Search for an Object in Distress by Improved Scheme of the IAMSAR "Expanding Square" Methodology

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Abstract: There are actions being taken worldwide continuously to improve the safety of shipping. Nevertheless, sea accidents are not diminishing. According to the IMO SAR Convention, maritime states are required to provide surveillance of the entire coastline under their jurisdiction and to be able to carry out effective rescue operations. The success of the SAR operation depends on the speed of its planning and implementation. The captain of a ship, participating in a SAR operation, must have a clear methodology and criteria, which define the volume of the search. One of the methodologies, offered by the SAR Convention, is "Expanding Square". It has weaknesses, one of which is the large area where should be search the object in distress. The article deals with an improved "Expanding Square" to locate an object in distress in a minimum area with maximum probability of detection. The proposed methodology provides better opportunities for recalculating and repeating of the search and a high probability of discovering the object.

Key-Words: SAR operation, objects in distress, expanding square, ellipse of distraction

1 Introduction

Global action is continuously undertaken to improve the safety of shipping. Nevertheless, in the last 10-15 years, marine accidents have taken not only a significant number of human casualties but also have led to great material losses. This is related to the development of the world's nautical fleet, the rapid development of electronic technologies in navigation, the sharp increase in the number of unconventional vessels as well as the lack of a sufficient number of highly qualified seafarers.

The statistics for the past 10-15 years show that different types of ships with or without communication equipment have been in distress situations. Such cases have happened in all responsible areas. Of all cases, 75.5% are small vessels and only 24.5% are large vessels equipped with GMDSS communication equipment. 56.2% of the vessels were without means of communication. 10-15% of the cases have resulted in perish of the distressed vessel and its crew, or have never been found. Most cases have happened in the coastal area - 66%, in the shelf area they are 18% and in the deep water area - 16%. In 67% of the cases, the dimensions of the search areas have a radius greater than 10 nautical miles. In 51% of cases, the position and time information of the accident are incomplete, and in 19% of cases it is totally absent. [8]

Search and rescue operations are an international activity involving usually participants from different countries, in international or territorial waters of a country. For the effective conduct of such an operation, it appears that the general principles and rules laid down in the international instruments must be revised with the specifics of the area where the operation takes place. This requires a thorough knowledge of the natural conditions of each responsible area, as well as the capabilities of theavailable teams and equipment.

According to the SAR developed by the IMO, maritime states are required to provide surveillance of the entire coastline under their jurisdiction and, if necessary, to be able to effectively carry out rescue operations. [1]

2 Essence of the Problem

One of the main practical results of the existence of the Global Search and Rescue System (SAR) is that there isnoneed for establishing SAR Service by each country for the ships flying its flag. Instead, the World Ocean is divided into Search and Rescue Regions (SRRs), which have Rescue Coordination Centers (RCCs) and relevant SARs to assist any vessel in distress within the SRR, regardless of the flag and the circumstances. [1], [2]

There are three levels of coordination in the SAR system that are related to the Search and Rescue Coordinator (SC), Search and rescue mission coordinator (SMC) and the On-scene coordinator (OSC).

Any ship deemed by the relevant RCC to be in the most convenient position to perform a search and rescue operationof a vessel or people in distress on board a lifesaving appliance may act as an OSC and even perform the functions of an SMC.

The success of the SAR operation depends largely on the speed of planning and its execution. For an in-depth assessment of the situation and the timely SAR forces' actions, it is important to have all the information available in due time - accuracy and reliability of the on-scene preliminary data and the time of occurrence of the accident, the condition of the vessel in distress, the hydro meteorological conditions in the area and the capabilities of the search forces. Often, much of this data is missing.

Although SAR operations do not develop under one and the same scheme, actions performed in distress situations are divided into certain stages that must be reported. [1]

Exact planning is critical to the success of SAR operations. To this end, the SMC and the other participants in the operation should be trained appropriately. An important part of the training is the use of ready-made procedures with clearly formulated action steps, due to which:

- important details will not be omitted from the data about the object in distress;
- calculations will be made in the correct sequence;
- the time to estimate will be reduced;
- all parameters of the situation will be reviewed.

Case studies show that the number of accidents involving the search of small objects by a ship in the immediate vicinity of on-scene is significant. [3], [4], [5]

The master of such a ship must have a clear methodology on which to act and clearly defined criteria to define the amount of search. The methodology must provide for the determination of a minimum area with maximum probability of detection of the search object. This provides better opportunities for recalculation and repetition of the search and greater probability for detecting the object. [6], [7]

One of the methodologies for search and rescue, offered by the SAR Convention, is "Expanding Square". It has weaknesses, one of which is the large area where the object in distress should be searched. This substantially reduces the chances to locate the object.

The article suggests a methodology for making the search area more precise, taking into account the influence of the wind, the swell and the currents on the track of the object, by taking into account the velocity and velocity errors as well, and the position from which the distress signal is sent. In relation to that the search time is calculated, as well as the moment when the search should be called off if no objects are found, and the extent of the coverage of the estimated area under the selected maneuvering scheme.

3 Improved Scheme of the "Expanding Square" Methodology

The most commonly used search patterns for small craft or people fallen overboard are described in IAMSAR. Their use depends on the size of the area, the number and type of rescue units, the availabletime, the hydro-meteorological conditions, etc. The research is mostly interested in the search patterns with one SAR unit.

It is of paramount importance for the favorable outcome of the search to properly assess the factors that cause the drift of the object and to define a minimum area of search with maximum probability of detection.

The setting of the task is that the search ship is the closest one to on-scene and is the only unit that can be involvedin a rescue operation in the following hours. A signal from the GMDSS equipment of the ship or its EPIRB is sent, and this signal may either be received on board or received later by the SAR center. In both cases, the signal emitting coils $\varphi_{rad} = \varphi_{ob1}$ and $\lambda_{rad} = \lambda_{ob1}$ and their mid-square error Mo, which will be greatest when the position of EPIRB is known.

The ship involved in the rescue operation fixes the moment of T_{rad} on the distress signal transmission and determines as accurately as possible the coordinates of its own position at that moment - φ_1 and λ_1.

After a period of time ΔT_{lag} from the signal transmission, the SAR center gives an order to the ship to proceed to on-scene. If the SAR center does not receive information about the destination K_{lead} and the V_{lead} speed of the potential total leeway of the lifesaving appliances in the area, the master of the ship shall be obliged to set probable values for these parameters based on his own hydro-meteorological observations and the use of the relevant tables and schedules.

Determine our position at time $T_2 = T_{rad} + \Delta T_{lag}$ with coordinates φ_2 and λ_2 and the new potential position of the distressed φ_{ob2} and λ_{ob2}, the ship calculates its course K_2 and time ΔT_2 to sail to this point with the possible maximum speed V_{max}. The calculation should be done with the analytical calculation formulas with meridian parts (MP). Indicative time ΔT_2 for arrival at on-scene position will be:

$$\Delta T_2 = S_2 / V_{max} \qquad (1)$$

where: $S_2 = \Delta\varphi_2 / \cos K_2$;
$K_2 = \text{atg}\,(\Delta\lambda_2 / DMP_2)$;
$\Delta\varphi_2 = \varphi_{ob2} - \varphi_2$; $\Delta\lambda_2 = \lambda_{ob2} - \lambda_2$;
$DMP_2 = MP_{ob2} - MP_2$.

An estimate is made for the new coordinates φ_{ob3} and λ_{ob3} at the point where the disaster will be potentially located after time ΔT_2. Using meridian parts, calculate the course of the ship K_3, the sailed distance S_3 and the corrected time ΔT_3 to the final reach at the point.

This iterative approach has the advantage of avoiding possible graphical errors if the task is solved on a maneuvering plan or on a small-scale map, and the errors in an analytical calculation with a deviation.

The ship shall take measures to accurately steer the computed path of approach to on-scene, by controlling its position with high-level observation at a frequency at least twice as much of the normal voyages in the open sea.

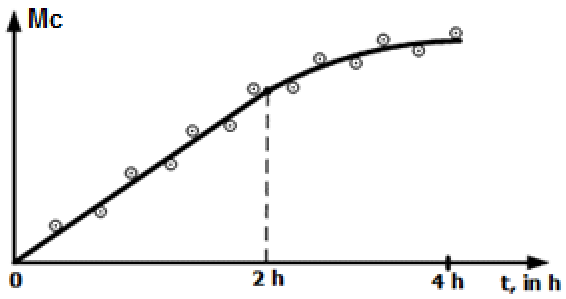

Fig. 1 Change of the mean square error (MSE) of the calculated position (M_c), where *t* is the time of sailing

The results of the methodology show that within the 2 hours interval the rate of change of the mean square error (MSE) of the calculated position (M_c) is subject to a linear law, after which the curve approaches parabola and the dependence becomes quadratic. (Figure 1) Thus, the error in the analytical calculation of the path can be determined at any moment.

The "Expanding Square Search" method is most effective when the situation of a distressed vessel is known in small margins, which is a good case for targeting a single ship. The point from which the search begins (Datum $D = M_c$) is determined by the above described sequence.

In order to achieve search efficiency and reduce search time, the ship master determines his first course in the direction of the minor semi axis *b* of the ellipse of distraction - (T - 90°). (Figure 2)

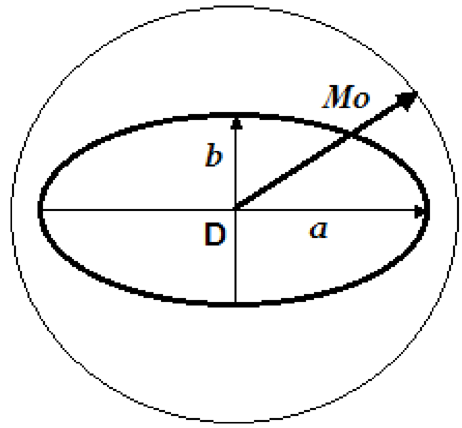

Fig. 2 Ellipse of distraction and circular error
a - a major semi axis of the ellipse;
b - a minor semi axis of the ellipse;
M_o - circular error.

Determine the distance S between the tracks by the formula:

$$S = f_w .\ S_u \qquad (2)$$

where: f_w - meteorological factor;
S_u - one unit per tracks of the ship.

The parameters f_w and S_u are defined by IAMSAR tables.

The search in the direction of the minor semi axis *b* of the ellipse will initially cover an area of 2*b* x 2*b*, the area of which, relative to the area of the ellipse, can be calculated as a percentage by the following relation:

$$W\,[\%] = (4/\pi\ .\ b/a)\ .\ 100 \qquad (3)$$

where W is the percentage of the area of the area surveyed to the area of the ellipse of distraction.

4. Practical Application of the Proposed Improved Methodology

The results in Table 1 show that, even in the boundary case, with the strongly flattened ellipse (b/a = 0.35), the initial survey covered almost 50% of the area of the area.

Relative share of the area initially searched W in relation to the area of the ellipse, in (%)

Table 1

№	*a*	*b*	*b*/*a*	W
1	5,00	1,75	0,35	44,6 %
2	5,00	2,50	0,50	63.7 %
3	5,00	3,75	0,75	95.5 %
4	5,00	3,95	0,79	100,0 %

Due to the small area that is covered, the method should not be used simultaneously by several ships or aircraft, until the spiral does not cover a square with the side of double size of the minor semi axis *b* of the ellipse.

The next stage of the search should cover the remaining areas that are in the direction of the major semi axis *a* of the ellipse, starting from that part located on the leeward side. Here, the search must continue parallel to the major semi axis *a* tracks, while maintaining the same distance between them.

In order to save time, the next ship or aircraft which arrives in the area can be guided to the non-searched weather side by setting the maneuvering parameters. If there is no such aircraft in the area, the ship last searches the weather side section of the ellipse and, on its way to it, carries out a control survey in the already searched sections.

Under the "Expanding Square" scheme, the master of the ship pre-calculates the direction and magnitude of each track (Table 2), with the number of tracks X being determined by the dependence:

$$X = 2\,(n-1) \qquad (4)$$

where: $n = 2b / S_u . f_w$

The parameters f_w and S_u are described in formula (2). The minor semi axis of the ellipse is in nautical miles (NM).

The result obtained for X is rounded off to the nearest whole integer, entered in Table 2 and the total distance run for the stage is taken into account, and the search time is calculated by the speed entered.

Calculation of tracks parameters for initial search in direction of minor semi axis on the ellipse

Table 2

№ of track	Course of track, C (°)	Length of track, (NM)	Total distance to course, (NM)	Total distance to route, (NM)
1	$K_1 = K$	S	2 S	S
2	$K_2 = K + 90^0$	S	2 S	2 S
3	$K_3 = K + 180^0$	2 S	3 S	4 S
4	$K_4 = K + 270^0$	2 S	3 S	6 S
5	$K_5 = K$	3 S	4 S	9 S
6	$K_6 = K + 90^0$	3 S	4 S	12 S
7	$K_7 = K + 180^0$	4 S	5 S	16 S
8	$K_8 = K + 270^0$	4 S	5 S	20 S
9	$K_9 = K$	5 S	6 S	25 S
10	$K_{10} = K + 90^0$	5 S	6 S	30 S

Next, the left or right remaining part of the ellipse is searched according to the schemes shown in Tables 3 and 4, where the last track has a length equal to the difference in the ellipse semi axes.

Calculation of the search parameters of the tracks for the remaining ellipse area

Table 3

№ of track	Course of track, C (°)	Length of track, (NM)	Total distance to course, (NM)	Total distance to route, (NM)
Left hand side (Port side)				
1	$K_1 = K$	S	2 S	S
2	$K_2 = K - 90^0$	2*b*	2*b* + S	2*b* + S
3	$K_3 = K$	S	2 S	2*b* + 2S
4	$K_4 = K + 90^0$	2*b*	2*b* + S	4*b* + 2S
5	....	…..	…..	…..
i	K_i	…..	i.*b*+S=*a*-*b*	…..

Calculation of the search parameters of the tracks for the remaining ellipse area

Table 4

№ of track	Course of track, C (°)	Length of track, (NM)	Total distance to course, (NM)	Total distance to route, (NM)
Right hand side (Starboard side)				
1	$K_1 = K + 180^0$	2*b*	2*b* + S	2*b*
2	$K_2 = K + 90^0$	S	2 S	2*b* + 2S
3	$K_3 = K + 180^0$	2*b*	2*b* + S	4*b* + 2S
4	$K_4 = K + 90^0$	S	2 S	4*b* + 3S
5	....	…..	…..	…..
i	K_i	…..	i.*b*+S=*a*-*b*	…..

The final stage envisages maneuvering at 45^0 turn in relation to the main system of courses, designed to cover the entire area of the ellipse. (Figure 3) This may be necessary if the initial search did not work.

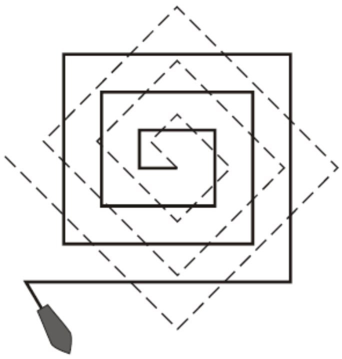

Fig. 3 Checking the area of the ellipse

When the ship arrives at the starting point for a search and finds a change in the general direction of the leeway due to the modified hydro meteorological situation, the first course of departure is in the direction of the contiguous diameter of the ellipse, which coincides with the new sum total of the leeway direction in the area.

5 Conclusion

Problems of the search and rescue at sea have existed since shipping does and despite the fact that the aid systems are constantly improving with the introduction of new technologies in the fields of logistics, satellite navigation, communications and the adoption of amendments to the conventions and resolutions of the IMO, the number of unsuccessful rescue operations remains relatively high.

The reasons are many and are subject to a special analysis, but one is related to the minimum requirements set out in the IMO Model Search and Rescue Model Courses. This reflects on the training of officers who are engaged in merchant shipping. As an argument it can be said that the specialized SAR training is implemented in full in the SAR programs, with naval forces and, to some extent, with the volunteer organizations.

Considering that a merchant ship, yacht, etc., which is in the area of distress very often, becomes a rescue unit, this requires while being trained to find a rational decision for the seafarers in order to know what they are going to do, if they actually take sole responsibility for the search of survivors in case of an incident at sea.

The article aims to detail the search actions under the "Expanding Square" scheme, giving a pragmatic form for making the necessary calculations and directing the attention to analyzing the possible real position of the survivors, which in the search process maintains the officers' believes that they have taken the right and appropriate actions, regardless of the outcome of the situation.

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