Multiple Encounter Avoidance Manoeuvres

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Following on from an earlier paper, the authors have analysed some of the options available to mariners who are faced with taking avoiding action in multiple encounters and have considered the effect of these options on manoeuvre distance.

KEY WORDS

1. Collision Avoidance. 2. Multiple Encounters.

1. INTRODUCTION. In an earlier paper,[1] the authors presented the results of a theoretical investigation concerning the occurrence of multiple encounters when a ship in the give-way position crosses a busy shipping route. In particular, it was shown that for the present traffic flow rate in the English Channel of 4·5 ships per hour, about 20 percent of the crossing encounters could be expected to be multiple encounters; that is, they would involve more than one route ship. Consequently, in view of the significant frequency at which multiple encounters appear to occur, it was thought useful to attempt an analysis of some of the options available to a mariner faced with taking avoidance action when such situations arise. Marine radar equipment allows multiple targets to be detected and displayed but, in the main, the calculation of avoidance manoeuvres on a priority basis together with a complete analysis of the consequences has been limited to experimental systems. Thus it seemed likely that a systematic analysis of the avoidance action required in a multiple encounter might offer some insight into the phenomena and perhaps be helpful in practice. The options available in a multiple crossing encounter would seem to be:

(i) a conventional manoeuvre to starboard by the give-way vessel at an earlier time and position than would otherwise be chosen,
(ii) an increased angle of manoeuvre, or
(iii) a reduction in speed.

Other somewhat more drastic possibilities would appear to include: a turn to starboard so as to follow a course parallel to the direction of the on-coming route ships until a suitable gap in the traffic appears, to proceed temporarily in a circle, or even stop. The work reported here is concerned with the first three possibilities only, as these would appear to be the options most likely to be acceptable to most mariners.

2. METHOD OF CALCULATION. The calculation of the distance at which an early manoeuvre needs to be instigated by a crossing ship in a multiple encounter was based on the relative velocity diagram shown in Figure 1. This is essentially similar to that given in the previous paper,[1] except that the crossing ship is shown making a turn to starboard at the point M in order to avoid a second route ship present

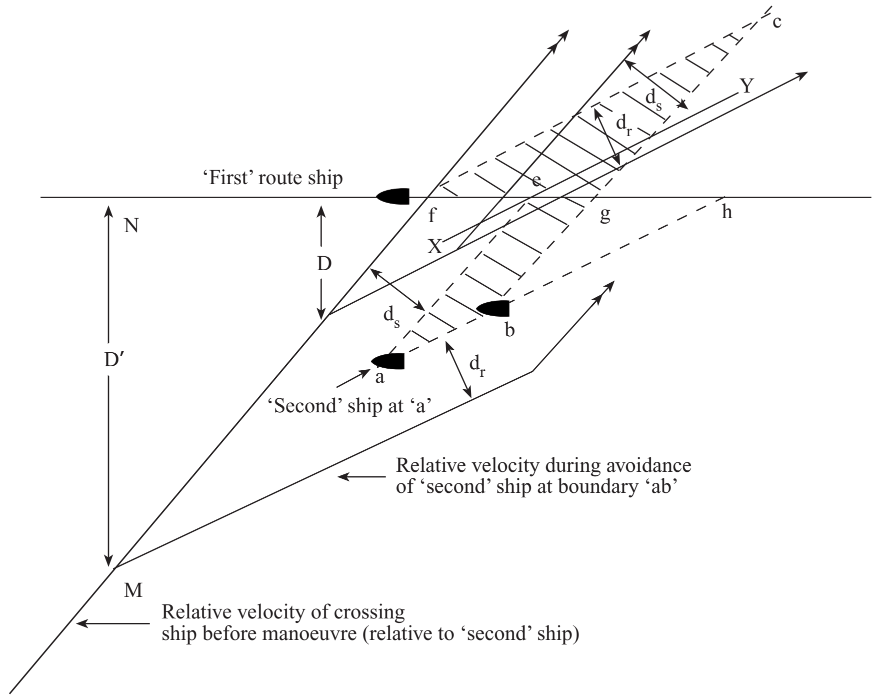

Figure 1. Relative velocities of a crossing vessel with respect to a second route ship.

within the areas 'abge' or 'fcg'. The position of M was calculated from the intersection of the relative velocity vectors of the crossing ship before and during the manoeuvre, and the distance MN perpendicular to the line of travel of the first route ship gave the point at which the avoidance action is required. For mathematical convenience, the manoeuvre was regarded as taking place abruptly at the point M although, as is well known, a change of course involves a delay and a temporary loss of speed before a new course is fully taken up. However, from the data given by Muller and Krauss,[2] it would appear that for the 30 degree change of course used in most of the calculations reported here, the delay corresponds to about 1·5 times the ship's length, and the temporary loss of speed is only about one or two knots. It therefore did not seem unreasonable to neglect these effects and assume an abrupt change of course. In the previous paper, a circular domain having a radius of 0·8 nm was used but, in the present investigation, it was decided to approximate the domain more closely to the asymmetric pattern that had been observed by Goodwin.[3] Consequently, a domain with a port side radius of 0·7 nm and a starboard radius of 0·9 nm was employed. Goodwin's domain included a rear segment of relatively small radius, but as this was expected to play little or no part in the manoeuvres under consideration, it was decided to ignore this feature and extrapolate the port and starboard segments round to the stern. The computer program was written to permit the first route ship to be positioned at any point across the domain sweep of the crossing ship by the adjustment of a factor k. This could be set within the range 0 to 1, corresponding to the extreme port and starboard positions respectively. Many of the calculations were made with k equal to 0·5 which placed the route ship a little to starboard of the line of the crossing vessel corresponding to a mean position. The program also allowed the angle of the manoeuvre to be changed, and the speed of the crossing ship to be altered after the beginning of the avoidance action.

3. RESULTS. Plots of the manoeuvre distance measured from the line of travel of the first route ship for a range of crossing vessel speeds are shown in Figure 2. The

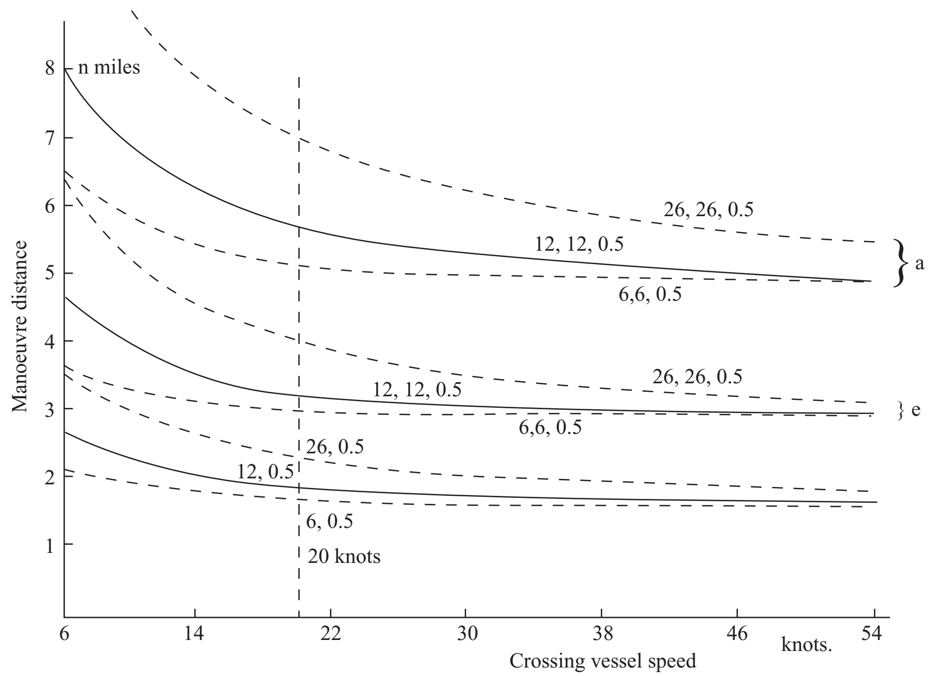

Figure 2. Manoeuvre distance as a function of crossing vessel speed.

uppermost set of curves refers to the manoeuvre distance needed by a crossing vessel to clear a second route ship positioned at a point along the boundary 'ab' of the multiple encounter area shown in Figure 1. The middle set of curves applies when the second ship is located on the line 'XY' parallel to 'ab', and which passes through the point 'e', whilst the lower set refers to the normal manoeuvre required when only one route ship is to be avoided. The curves have been calculated for k equal to 0·5, and a manoeuvre angle of 30 degrees. The centre curve of each set applies when both route ships have speeds of 12 knots, and the outer curves apply to the extreme cases when both route ships have speeds of 6 and 26 knots respectively. The situation when both ships have speeds of 12 knots is reasonably close to the combination most likely to produce multiple encounters amongst the Dover Strait traffic assuming a Gaussian speed distribution centered about 12·0 knots and a standard deviation of 3·7 knots. When the angle of manoeuvre during a multiple encounter has the same value as when only one route ship is involved, and the speed of the crossing vessel remains unchanged, the manoeuvre distance is independent of the position of the second ship along the line 'XY' parallel to the boundary 'ab'. The manoeuvre distance has a maximum value when 'XY' coincides with 'ab', and decreases linearly as it is shifted across the multiple encounter areas until it reaches the boundary 'fc', at which position the manoeuvre distance becomes equal to the distance required for the avoidance of one ship only. The effect of increasing the angle of manoeuvre when more than one ship is present, as well as reducing the speed after the manoeuvre has begun, is shown in Figure 3.

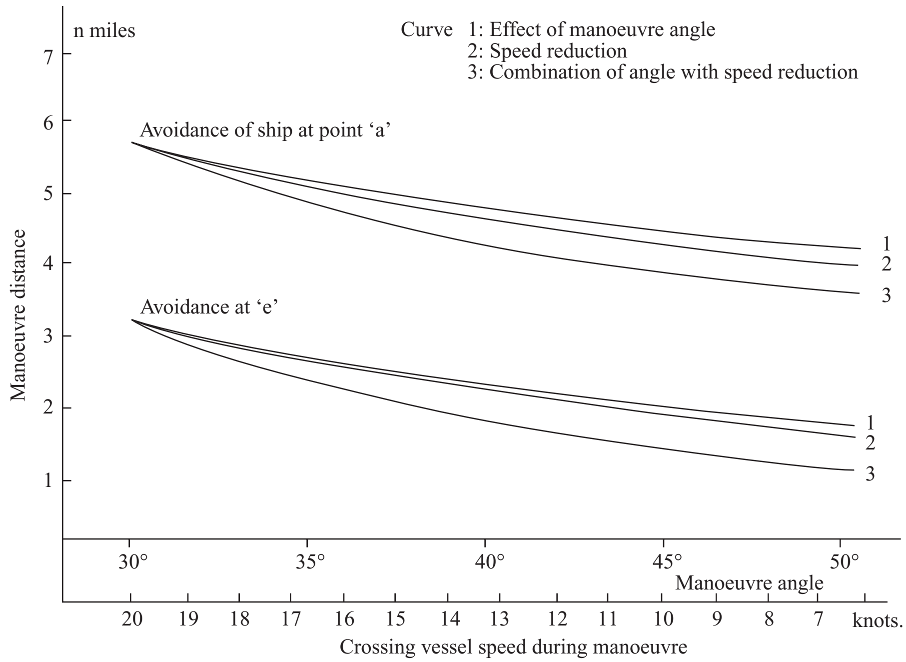

Figure 3. The effect of manoeuvre angle and speed reduction on manoeuvre distance.

The result of increasing the angle and reducing the speed together is also shown. An increase in the angle from 30 to 45 degrees causes a drop of about 22 percent in the manoeuvre distance for the avoidance of a second ship at 'a' for a 20, 12, 12, 0·5 configuration (where 20 is the crossing vessel speed and both route ships have a speed of 12 knots, and k is 0·5). Halving the speed of the crossing ship from 20 to 10 knots produces a 24 percent reduction, and if the angle is also increased to 45 degrees, the manoeuvre distance is reduced by about 31 percent. The extent of the reduction varies with the position of the second route ship within the multiple encounter areas. For example, if the second ship is at the point 'e', a reduction of about 54 percent is obtained when the crossing vessel reduces speed to 10 knots and the angle of manoeuvre is 45 degrees. When either the angle of manoeuvre or the speed of the crossing ship is altered during the manoeuvre, the line 'XY' is no longer parallel to the boundary 'ab' but lies at an angle determined by the new relative velocity of the crossing vessel.

4. CONCLUSIONS.

Perhaps the most significant result yielded by the computations is that, when a crossing vessel speed exceeds about 20 knots, the manoeuvre distance remains fairly constant, decreasing asymptotically as the higher crossing speeds are approached. Moreover, the speed of the route ships have only a limited effect on the manoeuvre distance particularly at the higher crossing speeds. As would be expected, earlier manoeuvres are necessary when the second route ship is located within the nearer area 'abge' than when it is in the triangular area 'fcg' beyond the line of travel of the first route ship. The manoeuvre distance is sensitive to the position of the first route ship with respect to the sweep of the domain of the crossing ship, that is to the value of k. Thus when k is 0·1, corresponding to the first route ship being located close to the port side edge of the crossing ship's domain, the manoeuvre distance is 4·6 nm when the crossing ship has a speed of 20 knots, and both route ships have speeds of 12 knots, and the second ship is on the boundary 'ab'. The manoeuvre distance increases to 5·7 nm when k is 0·5, and to 7·1 nm when k has the maximum value of 1·0. Some of the manoeuvre distances are quite large; however, it has been assumed that the second ship is to be cleared by the port side domain radius of the crossing vessel. In practice, it may be that mariners faced with a multiple encounter are willing to tolerate smaller clearances because of the exigiences of the situation. In addition, there is some evidence that domains are significantly smaller in the Dover Strait than those observed off Harwich, perhaps due to the higher traffic density in the English Channel, and the considerable manoeuvrability of the cross-channel ferries.

The calculated manoeuvre distances depend linearly on the size of the domains, so that, if for example, the port and starboard radii are halved to 0·35 nm and 0·45 nm respectively, the calculated manoeuvre distances will also be halved. Smaller domains decrease the frequency of encounters and also reduce the probability that those encounters that do occur will develop into multiple encounters. The calculations showed that increasing the angle of manoeuvre, or reducing the speed of the crossing vessel during a manoeuvre, both serve to reduce the manoeuvre distance by a useful amount and that, when both procedures are applied together, a greater reduction is obtained. An alteration in speed whilst manoeuvring is by no means uncommon, but it has been suggested that there are risks involved, although it would seem that these are more likely to be associated with manoeuvres involving an increase rather than a decrease in speed. If more than one route ship is present within the multiple encounter areas, it is necessary to compute each manoeuvre distance and accept the largest of the values. In this way, all the other ships that require smaller distances will automatically be cleared. Clearly, each route ship will have its own multiple encounter area depending on its speed relative to the crossing vessel. Some such multiple encounters can become quite involved, and may require a crossing vessel that is in the process of making an avoidance manoeuvre to postpone the return to its original course. This may sometimes happen even if only two route ships are involved when the second route ship has a much greater speed than the first.

It must be admitted that the present work does little to assist the mariner to identify a multiple encounter before avoidance action has been instigated, although once a manoeuvre is in progress, a potential multiple encounter will become apparent since a second route ship will appear to be on a near constant heading bringing it within the sweep of the crossing ship's domain. However, an appreciation of the results presented in this paper may perhaps give additional understanding of the phenomenon of multiple encounters and help to facilitate the taking of appropriate avoidance action. Nevertheless, it would seem that further work on the detection of multiple encounters might be useful. Work on the complementary problem in which the route ships are in the give-way position would also seem desirable, and some preliminary calculations indicate that the probability of multiple encounters is very similar to those calculated in the previous paper,[1] which dealt with the crossing ship in the give-way position.

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