calculated route between two waypoints will be too short for the execution of two changes of course. This example is illustrated for a 33,000 DWT bulk carrier with manoeuvrability parameters d = 4.4 cb and r = 6.0 cb.

The second problem is the increased difficulty in detecting the search object. We should take into account the shifting of individual legs as a result of hydro-meteorological conditions.

We assume at this point that the observation range is 0.5 S port and starboard. If we consider the turning radius, the distance between the spiral arms is increased to a value exceeding the recommended spacing. This excessive distance between arms results in so-called blind sectors (Figure 4), unexamined portions of the search area, which are usually circles with a radius of 10 Nm (IMO, 2013).

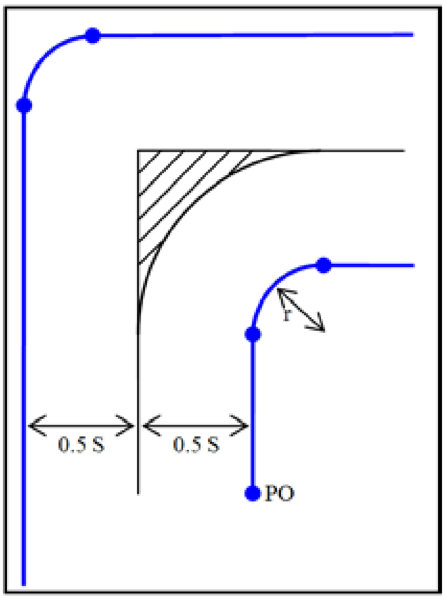

Figure 4. A blind sector

An area P of an unsearched blind sector is given by the following expression:

$$P = \frac{1}{4}\left[(2r + S)^2 - \pi\left(r + \frac{1}{2}S\right)^2\right] \qquad (1)$$

where r is turning radius, and S is the distance between the arms of the expanding square.

This study assumes that the turning radius is equal to the radius of circulation, at a speed and manoeuvrability when the lay of the rudder is equal to 15 degrees. Depending on the type of search object and visibility, we change the distance between the arms of the expanding square diagram (IMO, 2013). Also, to search a predetermined search area, the number of arms in the diagram changes (Figure 5).

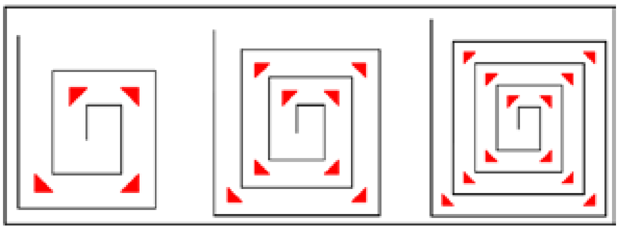

Figure 5. A variable number of blind sectors for different values of S (5.5 Nm, 3.2 Nm, 2.3 Nm)

When the search object is a 4-person raft and visibility is 3 Nm, distance S is equal to 2.3 Nm, the Diagram of the Expanding Square has 17 arms and 12 blind sectors. Depending on the turning radius, the blind sectors have an area equal to 6.6 Nm^2 (r = 0.45 Nm) or 8.1 Nm^2 (r = 0.62 Nm) or 11 Nm^2 (r = 0.92 Nm).

When the search object is a 4-person raft and visibility is 5 Nm, the distance S is equal to 3.2 Nm. Then, the Diagram of the Expanding Square has 13 arms and 8 blind sectors. Again, depending on the turning radius, the blind sectors have an area equal to 7.2 Nm^2 (r = 0.45 Nm) or 8.46 Nm^2 (r = 0.62 Nm) or 10.9 Nm^2 (r = 0.92 Nm).

When the search object is a 4-person raft and visibility is 20 Nm, the distance S is equal to 5.5 Nm. The Diagram of the Expanding Square then has 9 arms and 4 blind sectors. Depending on the turning radius, the blind sectors under this scenario have an area equal to 8.8 Nm^2 (r = 0.45 Nm) or 9.75 Nm^2 (r = 0.62 Nm) or 11.56 Nm^2 (r = 0.92 Nm).

Finally, when the search object is a 25-person raft and visibility is 20 Nm, the distance S will be 7.5 Nm. The Diagram of the Expanding Square then has 6 arms and 1 blind sector which, depending on the turning radius, has an area equal to 3.8 Nm^2 (r = 0.45 Nm) or 4.1 Nm^2 (r = 0.62 Nm) or 4.7 Nm^2 (r = 0.92 Nm).

Thus, for many ships, these examples show that the textbook diagram of the search leaves large areas uncovered. In addition, some of these areas are located close to the reference position where the probability of finding survivors is greater than in the more remote areas. This fact makes it clear that it is necessary to modify the search scheme in such a way as to correct for the manoeuvrability parameters of the search vessel.

Proposed modifications

The answer to the first problem may be either to extend the first sections of the Diagram of the Expanding Square to take into account the manoeuvrability characteristics of the vessel, or to develop a completely different search scheme taking into account the manoeuvrability of the rescue vessels.

On the other hand, to seal the search area, it is possible that earlier course alterations could result in a more complete search of the designated area. This would lead to increased density of the arms of the diagram, which would greatly increase the time required to search the designated area. It would, however, eliminate blind sectors.

Another option would be for the lead ship to take an appropriate curve to ensure an exact search distance (e.g., arc AB in Figure 6). Each such arc would be approximately a quarter of a circle with a radius expressing, respectively, the following formula for i-th loop:

$$R = r + i \cdot S \tag{2}$$

The centre of curvature of each of these arcs is located in the middle of curvature of the first (and

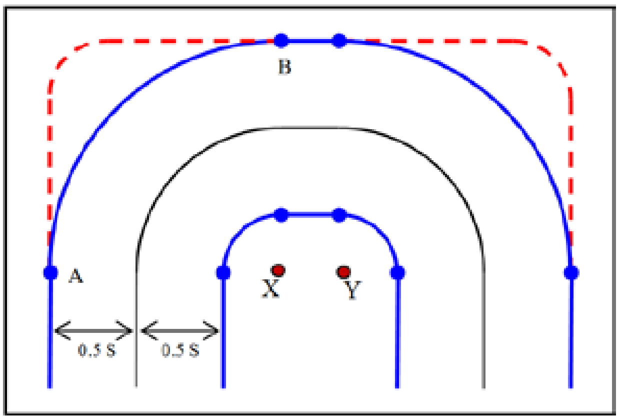

Figure 6. The new route, with an optimal, well-chosen search scheme

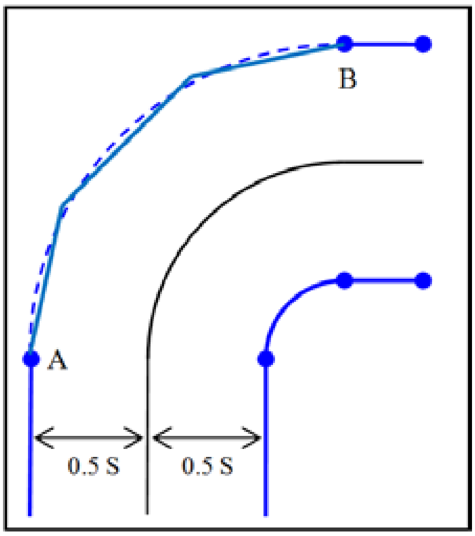

Figure 7. The approximate route with well-chosen search scheme

respectively second, third and fourth) turns (points X and Y in Figure 6). The dashed line represents a textbook route, while the solid-line route allows a search of the entire area.

However, such a trajectory is difficult to achieve in practice, due to hydro-meteorological factors. Using the Electronic Chart Display and Information System (ECDIS) system, arc AB can replace the plotline consisting of an adequate number of sections (Figure 7). Such a modification makes it easier to control the ship's course and to instruct the helmsman.

Optimization of search and rescue

An optimal search route is most advantageous because it accounts for the vessel's manoeuvrability characteristics. In order to develop it for navigation and to meet formal requirements, the navigator could make use of a combination of ECDIS and such generally available supporting navigation planning programs as Navi-Planner 4000, produced by the TRANSAS Company.

By using such a program, the navigator would create an itinerary using electronic navigation maps which contain the following information:

- safety contour – includes draft and under-keel clearance;
- safety depth – a parameter defined by the navigator that extends the ability to detect underwater hazards found at depths greater values specified by safety contours;
- sounder depth – a parameter defined in the echo sounder as a sensor of the ECDIS system;
- limits of waterways and canals;
- prohibited and restricted areas;
- traffic control systems and ferry routes;
- navigational danger ring – which enables the detection of underwater hazards on the basis of ENC.

The program also allows detection of NAVTEX objects that have the attribute "Danger" added, as well as objects inserted by the user such as a "user chart object" or "manual correction object" which have been given the attribute "danger" and/or inserted at a depth less than the "safety depth".

Such a combination would allow the navigator to make optimal decisions.

Conclusions

Conflict between assumptions concerning search schemes in the IAMSAR manual and the manoeuvrability characteristics of ships stems from the fact that the manual was developed as a universal source for SAR vessels, military ships, and small units and aircraft which are good at turning. However, the manual notes that it is difficult for patrol aircraft to perform a flight close to the reference point if the first section is less than 2 NM, as is also the case with ships.

The only adequate solution that accounts for the manoeuvrability of each vessel is the extension of certain sections and appropriate fine-tuning of the search and rescue scheme.

It is important to gather information from a variety of sources that expand and improve credibility and create the ability to appropriately process and analyse search and rescue procedures.

The implementation of a proactive safety management strategy offers a chance to take appropriate action – correction, prevention and improvement – in order to minimize the risks.

The proposed product clearly fits the trends of modern science. The benefits of "nurturing" a good safety culture and economic impacts clearly include the following elements:

- optimizing effectiveness of search and rescue;
- full review of the current and future situations;
- optimization of economic costs – time and fuel consumption;
- reduced bureaucracy on the ship.

Its implementation in a given vessel is simple, due to the mandatory requirements of equipment and, most importantly, the fact that it can be used without modification throughout the life of the vessel.

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