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Dependence of the Maximum Approach Distance on the Shape of the Ship's Safe Domain

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ABSTRACT: In work analytical expressions are resulted for a calculation minimum - possible distance of rapprochement in the case of application of domains of elliptic and difficult form. Shown graphic dependence minimum - possible distance of rapprochement from foreshortening of ships which are drawn together, for the domains of both types.
It is shown that the domains of elliptic and difficult form have a similar character of change minimum - possible distance of rapprochement depending on foreshortening of ships.

1 INTRODUCTION

One of the most priority issues is the problem of ensuring the safety of navigation in narrow waters, the relevance of which is determined by the increase in the intensity of traffic on waterways, the increase in the size of vessels and the difficult navigation conditions of navigation. Solving this problem contributes to improving the protection of human life at sea and reducing damage to the environment, which requires improving methods for determining the parameters of a safe separation strategy.

2 A BRIEF REVIEW OF PUBLICATIONS ON THE TOPIC

The principle and methods of external control of the process of diverging vessels are set out in work [1], which considers the main methods of external control of the process of diverging vessels, which consist in using the areas of dangerous courses of approaching vessels and their dangerous speeds to assess the level of danger of the approach situation and, if necessary, select a diverging maneuver. The method of diverging vessels at sea by shifting to a line parallel to the path at one or another angle to the program course line is proposed in the monograph [2]. As it is noted in it, increasing the effectiveness of preventing vessel collisions can be achieved by creating new divergence algorithms and intelligent systems. The principles of external and locally independent control of the process of diverging vessels that are dangerously approaching are set out in work [3], which also analyzes the methods of their application in the event of a threat of collision of vessels. In the situation of dangerous convergence of a vessel with two targets, a method for forming regions of unacceptable values of the vessel's motion parameters with respect to each of them is proposed in the work [4]. A procedure for assessing the level of danger of the emerging convergence situation for each target is developed. The possibility of choosing a divergence maneuver by general evasion from both targets is shown, three situations of convergence of a vessel with two targets are considered.

A description of the process of vessel separation in terms of a differential antagonistic game is proposed in [5], and in [6] an emergency strategy of separation in a situation of excessive convergence of vessels is considered. In [7] the issue of choosing the optimal standard maneuver of separation of two vessels is considered. In [8] the distribution algorithms for forming a strategy of several vessels for situations of their dangerous convergence are considered. In [9] analytical expressions for calculating the boundaries of the areas of dangerous courses and dangerous speeds in the case of external control of the process of vessel separation are given. In the work, formulas for calculating the boundaries of the area of unacceptable values of the courses of one vessel and the speeds of another vessel are obtained and the procedure for graphically displaying the area is considered. The theoretical justification of an autonomous ship collision avoidance system is considered in [10], which provides an algorithm for collision avoidance. Generalizing approaches to research on ship control automation, which can be based on the application of mathematical models and algorithms, or on the use of artificial intelligence.

3 PURPOSE

The purpose of this publication is to study the dependence of the maximum approach distance on the shape of the ship's safe domain. Materials and methods as shown in [3], the condition for safe separation of ships is determined by the equality of the distances of the shortest approach and the maximum allowable approach, i.e., provided that the ships are approaching. Traditionally, the maximum allowable approach distance does not depend on the relative position of the approaching ships and is taken to be constant in magnitude, which means that the safe domain of the ship has the shape of a circle and is given in the space of relative motion. However, more than ten forms of the safe domain other than a circle have been proposed recently. Therefore, the maximum allowable approach distance when using such domains is not constant, but depends on the angle of view of the approaching ships. The value of the maximum permissible distance of convergence of vessels, taking into account the shape of the safe domain, depends on the side of the relative deviation and is determined by the maximum relative courses and. Therefore, we denote and - the maximum permissible distances of convergence with the relative deviation of the vessel to the right and left, respectively, as shown in Fig. 1. From the same figure, we can find expressions for determining the maximum permissible distances of convergence:

$$D_d^s = D\left|\sin(K_{ot}^s - \alpha)\right|. \;\; D_d^p = D\left|\sin(K_{ot}^p - \alpha)\right|$$

where D and α - respectively, distance and bearing to the target.

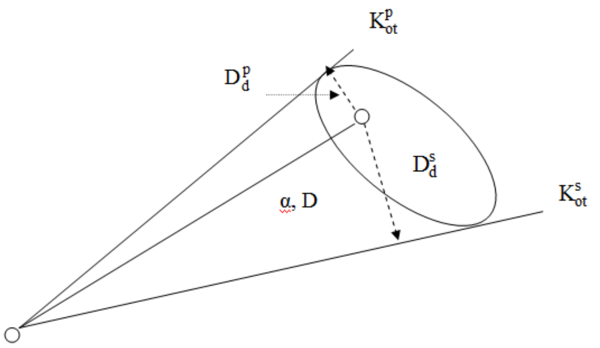

Figure 1. Maximum permissible approach distances

Results and their discussion Let us consider two types of domains, for each of which it is necessary to find expressions for the limiting relative deviation rates and with the subsequent development of procedures for calculating the maximum permissible distances of convergence and. First, we consider analytical expressions for the limiting relative deviation rates for an elliptical domain, which we will denote by. In this case, the relative rate of minimum deviation is determined by the tangent to the domain boundary, the position of which depends on the target angle. In work [11], expressions for calculating the limiting relative deviation rates were obtained, which are defined as follows:

$$K_{ot}^s = \max\left\{\bar{K}_{ymin1}, \bar{K}_{ymin2}, \bar{K}_{ymin3}, \bar{K}_{ymin4}\right\}$$

$$K_{ot}^p = \min\left\{\bar{K}_{ymin1}, \bar{K}_{ymin2}, \bar{K}_{ymin3}, \bar{K}_{ymin4}\right\}$$

In the last expression:

$$\bar{K}_{ymin1,2} = arctg\frac{\bar{X}_o \pm b\sqrt{1-\frac{x_1^2}{a^2}}\sin K_c + x_1\cos K_c}{\bar{Y}_o \pm b\sqrt{1-\frac{x_1^2}{a^2}}\cos K_c - x_1\sin K_c}$$

$$\bar{K}_{ymin3,4} = arctg\frac{\bar{X}_o \pm b\sqrt{1-\frac{x_2^2}{a^2}}\sin K_c + x_2\cos K_c}{\bar{Y}_o \pm b\sqrt{1-\frac{x_2^2}{a^2}}\cos K_c - x_2\sin K_c} \qquad (1)$$

where

$$x_1 = -\frac{a^2cb}{a^2+c^2r^2} + \sqrt{\left(\frac{a^2cb}{a^2+c^2r^2}\right)^2 - \frac{a^2c^2(b^2-r^2)}{(a^2+c^2r^2)}}$$

$$x_2 = -\frac{a^2cb}{a^2+c^2r^2} - \sqrt{(\frac{a^2cb}{a^2+c^2r^2})^2 - \frac{a^2c^2(b^2-r^2}{(a^2+c^2r^2)}}$$

moreover

$$c = \frac{a^2}{b(\bar{Y}_o \sin K_c - \bar{X}_o \cos K_c)}$$

$$r = (\bar{Y}_o \cos K_c + \bar{X}_o \sin K_c)$$

To calculate the maximum relative deviation rates and maximum permissible approach distances, a computer program was developed, in which the value of the maximum permissible approach distance is calculated depending on the angle, as shown in Fig. 2. By changing the bearing from 5° to 360°, the program calculated the corresponding values of the maximum relative deviation rate and distance. The calculation results are presented in Fig. 3, in the right part of which the graphical dependence of the maximum permissible approach distance on the angle value is shown. Let us consider the calculation of the maximum relative deviation rates for a safe domain of a complex shape, which is a combination of half an ellipse and half a circle. As previously indicated, the maximum relative deviation rate of the vessel is the tangent from the vessel's location to the target's safe domain. In work [11] it is shown that in the general case the minimum relative deviation rate of the vessel is:

$$\bar{K}_{y\min} = \begin{cases} K_{otn} + \arcsin \dfrac{R_b}{D} & if\ \sin\beta < 0 \\ \max\{\bar{K}_{y\min 1}, \bar{K}_{y\min 2}, \bar{K}_{y\min 3}, \bar{K}_{y\min 4}\} & if\ \sin\beta > 0 \end{cases}$$

where $\bar{K}_{ymin1}$, $\bar{K}_{ymin2}$, $\bar{K}_{ymin3}$ and $\bar{K}_{ymin4}$ are defined by the expression (1), β - relative bearing from target to ship.

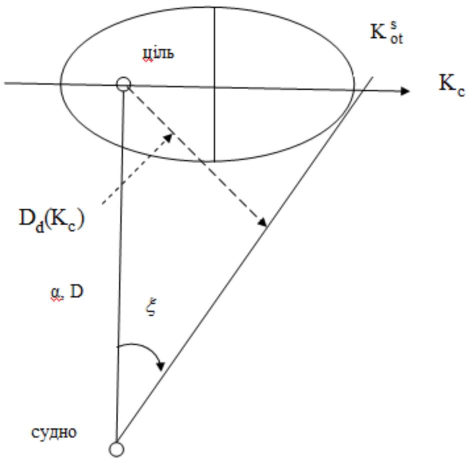

Figure 2. Distance dependence   by the angle

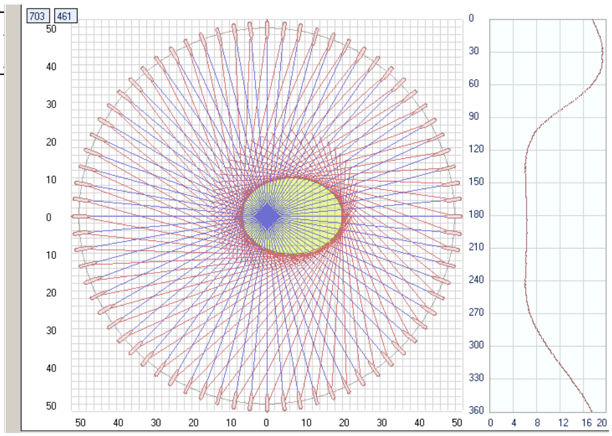

Figure 3. Changing the distance   with an elliptical domain shape

As in the previous case, the developed computer program calculated the limiting relative courses and the values of the maximum permissible convergence distance for a domain of complex shape, the nature of the change of which depending on the angle is shown in Fig. 4.

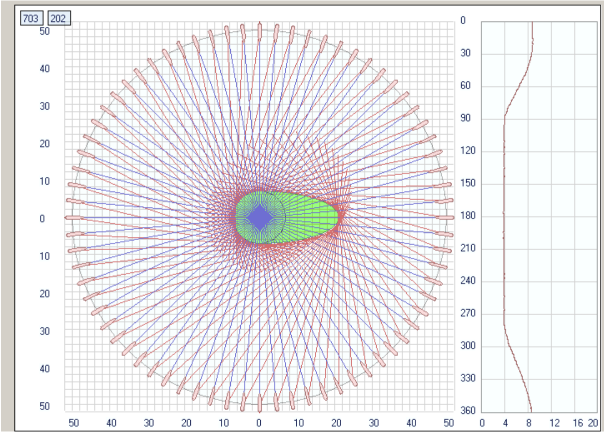

Figure 4. Changing the distance of a complex-shaped domain

Analyzing Fig. 3 and Fig. 4, we note that the domains of elliptical and complex shapes have a similar nature of change in the maximum permissible approach distance depending on the angle of the vessels. Therefore, it is advisable to use only one of them.

4 CONCLUSIONS

1. Analytical expressions are given for calculating the maximum permissible approach distance in the case of using domains of elliptical and complex shapes.
2. The graphical dependence of the maximum permissible approach distance on the angle of the approaching vessels for domains of both types is shown.
3. It is shown that the domains of elliptical and complex shapes have a similar nature of change in the maximum permissible approach distance.

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