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GLOSSARY

Advance. The distance a vessel moves in its original direction after the helm is put over.

Apparent wind. The speed and *true direction* from which the wind appears to blow with reference to a moving point. See RELATIVE WIND.

***Circle spacing.** The distance in yards between successive whole numbered circles. Unless otherwise designated, it is always 1,000 yards.

Cone of Courses. Mathematically calculated limits, relative to datum, within which a submarine must be in order to intercept the torpedo danger zone.

Course. Direction of actual movement relative to true north.

Datum. In ASW, the last known position of an enemy submarine at a specified time. (Lacking other knowledge this is the position and time of torpedoing.)

Direction. The position of one point in space relative to another without reference to the distance between them.

Direction of relative movement (DRM). The direction of movement of the maneuvering ship relative to the reference ship; the direction of the relative movement line.

***Distance circles.** Circles concentric to the formation center, with radii of specified distances, used in the designation of main body stations in a circular formation. Circles are designated by means of their radii, in thousands of yards from the formation center. Thus, "circle 5" is a circle whose radius is 5,000 yards from the formation center, while "circle 7.2" is a circle 7,200 yards from the formation center.

Distance of relative movement (MRM). The distance along the relative movement line between any two specified points or times.

Fictitious ship. An imaginary ship, presumed to maintain constant course and speed, substituted for a maneuvering ship which alters course and speed.

***Formation axis.** An arbitrarily selected direction from which all bearings used in the designation of main body stations in a circular formation are measured. The formation axis is always indicated as a true direction from the formation center.

***Formation center.** The arbitrarily selected point of origin for the polar coordinate system, around which a circular formation is formed. It is designated "station Zero".

***Formation guide.** A ship designated by the OTC as guide, and with reference to which all ships in the formation maintain position. The guide may or may not be at the formation center.

Geographical (navigational) plot. A plot of the actual movements of objects (ships) with respect to the earth.

Limited Lines of Approach. Mathematically calculated limits, relative to the force, within which an attacking submarine must be in order that it can reach the torpedo danger zone.

Maneuvering ship (M). Any moving unit set up in the problem except the reference ship.

Missile Danger Zone. An area which the submarine must enter in order to be within maximum effective missile firing range.

Range. Distance between ships.

Reference ship (*R*). The ship to which the movement of others is referred.

Relative distance (MRM). The distance along the relative movement line between any two specified points or times.

Relative movement. The motion of one ship relative to another.

Relative movement line. The locus of positions occupied by the maneuvering ship relative to the reference ship.

Relative plot. The plot of the positions occupied by the maneuvering ship relative to the reference ship.

Relative vector. A velocity vector which depicts the relative movement of an object (ship) in motion with respect to another object (ship), usually in motion.

Relative wind. The speed and *relative direction* from which the wind appears to blow with reference to a moving point. See APPARENT WIND.

***Screen axis.** An arbitrarily selected direction from which all bearings used in the designation of screen stations in a circular formation are measured. The screen axis is always indicated as a true direction from the screen center.

***Screen center.** The selected point of origin for the polar coordinate system, around which a screen is formed. The screen center usually coincides with the formation center, but may be a specified true bearing and distance from it.

***Screen station numbering.** Screening stations are designated by means of a "station number", consisting of four or more digits. The last three digits are the bearing of the screening station *relative to the screen axis*, while the prefixed digits indicate the radius of the distance circle in thousands of yards *from the screen center*.

Speed of relative movement (SRM). The speed of the maneuvering ship relative to the reference ship.

Speed triangle. The usual designation of the vector diagram when scaled in knots.

***Station numbering.** Positions in a circular formation (other than the formation center) are designated by means of a "station number," consisting of four or more digits. The last three digits are the bearing of the station *relative to the formation axis*, while the prefixed digits indicate the radius of the distance circle in thousands of yards. Thus, station 4090 indicates a position bearing 90 degrees *relative to the formation axis* on a distance circle with a radius of 4,000 yards from the formation center. Station 10.2340 indicates a position 10,200 yards from the formation center bearing 340 degrees relative to the axis.

Time line. A line joining the heads of two vectors which represent successive courses and speeds of a specific unit in passing from an initial to a final position in known time, via a specified intermediate point. This line also touches the head of a constructive unit which proceeds directly from the initial to the final position in the same time. By general usage this constructive unit is called the *fictitious ship*. The head of its vector divides the time line into segments inversely proportional to the times spent by the unit on the first and second legs. The time line is used in two-course problems.

Torpedo Danger Zone. An area which the submarine must enter in order to be within maximum effective torpedo firing range.

Transfer. The distance a vessel moves perpendicular to its initial direction in making a turn.

True vector. A velocity vector which depicts actual movement with respect to the earth.

True wind. True direction and force of wind relative to a fixed point on the earth.

Vector. A directed line segment representing direction and magnitude.

Vector diagram. A graphical means of adding and subtracting vectors. When the vector magnitude is scaled in knots, this diagram is usually called *Speed Triangle*.

Velocity Vector. A vector the magnitude of which represents rate of movement; a velocity vector may be either *true* or *relative* depending upon whether it depicts actual movement with respect to the earth or the relative movement of an object (ship) in motion with respect to another object (ship).

Wind direction. The direction from which the wind blows.

Wind speed. The rate of motion of air.

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ABBREVIATIONS

THE RELATIVE PLOT

CPA —**C**losest **P**oint of **A**pproach

CWC —**C**omposite **W**arfare **C**ommander

DRM —**D**irection of **R**elative **M**ovement; always plotted in the direction of $r \rightarrow m$

LLSuA —**L**imited **L**ines of **S**ubmerged **A**pproach

LLQA —**L**imited **L**ines of **Q**uiet **A**pproach

LLSnA —**L**imited **L**ines of **S**norkel **A**pproach

LLSA —**L**imited **L**ines of **S**urface **A**pproach

M —***M***aneuvering ship designation

$M_1M_2M_3$—designation of successive positions of the maneuvering ship; always plotted in the direction of $r \rightarrow m$

MRM —distance of relative movement (**M**iles of **R**elative **M**ovement); relative distance

OTC —**O**fficer in **T**actical **C**ommand

R —*R*eference ship designation

RML —**R**elative **M**ovement **L**ine

SRM —**S**peed of **R**elative **M**ovement; relative speed

THE VECTOR DIAGRAM (SPEED TRIANGLE)

e —point of origin; fixed with respect to the earth

er —reference ship vector designation

em —maneuvering ship vector designation

rm —relative movement vector designation representing SRM and DRM; always plotted in the direction $M_1 \rightarrow M_2$

FUNDAMENTALS OF RELATIVE MOTION

In the Universe there is no such condition as absolute rest or absolute motion. An object is only at rest or in motion relative to some reference. A mountain on the earth may be at rest relative to the earth, but it is in motion relative to the sun. Although all motion is relative, as used here *actual* or *true motion* is movement with respect to the earth; *relative motion* is motion with respect to an arbitrarily selected object, which may or may not have actual or true motion.

The actual or true motion of an object usually is defined in terms of its direction and rate of movement relative to the earth. If the object is a ship, this motion is defined in terms of the true course and speed. The motion of an object also may be defined in terms of its direction and rate of movement relative to another object which may or may not be in motion. The relative motion of a ship, or the motion of one ship relative to the motion of another ship, is defined in terms of the *Direction of Relative Movement (DRM)* and the *Speed of Relative Movement (SRM)*. Each form of motion may be depicted by a *velocity vector*, a line segment representing direction and rate of movement. Before further discussion of velocity vectors and their application, a situation involving relative motion between two ships will be examined.

In figure 1, ship A, at geographic position A1, on true course 000˚ at 15 knots initially observes ship B on PPI bearing 180˚ at 4 miles. The bearing and distance to ship B changes as ship A proceeds from geographic position A1 to A3. The changes in the positions of ship B relative to ship A are illustrated in the successive PPI presentations corresponding to the geographic positions of ships A and B. Likewise ship B, at geographic position B1, on true course 026˚ at 22 knots initially observes ship A on the PPI bearing 000˚ at 4 miles. The bearing and distance to ship A changes as ship B proceeds from geographic position B1 to B3. The changes in the positions of ship A relative to ship B are illustrated in the successive PPI presentations corresponding to the geographic positions of ship A and B.

If the radar observer aboard ship A plots successive positions of ship B relative to his position fixed at the center of the PPI, he will obtain a plot called the RELATIVE PLOT or RELATIVE MOTION PLOT as illustrated in figure 2. If the radar observer aboard ship B plots the successive positions of ship A relative to his position fixed at the center of the PPI, he will obtain a relative plot as illustrated in figure 3. The radar observer aboard ship A will determine that the Direction of Relative Movement (DRM) of ship B is 063˚.5, whereas the radar observer aboard ship B will determine that the DRM of ship A is 243˚.5.

Of primary significance at this point is the fact that the motion depicted by the relative plot on each PPI is not representative of the true motion or true course and speed of the other ship. Figure 4 illustrates the actual heading of ship B superimposed upon the relative plot obtained by ship A. For either radar observer to determine the true course and speed of the other ship, additional graphical constructions employing relative and true vectors are required.

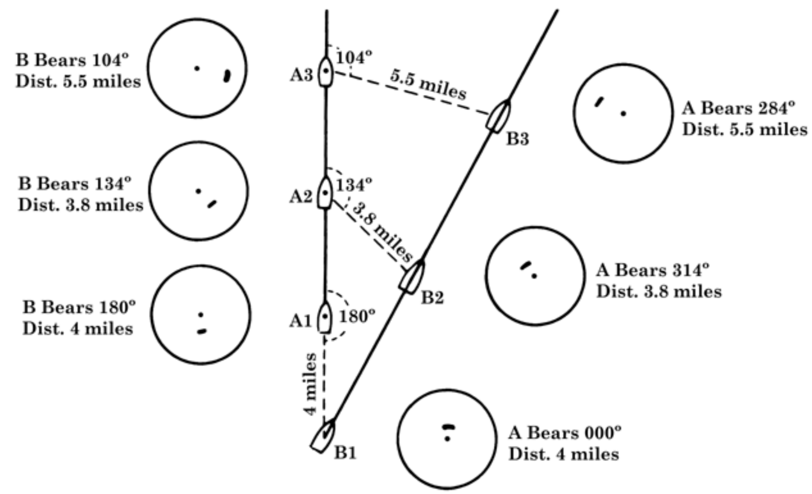

Figure 1. – Relative motion between two ships.

Figure 5 illustrates the *timed* movements of two ships, *R* and *M* with respect to the earth. This plot, similar to the plot made in ordinary chart navigation work, is called a **geographical (navigational) plot**. Ship *R* proceeding on course 045˚, at a constant speed passes through successive positions R_1, R_2, R_3, R_4...equally spaced at equal time intervals. Therefore, the line segments connecting successive positions represent direction and rate of movement with respect to the earth. Thus they are **true velocity vectors**. Likewise, for ship *M* on course 325˚ the line segments connecting the equally spaced plots for equal time intervals represent true velocity vectors of ship *M*. Although the movement of *R* relative to *M* or *M* relative to *R* may be obtained by additional graphical construction or by visualizing the changes in bearings and distances between plots coordinated in time, the geographical plot does not provide a *direct* presentation of the relative movement.

Figure 6 illustrates a modification of figure 5 in which the true bearing lines and ranges of ship *M* from ship *R* are shown at equal time intervals. On plotting these ranges and bearings from a fixed point *R*, the movement of *M* relative to ship *R* is directly illustrated. The lines between the equally spaced plots at equal time intervals provide direction and rate of movement of *M* relative to *R* and thus are **relative velocity vectors**.

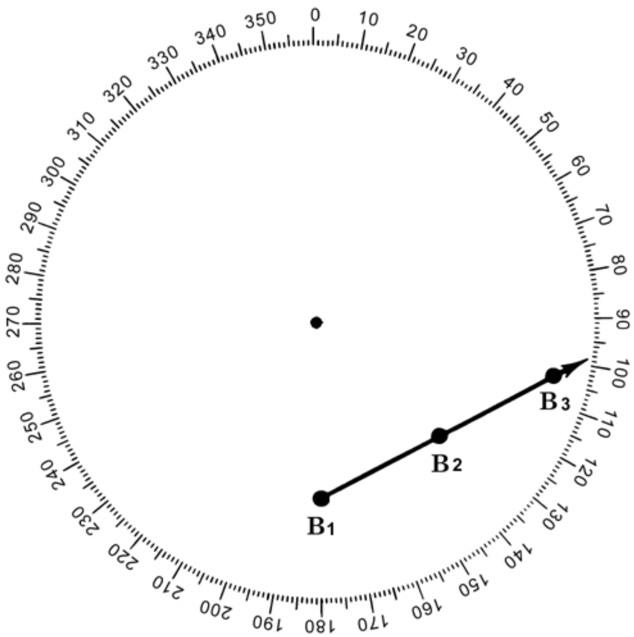

Figure 2. – Motion of ship B relative to ship A.

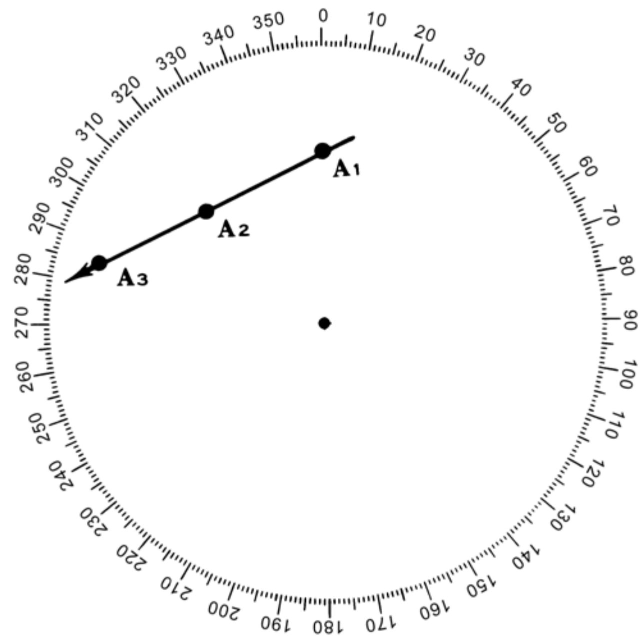

Figure 3. – Motion of ship A relative to ship B.

If ships *R* and *M* are on the same course at the same speed, each ship maintains a constant direction and distance from the other ship. There is no relative motion between the ships. The plot of successive bearings and ranges of ship *M* with respect to ship *R* is a point. The plot of successive bearings and ranges of ship *R* with respect to ship *M* is a point. There is no relative velocity vector.

In the foregoing discussion and illustration of true and relative velocity vectors, the magnitudes of each vector were determined by the time interval between successive plots. Actually any convenient time interval can be used as long as it is the same for each vector. Thus with plots equally spaced in time, the magnitude of the true velocity vector of ship *R* may be taken as the line segment between R_1 and R_3, R_1 and R_4, R_2 and R_4, etc., as long as the magnitudes of the other two vectors are determined by the same time intervals.

A plot of the successive positions of ship *M* in the same situation on a relative motion display on the PPI of the radar set aboard ship *R* would appear as in figure 7. With a Relative Movement Line (RML) drawn through the plot, the individual segments of the plot corresponding to relative distances traveled per elapsed time are relative (DRM-SRM) vectors, although the arrowheads are not shown. The **S**peed of **R**elative **M**ovement (**SRM**) is the rate of motion of ship *M* along the RML.

In figure 7, the RELATIVE PLOT or RELATIVE MOTION PLOT is the plot of the true bearings and distances of ship *M* from a fixed reference point (the center of the PPI). If the plots were not timed, vector magnitude would not be indicated. In such cases the relative plot would be *related* to the relative (DRM-SRM) vector *in direction only*.

Figure 8 illustrates the same situation as figure 7 plotted on a Maneuvering Board. The center of the Maneuvering Board corresponds to the center of the PPI. As with the PPI plot, all ranges and true bearings are plotted from a fixed point at the center, point *R*.

The ship used as the fixed reference for depicting the relative motion on the polar diagram (Maneuvering Board) is called the **reference ship** and is labeled "*R*". Any ship other than the reference ship is called the **maneuvering ship** and is labeled "*M*". The **relative plot** is now *defined as the polar coordinate presentation of the successive positions of one or more ships moving (maneuvering) with respect to a reference ship, which is fixed at the center of the polar coordinates.*

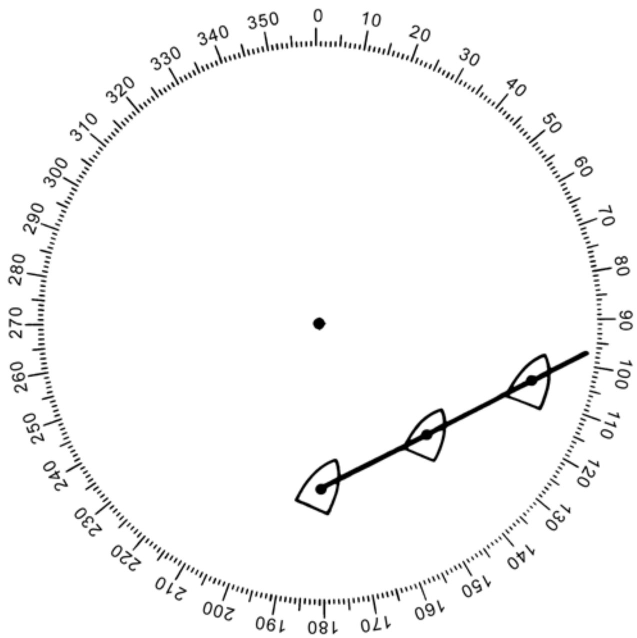

Figure 4. – The actual heading of ship B.

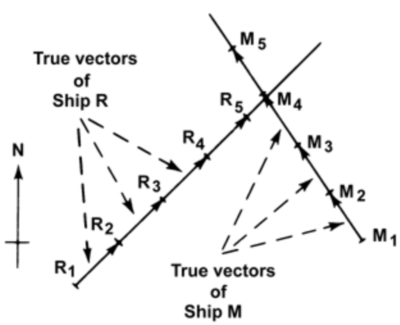

Figure 5. – True velocity vectors.

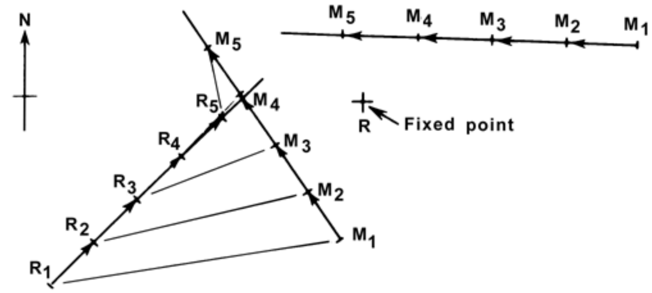

Figure 6. – Relative velocity vectors.

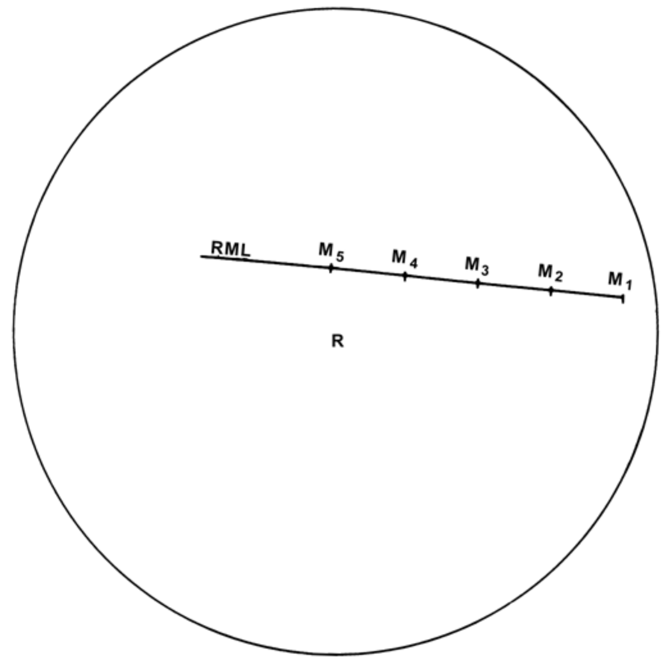

Figure 7. – Relative plot.

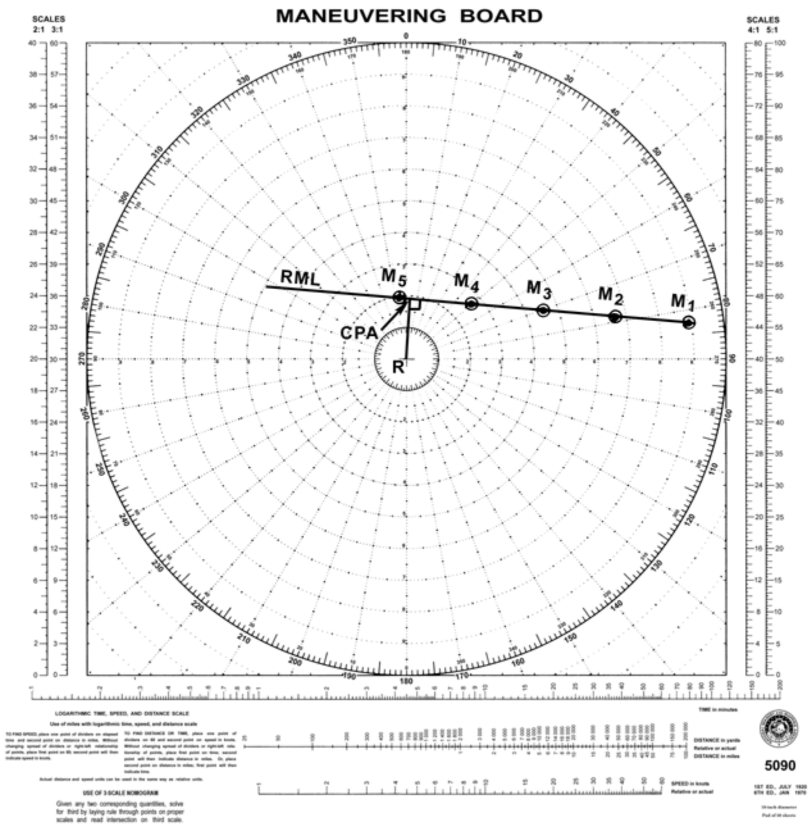

Figure 8. – Relative plot on the Maneuvering Board.

Figure 8 illustrates that the relative plot provides an almost direct indication of the CLOSEST POINT OF APPROACH (CPA). The CPA is the true bearing and distance of the closest approach of one ship to another.

The Vector Diagram

In the foregoing discussion, the relative motion of ship *M* with respect to ship *R* was developed graphically from the true motions of ship *M* and ship *R*. The usual problem is to determine the true motion (true course and speed) of ship *M*, knowing the true motion (true course and speed) of ship *R* and, through plotting, determining the motion of ship *M* relative to ship *R*.

The vector diagram is a graphical means of adding or subtracting two velocity vectors to obtain a resultant velocity vector. To determine the true (course-speed) vector of ship *M*, the true (course-speed) vector of ship *R* is added to the relative (DRM-SRM) vector derived from the relative plot, or the timed motion of ship *M* relative to ship *R*.

In the addition of vectors, the vectors are laid end to end, taking care that each vector maintains its *direction* and *magnitude*, the two essential elements of a vector. Just as there is no difference whether 5 is added to 3 or 3 is added to 5, there is no difference in the resultant vector whether the relative (DRM-SRM) vector is laid at the end of true (course-speed) vector of ship *R* or the true (course-speed) vector of ship *R* is laid at the end of the relative (DRM-SRM) vector. Because of the notations used in this manual, the relative (DRM-SRM) vector is laid at the end of the true (course-speed) vector of ship *R*, unless otherwise specified.

The resultant vector, the true (course-speed) vector of other ship *R*, is found by drawing a vector from the origin of the two connected vectors to their end point. Unless the two vectors added have the same or opposite directions, a triangle called the vector diagram (triangle) is formed on drawing the resultant vector.

Insight into the validity of this procedure may be obtained through the mariner's experience with the effect of a ship's motion on the wind.

If a ship is steaming due north at 15 knots while the true wind is 10 knots *from* due north, the mariner experiences a relative wind of 25 knots from due north. Assuming that the mariner does not know the true wind, it may be found by laying own ship's true (course-speed) vector and the relative wind (DRM-SRM) vector end to end as in figure 9.

If figure 9, own ship's true (course-speed) vector is laid down in a due north direction, using a vector magnitude scaled for 15 knots. At the end of the latter vector, the relative wind (DRM-SRM) vector is laid down in a due south direction, using a vector magnitude scaled for 25 knots. On drawing the resultant vector from the origin of the two connected vectors to their end point, a true wind vector of 10 knots in a due south direction is found.

If own ship maintains a due north course at 15 knots as the wind direction shifts, the relative wind (DRM-SRM) vector changes. In this case a vector triangle is formed on adding the relative wind (DRM-SRM) vector to own ship's true (course-speed) vector (see figure 10).

Returning now to the problem of relative motion between ships and using the same situation as in figure 7, a *timed* plot of the motion of ship *M* relative to ship *R* is made on the PPI as illustrated in figure 11.

Assuming that the true (course-speed) vector of ship *M* is unknown, it may be determined by adding the relative (DRM-SRM) vector to the true (course-speed) vector of ship *R*.

The vectors are laid end to end, while maintaining their respective directions and magnitudes. The resultant vector, the true (course-speed) vector of ship *M*,

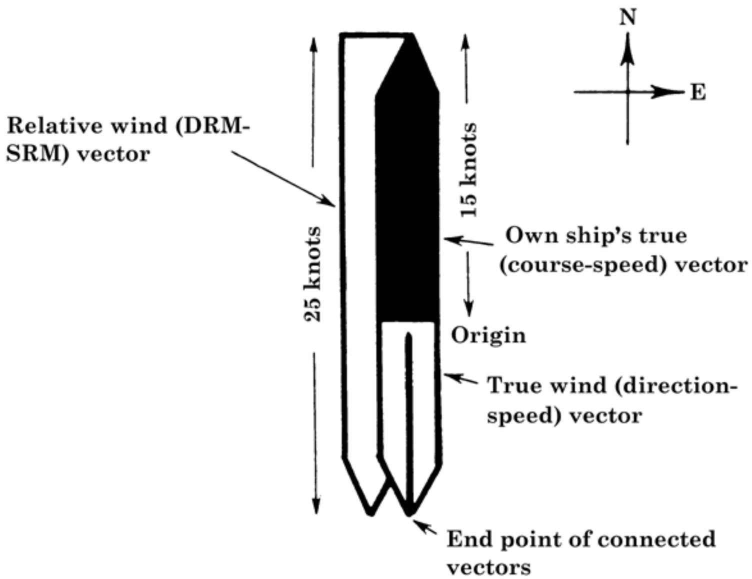

Figure 9. – Relative and true wind vectors.

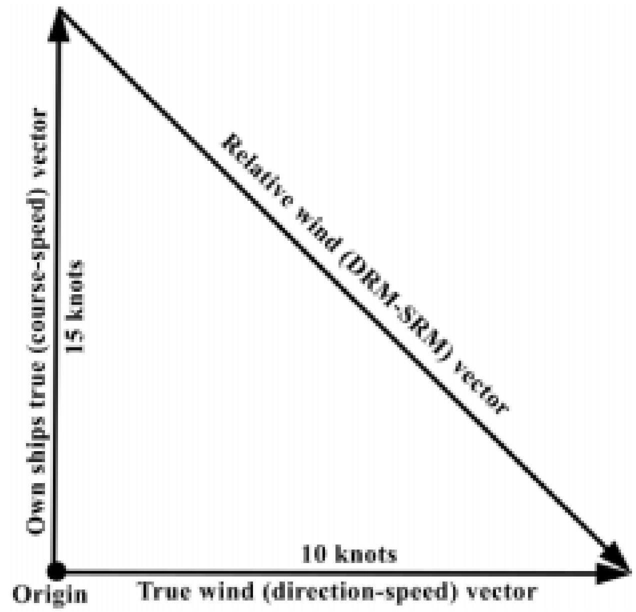

Figure 10. – Wind vector triangle.

is found by drawing a vector from the origin of the two connected (added) vectors to their end point.

Vector Equations

Where:

$\overrightarrow{em}$ is the true (course-speed) vector of the maneuvering ship.
$\overrightarrow{er}$ is the true (course-speed) vector of the reference ship.
$\overrightarrow{rm}$ is relative (DRM-SRM) vector.

$$\overrightarrow{em} = \overrightarrow{er} + \overrightarrow{rm}$$
$$\overrightarrow{er} = \overrightarrow{em} - \overrightarrow{rm}$$
$$\overrightarrow{rm} = \overrightarrow{em} - \overrightarrow{er}$$

(See figure 12.)

To determine vector *em* from vectors *er* and *rm*, vectors *er* and *rm* are added by laying them end to end and drawing a resultant vector, *em*, from the origin of the two connected vectors to their end point (see figure 13).

To determine vector *er* from vectors *em* and *rm*, vector *rm* is subtracted from vector *em* by laying vector *rm*, with its direction reversed, at the end of vector *em* and drawing a resultant vector, *er*, from the origin of the two connected vectors to their end point (see figure 14).

To determine vector *rm* from vectors *em* and *er*, vector *er* is subtracted from vector *em* by laying *er*, with its direction reversed, at the end of vector *em* and drawing a resultant vector from the origin of the two connected vectors to their end point (see figure 15).

Relative Movement Problems

Relative movement problems may be divided into two general categories:

a. *Tracking*: from observed relative movement data, determining the actual motion of the ship or ships being observed.

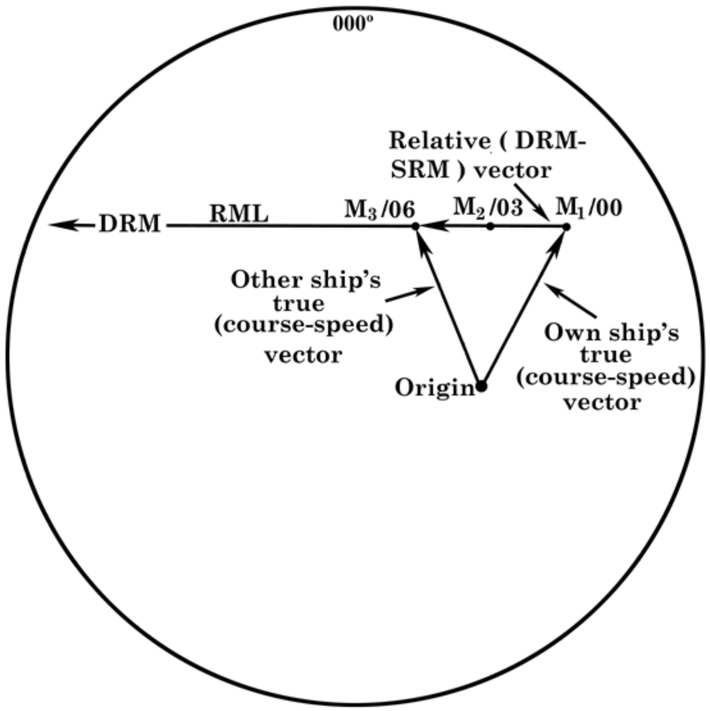

Figure 11. – Vector triangle on PPI.

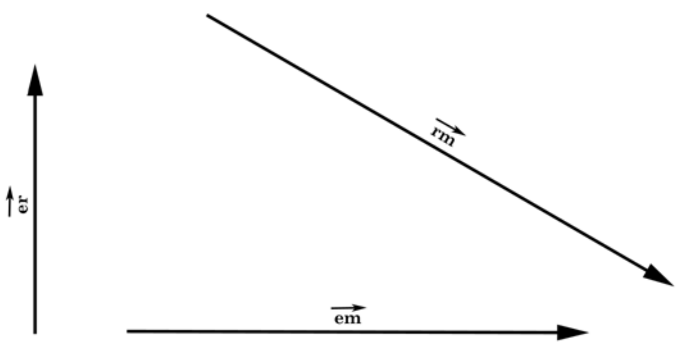

Figure 12. – True and relative vectors.

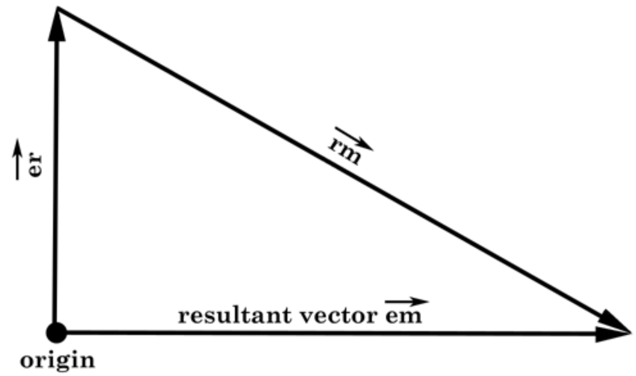

Figure 13. – Addition of the true (course-speed) vector of the reference ship and the relative (DRM-SRM) vector to find the true (course-speed) vector of the maneuvering ship.

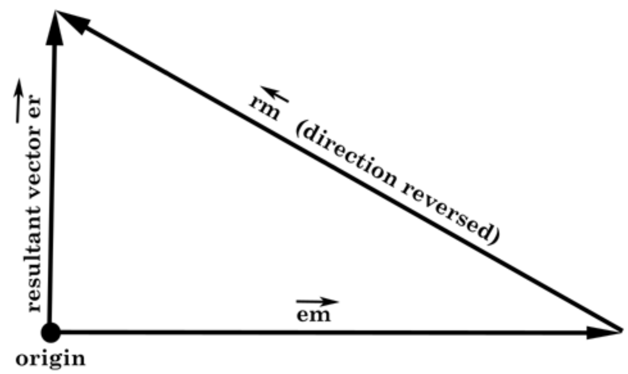

Figure 14. – Subtraction of the relative (DRM-SRM) vector from the maneuvering ship's true (course-speed) vector to find the reference ship's true (course-speed) vector.

b. *Maneuvering*: knowing, or having previously determined the actual motion of the ships involved in the problem, ascertaining the necessary changes to actual motion to obtain a desired relative movement.

Three separate and distinct plots are available for the solution of relative movement problems:

1. *Geographical or navigational plot.*
2. *Relative plot.*
3. *Vector diagram (Speed Triangle).*

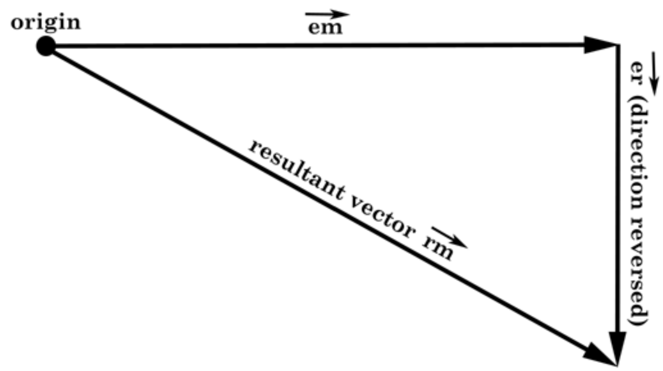

Figure 15. – Subtraction of the reference ship's true (course-speed) vector from the maneuvering ship's true (course-speed) vector to find the relative (DRM-SRM) vector.

Each of these plots provides a method either for complete solutions or for obtaining additional data required in the solution of more complex problems. In the foregoing treatment of the geographical and relative plots, the true and relative vector nature of those plots was illustrated. But in the use of vectors it is usually more convenient to scale the magnitudes of the vectors in knots while at the same time utilizing optimum distance and speed scales for plotting accuracy. Therefore, if the geographical and relative plots are used only for obtaining part of the required data, other means must be employed in completing the solution. This other means is the **vector diagram** which is a graphical means of adding or subtracting vectors.

When the vector diagram is scaled in knots it is commonly called the **Speed Triangle**. Figure 16 illustrates the construction of a speed triangle in which the true vectors, scaled in knots, are drawn from a common point *e* (for earth) at the center of the polar diagram. The true vector of the reference ship is *er*; the true vector of ship *M*, commonly called the maneuvering ship, is *em*, and the relative vector is *rm*. The vector directions are shown by the arrowheads.

The direction of the relative vector rm in the speed triangle is the same as the DRM in the relative plot. The DRM is the connecting link between the two diagrams. Also, the magnitude (SRM) of the relative vector in the speed triangle is determined by the rate of motion of ship *M* along the RML of the relative plot.

If in figure 16 the true vector of the reference ship were known and the relative vector were derived from the rate and direction of the relative plot, the vectors could be added to obtain the true vector of the maneuvering ship ($\overrightarrow{em} = \overrightarrow{er} + \overrightarrow{rm}$). In the addition of vectors, the vectors are constructed end to end while maintaining vector magnitude and direction. The sum is the magnitude and direction of the line joining the initial and terminal points of the vectors.

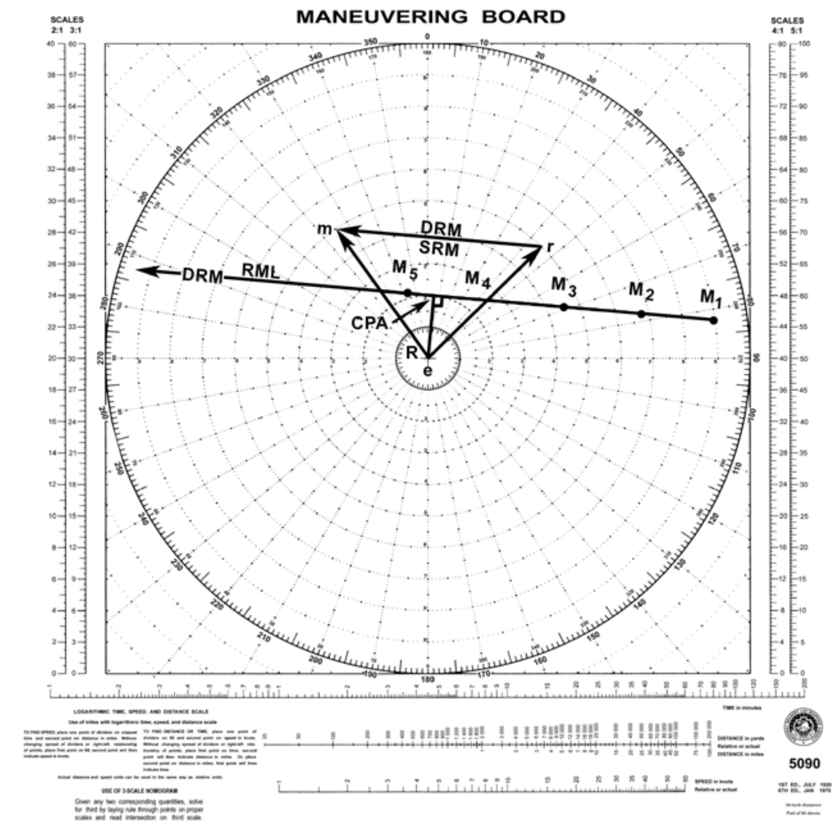

Figure 16. – Speed triangle and relative plot.

If in figure 16 the true vector of the maneuvering ship were known as well as that of the reference ship, the relative vector could be obtained by subtracting the true vector of the reference ship from the true vector of the maneuvering ship ($\overrightarrow{rm} = \overrightarrow{em} - \overrightarrow{er}$).

In this vector subtraction, the true vectors are constructed end to end as before, but the direction of the reference ship true vector is reversed.

If in figure 16 the true vector of the maneuvering ship were known as well as the relative vector, the true vector of the reference ship could be obtained by subtracting the relative vector from the true vector of the maneuvering ship ($\overrightarrow{er} = \overrightarrow{em} - \overrightarrow{rm}$).

But in the practical application of constructing two of the known vectors, the third vector may be found by completing the triangle. The formulas as such may be ignored as long as care is exercised to insure that the vectors are constructed in the right direction. Particular care must be exercised to insure that the DRM is not reversed. The relative vector *rm* is always in the direction of the relative movement as shown on the relative plot and always join the heads of the true vectors at points *r* and *m*.

Fundamental to this construction of the speed triangle (vector diagram) with the origin of the true vectors at the center of the polar diagram is the fact that the locations where the actual movement is taking place do not affect the results of vector addition or subtraction. Or, for given true courses and speeds of the reference and maneuvering ships, the vector diagram is independent of the relative positions of the ships. In turn, the place of construction of the vector diagram is independent of the position of the relative plot.

In figure 16 the vector diagram was constructed with the origins of the true vectors at the center of the polar diagram in order to make most effective use of the compass rose and distance circles in constructing true vectors. But in this application of the vector diagram in which the vector magnitudes are scaled in knots, to determine the true vector of the maneuvering ship an intermediate calculation is required to convert the rate of relative movement to relative speed in knots before the relative vector may be constructed with its origin at the head of the true vector of the reference ship. This intermediate calculation as well as the transfer of the DRM to the vector diagram may be avoided through direct use of the relative plot as the relative vector. In this application the vector diagram is constructed with the true vectors set to the same magnitude scale as the relative vector. This scale is the distance traveled per the time interval of the relative plot.

There are two basic techniques used in the construction of this type of vector diagram. Figures 17 and 18(a) illustrate the construction in which the reference ship's true vector is drawn to terminate at the initial plot of the segment of the relative plot used directly as the relative vector. The vector diagram is completed by constructing the true vector of the maneuvering ship from the origin of the reference ship's true vector, terminating at the end of the relative vector. Figure 18(b) illustrates the construction in which the reference ship's true vector is drawn to originate at the final plot of the segment of the relative plot used directly as the relative vector. The vector diagram is completed by constructing the true vector of the maneuvering ship from the origin of the relative vector, terminating at the head of the reference ship's true vector. In the latter method the advantages of the conventional vector notation are lost. Either method is facilitated through the use of convenient time lapses (**selected plotting intervals**) such as 3 or 6 minutes, or other multiples thereof, with which well known rules of thumb may be used in determining the vector lengths. Figure 19 illustrates that even though the vector diagram may be constructed initially in accordance with a particular selected plotting interval, the vector diagram subsequently may be subdivided or expanded in geometrically similar triangles as the actual time lapse of the plot differs from that previously selected. If own ship's true vector *er* is drawn initially for a time lapse of 6 minutes and the actual plot is of 8 minutes duration, vector *er* is increased in magnitude by one third prior to completing the vector diagram.

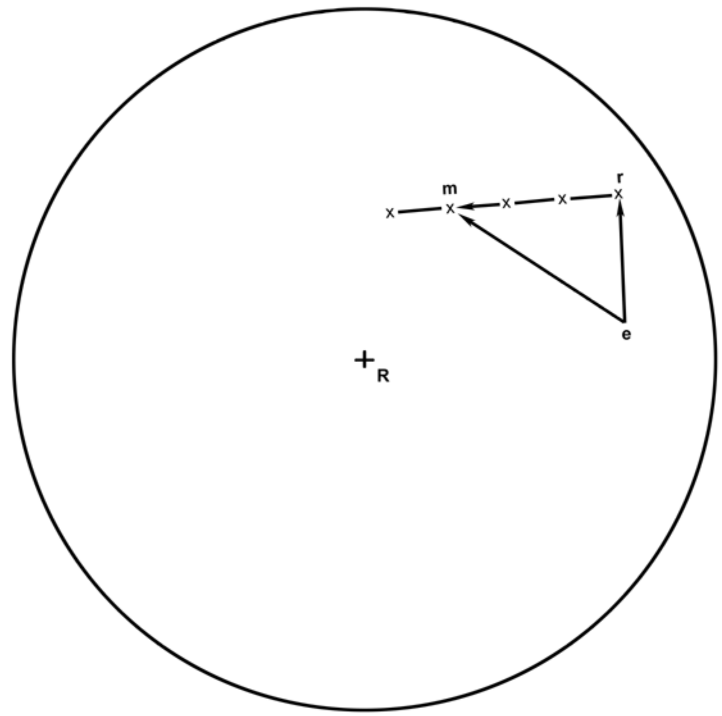

Figure 17. – Vector diagram.

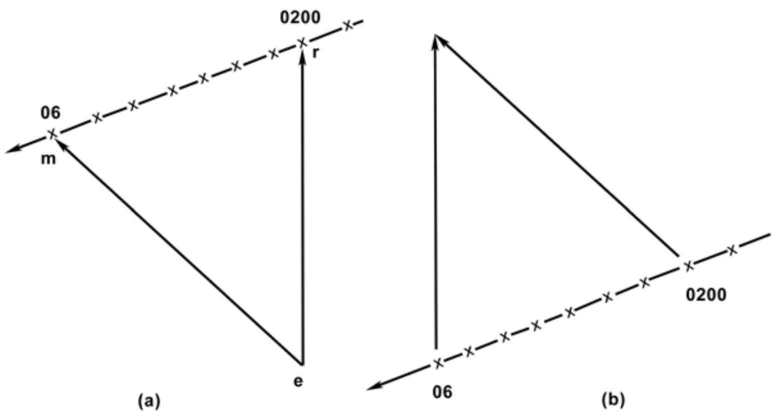

Figure 18. – Vector diagrams.

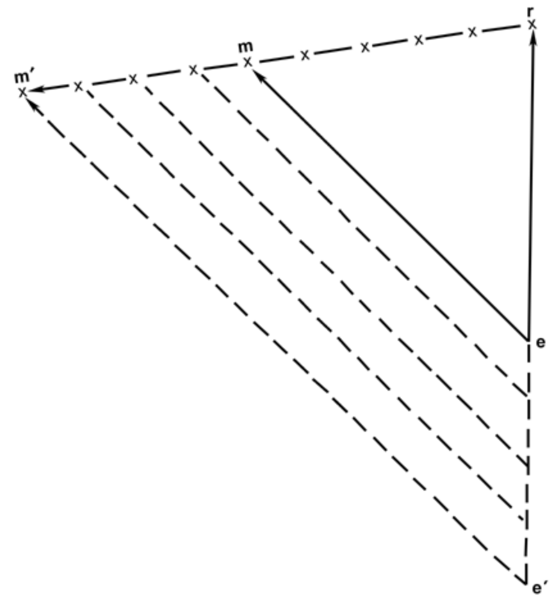

Figure 19. – Vector diagram.

THE LOGARITHMIC TIME-SPEED-DISTANCE NOMOGRAM

At the bottom of the Maneuvering Board Chart 5090 a nomogram consisting of three equally spaced logarithmic scales is printed for the rapid solution of time, speed, distance problems.

The nomogram has a logarithmic scale for each of the terms of the basic equation:

$$\text{Distance} = \text{Speed} \times \text{Time}$$

The upper scale is graduated logarithmically in minutes of time; the middle scale is graduated logarithmically in both miles and yards; and the lower scale is graduated logarithmically in knots. By marking the values of two known terms on their respective scales and connecting such marks by a straight line, the value of the third term is found at the intersection of this line with the remaining scale.

Figure 1 illustrates a solution for speed when a distance of 4 miles is traveled in 11 minutes.

But only one of the three scales is required to solve for time, speed, or distance if any two of the three values are known. Any one of the three logarithmic scales may be used in the same manner as a slide rule for the addition or subtraction of logarithms of numbers. The upper scale is usually used for this purpose.

When using a single logarithmic scale for the solution of the basic equation with speed units in knots and distance units in miles or thousands of yards, either 60 or 30 has to be incorporated in the basic equation for proper cancellation of units.

Figure 1 illustrates the use of the upper scale for finding the speed in knots when the time in minutes and the distance in miles are known. In this problem the time is 11 minutes and the distance is 4 miles.

As shown in figure 1, one point of a pair of dividers is set at the time in minutes, 11, and the second at the distance in miles, 4. Without changing the spread of the dividers or the right-left relationship, set the first point at 60. The second point will then indicate the speed in knots, 21.8. If the speed and time are known, place one point at 60 and the second point at the speed in knots, 21.8. Without changing the spread of the dividers or the right-left relationship, place the first point at the time in minutes, 11. The second point then will indicate the distance in miles, 4.

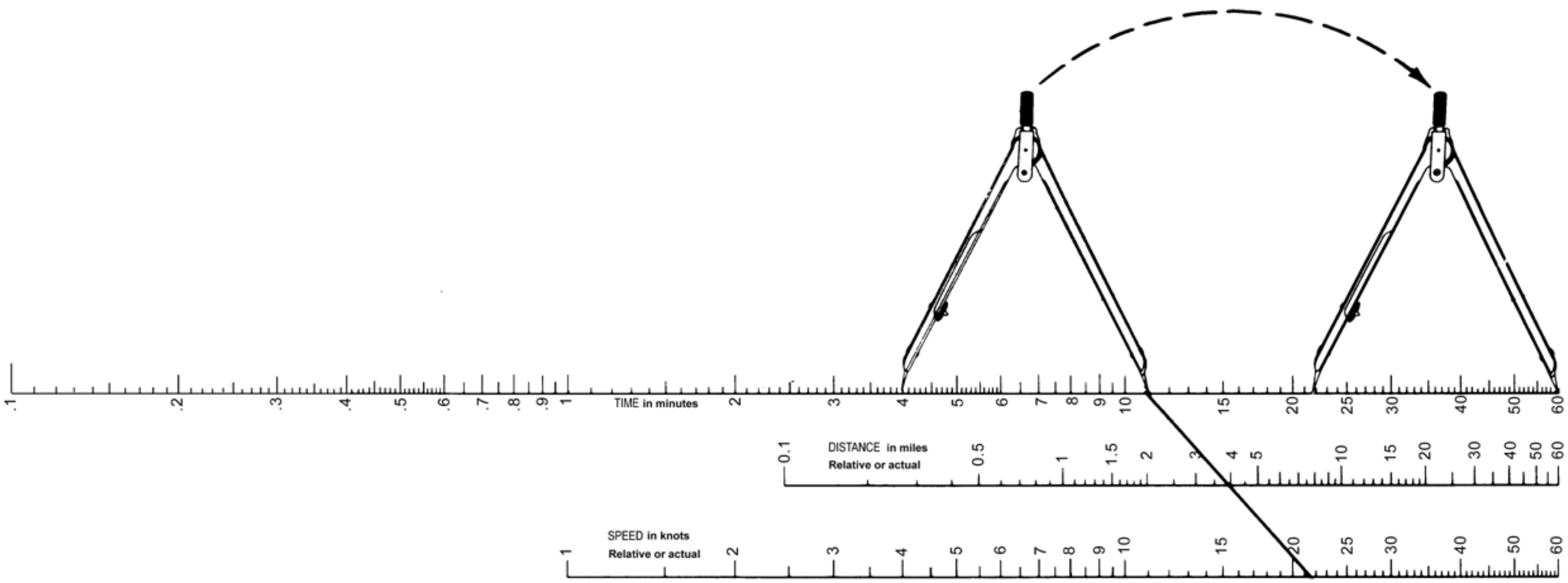

Figure 1. – Logarithmic time-speed-distance nomogram.

In the method described, there was no real requirement to maintain the right-left relationship of the points of the pair of dividers except to insure that for speeds of less than 60 knots the distance in miles numerically is less than the time in minutes. If the speed is in excess of 60 knots, the distance in miles will always be greater than the time in minutes, numerically.

If the distance is known in thousands of yards or if the distance is to be found in such units, a divider point is set at 30 instead of the 60 used with miles. If the speed is less than 30 knots in this application, the distance in thousands of yards will always be less than the time in minutes. If the speed is in excess of 30 knots, the distance in thousands of yards will always be greater than the time in minutes, numerically.

The use of the single logarithmic scale is based upon the fundamental property of logarithmic scales that equal lengths along the scale represent equal values of ratios. For example if one has the ratio 1/2 and with the dividers measures the length between 1 and 2, he finds the same length between 2 and 4, 5.5 and 11.0, or any other two values one of which is 1/2 the other. In using the single logarithmic scale for the solution of a specific problem in which a ship travels 10 nautical miles in 20 minutes, the basic formula is rearranged as follows:

$$\text{Speed} = \frac{\text{Distance (nautical miles)}}{\text{Time (minutes)}} \times \frac{\text{60 min.}}{\text{1 hr.}}.$$

On **substituting** known numerical values and canceling units, the formula is rearranged further as:

$$\frac{\text{Speed (knots)}}{60} = \frac{10}{20}.$$

The ratio 10/20 has the same numerical value as the ratio Speed (knots)/60. Since each ratio has the same numerical value, the length as measured on the logarithmic scale between the distance in nautical miles (10) and the time in minutes (20) will be the same as the length between 60 and the speed in knots. Thus, on measuring the length between 10 and 20 and measuring the same length from 60 the speed is found to be 30 knots.

RADAR AND THE NAVIGATION RULES

(Excerpts from *International Regulations for Preventing Collisions at Sea*, COMDTINST, M16672.2, AUG 1982, Revised June 1, 1983.)

PART B—STEERING AND SAILING RULES

SUBPART I—CONDUCT OF VESSELS IN ANY CONDITION OF VISIBILITY

RULE 5
Look-out

Every vessel shall at all times maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision.

RULE 6
Safe speed

Every vessel shall at all times proceed at a safe speed so that she can take proper and effective action to avoid collision and be stopped within a distance appropriate to the prevailing circumstances and conditions.

In determining a safe speed the following factors shall be among those taken into account:

(a) By all vessels:

- (i) the state of visibility;
- (ii) the traffic density including concentrations of fishing vessels or any other vessels;
- (iii) the maneuverability of the vessel with special reference to stopping distance and turning ability in the prevailing conditions;
- (iv) at night the presence of background light such as from shore lights or from back scatter of her own lights;
- (v) the state of wind, sea and current, and the proximity of navigational hazards;
- (vi) the draft in relation to the available depth of water.

(b) Additionally, by vessels with operational radar:

- (i) the characteristics, efficiency and limitations of the radar equipment;
- (ii) any constraints imposed by the radar range scale in use;
- (iii) the effect on radar detection of the sea state, weather and other sources of interference;
- (iv) the possibility that small vessels, ice and other floating objects may not be detected by radar at an adequate range;
- (v) the number, location and movement of vessels detected by radar;
- (vi) the more exact assessment of the visibility that may be possible when radar is used to determine the range of vessels or other objects in the vicinity.

RULE 7
Risk of collision

(a) Every vessel shall use all available means appropriate to the prevailing circumstances and conditions to determine if risk of collision exists. If there is any doubt, such risk shall be deemed to exist.

(b) Proper use shall be made of radar equipment if fitted and operational, including long-range scanning to obtain early warning of risk of collision and radar plotting or equivalent systematic observation of detected objects.

(c) Assumptions shall not be made on the basis of scanty information, especially scanty radar information.

(d) In determining if risk of collision exists the following considerations shall be among those taken into account:

- (i) such risk shall be deemed to exist if the compass bearing of an approaching vessel does not appreciably change;
- (ii) such risk may sometimes exist even when an appreciable bearing change is evident, particularly when approaching a very large vessel or a tow or when approaching a vessel at close range.

RULE 8
Action to avoid collision

(a) Any action taken to avoid collision shall, if the circumstances of the case admit, be positive, made in ample time and with due regard to the observance of good seamanship.

(b) Any alteration of course and/or speed to avoid collision shall, if the circumstances of the case admit, be large enough to be readily apparent to another vessel observing visually or by radar; a succession of small alterations of course and/or speed should be avoided.

(c) If there is sufficient sea room, alteration of course alone may be the most effective action to avoid a close-quarters situation provided that it is made in good time, is substantial and does not result in another close-quarters situation.

(d) Action taken to avoid collision with another vessel shall be such as to result in passing at a safe distance. The effectiveness of the action shall be carefully checked until the other vessel is finally past and clear.

(e) If necessary to avoid collision or allow more time to assess the situation, a vessel shall slacken her speed or take all way off by stopping or reversing her means of propulsion.

RULE 9
Narrow channels

(a) A vessel proceeding along the course of a narrow channel or fairway shall keep as near to the outer limit of the channel or fairway which lies on her starboard side as is safe and practicable.

(b) A vessel of less than 20 meters in length or a sailing vessel shall not impede the passage of a vessel which can safely navigate only within a narrow channel or fairway.

(c) A vessel engaged in fishing shall not impede the passage of any vessel navigating within a narrow channel or fairway.

(d) A vessel shall not cross a narrow channel or fairway if such crossing impedes the passage of a vessel which can safely navigate only within such channel or fairway. The latter vessel may use the sound signal prescribed in Rule 34(d) if in doubt as to the intention of the crossing vessel.

(e) (i) In a narrow channel or fairway when overtaking can take place only if the vessel to be overtaken has to take action to permit safe passing, the vessel intending to overtake shall indicate her intention by sounding the appropriate signal prescribed in Rule 34(c)(i). The vessel to be overtaken shall, if in agreement, sound the appropriate signal prescribed in Rule 34(c)(ii) and take steps to permit safe passing. If in doubt she may sound the signals prescribed in Rule 34(d).

(ii) This Rule does not relieve the overtaking vessel of her obligation under Rule 13.

(f) A vessel nearing a bend or an area of a narrow channel or fairway where other vessels may be obscured by an intervening obstruction shall navigate with particular alertness and caution and shall sound the appropriate signal prescribed in Rule 34(e).

(g) Any vessel shall, if the circumstances of the case admit, avoid anchoring in a narrow channel.

RULE 10
Traffic separation schemes

(a) This Rule applies to traffic separation schemes adopted by the Organization.

(b) A vessel using a traffic separation scheme shall:

(i) proceed in the appropriate traffic lane in the general direction of traffic flow for that lane;

(ii) so far as practicable keep clear of a traffic separation line or separation zone;

(iii) normally join or leave a traffic lane at the terminating of the lane, but when joining or leaving from either side shall do so at as small an angle to the general direction of traffic flow as practicable.

(c) A vessel shall so far as practicable avoid crossing traffic lanes, but if obliged to do so shall cross as nearly as practicable at right angles to the general direction of traffic flow.

(d) Inshore traffic zones shall not normally be used by through traffic which can safely use the appropriate traffic lane within the adjacent traffic separation scheme. However, vessels of less than 20 meters in length and sailing vessels may under all circumstances use inshore traffic zones.

(e) A vessel other than a crossing vessel or a vessel joining or leaving a lane shall not normally enter a separation zone or cross a separation line except:

(i) in cases of emergency to avoid immediate danger;

(ii) to engage in fishing within a separation zone.

(f) A vessel navigating in areas near the terminations of traffic separation schemes shall do so with particular caution.

(g) A vessel shall so far as practicable avoid anchoring in a traffic separation scheme or in areas near its terminations.

(h) A vessel not using a traffic separation scheme shall avoid it by as wide a margin as is practicable.

(i) A vessel engaged in fishing shall not impede the passage of any vessel following a traffic lane.

(j) A vessel of less than 20 meters in length or a sailing vessel shall not impede the safe passage of a power-driven vessel following a traffic lane.

(k) A vessel restricted in her ability to maneuver when engaged in an operation for the maintenance of safety of navigation in a traffic separation scheme is exempted from complying with this Rule to the extent necessary to carry out the operation.

(l) A vessel restricted in her ability to maneuver when engaged in an operation for the laying, servicing or picking up of a submarine cable, within a traffic separation scheme, is exempted from complying with this Rule to the extent necessary to carry out the operation.

SECTION II—CONDUCT OF VESSELS IN SIGHT OF ONE ANOTHER

RULE 11
Application

Rules in this Section apply to vessels in sight of one another.

RULE 12
Sailing vessels

(a) When two sailing vessels are approaching one another, so as to involve risk of collision, one of them shall keep out of the way of the other as follows:

- (i) when each has the wind on a different side, the vessel which has the wind on the port side shall keep out of the way of the other;
- (ii) when both have the wind on the same side, the vessel which is to windward shall keep out of the way of the vessel which is to leeward;
- (iii) if a vessel with the wind on the port side sees a vessel to windward and cannot determine with certainty whether the other vessel has the wind on the port or on the starboard side, she shall keep out of the way of the other.

(b) For the purposes of this Rule the windward side shall be deemed to be the side opposite to that on which the mainsail is carried or, in the case of a square-rigged vessel, the side opposite to that on which the largest fore-and-aft sail is carried.

RULE 13
Overtaking

(a) Notwithstanding anything contained in the Rules of Part B, Sections I and II any vessel overtaking any other shall keep out of the way of the vessel being overtaken.

(b) A vessel shall be deemed to be overtaking when coming up with another vessel from a direction more than 22.5 degrees abaft her beam, that is, in such a position with reference to the vessel she is overtaking, that at night she would be able to see only the sternlight of that vessel but neither of her sidelights.

(c) When a vessel is in any doubt as to whether she is overtaking another, she shall assume that this is the case and act accordingly.

(d) Any subsequent alteration of the bearing between the two vessels shall not make the overtaking vessel a crossing vessel within the meaning of these Rules or relieve her of the duty of keeping clear of the overtaken vessel until she is finally past and clear.

RULE 14
Head-on situation

(a) When two power-driven vessels are meeting on reciprocal or nearly reciprocal courses so as to involve risk of collision, each shall alter her course to starboard so that each shall pass on the port side of the other.

(b) Such a situation shall be deemed to exist when a vessel sees the other ahead or nearly ahead and by night she could see the masthead lights of the other in a line or nearly in a line and/or both sidelights and by day she observes the corresponding aspect of the other vessel.

(c) When a vessel is in any doubt as to whether such a situation exists, she shall assume that it does exist and act accordingly.

RULE 15
Crossing situation

When two power-driven vessels are crossing so as to involve risk of collision, the vessel which has the other on her own starboard side shall keep out of the way and shall, if the circumstances of the case admit, avoid crossing ahead of the other vessel.

RULE 16
Action by give-way vessel

Every vessel which is directed to keep out of the way of another vessel shall, so far as possible, take early and substantial action to keep well clear.

RULE 17
Action by stand-on vessel

(a) (i) Where one of two vessels is to keep out of the way the other shall keep her course and speed.

(ii) The latter vessel may however take action to avoid collision by her maneuver alone, as soon as it becomes apparent to her that the vessel required to keep out of the way is not taking appropriate action in compliance with the Rules.

(b) When, from any cause, the vessel required to keep her course and speed finds herself so close that collision cannot be avoided by the action of the give-way vessel alone, she shall take such action as will best aid to avoid collision.

(c) A power-driven vessel which takes action in a crossing situation in accordance with sub-paragraph (a) (ii) of this Rule to avoid collision with another power-driven vessel shall, if the circumstances of the case admit, not alter course to port for a vessel on her own port side.

(d) This Rule does not relieve the give-way vessel of her obligation to keep out of the way.

RULE 18
Responsibilities between vessels

Except where Rules 9, 10 and 13 otherwise require:

(a) A power-driven vessel underway shall keep out of the way of:

- (i) a vessel not under command;
- (ii) a vessel restricted in her ability to maneuver;
- (iii) a vessel engaged in fishing;
- (iv) a sailing vessel.

(b) A sailing vessel underway shall keep out of the way of:

- (i) a vessel not under command;
- (ii) a vessel restricted in her ability to maneuver;
- (iii) a vessel engaged in fishing.

(c) A vessel engaged in fishing when underway shall, so far as possible, keep out of the way of:

- (i) a vessel not under command;
- (ii) a vessel restricted in her ability to maneuver.

(d) (i) Any vessel other than a vessel not under command or a vessel restricted in her ability to maneuver shall, if the circumstances of the case admit, avoid impeding the safe passage of a vessel constrained by her draft, exhibiting the signals in Rule 28.

(ii) A vessel constrained by her draft shall navigate with particular caution having full regard to her special condition.

(e) A seaplane on the water shall, in general, keep well clear of all vessels and avoid impeding their navigation. In circumstances, however, where risk of collision exists, she shall comply with the Rules of this Part.

SECTION III—CONDUCT OF VESSELS IN RESTRICTED VISIBILITY

RULE 19
Conduct of vessels in restricted visibility

(a) This Rule applies to vessels not in sight of one another when navigating in or near an area of restricted visibility.

(b) Every vessel shall proceed at a safe speed adapted to the prevailing circumstances and conditions of restricted visibility. A power-driven vessel shall have her engines ready for immediate maneuver.

(c) Every vessel shall have due regard to the prevailing circumstances and conditions of restricted visibility when complying with the Rules of Section I of this Part.

(d) A vessel which detects by radar alone the presence of another vessel shall determine if a close-quarters situation is developing and/or risk of collision exists. If so, she shall take avoiding action in ample time, provided that when such action consists of an alteration of course, so far as possible the following shall be avoided:

- (i) an alteration of course to port for a vessel forward of the beam, other than for a vessel being overtaken;
- (ii) an alteration of course towards a vessel abeam or abaft the beam.

(e) Except where it has been determined that a risk of collision does not exist, every vessel which hears apparently forward of her beam the fog signal of another vessel, or which cannot avoid a close-quarters situation with another vessel forward of her beam, shall reduce her speed to the minimum at which she can be kept on her course. She shall if necessary take all her way off and in any event navigate with extreme caution until danger of collision is over.