Pub 1310

RADAR NAVIGATION AND MANEUVERING BOARD MANUAL

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PREFACE

The 2001 edition of Pub. 1310 *Radar Navigation and Maneuvering Board Manual* combines selected chapters from the sixth edition of Pub. 1310, *Radar Navigation Manual,* and the fourth edition of Pub. 217, *Maneuvering Board Manual*.

This manual has been compiled by the editorial staff of the Maritime Safety Information Center at the National Imagery and Mapping Agency. It is intended to be used primarily as a manual of instruction in navigation schools and by naval and merchant marine personnel. By combining the previous editions of Pub. 1310 and Pub. 217 into one book we hope that we have provided a practical reference for mariners on board ship and instructors ashore. It is also intended to be of assistance to others who are concerned with marine radar in different and less direct ways.

In combining the two manuals, every effort has been made to retain the original style and format which has proven to be clear and helpful to the maritime community. Most of the illustrations and examples have been carried forward into this edition.

The chapter on ARPA has been expanded and now includes a sample operating manual for a modern commercial radar and ARPA. Many excellent other publications on ARPA are available and should be consulted for a more thorough understanding on this subject matter.

Users should refer corrections, additions, and comments for improving this product to:

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Particular thanks are due to Mr. Eric K. Larsson, Director, Center for Maritime Education, Seaman’s Church Institute, New York and the Furuno Electric Co., LTD. for providing the instruction manual for their latest raster scan radar and ARPA units.

TABLE OF CONTENTS

CHAPTER 1—BASIC RADAR PRINCIPLES AND GENERAL CHARACTERISTICS

CHAPTER 2—RADAR OPERATION

CHAPTER 3—COLLISION AVOIDANCE

CHAPTER 4—RADAR NAVIGATION

CHAPTER 5—AUTOMATIC RADAR PLOTTING AIDS (ARPA)

CHAPTER 6—MANEUVERING BOARD MANUAL

APPENDICES

INDEX OF MANEUVERING BOARD EXAMPLES

CHAPTER 1 — BASIC RADAR PRINCIPLES AND GENERAL CHARACTERISTICS

INTRODUCTION

The word radar is an acronym derived from the phrase **RA**dio **D**etection **A**nd **R**anging and applies to electronic equipment designed for detecting and tracking objects (targets) at considerable distances. The basic principle behind radar is simple - extremely short bursts of radio energy (traveling at the speed of light) are transmitted, reflected off a target and then returned as an echo.

Radar makes use of a phenomenon we have all observed, that of the ECHO PRINCIPLE. To illustrate this principle, if a ship's whistle were sounded in the middle of the ocean, the sound waves would dissipate their energy as they traveled outward and at some point would disappear entirely. If, however the whistle sounded near an object such as a cliff some of the radiated sound waves would be reflected back to the ship as an echo.

The form of electromagnetic signal radiated by the radar depends upon the type of information needed about the target. Radar, as designed for marine navigation applications, is pulse modulated. Pulse-modulated radar can determine the distance to a target by measuring the time required for an extremely short burst of radio-frequency (r-f) energy to travel to the target and return to its source as a reflected echo. Directional antennas are used for transmitting the pulse and receiving the reflected echo, thereby allowing determination of the direction or bearing of the target echo.

Once time and bearing are measured, these targets or echoes are calculated and displayed on the radar display. The radar display provides the operator a birds eye view of where other targets are relative to own ship.

Radar is an active device. It utilizes its own radio energy to detect and track the target. It does not depend on energy radiated by the target itself. The ability to detect a target at great distances and to locate its position with high accuracy are two of the chief attributes of radar.

There are two groups of radio frequencies allocated by international standards for use by civil marine radar systems. The first group lies in the X-band which corresponds to a wavelength of 3 cm. and has a frequency range between 9300 and 9500 MHz. The second group lies in the S-band with a wavelength of 10 cm. and has a frequency range of 2900 to 3100 MHz. It is sometimes more convenient to speak in terms of wavelength rather than frequency because of the high values associated with the latter.

A fundamental requirement of marine radar is that of directional transmission and reception, which is achieved by producing a narrow horizontal beam. In order to focus the radio energy into a narrow beam the laws of physics prevail and the wavelength must be within the few centimeters range.

The radio-frequency energy transmitted by pulse-modulated radars consists of a series of equally spaced pulses, frequently having durations of about 1 microsecond or less, separated by very short but relatively long periods during which no energy is transmitted. The terms PULSE-MODULATED RADAR and PULSE MODULATION are derived from this method of transmission of radio-frequency energy.

If the distance to a target is to be determined by measuring the time required for one pulse to travel to the target and return as a reflected echo, it is necessary that this cycle be completed before the pulse immediately following is transmitted. This is the reason why the transmitted pulses must be separated by relatively long nontransmitting time periods. Otherwise, transmission would occur during reception of the reflected echo of the preceding pulse. Using the same antenna for both transmitting and receiving, the relatively weak reflected echo would be blocked by the relatively strong transmitted pulse.

A BRIEF HISTORY

Radar, the device which is used for detection and ranging of contacts, independent of time and weather conditions, was one of the most important scientific discoveries and technological developments that emerged from WWII. It's development, like that of most great inventions was mothered by necessity. Behind the development of radar lay more than a century of radio development.

The basic idea of radar can be traced back to the classical experiments on electromagnetic radiation conducted by the scientific community in the 19th century. In the early 1800s, an English physicist, Michael Faraday, demonstrated that electric current produces a magnetic field and that the energy in this field returns to the circuit when the current is stopped. In 1864 the Scottish physicist, James Maxwell, had formulated the general equations of the electromagnetic field, determining that both light and radio waves are actually electromagnetic waves governed by the same fundamental laws but having different frequencies. He proved mathematically that any electrical disturbance could produce an effect at a considerable distance from the point of origin and that this electromagnetic energy travels outward from the source in the form of waves moving at the speed of light.

At the time of Maxwell's conclusions there was no available means to propagate or detect electromagnetic waves. It was not until 1886 that Maxwell's theories were tested. The German physicist, Heinrich Hertz, set out to validate Maxwell's general equations. Hertz was able to show that electromagnetic waves travelled in straight lines and that they can be reflected from a metal object just as light waves are reflected by a mirror.

In 1904 the German engineer, Christian Hulsmeyer obtained a patent for a device capable of detecting ships. This device was demonstrated to the German navy, but failed to arouse interest probably due in part to its very limited range. In 1922, Guglielmo Marconi drew attention to the work of Hertz and repeated Hertz's experiments and eventually proposed in principle what we know now as marine radar.

The first observation of the radar effect was made in 1922 by Dr. Albert Taylor of the Naval Research Laboratory (NRL) in Washington, D.C. Dr. Taylor observed that a ship passing between a radio transmitter and receiver reflected some of the waves back to the transmitter. In 1930 further tests at the NRL observed that a plane flying through a beam from a transmitting antenna caused a fluctuation in the signal. The importance of radar for the purposes of tracking aircraft and ships finally became recognized when scientists and engineers learned how to use a single antenna for transmitting and receiving.

Due to the prevailing political and military conditions at the time, the United States, Great Britain, Soviet Union, France, Italy, Germany and Japan all began experimenting with radar, with varying degrees of success. During the 1930s, efforts were made by several countries to use radio echo for aircraft detection. Most of these countries were able to produce some form of operational radar equipment for use by the military at the start of the war in 1939.

At the beginning of WWII, Germany had progressed further in radar development and employed radar units on the ground and in the air for defense against allied aircraft. The ability of radar to serve as an early warning device proved valuable as a defensive tool for the British and the Germans.

Although radar was employed at the start of the war as a defensive weapon, as the war progressed, it came to be used for offensive purposes too. By the middle of 1941 radar had been employed to track aircraft automatically in azimuth and elevation and later to track targets automatically in range.

All of the proven radar systems developed prior to the war were in the VHF band. These low frequency radar signals are subject to several limitations, but despite the drawbacks, VHF represented the frontier of radar technology. Late in 1939, British physicists created the cavity magnetron oscillator which operated at higher frequencies. It was the magnetron that made microwave radar a reality. It was this technological advance that marks the beginning of modern radar.

Following the war, progress in radar technology slowed as post war priorities were directed elsewhere. In the 1950s new and better radar systems began to emerge and the benefits to the civil mariner became more important. Although radar technology has been advanced primarily by the military, the benefits have spilled over into many important civilian applications, of which a principal example is the safety of marine navigation. The same fundamental principles discovered nearly a century ago and the basic data they provide, namely target range and bearing, still apply to today's modern marine radar units.

RADAR PROPAGATION CHARACTERISTICS

THE RADIO WAVE

To appreciate the capabilities and limitations of a marine radar and to be able to use it to full advantage, it is necessary to comprehend the characteristics and behavior of radio waves and to grasp the principles of their generation and reception, including the echo display as seen by the observer. Understanding the theory behind the target presentation on the radar scope will provide the radar observer a better understanding of the art and science of radar interpretation.

Radar (radio) waves, emitted in pulses of electromagnetic energy in the radio-frequency band 3,000 to 10,000 MHz used for shipborne navigational radar, have many characteristics similar to those of other waves. Like light waves of much higher frequency, radar waves tend to travel in straight lines or rays at speeds approximating that of light. Also, like light waves, radar waves are subject to refraction or bending in the atmosphere.

Radio-frequency energy travels at the speed of light, approximately 162,000 nautical miles per second; therefore, the time required for a pulse to travel to the target and return to its source is a measure of the distance to the target. Since the radio-frequency energy makes a round trip, only half the time of travel determines the distance to the target. The round trip time is accounted for in the calibration of the radar.

The speed of a pulse of radio-frequency energy is so fast that the pulse can circumnavigate the earth at the equator more than 7 times in 1 second. It should be obvious that in measuring the time of travel of a radar pulse or signal from one ship to a target ship, the measurement must be an extremely short time interval. For this reason, the MICROSECOND (µsec) is used as a measure of time for radar applications. The microsecond is one-millionth part of 1 second, i.e., there are 1,000,000 microseconds in 1 second of time.

Radio waves have characteristics common to other forms of wave motion such as ocean waves. Wave motion consists of a succession of crests and troughs which follow one another at equal intervals and move along at a constant speed. Like waves in the sea, radar waves have energy, frequency, amplitude, wavelength, and rate of travel. Whereas waves in the sea have mechanical energy, radar waves have electromagnetic energy, usually expressed in watt units of power. An important characteristic of radio waves in connection with radar is polarization. This electromagnetic energy has associated electric and magnetic fields, the directions of which are at right angles to each other. The orientation of the ELECTRIC AXIS in space establishes what is known as the POLARIZATION of the wave. Horizontal polarization is normally used with navigational radars, i.e., the direction of the electric axis is horizontal in space. Horizontal polarization has been found to be the most satisfactory type of polarization for navigational radars in that stronger echoes are received from the targets normally used with these radars when the electric axis is horizontal.

Each pulse of energy transmitted during a few tenths of a microsecond or a few microseconds contains hundreds of complete oscillations. A CYCLE is one complete oscillation or one complete wave, i.e., that part of the wave motion passing zero in one direction until it next passes zero in the same direction (see figure 1.1). The FREQUENCY is the number of cycles completed per second. The unit now being used for frequency in cycles per second is the HERTZ. One hertz is one cycle per second; one kilohertz (kHz) is one thousand cycles per second; one megahertz (MHz) is one million cycles per second.

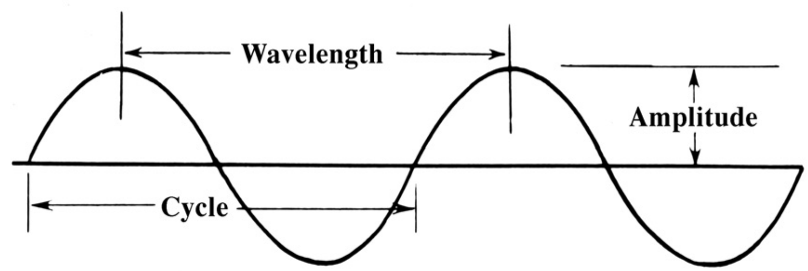

Figure 1.1 - Wave.

WAVELENGTH is the distance along the direction of propagation between successive crests or troughs. When one cycle has been completed, the wave has traveled one wavelength.

The AMPLITUDE is the maximum displacement of the wave from its mean or zero value.

Since the speed of radar waves is constant at 300,000 kilometers per second, there is a definite relationship between frequency and wavelength.

The CYCLE is a complete alternation or oscillation from one crest through a trough to the next crest.

$$\text{frequency} = \frac{\text{speed of radar waves}}{\text{wavelength}}$$

When the wavelength is 3.2 centimeters (0.000032 km),

$$\text{frequency} = \frac{300,000 \text{ km}}{\text{second}} \div \frac{0.000032 \text{ km}}{\text{cycle}}$$

$$\text{frequency} = 9375 \text{ megahertz}$$

THE RADAR BEAM

The pulses of r-f energy emitted from the feedhorn at the focal point of a reflector or emitted and radiated directly from the slots of a slotted waveguide antenna would, for the most part, form a single lobe-shaped pattern of radiation if emitted in free space. Figure 1.2 illustrates this free space radiation pattern, including the undesirable minor lobes or SIDE LOBES associated with practical antenna design. Because of the large differences in the various dimensions of the radiation pattern, figure 1.2 is necessarily distorted.

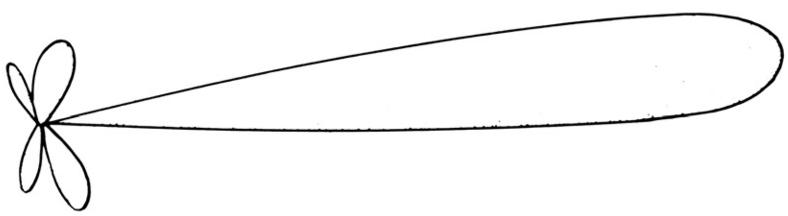

Figure 1.2 - Free space radiation pattern.

Although the radiated energy is concentrated or focused into a relatively narrow main beam by the antenna, similar to a beam of light from a flashlight, there is no clearly defined envelope of the energy radiated. While the energy is concentrated along the axis of the beam, its strength decreases with distance along the axis. The strength of the energy decreases rapidly in directions away from the beam axis. The power in watts at points in the beam is inversely proportional to the square of the distance. Therefore, the power at 3 miles is only 1/9th of the power at 1 mile in a given direction. The field intensity in volts at points in the beam is inversely proportional to the distance. Therefore, the voltage at 2 miles is only one-half the voltage at 1 mile in a given direction. With the rapid decrease in the amount of radiated energy in directions away from the axis and in conjunction with the rapid decreases of this energy with distance, it follows that practical limits of power or voltage may be used to define the dimensions of the radar beam or to establish its envelope of useful energy.

Beam Width

The three-dimensional radar beam is normally defined by its horizontal and vertical beam widths. Beam width is the angular width of a radar beam between points within which the field strength or power is greater than arbitrarily selected lower limits of field strength or power.

There are two limiting values, expressed either in terms of field intensity or power ratios, used conventionally to define beam width. One convention defines beam width as the angular width between points at which the field strength is 71 percent of its maximum value. Expressed in terms of power ratio, this convention defines beam width as the angular width between HALF-POWER POINTS. The other convention defines beam width as the angular width between points at which the field strength is 50 percent of its maximum value. Expressed in terms of power ratio, the latter convention defines beam width as the angular width between QUARTER-POWER POINTS.

The half-power ratio is the most frequently used convention. Which convention has been used in stating the beam width may be identified from the decibel (dB) figure normally included with the specifications of a radar set. Half power and 71 percent field strength correspond to -3 dB; quarter power and 50 percent field strength correspond to -6 dB.

The radiation diagram illustrated in figure 1.3 depicts relative values of power in the same plane existing at the same distances from the antenna or the origin of the radar beam. Maximum power is in the direction of the axis of the beam. Power values diminish rapidly in directions away from the axis. The beam width in this case is taken as the angle between the half-power points.

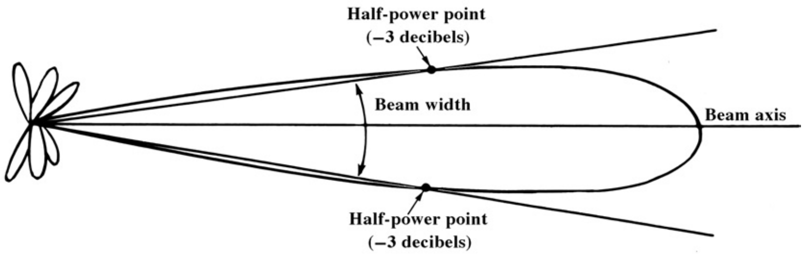

Figure 1.3 - Radiation diagram.

For a given amount of transmitted power, the main lobe of the radar beam extends to a greater distance at a given power level with greater concentration of power in narrower beam widths. To increase maximum detection range capabilities, the energy is concentrated into as narrow a beam as is feasible. Because of practical considerations related to target detection and discrimination, only the horizontal beam width is quite narrow, typical values being between about 0.65˚ to 2.0˚. The vertical beam width is relatively broad, typical values being between about 15˚ to 30˚.

The beam width is dependent upon the frequency or wavelength of the transmitted energy, antenna design, and the dimensions of the antenna.

For a given antenna size (antenna aperture), narrower beam widths are obtained when using shorter wavelengths. For a given wavelength, narrower beam widths are obtained when using larger antennas.

The slotted waveguide antenna has largely eliminated the side-lobe problem.

EFFECT OF SEA SURFACE ON RADAR BEAM

With radar waves being propagated in the vicinity of the surface of the sea, the main lobe of the radar beam, as a whole, is composed of a number of separate lobes as opposed to the single lobe-shaped pattern of radiation as emitted in free space. This phenomenon is the result of interference between radar waves directly transmitted and those waves which are reflected from the surface of the sea. The vertical beam widths of navigational radars are such that during normal transmission, radar waves will strike the surface of the sea at points from near the antenna (depending upon antenna height and vertical beam width) to the radar horizon. The indirect waves (see figure 1.4) reflected from the surface of the sea may, on rejoining the direct waves, either reinforce or cancel the direct waves depending upon whether they are in phase or out of phase with the direct waves, respectively. Where the direct and indirect waves are exactly in phase, i.e., the crests and troughs of the waves coincide, hyperbolic lines of maximum radiation known as LINES OF MAXIMA are produced. Where the direct and indirect waves are exactly of opposite phase, i.e., the trough of one wave coincides with the crest of the other wave, hyperbolic lines of minimum radiation known as LINES OF MINIMA are produced. Along directions away from the antenna, the direct and indirect waves will gradually come into and pass out of phase, producing lobes of useful radiation separated by regions within which, for practical purposes, there is no useful radiation.

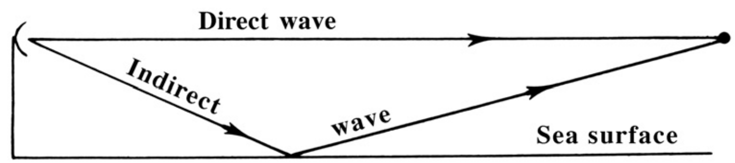

Figure 1.4 - Direct and indirect waves.

Figure 1.5 illustrates the lower region of the INTERFERENCE PATTERN of a representative navigational radar. Since the first line of minima is at the surface of the sea, the first region of minimum radiation or energy is adjacent to the sea's surface.

From figure 1.5 it should be obvious that if r-f energy is to be reflected from a target, the target must extend somewhat above the radar horizon, the amount of extension being dependent upon the reflecting properties of the target.

A VERTICAL-PLANE COVERAGE DIAGRAM as illustrated in figure 1.5 is used by radar designers and analysts to predict regions in which targets will and will not be detected.

Of course, on the small page of a book it would be impossible to illustrate the coverage of a radar beam to scale with antenna height being in feet and the lengths of the various lobes of the interference pattern being in miles. In providing greater clarity of the presentation of the lobes, non-linear graduations of the arc of the vertical beam width are used.

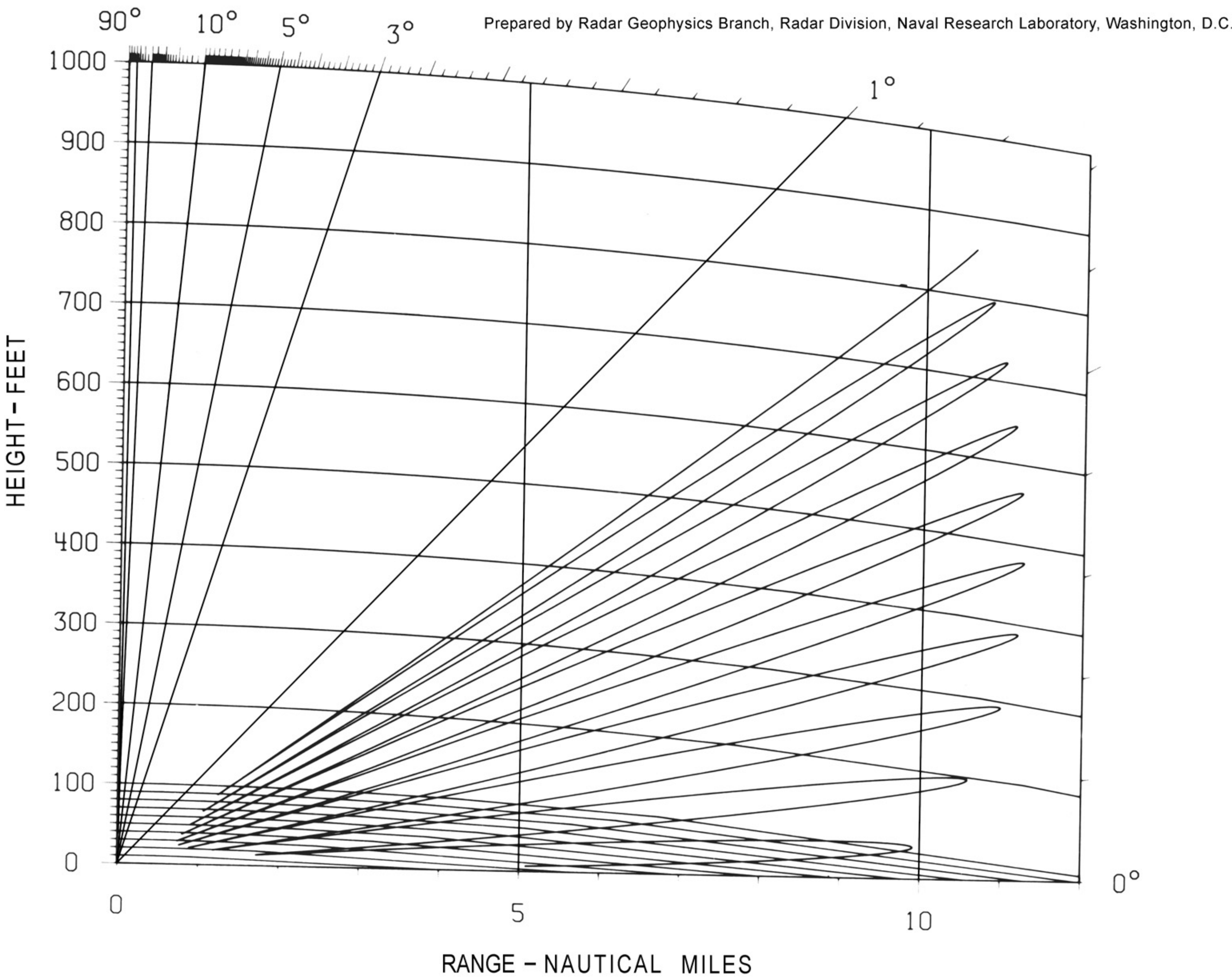

Figure 1.5 - Vertical-plane coverage diagram (3050 MHz, antenna height 125 feet, wave height 4 feet).

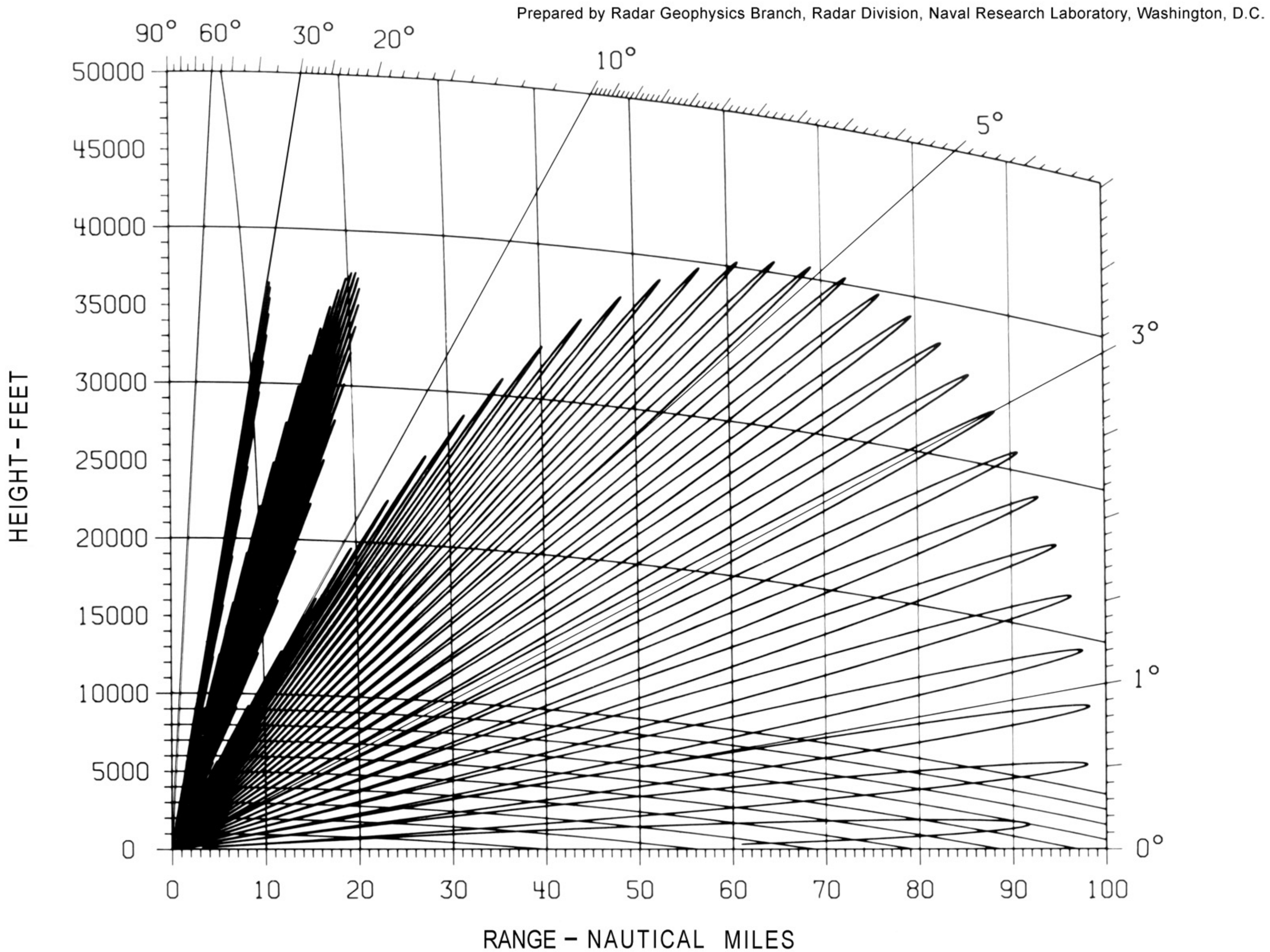

Figure 1.6 - Vertical-plane coverage diagram (1000 MHz, vertical beam width 10°, antenna height 80 feet, wave height 0 feet).

The lengths of the various lobes illustrated in figures 1.5 and 1.6 should be given no special significance with respect to the range capabilities of a particular radar set. As with other coverage diagrams, the lobes are drawn to connect points of equal field intensities. Longer and broader lobes may be drawn connecting points of equal, but lesser, field intensities.

The vertical-plane coverage diagram as illustrated in figure 1.6, while not representative of navigational radars, does indicate that at the lower frequencies the interference pattern is more coarse than the patterns for higher frequencies. This particular diagram was constructed with the assumption that the free space useful range of the radar beam was 50 nautical miles. From this diagram it is seen that the ranges of the useful lobes are extended to considerably greater distances because of the reinforcement of the direct radar waves by the indirect waves. Also, the elevation of the lowest lobe is higher than it would be for a higher frequency. Figure 1.6 also illustrates the vertical view of the undesirable side lobes associated with practical antenna design. In examining these radiation coverage diagrams, the reader should keep in mind that the radiation pattern is three-dimensional.

Antenna height as well as frequency or wavelength governs the number of lobes in the interference pattern. The number of the lobes and the fineness of the interference pattern increase with antenna height. Increased antenna height as well as increases in frequency tends to lower the lobes of the interference pattern.

The pitch and roll of the ship radiating does not affect the structure of the interference pattern.

ATMOSPHERIC FACTORS AFFECTING THE RADAR HORIZON

THE RADAR HORIZON

The affect of the atmosphere on the horizon is a further factor which should be taken into account when assessing the likelihood of detecting a particular target and especially where the coastline is expected.

Generally, radar waves are restricted in the recording of the range of low-lying objects by the radar horizon. The range of the radar horizon depends on the height of the antenna and on the amount of bending of the radar wave. The bending is caused by diffraction and refraction. Diffraction is a property of the electromagnetic wave itself. Refraction is due to the prevailing atmospheric conditions. There is, therefore, a definite radar horizon.

DIFFRACTION

Diffraction is the bending of a wave as it passes an obstruction. Because of diffraction there is some illumination of the region behind an obstruction or target by the radar beam. Diffraction effects are greater at the lower frequencies. Thus, the radar beam of a lower frequency radar tends to illuminate more of the shadow region behind an obstruction than the beam of radar of higher frequency or shorter wavelength.

REFRACTION

Refraction affects the range at which objects are detected. The phenomenon of refraction should be well-known to every navigation officer. Refraction takes place when the velocity of the wave is changed. This can happen when the wave front passes the boundary of two substances of differing densities. One substance offers more resistance to the wave than the other and therefore the velocity of the wave will change. Like light rays, radar rays are subject to bending or refraction in the atmosphere resulting from travel through regions of different density. However, radar rays are refracted slightly more than light rays because of the frequencies used. If the radar waves actually traveled in straight lines or rays, the distance to the horizon grazed by these rays would be dependent only on the height of the antenna, assuming adequate power for the rays to reach this horizon. Without the effects of refraction, the distance to the RADAR HORIZON would be the same as that of the geometrical horizon for the antenna height.

Standard Atmospheric Conditions

The distance to the radar horizon, ignoring refraction can be expressed in the following formula. Where h is the height of the antenna in feet, the distance, d, to the radar horizon in nautical miles, assuming standard atmospheric conditions, may be found as follows:

$$d = 1.22\sqrt{h}$$

With the distances to the geometrical or ordinary horizon being $1.06\sqrt{h}$ and the distance to the visible or optical horizon being $1.15\sqrt{h}$. We see that the range of the radar horizon is greater than that of the optical horizon, which again is greater than that of the geometrical horizon. Thus, like light rays in the standard atmosphere, radar rays are bent or refracted slightly downwards approximating the curvature of the earth (see figure 1.7).

The distance to the radar horizon does not in itself limit the distance from which echoes may be received from targets. Assuming that adequate power is transmitted, echoes may be received from targets beyond the radar horizon if their reflecting surfaces extend above it. Note that the distance to the radar horizon is the distance at which the radar rays graze the surface of the earth.

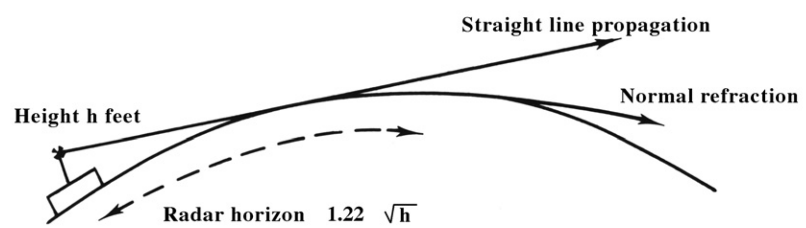

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Figure 1.7 - Refraction.

In the preceding discussion standard atmospheric conditions were assumed. The standard atmosphere is a hypothetical vertical distribution of atmospheric temperature, pressure, and density which is taken to be representative of the atmosphere for various purposes.

Standard conditions are precisely defined as follows:

Pressure = 1013 mb decreasing at 36 mb/1000 ft of height
Temperature = 15˚C decreasing at 2˚C/1000 ft of height
Relative Humidity = 60% and constant with height.

These conditions give a refractive index of 1.00325 which decreases at 0.00013 units/1000 ft of height. The definition of “standard” conditions relates to the vertical composition of the atmosphere. Mariners may not be able to obtain a precise knowledge of this and so must rely on a more general appreciation of the weather conditions, the area of the world, and of the time of the year.

While the atmospheric conditions at any one locality during a given season may differ considerably from standard atmospheric conditions, the slightly downward bending of the light and radar rays may be described as the typical case.

While the formula for the distance to the radar horizon $(d = 1.22\sqrt{h})$ is based upon a wavelength of 3cm, this formula may be used in the computation of the distance to the radar horizon for other wavelengths used with navigational radar. The value so determined should be considered only as an approximate value because the mariner generally has no means of knowing what actual refraction conditions exist.

Sub-refraction

The distance to the radar horizon is reduced. This condition is not as common as super-refraction. Sub-refraction can occur in polar regions where Arctic winds blow over water where a warm current is prevalent. If a layer of cold, moist air overrides a shallow layer of warm, dry air, a condition known as SUB-REFRACTION may occur (see figure 1.8). The effect of sub-refraction is to bend the radar rays upward and thus decrease the maximum ranges at which targets may be detected.

Sub-refraction also affects minimum ranges and may result in failure to detect low lying targets at short range. It is important to note that sub-refraction may involve an element of danger to shipping where small vessels and ice may go undetected. The officer in charge of the watch should be especially mindful of this condition and extra precautions be administered such as a reduction in speed and the posting of extra lookouts.

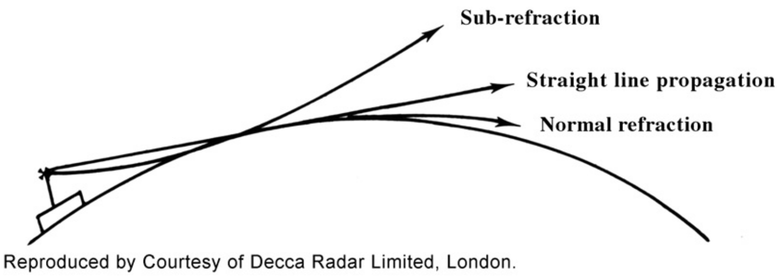

Figure 1.8 - Sub-refraction.

Super-refraction

The distance to the radar horizon is extended. In calm weather with no turbulence when there is an upper layer of warm, dry air over a surface layer of cold, moist air, a condition known as SUPER-REFRACTION may occur (see figure 1.9). For this condition to exist, the weather must be calm with little or no turbulence, otherwise the layers of different densities will mix and the boundary conditions disappear. The effect of super-refraction will increase the downward bending of the radar rays and thus increase the ranges at which targets may be detected. Super-refraction frequently occurs in the tropics when a warm land breeze blows over cooler ocean currents. It is especially noticeable on the longer range scales.

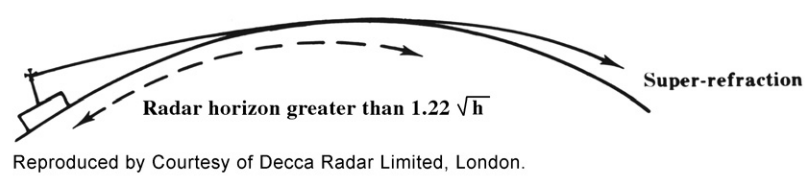

Figure 1.9 - Super-refraction.

Extra Super-refraction or Ducting

Most radar operators are aware that at certain times they are able to detect targets at extremely long ranges, but at other times they cannot detect targets within visual ranges, even though their radars may be in top operating condition in both instances.

These phenomena occur during extreme cases of super-refraction. Energy radiated at angles of 1˚ or less may be trapped in a layer of the atmosphere called a SURFACE RADIO DUCT. In the surface radio duct illustrated in figure 1.10, the radar rays are refracted downward to the surface of the sea, reflected upward, refracted downward again within the duct, and so on continuously.

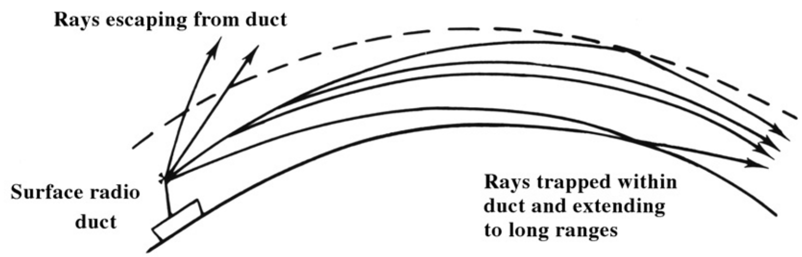

Figure 1.10 - Ducting.

The energy trapped by the duct suffers little loss; thus, targets may be detected at exceptionally long ranges. Surface targets have been detected at ranges in excess of 1,400 miles with relatively low-powered equipment. There is a great loss in the energy of the rays escaping the duct, thus reducing the chances for detection of targets above the duct.

Ducting sometimes reduces the effective radar range. If the antenna is below a duct, it is improbable that targets above the duct will be detected. In instances of extremely low-level ducts when the antenna is above the duct, surface targets lying below the duct may not be detected. The latter situation does not occur very often.

Ducting Areas

Although ducting conditions can happen any place in the world, the climate and weather in some areas make their occurrence more likely. In some parts of the world, particularly those having a monsoonal climate, variation in the degree of ducting is mainly seasonal, and great changes from day to day may not take place. In other parts of the world, especially those in which low barometric pressure areas recur often, the extent of nonstandard propagation conditions varies considerably from day to day.

Figure 1.11 illustrates the different places in the world where known ducting occurs frequently. Refer to the map to see their location in relation to the climate that exists in each area during different seasons of the year.

Atlantic Coast of the United States (Area 1). Ducting is common in summer along the northern part of the coast, but in the Florida region the seasonal trend is the reverse, with a maximum in the winter season.

Western Europe (Area 2). A pronounced maximum of ducting conditions exists in the summer months on the eastern side of the Atlantic around the British Isles and in the North Sea.

Mediterranean Region (Area 3). Available reports indicate that the seasonal variation in the Mediterranean region is very marked, with ducting more or less the rule in summer. Conditions are approximately standard in winter. Ducting in the central Mediterranean area is caused by the flow of warm, dry air from the south, which moves across the sea and thus provides an excellent opportunity for the formation of ducts. In winter, however, the climate in the central Mediterranean is more or less the same as Atlantic conditions, therefore not favorable for duct formation.

Arabian Sea (Area 4). The dominating meteorological factor in the Arabian Sea region is the southwest monsoon, which blows from early June to mid-September and covers the whole Arabian Sea with moist-equatorial air up to considerable heights. When this meteorological situation is developed fully, no occurrence of ducting is to be expected. During the dry season, on the other hand, conditions are different. Ducting then is the rule, not the exception, and on some occasions extremely long ranges (up to 1,500 miles) have been observed on fixed targets.

When the southwest monsoon begins early in June, ducting disappears on the Indian side of the Arabian Sea. Along the western coasts, however, conditions favoring ducting may still linger. The Strait of Hormuz (Persian Gulf) is particularly interesting as the monsoon there has to contend with the shamal (a northwesterly wind) over Iraq and the Persian Gulf from the north. The strait itself lies at the boundary between the two wind systems; a front is formed with the warm, dry shamal on top and the colder, humid monsoon underneath. Consequently, conditions are favorable for the formation of an extensive duct, which is of great importance to radar operation in the Strait of Hormuz.

Bay of Bengal (Area 5). The seasonal trend of ducting conditions in the Bay of Bengal is the same as in the Arabian Sea, with standard conditions during the summer southwest monsoon. Ducting is found during the dry season.

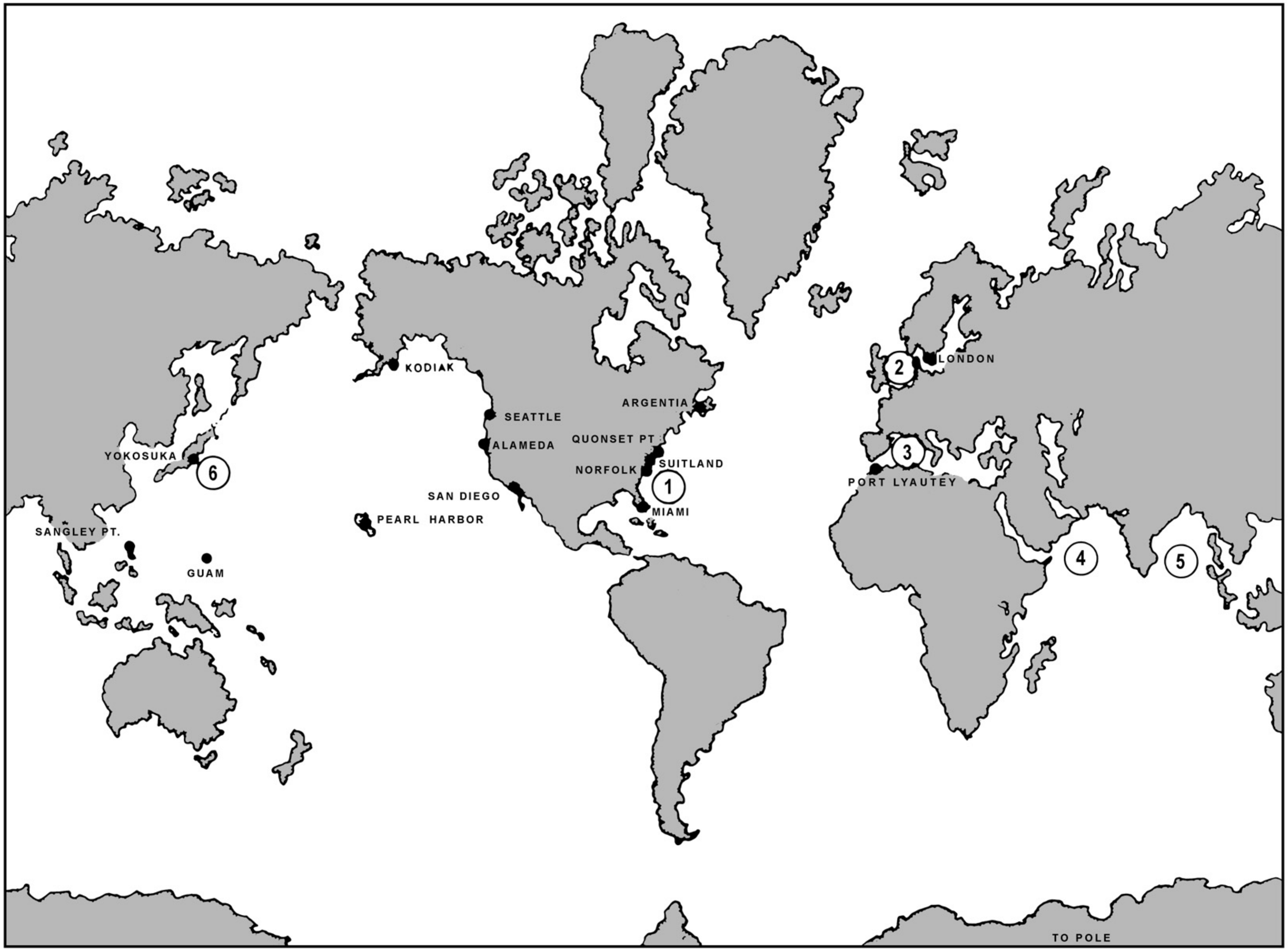

Figure 1.11 - Ducting areas.

Pacific Ocean (Area 6). Frequent occurrences of ducting around Guadalcanal, the east coast of Australia, and around New Guinea and Korea have been experienced. Observations along the Pacific coast of the United States indicate frequent ducting, but no clear indication of its seasonal trend is available. Meteorological conditions in the Yellow Sea and Sea of Japan, including the island of Honshu, are approximately like those of the northeastern coast of the United States. Therefore, ducting in this area should be common in the summer. Conditions in the South China Sea approximate those off the southeastern coast of the United States only during the winter months, when ducting can be expected. During the rest of the year, the Asiatic monsoon modifies the climate in this area, but no information is available on the prevalence of ducting during this time. Trade winds in the Pacific quite generally lead to the formation of rather low ducts over the open ocean.

WEATHER FACTORS AFFECTING THE RADAR HORIZON

The usual effects of weather are to reduce the ranges at which targets can be detected and to produce unwanted echoes on the radarscope which may obscure the returns from important targets or from targets which may be dangerous to one's ship. The reduction of intensity of the wave experienced along its path is known as *attenuation.*

Attenuation is caused by the absorption and scattering of energy by the various forms of precipitation. The amount of attenuation caused by each of the various factors depends to a substantial degree on the radar wavelength. It causes a decrease in echo strength. Attenuation is greater at the higher frequencies or shorter wavelengths.

Attenuation by rain, fog, clouds, hail, snow, and dust

The amount of attenuation caused by these weather factors is dependent upon the amount of water, liquid or frozen, present in a unit volume of air and upon the temperature. Therefore, as one would expect, the affects can differ widely. The further the radar wave and returning echo must travel through this medium then the greater will be the attenuation and subsequent decrease in detection range. This is the case whether the target is in or outside the precipitation. A certain amount of attenuation takes place even when radar waves travel through a clear atmosphere. The affect will not be noticeable to the radar observer. The effect of precipitation starts to become of practical significance at wavelengths shorter than 10cm. In any given set of precipitation conditions, the (S-band) or 10cm will suffer less attenuation than the (X-band) or 3cm.

Rain

In the case of rain the particles which affect the scattering and attenuation take the form of water droplets. It is possible to relate the amount of attenuation to the rate of precipitation. If the size of the droplet is an appreciable proportion of the 3cm wavelength, strong clutter echoes will be produced and there will be serious loss of energy due to scattering and attenuation. If the target is within the area of rainfall, any echoes from raindrops will further decrease its detection range. Weaker target responses, as from small vessels and buoys, will be undetectable if their echoes are not stronger than that of the rain. A very heavy rainstorm, like those sometimes encountered in the tropics, can obliterate most of the (X-band) radar picture.

Continuous rainfall over a large area will make the center part of the screen brighter than the rest and the rain clutter, moving along with the ship, looks similar to sea clutter. It can be clearly seen on long range scales. This is due to a gradual decrease in returning power as the pulse penetrates further into the rain area.

Fog

In most cases fog does not actually produce echoes on the radar display, but a very dense fogbank which arises in polar regions may produce a significant reduction in detection range.

A vessel encountering areas known for industrial pollution in the form of smog may find a somewhat higher degree of attenuation than sea fog.

Clouds

The water droplets which form clouds are too small to produce a detectable response at the 3cm wavelength. If there is precipitation in the cloud then the operator can expect a detectable echo.

Hail

With respect to water, hail which is essentially frozen rain reflects radar energy less effectively than water. Therefore, in general the clutter and attenuation from hail are likely to prove less detectable than that from rain.

Snow

Similar to the effects of hail, the overall effect of clutter on the picture is less than that due to rain. Falling snow will only be observed on the displays of 3cm except during heavy snowfall where attenuation can be observed on a 10cm set.

The strength of echoes from snow depends upon the size of the snowflake and the rate of precipitation. For practical purposes, however, the significant factor is the rate of precipitation, because the water content of the heaviest snowfall will very rarely equal that of even moderate rain.

It is important to keep in mind that in areas receiving and collecting snowfall and where the snow is collecting on possible danger targets it may render them less detectable. Accumulation of snow produces a limited absorption characteristic and reduces the detection range of an otherwise strong target.

Dust

There is a general reduction in radar detection in the presence of dust and sandstorms. On the basis of particle size, detectable responses are extremely unlikely and the operator can expect a low level of attenuation.

Unusual Propagation Conditions

Similar to light waves, radar waves going through the earth's atmosphere are subject to refraction and normally bend slightly with the curvature of the earth. Certain atmospheric conditions will produce a modification of this normal refraction.

RADAR SYSTEM CONSTANTS

Before describing the functions of the components of a marine radar, there are certain constants associated with any radar system that will be discussed. These are carrier frequency, pulse repetition frequency, pulse length, and power relation. The choice of these constants for a particular system is determined by its operational use, the accuracy required, the range to be covered, the practical physical size, and the problems of generating and receiving the signals.

Carrier Frequency

The carrier frequency is the frequency at which the radio-frequency energy is generated. The principal factors influencing the selection of the carrier frequency are the desired directivity and the generation and reception of the necessary microwave radio-frequency energy.

For the determination of direction and for the concentration of the transmitted energy so that a greater portion of it is useful, the antenna should be highly directive. The higher the carrier frequency, the shorter the wavelength and hence the smaller is the antenna required for a given sharpness of the pattern of radiated energy.

The problem of generating and amplifying reasonable amounts of radio-frequency energy at extremely high frequencies is complicated by the physical construction of the tubes to be used. The common tube becomes impractical for certain functions and must be replaced by tubes of special design. Among these are the *klystron* and *magnetron.*

Since it is very difficult to amplify the radio-frequency echoes of the carrier wave, radio-frequency amplifiers are not used. Instead, the frequency of the incoming signals (echoes) is mixed (heterodyned) with that of a local oscillator in a *crystal mixer* to produce a difference frequency called the *intermediate frequency.* This intermediate frequency is low enough to be amplified in suitable *intermediate frequency* amplifier stages in the receiver.

Pulse Repetition Frequency

The Pulse Repetition Frequency (PRF), sometimes referred to as Pulse Repetition Rate (PRR) is the number of pulses transmitted per second. Some characteristic values may be 600, 1000, 1500, 2200 and 3000 pulses per second. The majority of modern marine radars operate within a range of 400 to 4000 pulses per second.

If the distance to a target is to be determined by measuring the time required for one pulse to travel to the target and return as a reflected echo, it is necessary that this cycle be completed before the pulse immediately following is transmitted. This is the reason why the transmitted pulses must be separated by relatively long nontransmitting time periods. Otherwise, transmission would occur during reception of the reflected echo of the preceding pulse. Using the same antenna for both transmitting and receiving, the relatively weak reflected echo would be blocked by the relatively strong transmitted pulse.

Sufficient time must be allowed between each transmitted pulse for an echo to return from any target located within the maximum workable range of the system. Otherwise, the reception of the echoes from the more distant targets would be blocked by succeeding transmitted pulses. The maximum measurable range of a radar set depends upon the peak power in relation to the pulse repetition rate. Assuming sufficient power is radiated, the maximum range at which echoes can be received may be increased through lowering the pulse repetition rate to provide more time between transmitted pulses. The PRR must be high enough so that sufficient pulses hit the target and enough are returned to detect the target. The maximum measurable range, assuming that the echoes are strong enough for detection, can be determined by dividing 80,915 (radar nautical miles per second) by the PRR.

With the antenna being rotated, the beam of energy strikes a target for a relatively short time. During this time, a sufficient number of pulses must be transmitted in order to receive sufficient echoes to produce the necessary indication on the radarscope. With the antenna rotating at 15 revolutions per minute, a radar set having a PRR of 800 pulses per second will produce approximately 9 pulses for each degree of antenna rotation. The PERSISTENCE of the radarscope, i.e., a measure of the time it retains images of echoes, and the rotational speed of the antenna, therefore, determine the lowest PRR that can be used.

Pulse Length

Pulse length is defined as the duration of the transmitted radar pulse and is usually measured in microseconds.

The minimum range at which a target can be detected is determined largely by the pulse length. If a target is so close to the transmitter that the echo is returned to the receiver before the transmission stops, the reception of the echo, obviously, will be masked by the transmitted pulse. For example, a radar set having a pulse length of 1 microsecond will have a minimum range of 164 yards. This means that the echo of a target within this range will not be seen on the radarscope because of being masked by the transmitted pulse.

Since the radio-frequency energy travels at a speed of 161,829 nautical miles per second or 161,829 nautical miles in one million microseconds, the distance the energy travels in 1 microsecond is approximately 0.162 nautical mile or 328 yards. Because the energy must make a round trip, the target cannot be closer than 164 yards if its echo is to be seen on the radarscope while using a pulse length of 1 microsecond. Consequently, relatively short pulse lengths, about 0.1 microsecond, must be used for close-in ranging.

Many radar sets are designed for operation with both short and long pulse lengths. Many of these radar sets are shifted automatically to the shorter pulse length on selecting the shorter range scales. On the other radar sets, the operator must select the radar pulse length in accordance with the operating conditions. Radar sets have greater range capabilities while functioning with the longer pulse length because a greater amount of energy is transmitted in each pulse.

While maximum detection range capability is sacrificed when using the shorter pulse length, better range accuracy and range resolution are obtained. With the shorter pulse, better definition of the target on the radar-scope is obtained; therefore, range accuracy is better. RANGE RESOLUTION is a measure of the capability of a radar set to detect the separation between those targets on the same bearing but having small differences in range. If the leading edge of a pulse strikes a target at a slightly greater range while the trailing part of the pulse is still striking a closer target, it is obvious that the reflected echoes of the two targets will appear as a single elongated image on the radarscope.

Power Relation

The useful power of the transmitter is that contained in the radiated pulses and is called the PEAK POWER of the system. Power is normally measured as an average value over a relatively long period of time. Because the radar transmitter is resting for a time that is long with respect to the operating time, the average power delivered during one cycle of operation is relatively low compared with the peak power available during the pulse time.

A definite relationship exists between the average power dissipated over an extended period of time and the peak power developed during the pulse time.

The PULSE REPETITION TIME, or the overall time of one cycle of operation, is the reciprocal of the pulse repetition rate (PRR). Other factors remaining constant, the longer the pulse length, the higher will be the average power; the longer the pulse repetition time, the lower will be the average power.

$$\frac{\text{average power}}{\text{peak power}} = \frac{\text{pulse length}}{\text{pulse repetition time}}$$

These general relationships are shown in figure 1.12.

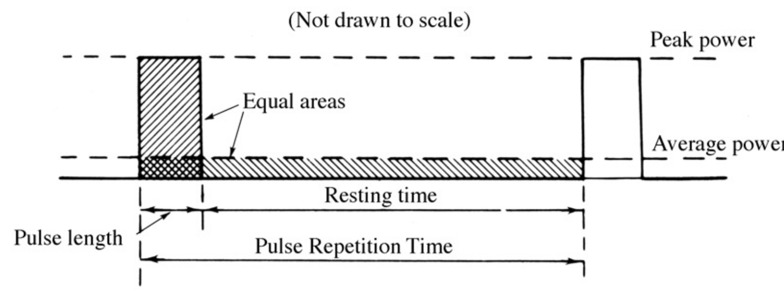

Figure 1.12 - Relationship of peak and average power.

The operating cycle of the radar transmitter can be described in terms of the fraction of the total time that radio-frequency energy is radiated. This time relationship is called the DUTY CYCLE and may be represented as follows:

$$\text{duty cycle} = \frac{\text{pulse length}}{\text{pulse repetition time}}$$

For a radar having a pulse length of 2 microseconds and a pulse repetition rate of 500 cycles per second (pulse repetition time = 2,000 microseconds), the

$$\text{duty cycle} = \frac{2\mu\text{sec}}{2{,}000\ \mu\text{sec}} = 0.001$$

Likewise, the ratio between the average power and peak power may be expressed in terms of the duty cycle.

$$\text{duty cycle} = \frac{\text{average power}}{\text{peak power}}$$

In the foregoing example assume that the peak power is 200 kilowatts. Therefore, for a period of 2 microseconds a peak power of 200 kilowatts is supplied to the antenna, while for the remaining 1998 microseconds the transmitter output is zero. Because average power is equal to peak power times the duty cycle,

$$\text{average power} = 200 \text{ kw} \times 0.001 = 0.2 \text{ kilowatt}$$

High peak power is desirable in order to produce a strong echo over the maximum range of the equipment. Low average power enables the transmitter tubes and circuit components to be made smaller and more compact. Thus, it is advantageous to have a low duty cycle. The peak power that can be developed is dependent upon the interrelation between peak and average power, pulse length, and pulse repetition time, or duty cycle.

COMPONENTS AND SUMMARY OF FUNCTIONS

While pulse-modulated radar systems vary greatly in detail, the principles of operation are essentially the same for all systems. Thus, a single basic radar system can be visualized in which the functional requirements are essentially the same as for all specific equipments.

The functional breakdown of a basic pulse-modulated radar system usually includes six major components, as shown in the block diagram, figure 1.13. The functions of the components may be summarized as follows:

The *power supply* furnishes all AC and DC voltages necessary for the operation of the system components.

The *modulator* produces the synchronizing signals that trigger the transmitter the required number of times per second. It also triggers the indicator sweep and coordinates the other associated circuits.

The *transmitter* generates the radio-frequency energy in the form of short powerful pulses.

The *antenna system* takes the radio-frequency energy from the transmitter, radiates it in a highly directional beam, receives any returning echoes, and passes these echoes to the receiver.

The *receiver* amplifies the weak radio-frequency pulses (echoes) returned by a target and reproduces them as video pulses passed to the indicator.

The *indicator* produces a visual indication of the echo pulses in a manner that furnishes the desired information.

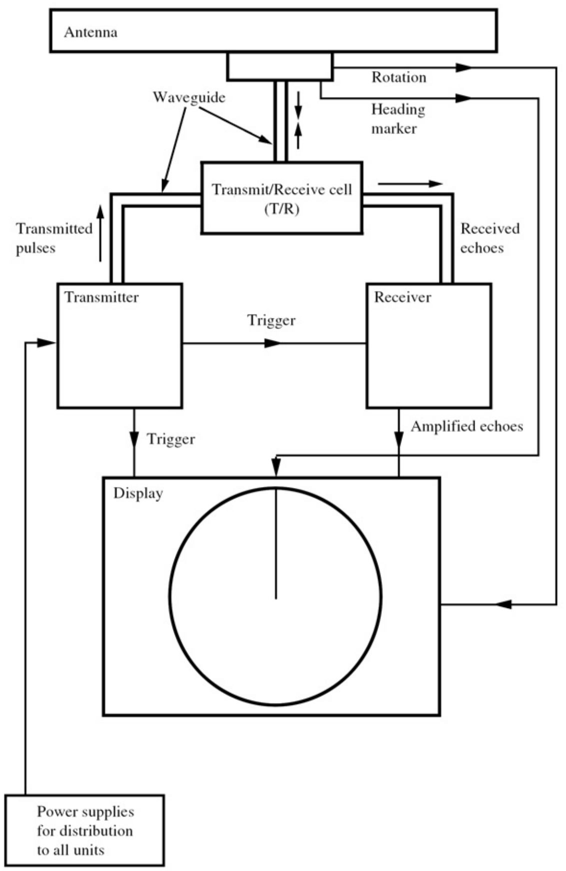

Figure 1.13 - Block diagram of a basic pulse-modulated radar system

FUNCTIONS OF COMPONENTS

Power Supply

In figure 1.13 the power supply is represented as a single block. Functionally, this block is representative. However, it is unlikely that any one supply source could meet all the power requirements of a radar set. The distribution of the physical components of a system may be such as to make it impractical to group the power-supply circuits into a single physical unit. Different supplies are needed to meet the varying requirements of a system and must be designed accordingly. The power supply function is performed by various types of power supplies distributed among the circuit components of a radar set.

In figure 1.14 the modulator, transmitter, and receiver are contained in the same chassis. In this arrangement, the group of components is called a TRANSCEIVER. (The term transceiver is an acronym composed from the words TRANSmitter and reCEIVER.)

Modulator

The function of the modulator is to insure that all circuits connected with the radar system operate in a definite time relationship with each other and that the time interval between pulses is of the proper length. The modulator simultaneously sends a synchronizing signal to trigger the transmitter and the indicator sweep. This establishes a control for the pulse repetition rate (PRR) and provides a reference for the timing of the travel of a transmitted pulse to a target and its return as an echo.

Transmitter

The transmitter is basically an oscillator which generates radio-frequency (r-f) energy in the form of short powerful pulses as a result of being turned on and off by the triggering signals from the modulator. Because of the frequencies and power outputs required, the transmitter oscillator is a special type known as a MAGNETRON.

Transmitting and Receiving Antenna System

The function of the antenna system is to take the r-f energy from the transmitter, radiate this energy in a highly directional beam, receive any echoes or reflections of transmitted pulses from targets, and pass these echoes to the receiver.

In carrying out this function the r-f pulses generated in the transmitter are conducted to a FEEDHORN at the focal point of a directional reflector, from which the energy is radiated in a highly directional pattern. The transmitted and reflected energy (returned by the same dual purpose reflector) are conducted by a common path.

This common path is an electrical conductor known as a WAVEGUIDE. A waveguide is hollow copper tubing, usually rectangular in cross section, having dimensions according to the wavelength or the carrier frequency, i.e., the frequency of the oscillations within the transmitted pulse or echo.

Because of this use of a common waveguide, an electronic switch, a TRANSMIT-RECEIVE (TR) TUBE capable of rapidly switching from transmit to receive functions, and vice versa, must be utilized to protect the receiver from damage by the potent energy generated by the transmitter. The TR tube, as shown in figure 1.14 blocks the transmitter pulses from the receiver. During the relatively long periods when the transmitter is inactive, the TR tube permits the returning echoes to pass to the receiver. To prevent any of the very weak echoes from being absorbed by the transmitter, another device known as an ANTI-TR (A-TR) TUBE is used to block the passage of these echoes to the transmitter.

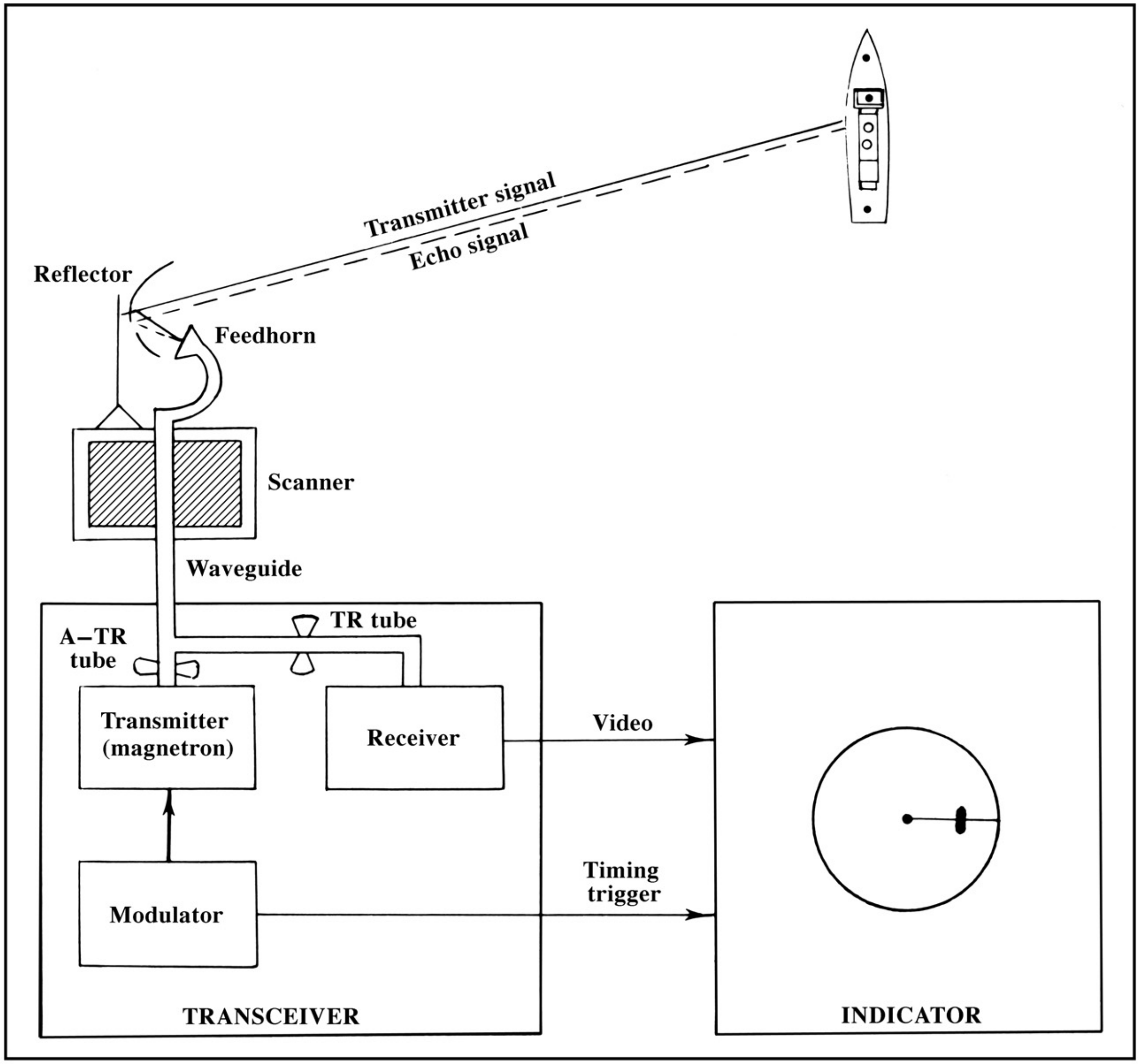

Figure 1.14 - A basic radar system.

The feedhorn at the upper extremity of the waveguide directs the transmitted energy towards the reflector, which focuses this energy into a narrow beam. Any returning echoes are focused by the reflector and directed toward the feedhorn. The echoes pass through both the feedhorn and waveguide enroute to the receiver. The principles of a parabolic reflector are illustrated in figure 1.15.

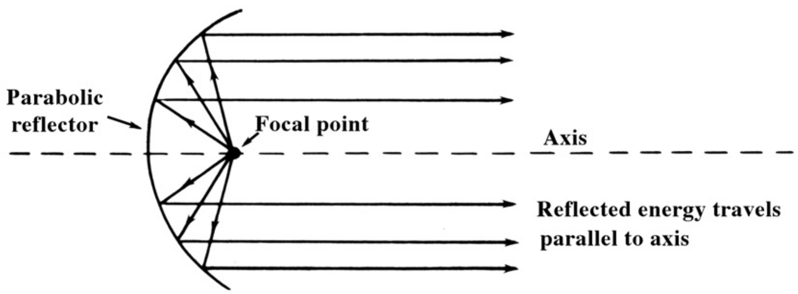

Figure 1.15 - Principles of a parabolic reflector.

Since the r-f energy is transmitted in a narrow beam, particularly narrow in its horizontal dimension, provision must be made for directing this beam towards a target so that its range and bearing may be measured. Normally, this is accomplished through continuous rotation of the radar beam at a rate of about 10 to 20 revolutions per minute so that it will impinge upon any targets which might be in its path. Therefore, in this basic radar system the upper portion of the waveguide, including the feedhorn, and the reflector are constructed so that they can be rotated in the horizontal plane by a drive motor. This rotatable antenna and reflector assembly is called the SCANNER.

Figure 1.16 illustrates a SLOTTED WAVEGUIDE ANTENNA and notice that there is no reflector or feedhorn. The last few feet of the waveguide is constructed so that it can be rotated in the horizontal plane. The forward and narrower face of the rotatable waveguide section contains a series of slots from which the r-f energy is emitted to form a narrow radar beam. Returning echoes also pass through these slots and then pass through the waveguide to the receiver.

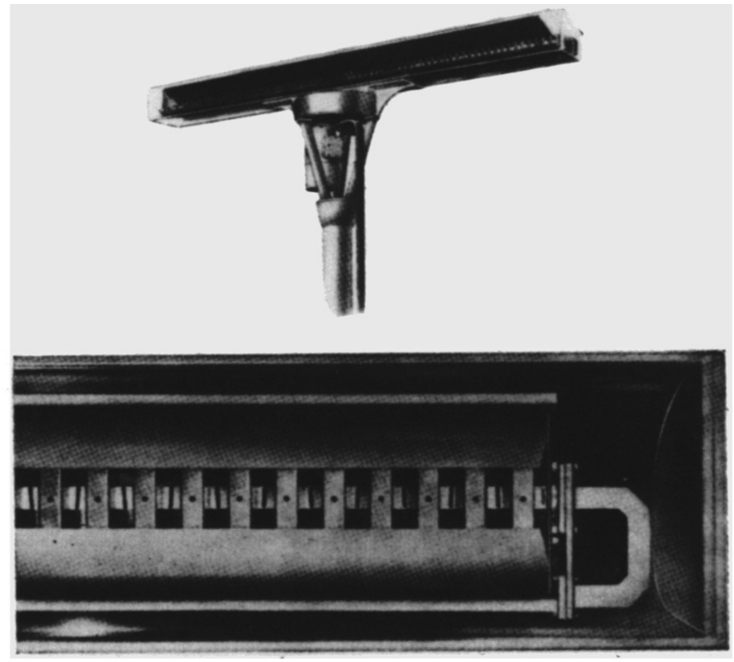

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Figure 1.16 - Slotted waveguide antenna.

Receiver

The function of the receiver is to amplify or increase the strength of the very weak r-f echoes and reproduce them as video signals to be passed to the indicator. The receiver contains a crystal mixer and intermediate frequency amplification stages required for producing video signals used by the indicator.

Indicator

The primary function of the indicator is to provide a visual display of the ranges and bearings of radar targets from which echoes are received. In this basic radar system, the type of display used is the PLAN POSITION INDICATOR (PPI), which is essentially a polar diagram, with the transmitting ship's position at the center. Images of target echoes are received and displayed at either their relative or true bearings, and at their distances from the PPI center. With a continuous display of the images of the targets, the motion of the target relative to the motion of the transmitting ship is also displayed.

The secondary function of the indicator is to provide the means for operating various controls of the radar system.

The CATHODE-RAY TUBE (CRT), illustrated in figure 1.17, is the heart of the indicator. The CRT face or screen, which is coated with a film of phosphorescent material, is the PPI. The ELECTRON GUN at the opposite end of the tube (see figure 1.18) emits a very narrow beam of electrons which impinges upon the center of the PPI unless deflected by electrostatic or electromagnetic means. Since the inside face of the PPI is coated with phosphorescent material, a small bright spot is formed at the center of the PPI.

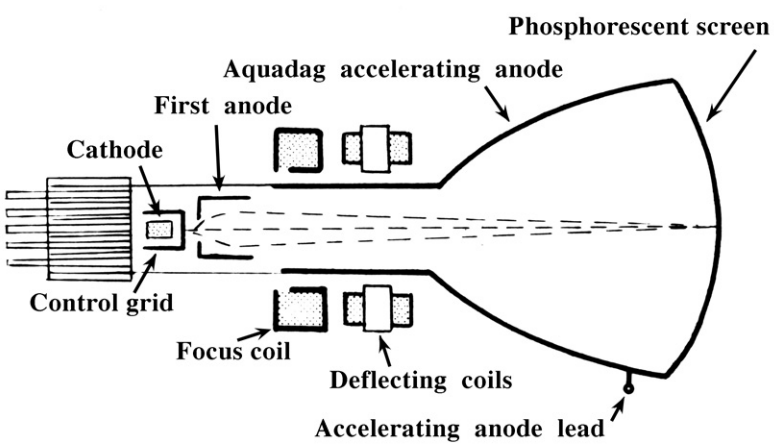


Figure 1.17 - Electromagnetic cathode-ray tube.

If the electron beam is rapidly and repeatedly deflected radially from the center, a bright line called a TRACE is formed on the PPI. Should the flow of electrons be stopped, this trace will continue to glow for a short period following the stoppage of the electron beam because of the phosphorescent coating. The slow decay of the brightness is known as PERSISTENCE; the slower the decay the higher the persistence.

At the instant the modulator triggers the transmitter, it sends a TIMING TRIGGER signal to the indicator. The latter signal acts to deflect the electron beam radially from the center of the CRT screen (PPI) to form a trace of the radial movement of the electron beam. This radial movement of the electron beam is called the SWEEP or TIME BASE. While the terms trace and sweep are frequently used interchangeably, the term trace is descriptive only of the visible evidence of the sweep movement.

Since the electron beam is deflected from the center of the CRT screen with each pulse of the transmitter, the sweep must be repeated very rapidly even when the lower pulse repetition rates are used. With a pulse repetition rate of 750 pulses per second, the sweep must be repeated 750 times per second. Thus, it should be quite obvious why the sweep appears as a solid luminous line on the PPI. The speed of movement of the point of impingement of the electron beam is far in excess of the capability of detection by the human eye.

While the sweep must be repeated in accordance with the PRR, the actual rate of radial movement of the electron beam is governed by the size of the CRT screen and the distance represented by the radius of this screen according to the range scale being used. If the 20-mile range scale is selected, the electron beam must be deflected radially from the center of the CRT screen having a particular radius at a rate corresponding to the time required for radio-frequency energy to travel twice the distance of the range scale or 40 nautical miles. When using the 20-mile range scale, the electron beam must move radially from the center of the CRT screen to its periphery in 247 microseconds.

Speed of radio frequency - frequency energy =
0.161829 nm per microsecond

Distance = Speed X Time

40 nm ÷ 0.161829 nm per microsecond =
247 microseconds

The objective of regulating the rate of travel of the electron beam in this manner is to establish a time base on the PPI which may be used for direct measurements of distances to targets without further need to take into

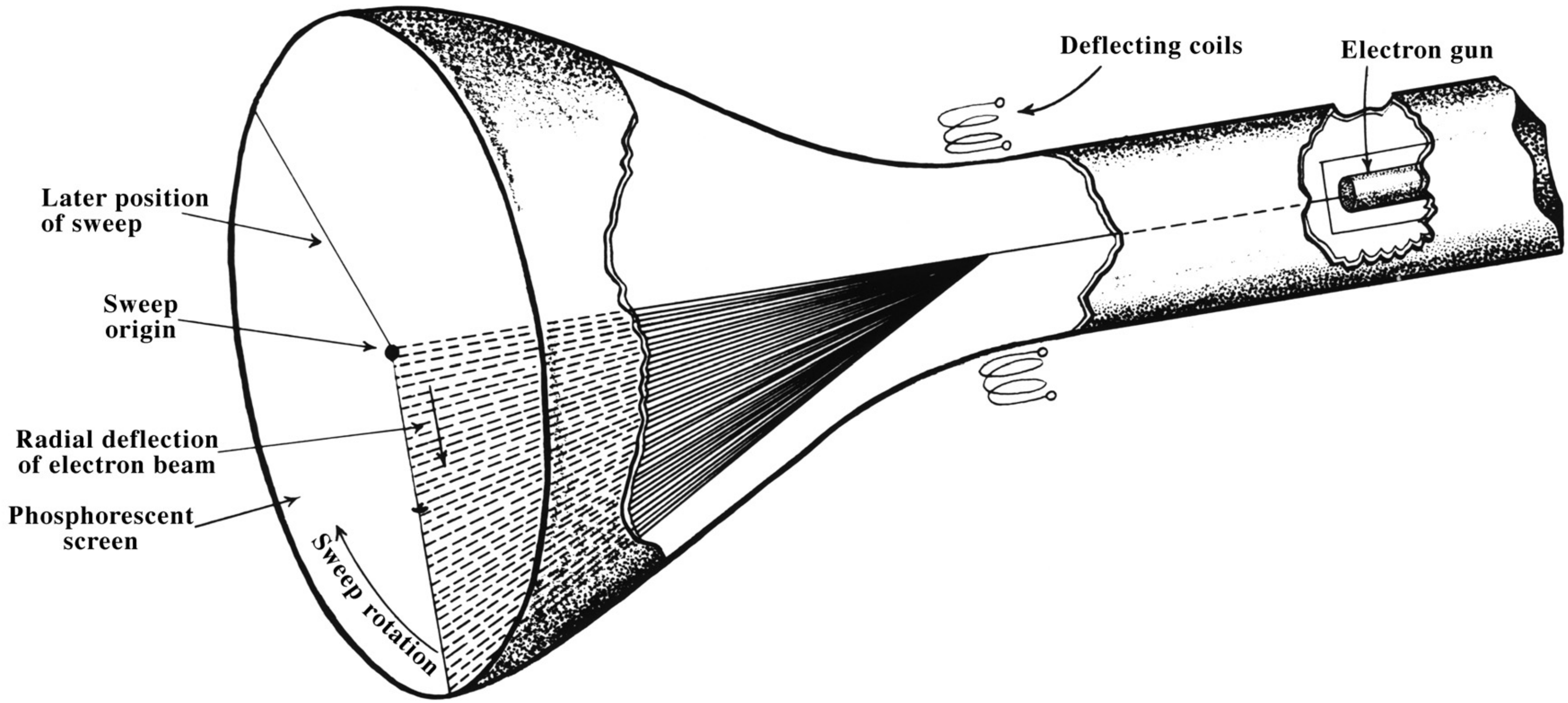


Figure 1.18 - The sweep on the plan position indicator.

account the fact that the transmitted pulse and its reflected echo make a round trip to and from the target. With the periphery of the PPI representing a distance of 20 miles from the center of the PPI at the 20-mile range scale setting, the time required for the electron beam to move radially from the center to the periphery is the same as the time required for the transmitted pulse to travel to a target at 20 miles and return to the antenna as a reflected echo or the time to travel 40 miles in this case. It follows that a point on the sweep or time base halfway between the center of the PPI and its periphery represents a distance of 10 miles from the center of the PPI. The foregoing assumes that the rate of travel of the electron beam is constant, which is the usual case in the design of indicators for navigational radar.

If the antenna is trained on a target at 10 miles while using the 20-mile range scale, the time for the 20-mile round trip of the transmitted pulse and the returning echo is 123.5 microseconds. At 123.5 microseconds, following the instant of triggering the transmitter and sending the timing trigger pulse to the indicator to deflect the electron beam radially, the electron beam will have moved a distance of 10 miles in its sweep or on the time base. On receiving the echo at 123.5 microseconds after the instant of the pulse, the receiver sends a video signal to the indicator which in turn acts to intensify or brighten the electron beam at the point in its sweep at 123.5 microseconds, i.e., at 10 miles on the time base. This brightening of the trace produced by the sweep at the point corresponding to the distance to the target in conjunction with the persistence of the PPI produces a visible image of the target. Because of the pulse repetition rate, this painting of an image on the PPI is repeated many times in a short period, resulting in a steady glow of the target image if the target is a reasonably good reflector.

In navigational and collision avoidance applications of radar, the antenna and the beam of r-f energy radiated from it are rotated at a constant rate, usually about 10 to 20 revolutions per minute in order to detect targets all around the observer's ship. In the preceding discussion of how a target image is painted on the PPI, reference is made only to radial deflection of the electron beam to produce the sweep or time base. If target images are to be painted at their relative bearings as well as distances from the center of the PPI, the sweep must be rotated in synchronization with the rotation of the antenna. Just as the electron beam may be deflected radially by electrostatic or electromagnetic means, the sweep may be rotated by the same means. The sweep is usually rotated electromagnetically in modern radars.

As the antenna is rotated past the ship's heading, the sweep, in synchronization with the antenna, is rotated past the 0˚ graduation on the relative bearing dial of the PPI. The image of any target detected ahead is painted on the PPI at its relative bearing and distance from the center of the PPI. As targets are detected in other directions, their images are painted on the PPI at their relative bearings and distances from the center of the PPI.

Up to this point the discussion of how target information is displayed on the PPI has been limited to how the target images are painted, virtually instantaneously, at their distances and relative bearings from the reference ship at the center of the PPI. It follows that through continuous display (continuous because of the persistence of the CRT screen and the pulse repetition rate) of the positions of targets on the PPI, their motions relative to the motion of the reference ship are also displayed.

In summary, the indicator of this basic radar system provides the means for measuring and displaying, in a useful form, the relative bearings and distances to targets from which reflected echoes may be received. In displaying the positions of the targets relative to the reference ship continuously, the motions of the targets relative to the motion of the reference ship are evident.

FACTORS AFFECTING DETECTION, DISPLAY, AND MEASUREMENT OF RADAR TARGETS

FACTORS AFFECTING MAXIMUM RANGE

Frequency

The higher the frequency of a radar (radio) wave, the greater is the attenuation (loss in power), regardless of weather. Lower radar frequencies (longer wavelengths) have, therefore, been generally superior for longer detection ranges.

Peak Power

The peak power of a radar is its useful power. Range capabilities of the radar increase with peak power. Doubling the peak power increases the range capabilities by about 25 percent.

Pulse Length

The longer the pulse length, the greater is the range capability of the radar because of the greater amount of energy transmitted.

Pulse Repetition Rate

The pulse repetition rate (PRR) determines the maximum measurable range of the radar. Ample time must be allowed between pulses for an echo to return from any target located within the maximum workable range of the system. Otherwise, echoes returning from the more distant targets are blocked by succeeding transmitted pulses. This necessary time interval determines the highest PRR that can be used.

The PRR must be high enough, however, that sufficient pulses hit the target and enough echoes are returned to the radar. The maximum measurable range can be determined approximately by dividing 81,000 by the PRR.

Beam Width

The more concentrated the beam, the greater is the detection range of the radar.

Target Characteristics

Targets that are large can be seen on the scope at greater ranges, provided line-of-sight exists between the radar antenna and the target. Conducting materials (a ship's steel hull, for example) return relatively strong echoes while nonconducting materials (a wood hull of a fishing boat, for example) return much weaker echoes.

Receiver Sensitivity

The more sensitive receivers provide greater detection ranges but are more subject to jamming.

Antenna Rotation Rate

The more slowly the antenna rotates, the greater is the detection range of the radar.

For a radar set having a PRR of 1,000 pulses per second, a horizontal beam width of 2.0˚, and an antenna rotation rate of 6 RPM (1 revolution in 10 seconds or 36 scanning degrees per second), there is 1 pulse transmitted each 0.036˚ of rotation. There are 56 pulses transmitted during the time required for the antenna to rotate through its beam width.

$$\frac{\text{Beam Width}}{\text{Degrees per Pulse}} = \frac{2.0°}{0.036°} = 56 \text{ pulses}$$

With an antenna rotation rate of 15 RPM (1 revolution in 4 seconds or 90 scanning degrees per second), there is only 1 pulse transmitted each 0.090˚ of rotation. There are only 22 pulses transmitted during the time required for the antenna to rotate through its beam width.

$$\frac{\text{Beam Width}}{\text{Degrees per Pulse}} = \frac{2.0°}{0.090°} = 22 \text{ pulses}$$

From the foregoing it is apparent that at the higher antenna rotation rates, the maximum ranges at which targets, particularly small targets, may be detected are reduced.

FACTORS AFFECTING MINIMUM RANGE

Pulse Length

The minimum range capability of a radar is determined primarily by the pulse length. It is equal to half the pulse length of the radar (164 yards per microsecond of pulse length). Electronic considerations such as the recovery time of the receiver and the duplexer (TR and anti-TR tubes assembly) extend the minimum range at which a target can be detected beyond the range determined by the pulse length.

Sea Return

Sea return or echoes received from waves may clutter the indicator within and beyond the minimum range established by the pulse length and recovery time.

Side-Lobe Echoes

Targets detected by the side-lobes of the antenna beam pattern are called side-lobe echoes. When operating near land or large targets, side-lobe echoes may clutter the indicator and prevent detection of close targets, without regard to the direction in which the antenna is trained.

Vertical Beam Width

Small surface targets may escape the lower edge of the vertical beam when close.

FACTORS AFFECTING RANGE ACCURACY

The range accuracy of radar depends upon the exactness with which the time interval between the instants of transmitting a pulse and receiving the echo can be measured.

Fixed Error

A fixed range error is caused by the starting of the sweep on the indicator before the r-f energy leaves the antenna. The zero reference for all range measurements must be the leading edge of the transmitted pulse as it appears on the indicator. Inasmuch as part of the transmitted pulse leaks directly into the receiver without going to the antenna, a fixed error results from the time required for r-f energy to go up to the antenna and return to the receiver. This error causes the indicated ranges to be greater than their true values.

A device called a trigger delay circuit is used to eliminate the fixed error. By this means the trigger pulse to the indicator can be delayed a small amount. Such a delay results in the sweep starting at the instant an echo would return to the indicator from a flat plate right at the antenna not at the instant that the pulse is generated in the transmitter.

Line Voltage

Accuracy of range measurement depends on the constancy of the line voltage supplied to the radar equipment. If supply voltage varies from its nominal value, ranges indicated on the radar may be unreliable. This fluctuation usually happens only momentarily, however, and after a short wait ranges normally are accurate.

Frequency Drift

Errors in ranging also can be caused by slight variations in the frequency of the oscillator used to divide the sweep (time base) into equal range intervals. If such a frequency error exists, the ranges read from the radar generally are in error by some small percentage of the range.

To reduce range errors caused by frequency drift, precision oscillators in radars usually are placed in a constant temperature oven. The oven is always heated, so there is no drift of range accuracy while the rest of the set is warming up.

Calibration

The range to a target can be measured most accurately on the PPI when the leading edge of its pip just touches a fixed range ring. The accuracy of this measurement is dependent upon the maximum range of the scale in use. Representative maximum error in the calibration of the fixed range rings is 75 yards or $1^1/_2$ percent of the maximum range of the range scale in use, whichever is greater. With the indicator set on the 6-mile range scale, the error in the range of a pip just touching a range ring may be about 180 yards or about 0.1 nautical mile because of calibration error alone when the range calibration is within acceptable limits.

On some PPI's, range can only be estimated by reference to the fixed range rings. When the pip lies between the range rings, the estimate is usually in error by 2 to 3 percent of the maximum range of the range scale setting plus any error in the calibration of the range rings.

Radar indicators usually have a variable range marker (VRM) or adjustable range ring which is the normal means for range measurements. With the VRM calibrated with respect to the fixed range rings within a tolerance of 1 percent of the maximum range of the scale in use, ranges as measured by the VRM may be in error by as much as $2^1/_2$ percent of the maximum range of the scale in use. With the indicator set on the 8-mile range scale, the error in a range as measured by the VRM may be in error by as much as 0.2 nautical mile.

Pip and VRM Alignment

The accuracy of measuring ranges with the VRM is dependent upon the ability of the radar observer to align the VRM with the leading edge of the pip on the PPI. On the longer range scales it is more difficult to align the VRM with the pip because small changes in the reading of the VRM range counter do not result in appreciable changes in the position of the VRM on the PPI.

Range Scale

The higher range scale settings result in reduced accuracy of fixed range ring and VRM measurements because of greater calibration errors and the greater difficulty of pip and VRM alignment associated with the higher settings.

PPI Curvature

Because of the curvature of the PPI, particularly in the area near its periphery, range measurements of pips near the edge are of lesser accuracy than the measurements nearer the center of the PPI.

Radarscope Interpretation

Relatively large range errors can result from incorrect interpretation of a landmass image on the PPI. The difficulty of radarscope interpretation can be reduced through more extensive use of height contours on charts.

For reliable interpretation it is essential that the radar operating controls be adjusted properly. If the receiver gain is too low, features at or near the shoreline, which would reflect echoes at a higher gain setting, will not appear as part of the landmass image. If the receiver gain is too high, the landmass image on the PPI will “bloom”. With blooming the shoreline will appear closer than it actually is.

A fine focus adjustment is necessary to obtain a sharp landmass image on the PPI.

Because of the various factors introducing errors in radar range measurements, one should not expect the accuracy of navigational radar to be better than + or - 50 yards under the best conditions.

FACTORS AFFECTING RANGE RESOLUTION

Range resolution is a measure of the capability of a radar to display as separate pips the echoes received from two targets which are on the same bearing and are close together.

The principal factors that affect the range resolution of a radar are the length of the transmitted pulse, receiver gain, CRT spot size, and the range scale. A high degree of range resolution requires a short pulse, low receiver gain, and a short range scale.

Pulse Length

Two targets on the same bearing, close together, cannot be seen as two distinct pips on the PPI unless they are separated by a distance greater than one-half the pulse length (164 yards per microsecond of pulse length). If a radar has a pulse length of 1-microsecond duration, the targets would have to be separated by more than 164 yards before they would appear as two pips on the PPI.

Radio-frequency energy travels through space at the rate of approximately 328 yards per microsecond. Thus, the end of a 1-microsecond pulse traveling through the air is 328 yards behind the leading edge, or start, of the pulse. If a 1-microsecond pulse is sent toward two objects on the same bearing, separated by 164 yards, the leading edge of the echo from the distant target coincides in space with the trailing edge of the echo from the near target. As a result the echoes from the two objects blend into a single pip, and range can be measured only to the nearest object. The reason for this blending is illustrated in figure 1.19.

In part A of figure 1.19, the transmitted pulse is just striking the near target. Part B shows energy being reflected from the near target, while the leading edge of the transmitted pulse continues toward the far target. In part C, $^1/_2$ microsecond later, the transmitted pulse is just striking the far target; the echo from the near target has traveled 164 yards back toward the antenna. The reflection process at the near target is only half completed. In part D echoes are traveling back toward the antenna from both targets. In part E reflection is completed at the near target. At this time the leading edge of the echo from the far target coincides with the trailing edge of the first echo. When the echoes reach the antenna, energy is delivered to the set during a period of 2 microseconds so that a single pip appears on the PPI.

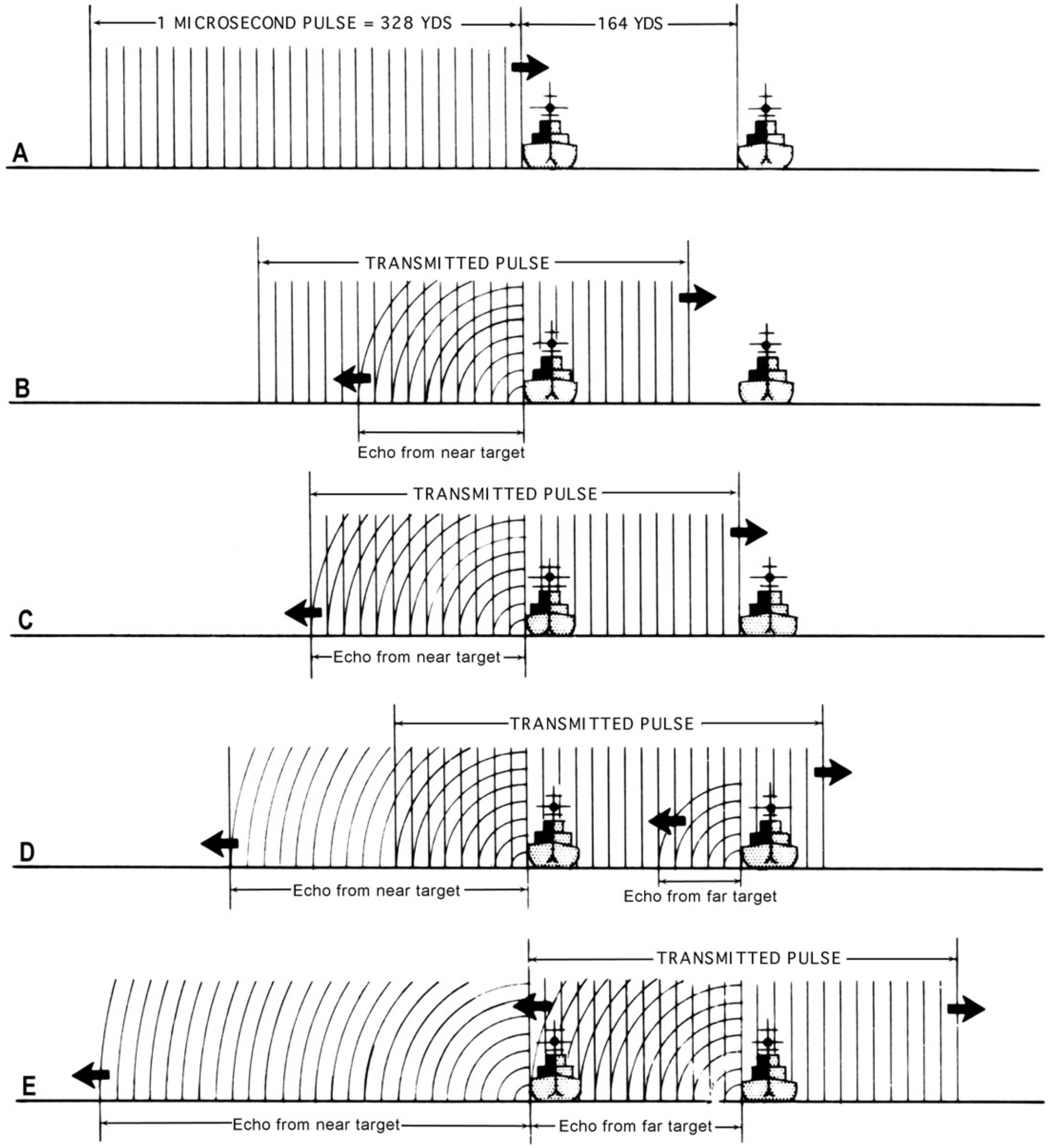


Figure 1.19 - Pulse length and range resolution.

The data below indicates the minimum separation in range for two targets to appear as separate echoes on the PPI for various pulse lengths.

Pulse Length (microseconds)	Range Resolution (yards)
0.05	8
0.10	16
0.20	33
0.25	41
0.5	82
1.2	197

Receiver Gain

Range resolution can be improved by proper adjustment of the receiver gain control. As illustrated in figure 1.20, the echoes from two targets on the same bearing may appear as a single pip on the PPI if the receiver gain setting is too high. With reduction in the receiver gain setting, the echoes may appear as separate pips on the PPI.

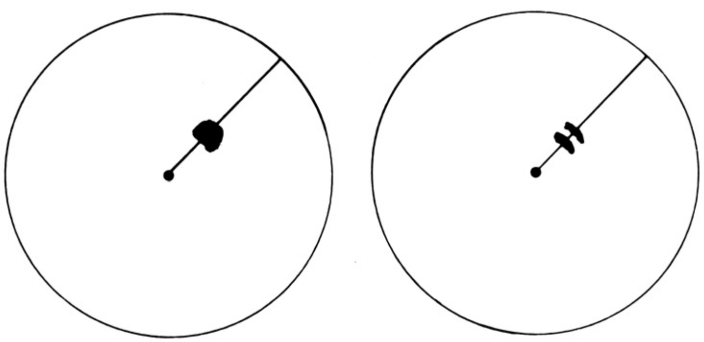


Figure 1.20 - Receiver gain and range resolution.

CRT Spot Size

The range separation required for resolution is increased because the spot formed by the electron beam on the screen of the CRT cannot be focused into a point of light. The increase in echo image (pip) length and width varies with the size of the CRT and the range scale in use.

CRT Diameter (Inches)		Range Scale (nautical mi.)	Spot Length or Width (yards)
Nominal	Effective		
9	7.5	0.5	5
		24	220
12	10.5	0.5	4
		24	185
16	14.4	0.5	3
		24	134

On the longer range scales, the increase in echo size because of spot size is appreciable.

Range Scale

The pips of two targets separated by a few hundred yards may merge on the PPI when one of the longer range scales is used. The use of the shortest range scale possible and proper adjustment of the receiver gain may enable their detection as separate targets. If the display can be off-centered, this may permit display of the targets on a shorter range scale than would be possible otherwise.

FACTORS AFFECTING BEARING ACCURACY

Horizontal Beam Width

Bearing measurements can be made more accurately with the narrower horizontal beam widths. The narrower beam widths afford better definition of the target and, thus, more accurate identification of the center of the target. Several targets close together may return echoes which produce pips on the PPI which merge, thus preventing accurate determination of the bearing of a single target within the group.

The effective beam width can be reduced through lowering the receiver gain setting. In reducing the sensitivity of the receiver, the maximum detection range is reduced, but the narrower effective beam width provides better bearing accuracy.

Target Size

For a specific beam width, bearing measurements of small targets are more accurate than large targets because the centers of the smaller pips of the small targets can be identified more accurately.

Target Rate of Movement

The bearings of stationary or slowly moving targets can be measured more accurately than the bearings of faster moving targets.

Stabilization of Display

Stabilized PPI displays provide higher bearing accuracies than unstabilized displays because they are not affected by yawing of the ship.

Sweep Centering Error

If the origin of the sweep is not accurately centered on the PPI, bearing measurements will be in error. Greater bearing errors are incurred when the pip is near the center of the PPI than when the pip is near the edge of the PPI. Since there is normally some centering error, more accurate bearing measurements can be made by changing the range scale to shift the pip position away from the center of the PPI.

Parallax Error

Improper use of the mechanical bearing cursor will introduce bearing errors. On setting the cursor to bisect the pip, the cursor should be viewed from a position directly in front of it. Electronic bearing cursors used with some stabilized displays provide more accurate bearing measurements than mechanical bearing cursors because measurements made with the electronic cursor are not affected by parallax or centering errors.

Heading Flash Alignment

For accurate bearing measurements, the alignment of the heading flash with the PPI display must be such that radar bearings are in close agreement with relatively accurate visual bearings observed from near the radar antenna.

FACTORS AFFECTING BEARING RESOLUTION

Bearing resolution is a measure of the capability of a radar to display as separate pips the echoes received from two targets which are at the same range and are close together.

The principal factors that affect the bearing resolution of a radar are horizontal beam width, the range to the targets, and CRT spot size.

Horizontal Beam Width

As the radar beam is rotated, the painting of a pip on the PPI begins as soon as the leading edge of the radar beam strikes the target. The painting of the pip is continued until the trailing edge of the beam is rotated beyond the target. Therefore, the pip is distorted angularly by an amount equal to the effective horizontal beam width.

As illustrated in figure 1.21, in which a horizontal beam width of 10˚ is used for graphical clarity only, the actual bearing of a small target having good reflecting properties is 090˚, but the pip as painted on the PPI extends from 095˚ to 085˚. The left 5˚ and the right 5˚ are painted while the antenna is not pointed directly towards the target. The bearing must be read at the center of the pip.

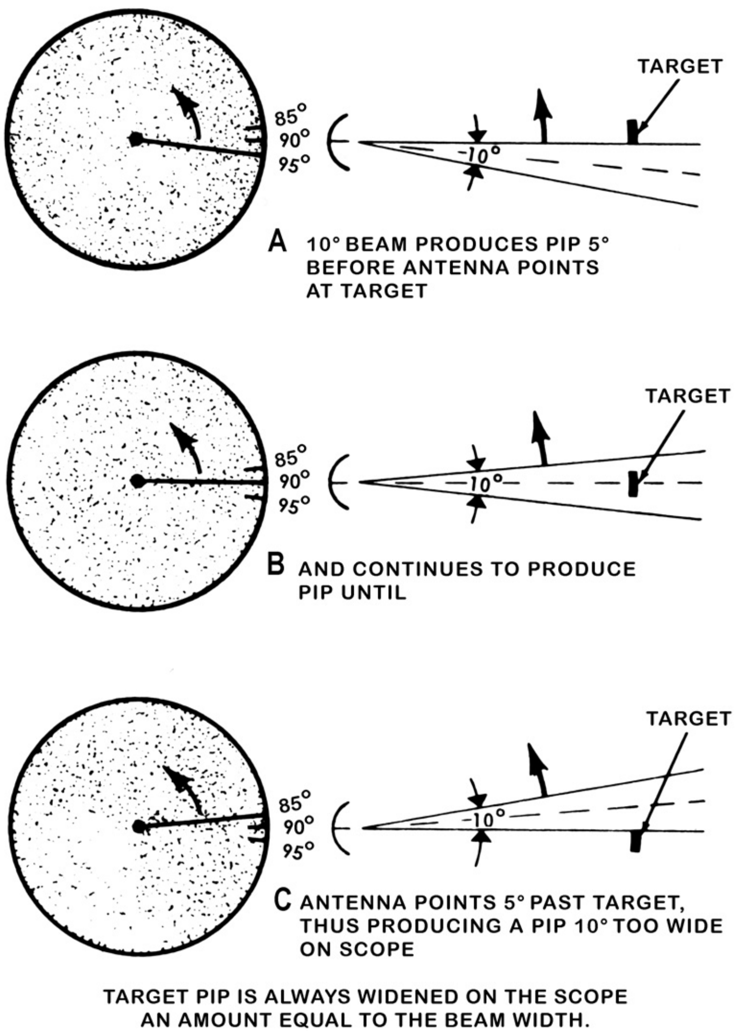


Figure 1.21 - Angular distortion.

Range of Targets

Assuming a more representative horizontal beam width of 2˚, the pip of a ship 400 feet long observed beam on at a distance of 10 nautical miles on a bearing of 090˚ would be painted on the PPI between 091.2˚ and 088.8˚, the actual angular width of the target being 0.4˚. The pip of a ship 900 feet long observed beam on at the same distance and bearing would be painted on the PPI between 091.4˚ and 088.6˚, the angular width of the target being 0.8˚. Since the angular widths of the pips painted for the 400 and 900-foot targets are 1.4˚ and 1.8˚, respectively, any attempt to estimate target size by the angular width of the pip is not practical, generally.

Since the pip of a single target as painted on the PPI is elongated angularly an amount equal to beam width, two targets at the same range must be separated by more than one beam width to appear as separate pips. The required distance separation depends upon range. Assuming a 2˚ beam width, targets at 10 miles must be separated by over 0.35 nautical miles or 700 yards to appear as separate pips on the PPI. At 5 miles the targets must be separated by over 350 yards to appear as separate pips if the beam width is 2˚.

Figure 1.22 illustrates a case in which echoes are being received from four targets, but only three pips are painted on the PPI. Targets A and B are painted as a single pip because they are not separated by more than one beam width; targets C and D are painted as separate pips because they are separated by more than one beam width.

In as much as bearing resolution is determined primarily by horizontal beam width, a radar with a narrow horizontal beam width provides better bearing resolution than one with a wide beam.

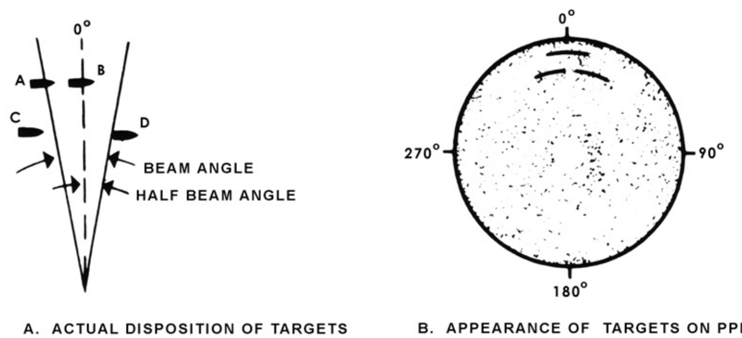


Figure 1.22 - Bearing resolution.

CRT Spot Size

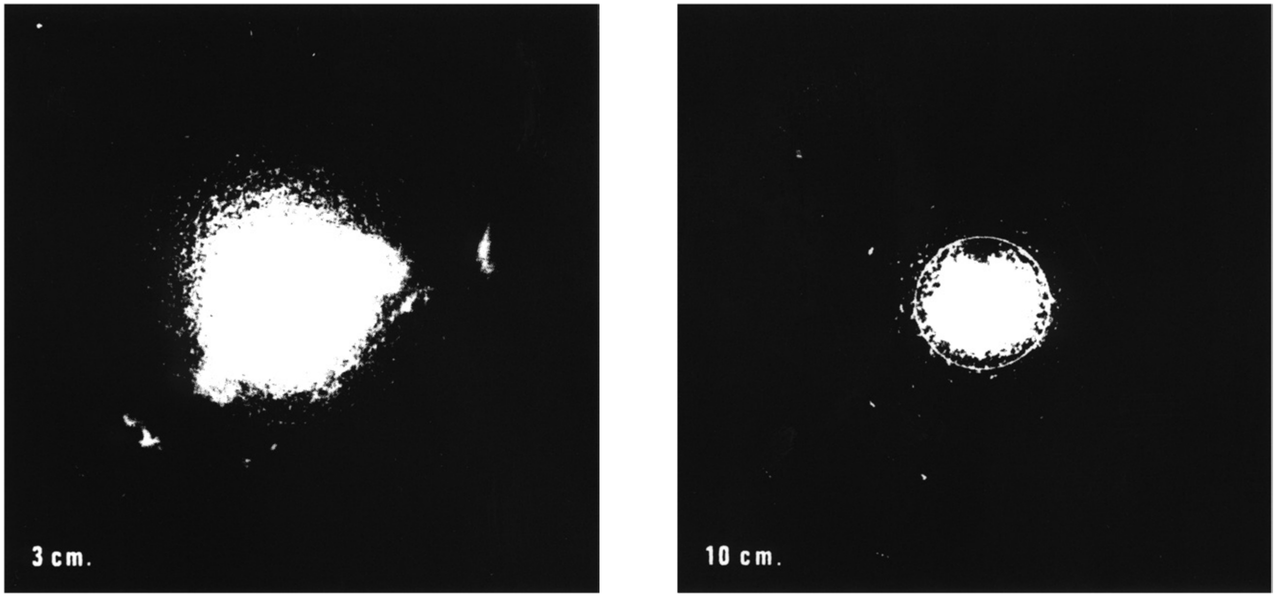
The bearing separation required for resolution is increased because the spot formed by the electron beam on the screen of the CRT cannot be focused into a point of light. The increase in the pip width because of CRT spot size varies with the size of the CRT and the range scale in use.

WAVELENGTH

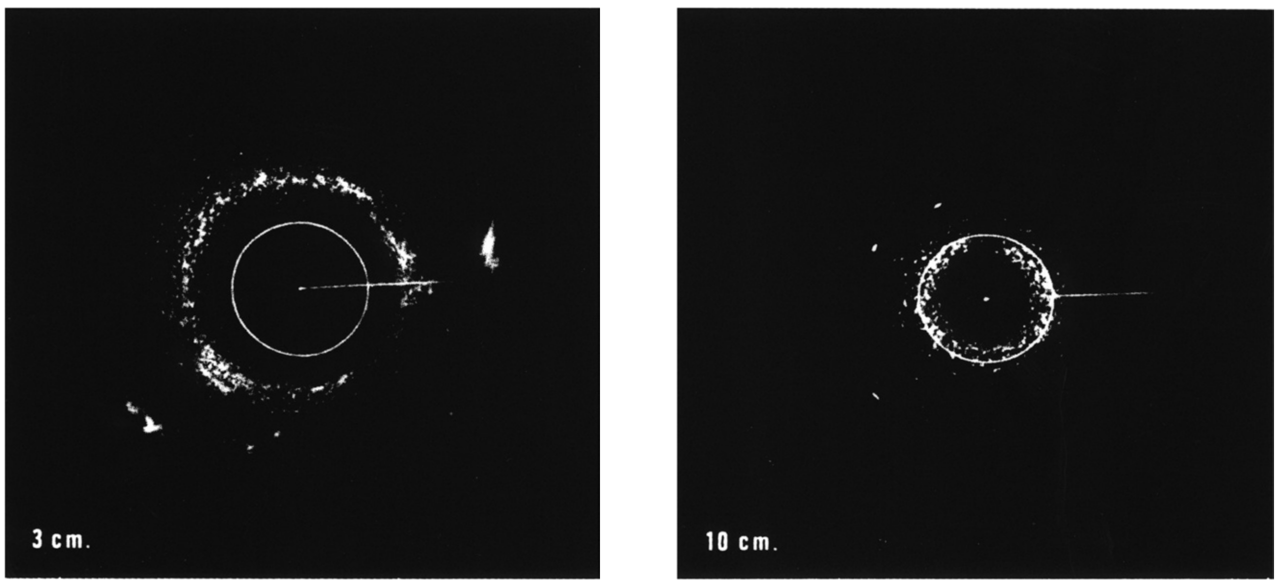
Generally, radars transmitting at the shorter wavelengths are more subject to the effects of weather than radars transmitting at the longer wavelengths.

Figure 1.23 illustrates the PPI displays of two radars of different wavelengths aboard a ship steaming in a rain squall and a choppy sea. Without use of anti-rain and anti-sea clutter controls, the clutter is more massive on the PPI of the radar having the shorter wavelength. Also, three targets, which can be detected on the PPI of the radar having the longer wavelength, cannot be detected on the PPI of the radar having the shorter wavelength. Following use of the anti-rain and anti-sea clutter controls, the three targets still cannot be detected on the PPI of the radar having the shorter wavelength because too much of the energy has been absorbed or attenuated by the rain.

Similarly, figure 1.24 illustrates detection of close targets by a radar having a relatively long wavelength and no detection of these targets by a radar having a relatively short wavelength.



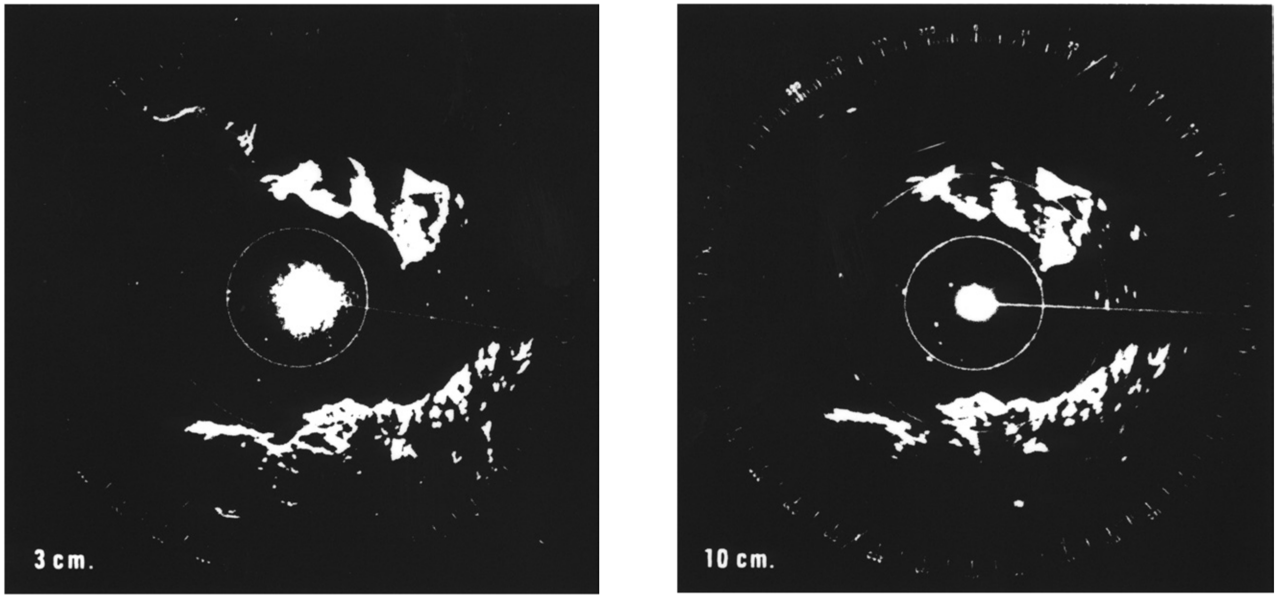
Two identical 8 mile range PPI pictures taken on Raytheon 3 cm. and 10 cm. radars in a rain squall and with a choppy sea. Three ships bearing 225°, 294° and 330° shown on the 10 cm. radar right are not shown on the 3 cm. radar left.



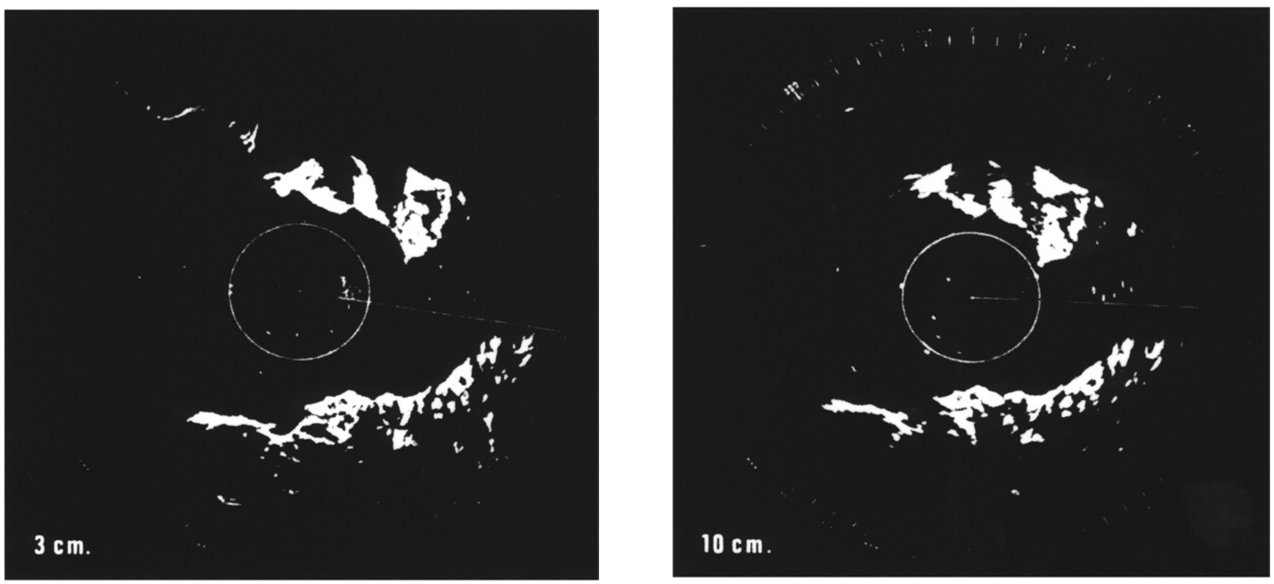
On both radars the anti-rain and anti-sea clutter devices are switched in. The three ships are clearly visible on the 10 cm. radar right. There are no targets visible on the 3 cm. radar left as the echo power has been absorbed by rain.

Reproduced by Courtesy of the Raytheon Company.

Figure 1.23- Effects of rain and sea on PPI displays of radars having different wavelengths.



Two identical 20 mile range PPI pictures taken on Raytheon 3 cm. and 10 cm. radars showing the effects of sea clutter. On the 10 cm. radar right targets inside the 5 mile range marker are clearly visible. On the 3 cm. radar left the close range targets are missing.



On both radars the anti-sea clutter control has been carefully adjusted to remove sea clutter. The close range targets are clearly visible on the 10 cm. right, whereas they are missing on the 3 cm. radar left.

Reproduced by Courtesy of the Raytheon Company.

Figure 1.24 - Effects of sea on PPI displays of radars having different wavelengths.

TARGET CHARACTERISTICS

There are several target characteristics which will enable one target to be detected at a greater range than another, or for one target to produce a stronger echo than another target of similar size.

Height

Since radar wave propagation is almost line of sight, the height of the target is of prime importance. If the target does not rise above the radar horizon, the radar beam cannot be reflected from the target. Because of the interference pattern, the target must rise somewhat above the radar horizon.

Size

Up to certain limits, targets having larger reflecting areas will return stronger echoes than targets having smaller reflecting areas. Should a target be wider than the horizontal beam width, the strength of the echoes will not be increased on account of the greater width of the target because the area not exposed to the radar beam at any instant cannot, of course, reflect an echo. Since the vertical dimensions of most targets are small compared to the vertical beam width of marine navigational radars, the beam width limitation is not normally applicable to the vertical dimensions. However, there is a vertical dimension limitation in the case of sloping surfaces or stepped surfaces. In this case, only the projected vertical area lying within the distance equivalent of the pulse length can return echoes at any instant.

Aspect

The aspect of a target is its orientation to the axis of the radar beam. With change in aspect, the effective reflecting area may change, depending upon the shape of the target. The nearer the angle between the reflecting area and the beam axis is to 90˚, the greater is the strength of the echo returned to the antenna.

Shape

Targets of identical shape may give echoes of varying strength, depending on aspect. Thus a flat surface at right angles to the radar beam, such as the side of a steel ship or a steep cliff along the shore, will reflect very strong echoes. As the aspect changes, this flat surface will tend to reflect more of the energy of the beam away from the antenna, and may give rather weak echoes. A concave surface will tend to focus the radar beam back to the antenna while a convex surface will tend to scatter the energy. A smooth conical surface will not reflect energy back to the antenna. However, echoes may be reflected to the antenna if the conical surface is rough.

Texture

The texture of the target may modify the effects of shape and aspect. A smooth texture tends to increase the reflection qualities, and will increase the strength of the reflection, but unless the aspect and shape of the target are such that the reflection is focused directly back to the antenna, the smooth surface will give a poor radar echo because most of the energy is reflected in another direction. On the other hand, a rough surface will tend to break up the reflection, and will improve the strength of echoes returned from those targets whose shape and aspect normally give weak echoes.

Composition

The ability of various substances to reflect radar pulses depends on the intrinsic electrical properties of those substances. Thus metal and water are good reflectors. Ice is a fair reflector, depending on aspect. Land areas vary in their reflection qualities depending on the amount and type of vegetation and the rock and mineral content. Wood and fiber glass boats are poor reflectors. It must be remembered that all of the characteristics interact with each other to determine the strength of the radar echo, and no factor can be singled out without considering the effects of the others.

CHAPTER 2 — RADAR OPERATION

RELATIVE AND TRUE MOTION DISPLAYS

GENERAL

There are two basic displays used to portray target position and motion on the PPI's of navigational radars. The relative motion display portrays the motion of a target relative to the motion of the observing ship. The true motion display portrays the actual or true motions of the target and the observing ship.

Depending upon the type of PPI display used, navigational radars are classified as either relative motion or true motion radars. However, true motion radars can be operated with a relative motion display. In fact, radars classified as true motion radars must be operated in their relative motion mode at the longer range scale settings. Some radars classified as relative motion radars are fitted with special adapters enabling operation with a true motion display. These radars do not have certain features normally associated with true motion radars, such as high persistence CRT screens.

RELATIVE MOTION RADAR

Through continuous display of target pips at their measured ranges and bearings from a fixed position of own ship on the PPI, relative motion radar displays the motion of a target relative to the motion of the observing (own) ship. With own ship and the target in motion, the successive pips of the target do not indicate the actual or true movement of the target. A graphical solution is required in order to determine the rate and direction of the actual movement of the target.

If own ship is in motion, the pips of fixed objects, such as landmasses, move on the PPI at a rate equal to and in a direction opposite to the motion of own ship. If own ship is stopped or motionless, target pips move on the PPI in accordance with their true motion.

Orientations of Relative Motion Display

There are two basic orientations used for the display of relative motion on PPI's. In the HEADING-UPWARD display, the target pips are painted at their measured distances in direction *relative* to own ship's heading. In the NORTH-UPWARD display, target pips are painted at their measured distances in true directions from own ship, north being upward or at the top of the PPI.

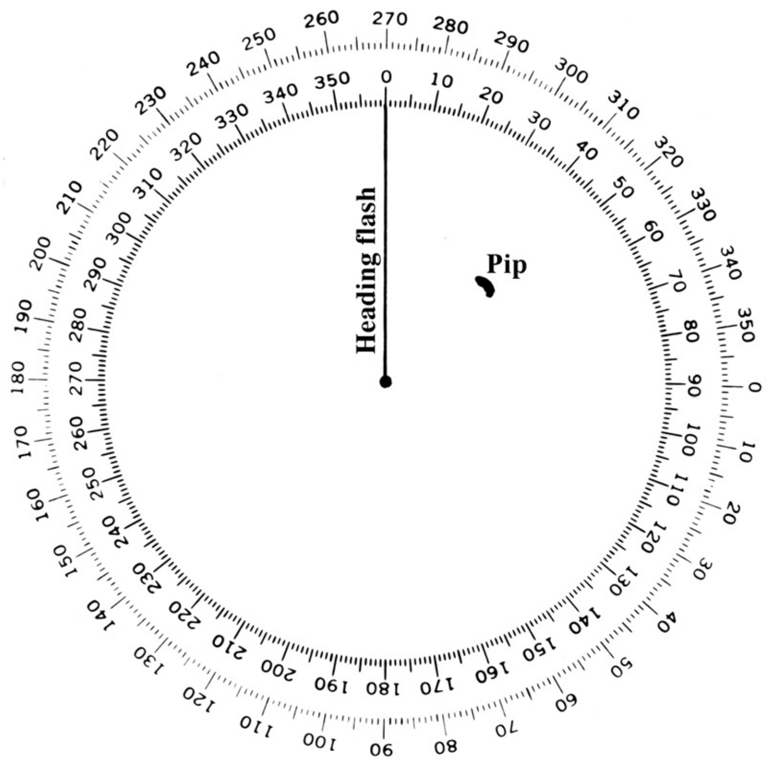


Figure 2.1 - Unstabilized Heading-Upward display.

In figure 2.1 own ship on a heading of 270˚ detects a target bearing 315˚ true. The target pip is painted 045˚ relative to ship's heading on this Heading-Upward display. In figure 2.2 the same target is painted at 315˚ true on a North-Upward display. While the target pip is painted 045˚ relative to the heading flash on each display, the Heading-Upward display provides a more immediate indication as to whether the target lies to port or starboard.

Stabilization

The North-Upward display in which the orientation of the display is fixed to an unchanging reference (north) is called a STABILIZED display. The Heading-Upward display in which the orientation changes with changes in own ship's heading is called an UNSTABILIZED display. Some radar indicator designs have displays which are both stabilized and Heading-Upward. In these displays, the cathode-ray tubes must be rotated as own ship changes heading in order to maintain ship's heading upward or at the top of the PPI.

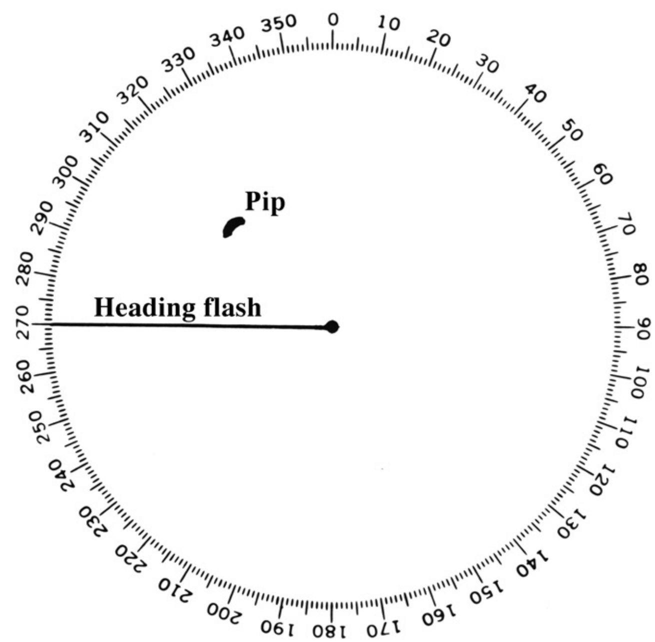


Figure 2.2 - Stabilized North-Upward display.

TRUE MOTION RADAR

True motion radar displays own ship and moving objects in their true motion. Unlike relative motion radar, own ship's position is not fixed on the PPI. Own ship and other moving objects move on the PPI in accordance with their true courses and speeds. Also unlike relative motion radar, fixed objects such as landmasses are stationary, or nearly so, on the PPI. Thus, one observes own ship and other ships moving with respect to landmasses.

True motion is displayed on modern indicators through the use of a microprocessor computing target true motion rather than depending on an extremely long persistence phosphor to leave "trails".

Stabilization

Usually, the true motion radar display is stabilized with North-Upward. With this stabilization, the display is similar to a plot on the navigational chart. On some models the display orientation is Heading-Upward. Because the true motion display must be stabilized to an unchanging reference, the cathode-ray tube must be rotated to place the heading at the top or upward.

Radarscope Persistence and Echo Trails

High persistence radarscopes are used to obtain maximum benefit from the true motion display. As the radar images of the targets are painted successively by the rotating sweep on the high persistence scope, the images continue to glow for a relatively longer period than the images on other scopes of lesser persistence. Depending upon the rates of movement, range scale, and degree of persistence, this afterglow may leave a visible echo trail or tail indicating the true motion of each target. If the afterglow of the moving sweep origin leaves a visible trail indicating the true motion of own ship, estimates of the true speeds of the radar targets can be made by comparing the lengths of their echo trails or tails with that of own ship. Because of the requirement for resetting own ship's position on the PPI, there is a practical limit to the degree of persistence (see figure 2.3).

Reset Requirements and Methods

Because own ship travels across the PPI, the position of own ship must be reset periodically. Depending upon design, own ship's position may be reset manually, automatically, or by manually overriding any automatic method. Usually, the design includes a signal (buzzer or indicator light) to warn the observer when resetting is required.

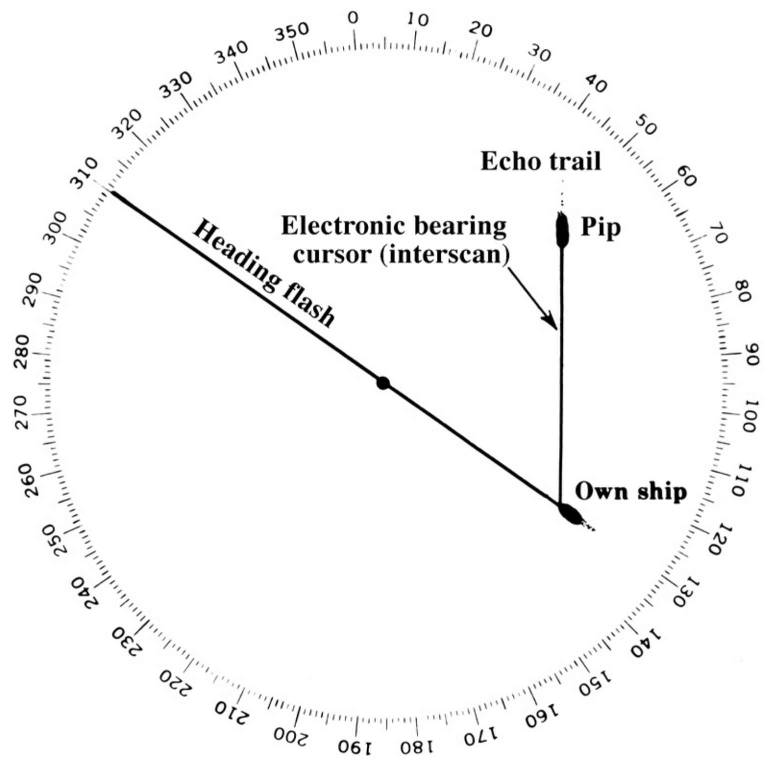


Figure 2.3 - True motion display.

A design may include North-South and East-West reset controls to enable the observer to place own ship's position at the most suitable place on the PPI. Other designs may be more limited as to where own ship's position can be reset on the PPI, being limited to a point from which the heading flash passes through the center of the PPI.

The radar observer must be alert with respect to reset requirements. To avoid either a manual or automatic reset at the most inopportune time, the radar observer should include in his evaluation of the situation a determination of the best time to reset own ship's position.

Range setting examples for Radiomarine true motion radar sets having double stabilization are as follows:

Type CRM-NID-75 (3.2cm) and Type CRM-N2D-30 (10cm)

True motion range settings 1, 2, 6, and 16 miles	Relative motion range settings $^1/_2$, 1, 2, 6, 16, and 40 miles

Maximum viewing times between automatic resets in the true motion mode are as follows:

Speed (knots)	Range setting (miles)	Initial view ahead (miles)	Viewing time (minutes)
20	16	26	66
12	6	9.75	41
8	2	3.25	24
8	1	1.6	16

The viewing time ahead can be extended by manually overriding the automatic reset feature.

Modes of Operation

True motion radars can be operated with either true motion or relative motion displays, with true motion operation being limited to the short and intermediate range settings.

In the relative motion mode, the sweep origin can be off-centered to extend the view ahead. With the view ahead extended, requirements for changing the range scale are reduced. Also, the off-center position of the fixed sweep origin can permit observation of a radar target on a shorter range scale than would be the case with the sweep origin fixed at the center of the PPI.

Through use of the shorter range scale, the relative motion of the radar target is more clearly indicated.

Types of True Motion Display

While fixed objects such as landmasses are stationary, or nearly so, on true motion displays, fixed objects will be stationary on the PPI only if there is no current or if the set and drift are compensated for by controls for this purpose. Dependent upon set design, current compensation may be effected through set and drift controls or by speed and course-made-good controls.

When using true motion radar primarily for collision avoidance purposes, the *sea-stabilized* display is preferred generally. The latter type of display differs from the *ground-stabilized* display only in that there is no compensation for current. Assuming that own ship and a radar contact are affected by the same current, the sea-stabilized display indicates true courses and speeds through the water. If own ship has leeway or is being affected by current, the echoes of stationary objects will move on the sea-stabilized display. Small echo trails will be formed in a direction opposite to the leeway or set. If the echo from a small rock appears to move due north at 2 knots, then the ship is being set due south at 2 knots. The usable afterglow of the CRT screen, which lasts from about $1^1/_2$ to 3 minutes, determines the minimum rate of movement which can be detected on the display. The minimum rate of movement has been found to be about $1^1/_2$ knots on the 6-mile range scale and proportional on other scales.

The *ground-stabilized* display provides the means for stopping the small movements of the echoes from stationary objects. This display may be used to obtain a clearer PPI presentation or to determine leeway or the effects of current on own ship.

In the *ground-stabilized* display own ship moves on the display in accordance with its course and speed over the ground. Thus, the movements of target echoes on the display indicate the true courses and speeds of the targets over the ground. Ground-stabilization is effected as follows:

(1) The speed control is adjusted to eliminate any movements of the echoes from stationary targets dead ahead or dead astern. If the echoes from stationary targets dead ahead are moving towards own ship, the speed setting is increased; otherwise the speed setting is decreased.

(2) The course-made-good control is adjusted to eliminate any remaining movement at right angles to own ship's heading. The course-made-good control should be adjusted in a direction counter to the echo movement.

Therefore, by trial and error procedures, the display can be ground-stabilized rapidly. However, the display should be considered only as an approximation of the course and speed made good over the ground. Among other factors, the accuracy of the ground-stabilization is dependent upon the minimum amount of movement which can be detected on the display. Small errors in speed and compass course inputs and other effects associated with any radar set may cause small false movements to appear on the true motion display. The information displayed should be interpreted with due regard to these factors. During a turn when compass errors will be greater and when speed estimation is more difficult, the radar observer should recognize that the accuracy of the ground stabilization may be degraded appreciably.

The varying effects of current, wind, and other factors make it unlikely that the display will remain ground stabilized for long periods. Consequently, the display must be readjusted periodically. Such readjustments should be carried out only when they do not detract from the primary duties of the radar observer.

While in rivers or estuaries, the only detectable movement may be the movement along own ship's heading. The movements of echoes of stationary objects at right angles to own ship's heading are usually small in these circumstances. Thus, in rivers and estuaries adjustment of the speed control is the only adjustment normally required to obtain ground stabilization of reasonable accuracy in these confined waters.

THE REFLECTION PLOTTER

The reflection plotter is a radarscope attachment which enables plotting of position and motion of radar targets with greater facility and accuracy by reduction of the effect of parallax (apparent displacement of an object due to observer's position). The reflection plotter is designed so that any mark made on its plotting surface is reflected to a point directly below on the PPI. Hence, to plot the instantaneous position of a target, it is only necessary to make a grease pencil mark so that its image reflected onto the PPI just touches the inside edge of the pip.

The plotter should not be marked when the display is viewed at a very low angle. Preferably, the observer's eye position should be directly over the center of the PPI.

Basic Reflection Plotter Designs

The reflection plotter on a majority of marine radar systems currently offered use a flat plotting surface.

The reflection plotters illustrated in figures 2.4 and 2.5 are designs that were previously used aboard many navy and merchant ships and may still be in use. The curvature of the plotting surface as illustrated in figure 2.4 matches, but is opposite to the curvature of the screen of the cathode-ray tube, i.e., the plotting surface is concave to the observer. A semi-reflecting mirror is installed halfway between the PPI and plotting surface. The plotting surface is edge-lighted. Without this lighting the reflections of the grease pencil marks do not appear on the PPI.

Marking the Reflection Plotter

The modern flat plotting surface uses a mirror which makes the mark appear on, not above, the surface of the oscilloscope as depicted in figure 2.5.

In marking the older flat plotter shown in figure 2.5, the grease pencil is placed over the pip and the point is pressed against the plotting surface with sufficient pressure that the reflected image of the grease pencil point is seen on the PPI below. The point of the pencil is adjusted to find the more precise position for the mark or plot (at the center and leading edge of the radar pip). With the more precise position for the plot so found, the grease pencil point is pressed harder against the plotting surface to leave a plot in the form of a small dot.

In marking the plotting surface of the concave glass plotters, the point of the grease pencil is offset from the position of the pip. Noting the position of the reflection of the grease pencil point on the PPI, a line is drawn rapidly through the middle of the leading edge of the radar pip. A second such line is drawn rapidly to form an "X", which is the plotted position of the radar target. Some skill is required to form the intersection at the desired point.

Cleanliness

The plotting surface of the reflection plotter should be cleaned frequently and judiciously to insure that previous markings do not obscure new radar targets, which could appear undetected by the observer otherwise. A cleaning agent which does not leave a film residue should be used. Any oily film which is left by an undesirable cleaning agent or by the smear of incompletely wiped grease pencil markings makes the plotting surface difficult to mark. A weak solution of ammonia and water is an effective cleaning agent. During plotting, a clean, soft rag should be used to wipe the plotting surface.

PLOTTING ON STABILIZED AND UNSTABILIZED DISPLAYS

Stabilized North-Upward Display

Assuming the normal condition in which the start of the sweep is at the center of the PPI, the pips of radar targets are painted on the PPI at their true bearings at distances from the PPI center corresponding to target ranges. Because of the persistence of the PPI and the normally continuous rotation of the radar beam, the pips of targets having reasonably good reflecting properties appear continuously on the PPI. As targets move relative to the motion of own ship, the pips, as painted successively, move in the direction of this motion. With lapse of time, the pips painted earlier fade from the PPI. Thus, it is necessary to record the positions of the pips through plotting to permit analysis of this radar data. Failure to plot the successive positions of the pips is conducive to the much publicized RADAR ASSISTED COLLISION.

Through periodically marking the positions of the pips, either on the glass plate (implosion cover) over the CRT screen or the reflection plotter mounted thereon, a visual indication of the past and present positions of the targets is made available for the required analysis. This analysis is aided by the HEADING FLASH (HEADING MARKER) which is a luminous line of the PPI indicating ship's heading.

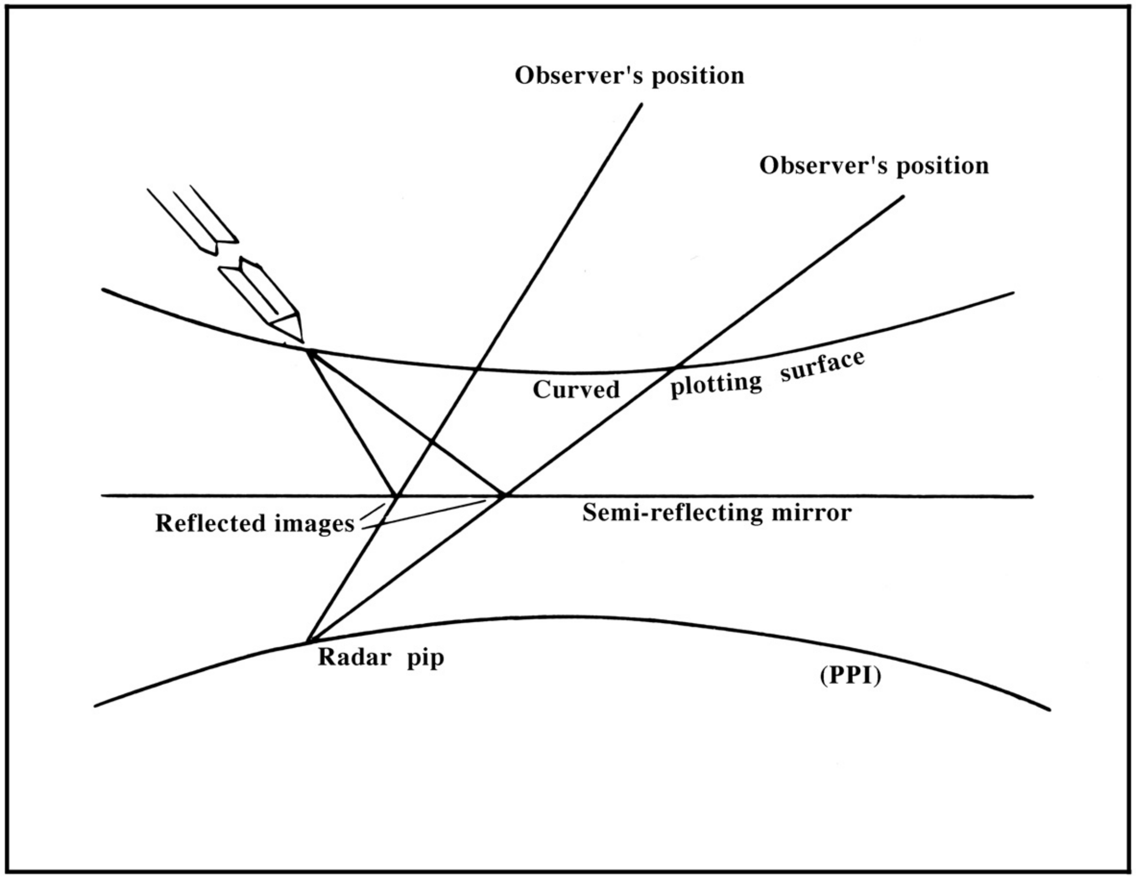


Figure 2.4 - Reflection plotter having curved plotting surface.

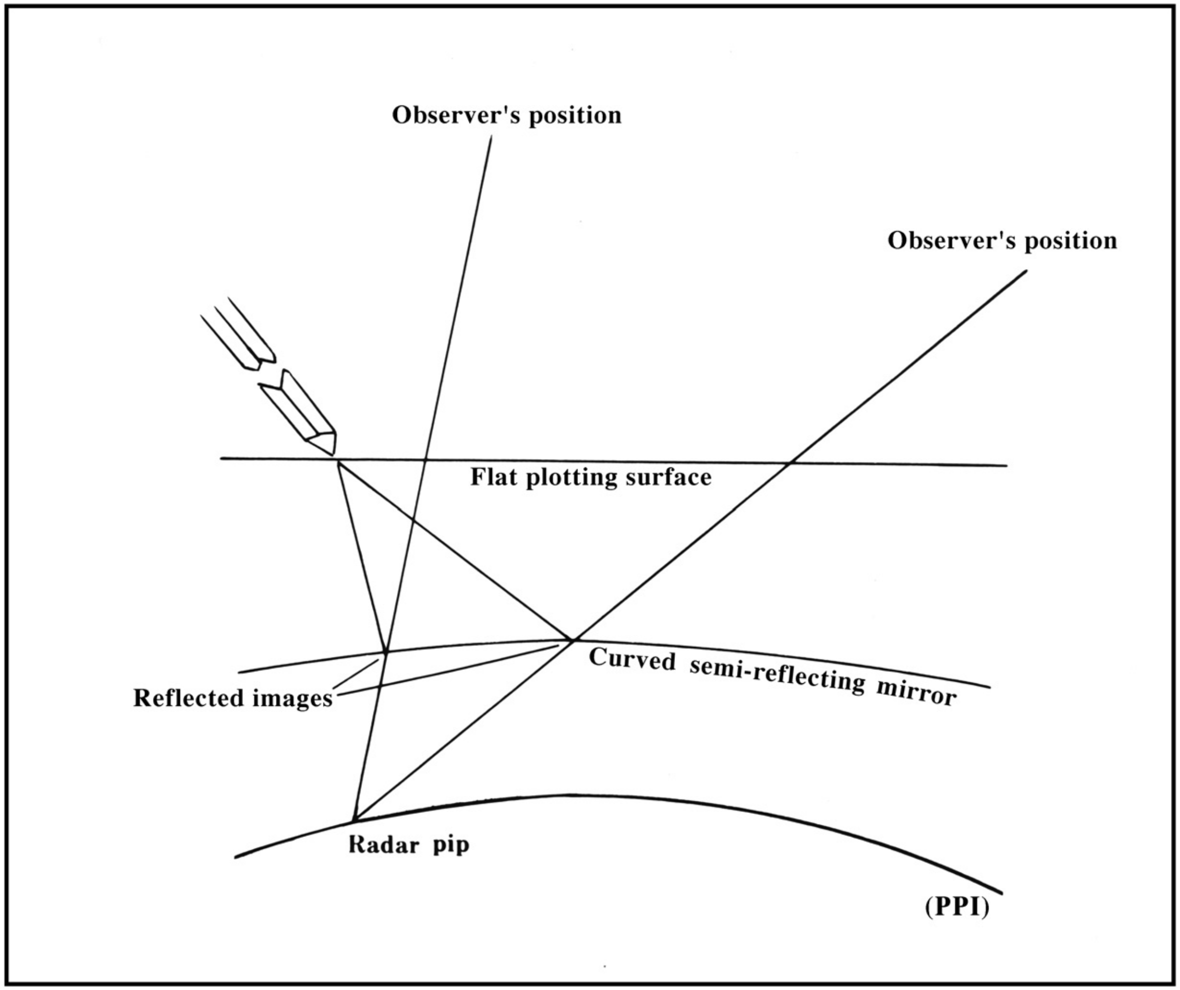


Figure 2.5 - Reflection plotter having flat plotting surface.

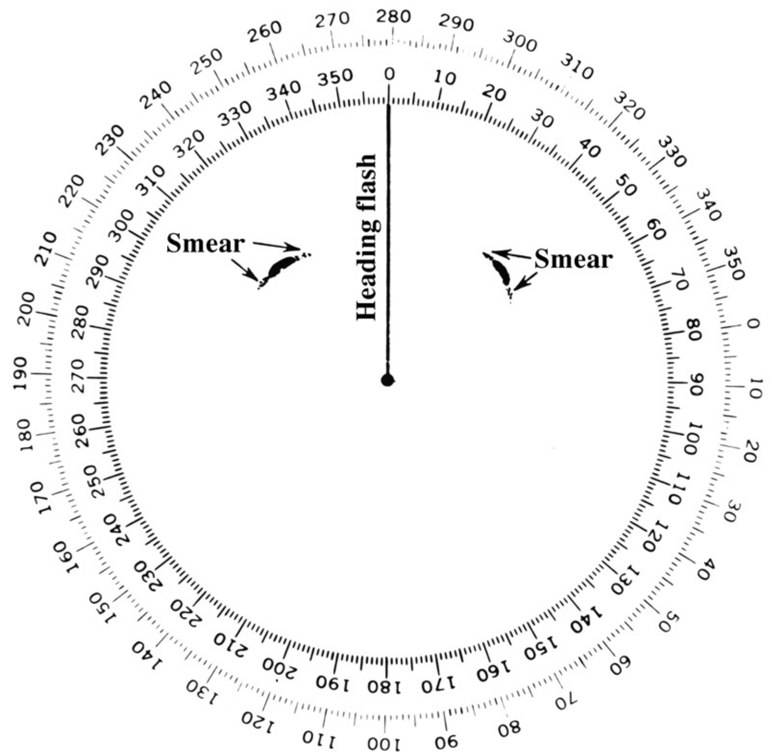


Figure 2.6 - Effect of yawing on unstabilized display.

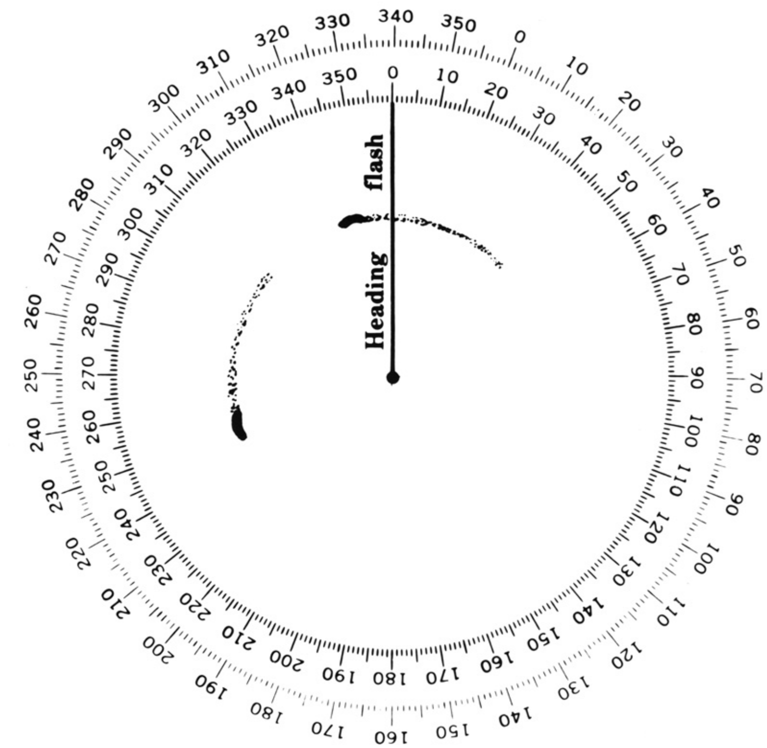


Figure 2.7 - Effect of course change on unstabilized display.

Unstabilized Heading-Upward Display

Plotting on the unstabilized Heading-Upward display is similar to plotting on the stabilized North-Upward display. Since the pips are painted at bearings relative to the heading of the observer's ship, a complication arises when the heading of the observer's ship is changed. If a continuous grease pencil plot is to be maintained on the unstabilized Heading-Upward relative motion display following course changes by the observer's ship, the plotting surface of the reflection plotter must be rotated the same number of degrees as the course or heading change in a direction opposite to this change. Otherwise, the portion of the plot made following the course change will not be continuous with the previous portion of the plot. Also the unstabilized display is affected by any yawing of the observer's ship. Plots made while the ship is off the desired heading will result in an erratic plot or a plot of lesser accuracy than would be afforded by a stabilized display. Under severe yawing conditions, plotting on the unstabilized display must be coordinated with the instants that the ship is on course if any reasonable accuracy of the plot is to be obtained.

Because of the persistence of the CRT screen and the illumination of the pips at their instantaneous relative bearings, as the observer's ship yaws or its course is changed the target pips on the PPI will smear.

Figure 2.6 illustrates an unstabilized Heading-Upward relative motion display for a situation in which a ship's course and present heading are 280˚, as indicated by the heading flash. The ship is yawing about a heading of 280˚. In this case there is slight smearing of the target pips. If the ship's course is changed to the right to 340˚ as illustrated in figure 2.7, the target pips smear to the left through 60˚, i.e., an amount equal and in a direction opposite to the course change. Thus, to maintain a continuous grease pencil plot on the reflection plotter it is necessary that the plotting surface of this plotter be rotated in a direction opposite to and equal to the course change.

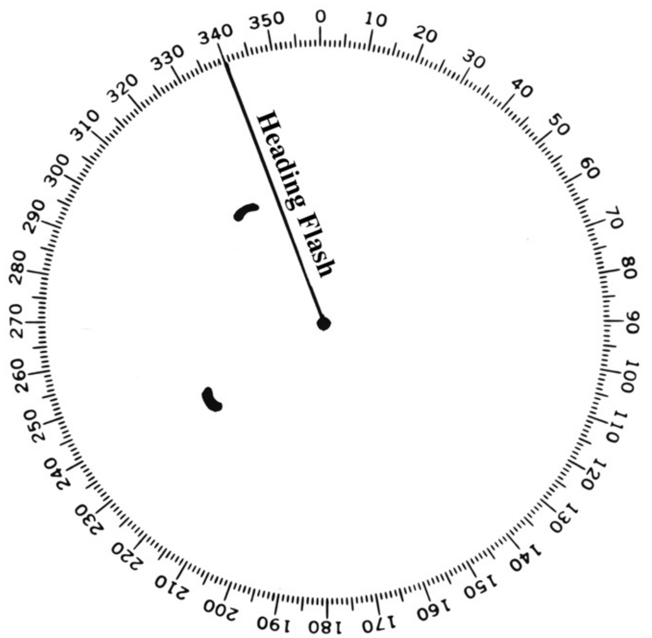


Figure 2.8 - Stabilized display following course change.

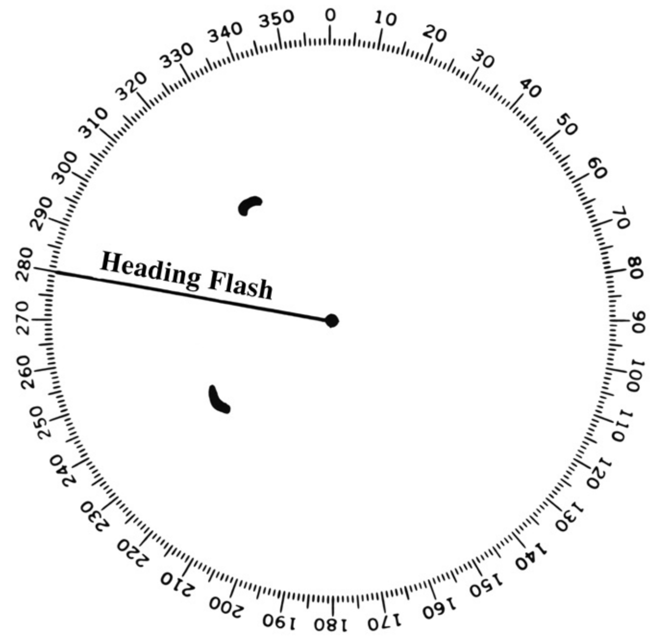


Figure 2.9 - Stabilized display preceding course change.

Figures 2.8 and 2.9 illustrate the same situation appearing on a stabilized North-Upward display. There is no pip smearing because of yawing. There is no shifting in the positions of the target pips because of the course change. Any changes in the position of the target pips are due solely to changes in the true bearings and distances to the targets during the course change. The plot during and following the course change is continuous with the plot preceding the course change. Thus, there is no need to rotate the plotting surface of the reflection plotter when the display is stabilized.

RANGE AND BEARING MEASUREMENT

Mechanical Bearing Cursor

The mechanical bearing cursor is a radial line or cross hair inscribed on a transparent disk which can be rotated manually about its axis coincident with the center of the PPI. This cursor is used for bearing determination. Frequently, the disk is inscribed with a series of lines parallel to the line inscribed through the center of the disk, in which case the bearing cursor is known as a PARALLEL-LINE CURSOR or PARALLEL INDEX (see figure 2.10.) To avoid parallax when reading the bearing, the lines are inscribed on each side of the disk.

When the sweep origin is at the center of the PPI, the usual case for relative motion displays, the bearing of a small, well defined target pip is determined by placing the radial line or one of the radial lines of the cross hair over the center of the pip. The true or relative bearing of the pip can be read from the respective bearing dial.

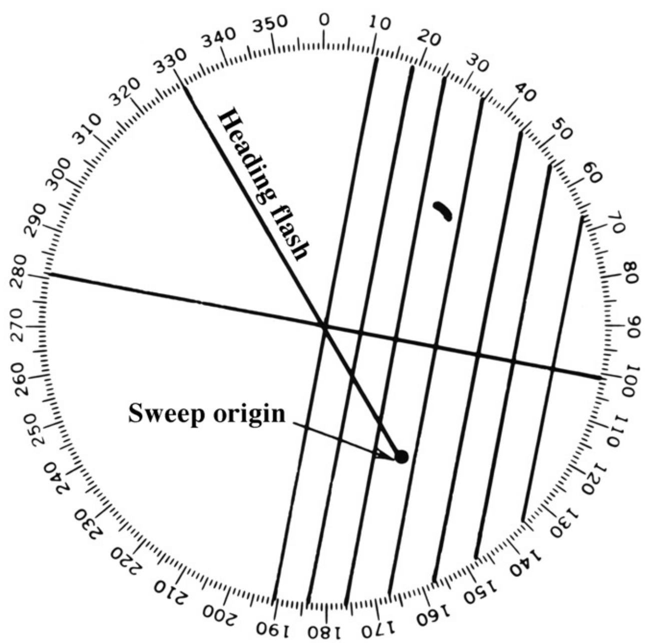


Figure 2.10 - Measuring bearing with parallel-line cursor.

Variable Range Marker (Range Strobe)

The variable range marker (VRM) is used primarily to determine the ranges to target pips on the PPI. Among its secondary uses is that of providing a visual indication of a limiting range about the position of the observer's ship, within which targets should not enter for reasons of safety.

The VRM is actually a small rotating luminous spot. The distance of the spot from the sweep origin corresponds to range; in effect, it is a variable range ring.

The distance to a target pip is measured by adjusting the circle described by the VRM so that it just touches the leading (inside) edge of the pip. The VRM is adjusted by means of a range crank. The distance is read on a range counter.

For better range accuracy, the VRM should be just bright enough to see and should be focused as sharply as possible.

Electronic Bearing Cursor

The designs of some radar indicators may include an electronic bearing cursor in addition to the mechanical bearing cursor. This electronic cursor is a luminous line on the PPI usually originating at the sweep origin. It is particularly useful when the sweep origin is not at the center of the PPI (see figure 2.3). Bearings are determined by placing the cursor in a position to bisect the pip. In setting the electronic cursor in this manner, there are no parallax problems such as are encountered in the use of the mechanical bearing cursor. The bearings to the pips or targets are read on an associated bearing indicator.

The electronic bearing cursor may have the same appearance as the heading flash. To avoid confusion between these two luminous lines originating at the sweep origin on the PPI, the design may be such that the electronic cursor appears as a dashed or dotted luminous line. Another design approach used to avoid confusion limits the painting of the cursor to that part of the radial beyond the setting of the VRM. Without special provision for differentiating between the two luminous lines, their brightness may be made different to serve as an aid in identification.

In the simpler designs of electronic bearing cursors, the cursor is independent of the VRM, i.e., the bearing is read by cursor and range is read by the rotating VRM. In more advanced designs, the VRM (range strobe) moves radially along the electronic bearing as the range crank is turned. This serves to expedite the reading of the range and bearing to a pip.

Interscan

The term INTERSCAN is descriptive of various designs of electronic bearing cursors, the lengths of which can be varied for determining the range to a pip.

Interscans are painted continuously on the PPI; the paintings of the other electronic bearing cursors are limited to one painting for each rotation of the antenna. Thus, the luminous lines of the latter cursors tend to fade between paintings. The continuously luminous line of the interscan serves to expedite measurements.

In some designs the interscan may be positioned at desired locations on the PPI; the length and direction of the luminous line may be adjusted to serve various requirements, including the determination of the bearing and distance between two pips.

Off-Center Display

While the design of most relative motion radar indicators places the sweep origin only at the center of the PPI, some indicators may have the capability for off-centering the sweep origin (see figure 2.11).

The primary advantage of the off-center display is that for any particular range scale setting, the view ahead can be extended. This lessens the requirement for changing range scale settings. The off-centering feature is particularly advantageous in river navigation.

With the sweep origin off-centered, the bearing dials concentric with the PPI cannot be used directly for bearing measurements. If the indicator does not have an electronic bearing cursor (interscan), the parallel-line cursor may be used for bearing measurements. By placing the cursor so that one of the parallel lines passes through both the observer's position on the PPI (sweep origin) and the pip, the bearing to the pip can be read on the bearing dial. Generally, the parallel lines inscribed on the disk are so spaced that it would be improbable that one of the parallel lines could be positioned to pass through the sweep origin and pip. This necessitates placing the cursor so that the inscribed lines are parallel to a line passing through the sweep origin and

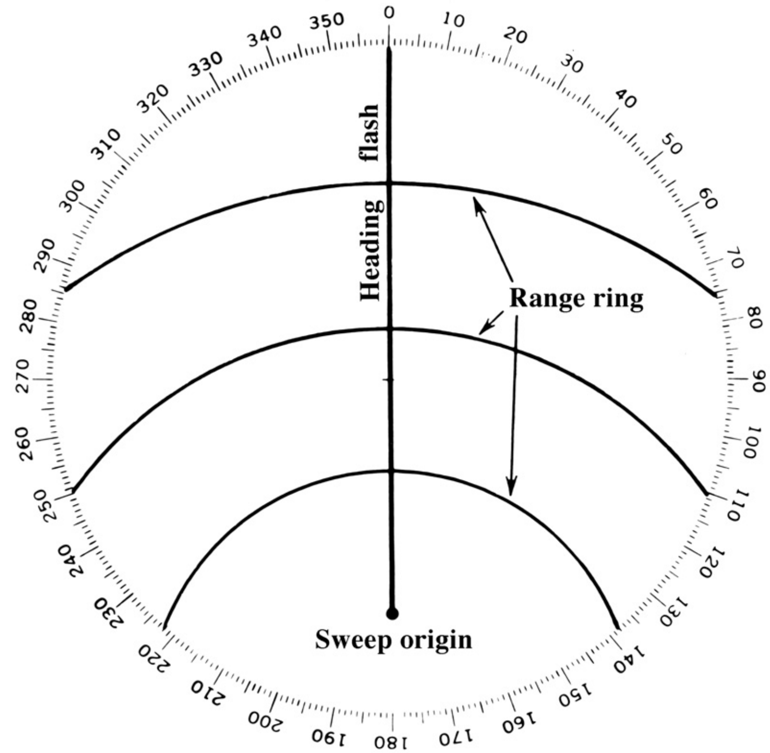


Figure 2.11 - Off-center display.

Expanded Center Display

Some radar indicator designs have the capability for expanding the center of the PPI on the shortest range scale, 1 mile for instance. While using an expanded center display, zero range is at one-half inch, for instance, from the center of the PPI rather than at its center. With sweep rotation the center of the PPI is dark out to the zero range circle.

Ranges must be measured from the zero range circle rather than the center of the PPI. While the display is distorted, the bearings of pips from the center of the PPI are not changed. Through shifting close target pips radially away from the PPI center, better resolution or discrimination between the pips is afforded. Also because of the normal small centering errors of the PPI display, the radial shifting of the target pips permits more accurate bearing determinations.

Figure 2.12 illustrates a normal display in which range is measured from the center of the PPI. Figure 2.13 illustrates an expanded center display of the same situation.

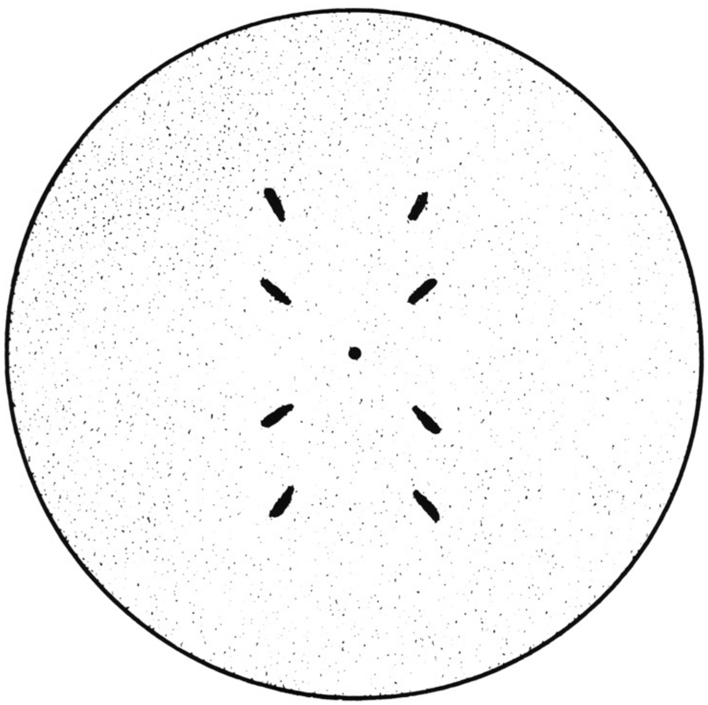


Figure 2.12 - Normal display.

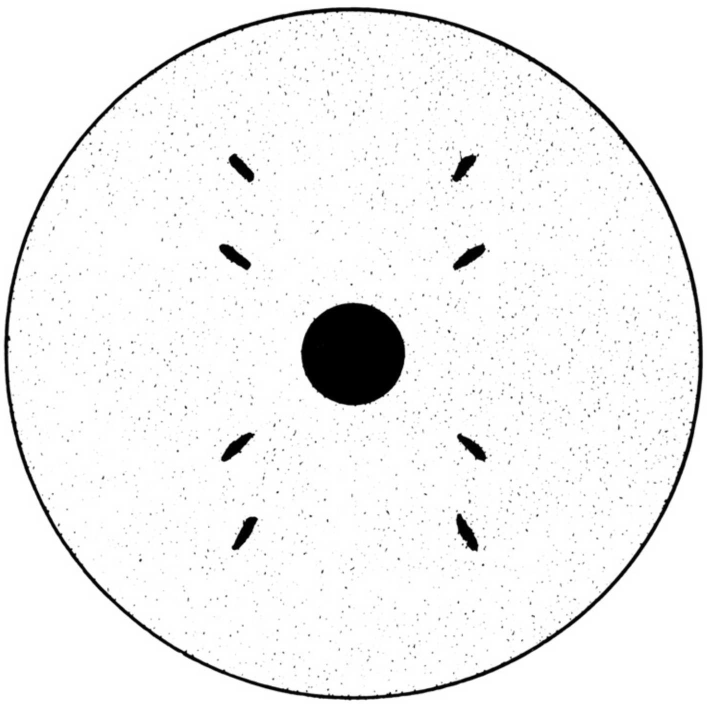


Figure 2.13 - Expanded center display.

RADAR OPERATING CONTROLS

POWER CONTROLS

Indicator Power Switch

This switch on the indicator has OFF, STANDBY, and OPERATE (ON) positions. If the switch is turned directly from the OFF to OPERATE positions, there is a warm-up period of about 3 minutes before the radar set is in full operation. During the warm-up period the cathodes of the tubes are heated, this heating being necessary prior to applying high voltages. If the switch is in the STANDBY position for a period longer than that required for warm-up, the radar set is placed in full operation immediately upon turning the switch to the OPERATE position. Keeping the radar set in STANDBY when not in use tends to lessen maintenance problems. Frequent switching from OFF to OPERATE tends to cause tube failures.

Antenna (Scanner) Power Switch

For reasons for safety, a radar set should have a separate switch for starting and stopping the rotation of the antenna. Separate switching permits antenna rotation for deicing purposes when the radar set is either off or in standby operation. Separate switching permits work on the antenna platform when power is applied to other components without the danger attendant to a rotating antenna.

Special Switches

Even when the radar set is off, provision may be made for applying power to heaters designed for keeping the set dry. In such case, a special switch is provided for turning this power on and off.

Note: Prior to placing the indicator power switch in the OPERATE position, the brilliance control, the receiver gain control, the sensitivity time control, and the fast time constant switch should be placed at their minimum or off positions. The setting of the brilliance control avoids excessive brilliance harmful to the CRT on applying power. The other settings are required prior to making initial adjustments of the performance controls.

Brilliance Control

Also referred to as Intensity or Brightness control. The brilliance control, which determines the overall brightness of the PPI display, is first adjusted to make the trace of the rotating sweep visible but not too bright. Then it is adjusted so that the trace just fades. This adjustment should be made with the receiver gain control at its minimum setting because it is difficult to judge the right degree of brilliance when there is a speckled background on the PPI. Figures 2.14, 2.15, and 2.16 illustrate the effects of different brilliance settings, the receiver gain control being set so that the speckled background does not appear on the PPI. With too little brilliance, the PPI display is difficult to see; with excessive brilliance, the display is unfocused.

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Figure 2.14 - Too little brilliance.

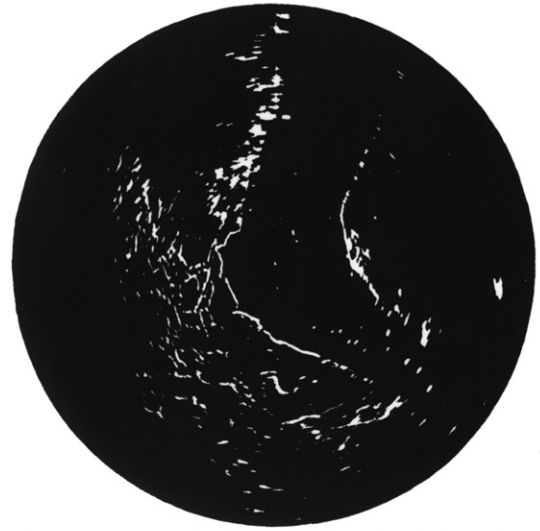

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Figure 2.15 - Normal brilliance.

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Figure 2.16 - Excessive brilliance.

Receiver Gain Control

The receiver gain control is adjusted until a speckled background just appears on the PPI. Figures 2.17, 2.18, and 2.19 illustrate too little gain, normal gain, and excessive gain, respectively. With too little gain, weak echoes may not be detected; with excessive gain, strong echoes may not be detected because of the poor contrast between echoes and the background of the PPI display.

In adjusting the receiver gain control to obtain the speckled background, the indicator should be set on one of the longer range scales because the speckled background is more apparent on these scales. On shifting to a different range scale, the brightness may change. Generally, the required readjustment may be effected through use of the receiver gain control alone although the brightness of the PPI display is dependent upon the settings of the receiver gain and brilliance controls. In some radar indicator designs, the brilliance control is preset at the factory. Even so, the brilliance control may have to be readjusted at times during the life of the cathode-ray tube. Also the preset brilliance control may have to be readjusted because of large changes in ambient light levels.

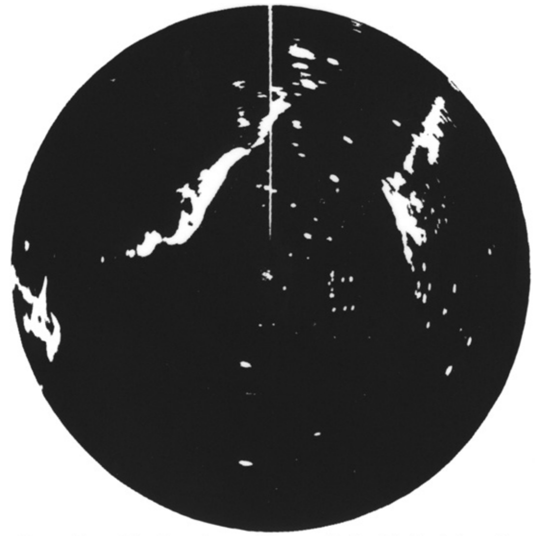

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Figure 2.18 - Normal gain.

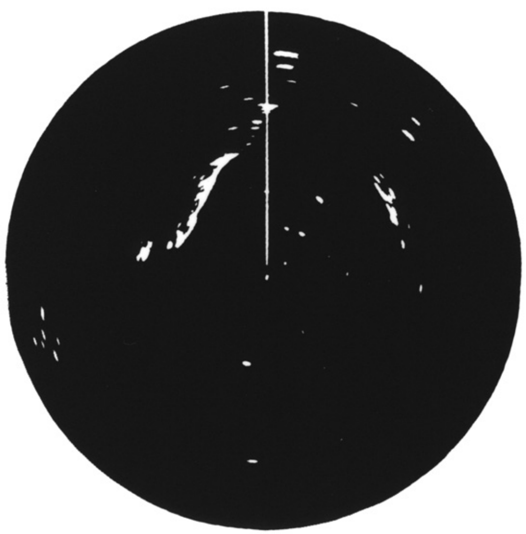

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Figure 2.17 - Too little gain.

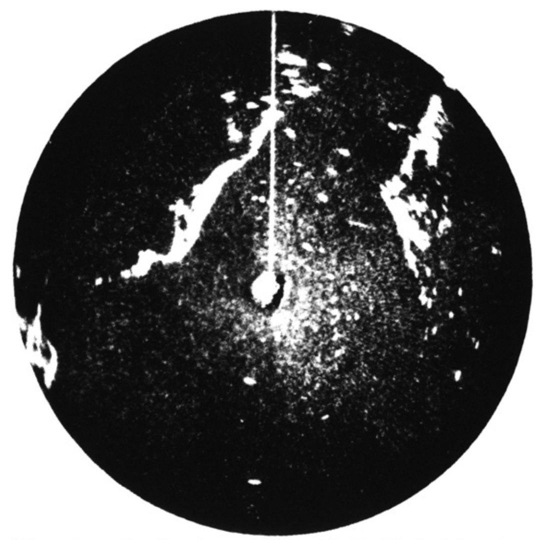

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Figure 2.19 - Excessive gain.

Tuning Control

Without ship or land targets, a performance monitor, or a tuning indicator, the receiver may be tuned by adjusting the manual tuning control for maximum sea clutter. An alternative to the use of normal sea clutter which is usually present out to a few hundred yards even when the sea is calm, is the use of echoes from the ship's wake during a turn. When sea clutter is used for manual tuning adjustment, all anti-clutter controls should be either off or placed at their minimum settings. Also, one of the shorter range scales should be used.

PERFORMANCE CONTROLS - ADJUSTMENTS ACCORDING TO OPERATING CONDITIONS

Receiver Gain Control

This control is adjusted in accordance with the range scale being used. Particular caution must be exercised so that while varying its adjustment for better detection of more distant targets, the area near the center of the PPI is not subjected to excessive brightness within which close targets may not be detected.

When detection at the maximum possible range is the primary objective, the receiver gain control should be adjusted so that a speckled background is just visible on the PPI. However, a temporary reduction of the gain setting may prove useful for detecting strong echoes from among weaker ones.

Fast Time Constant (FTC) Switch (Differentiator)

With the FTC switch in the ON position, the FTC circuit through shortening the echoes on the display reduces clutter on the PPI which might be caused by rain, snow, or hail. When used, this circuit has an effect over the entire PPI and generally tends to reduce receiver sensitivity and, thus, the strengths of the echoes as seen on the display.

Rain Clutter Control

The rain clutter control provides a variable fast time constant. Thus, it provides greater flexibility in the use of FTC according to the operating conditions. Whether the FTC is fixed or variable, it provides the means for breaking up clutter which otherwise could obscure the echo of a target of interest. When navigating in confined waters, the FTC feature provides better definition of the PPI display through better range resolution. Also, the use of FTC provides lower minimum range capability.

Figure 2.20 illustrates clutter on the PPI caused by a rain squall. Figure 2.21 illustrates the break up of this clutter by means of the rain clutter control.

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Figure 2.20 - Clutter caused by a rain squall.

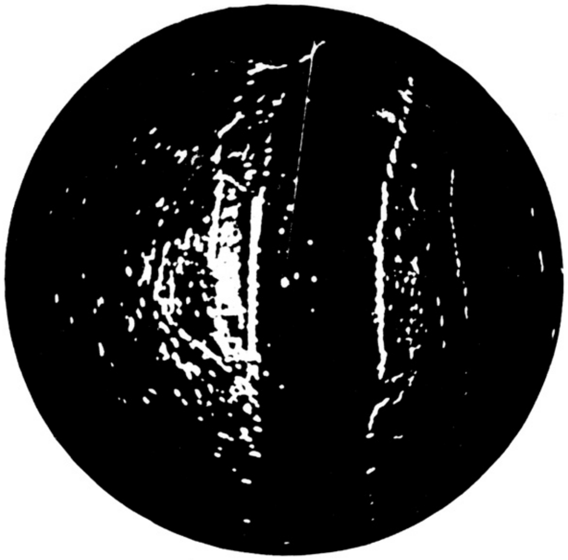

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Figure 2.21 - Break up of clutter by means of rain clutter control.

Figure 2.22 illustrates the appearance of a harbor on the PPI when the FTC circuit is not being used. Figure 2.23 illustrates the harbor when the FTC circuit is being used. With use of the FTC circuit, there is better definition.

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Figure 2.22 - FTC not in use.

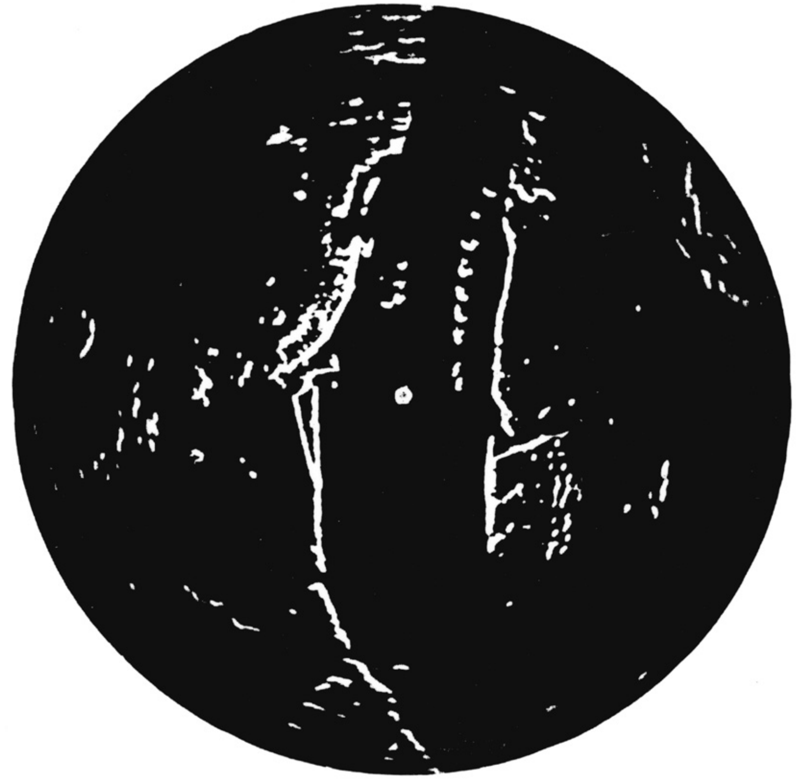

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Figure 2.23 - FTC in use.

Sensitivity Time Control (STC)

Also called SEA CLUTTER CONTROL, ANTI-CLUTTER CONTROL, SWEPT GAIN, SUPPRESSOR.

Normally, the STC should be placed at the minimum setting in calm seas. This control is used with a circuit which is designed to suppress sea clutter out to a limited distance from the ship. Its purpose is to enable the detection of close targets which otherwise might be obscured by sea clutter. This control must be used judiciously in conjunction with the receiver gain control. Generally, one should not attempt to eliminate all sea clutter with this control. Otherwise, echoes from small close targets may be suppressed also.

Figures 2.24, 2.25, and 2.26 illustrate STC settings which are too low, correct, and too high, respectively.

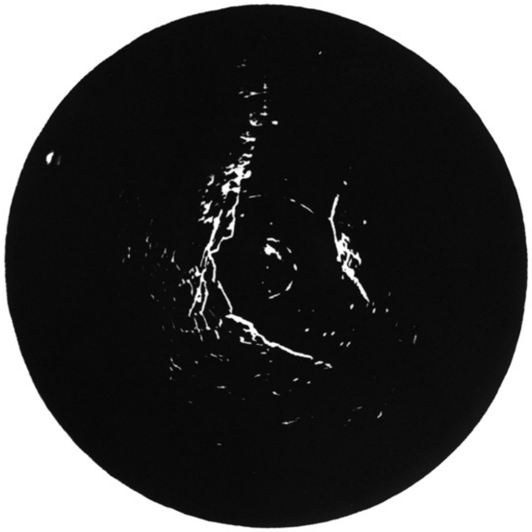

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Figure 2.24 - STC setting too low.

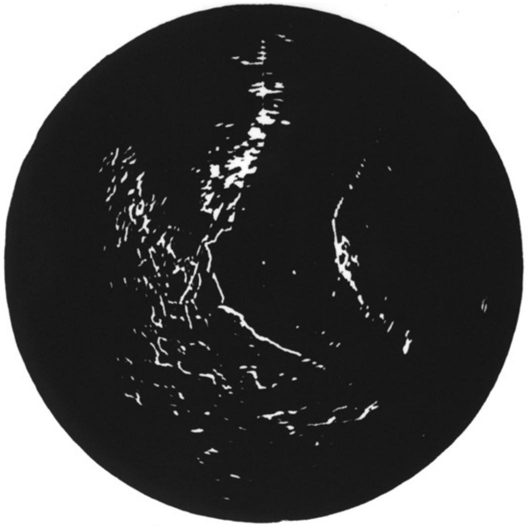

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Figure 2.25 - STC setting correct.

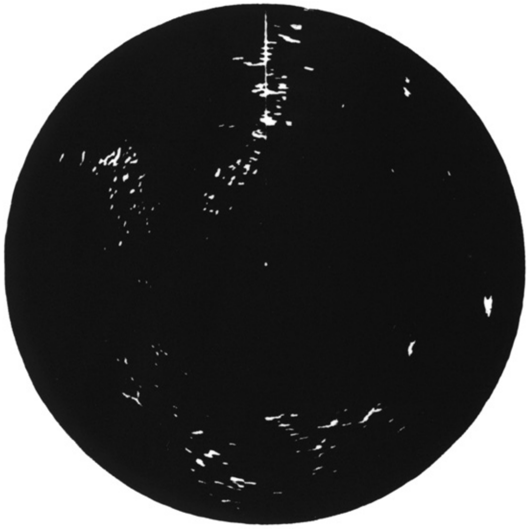

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Figure 2.26 - STC setting too high.

Performance Monitor

The performance monitor provides a check of the performance of the transmitter and receiver. Being limited to a check of the operation of the equipment, the performance monitor does not provide any indication of performance as it might be affected by the propagation of the radar waves through the atmosphere. Thus, a good check on the performance monitor does not necessarily indicate that targets will be detected.

When the performance monitor is used, a plume extends from the center of the PPI (see figure 2.27). The length of the plume, which is dependent upon the strength of the echo received from the echo box in the vicinity of the antenna, is an indication of the performance of the transmitter and the receiver. The length of this plume is compared with its length when the radar is known to be operating at high performance.

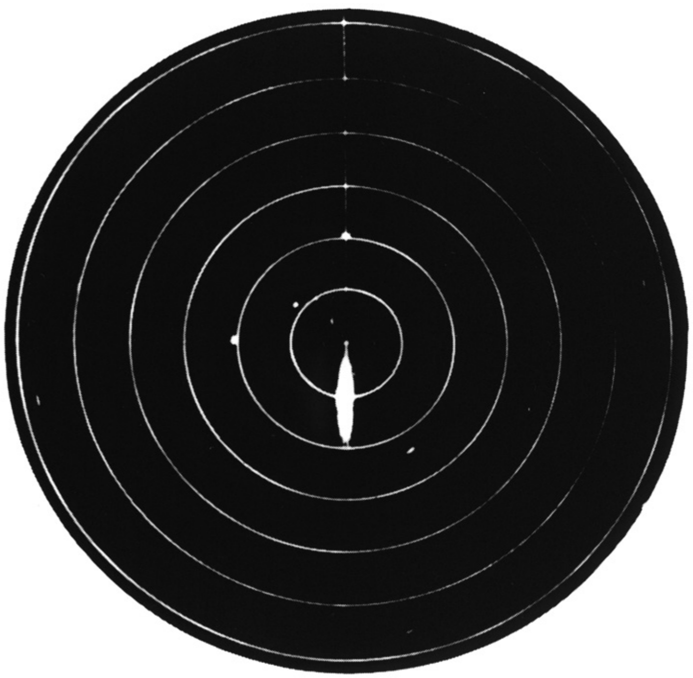

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Figure 2.27 - Performance monitor plume.

Any reduction of over 20 percent of the range to which the plume extends when the radar set is operating at its highest performance is indicative of the need for tuning adjustment. If tuning adjustment does not produce a plume length within specified limits, the need for equipment maintenance is indicated.

With malfunctioning of the performance monitor, the plume appears as illustrated in figure 2.28.

The effectiveness of the anti-clutter controls can be checked by inspecting their effects on the plume produced by the echo from the echo box.

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Figure 2.28 - Appearance of plume when performance monitor is malfunctioning.

Pulse Lengths and Pulse Repetition Rate Controls

On some radar sets the pulse length and pulse repetition rate (PRR) are changed automatically in accordance with the range scale setting. At the higher range scale settings the radar operation is shifted to longer pulse lengths and lower pulse repetition rates. The greater energy in the longer pulse is required for detection at longer ranges. The lower pulse repetition rate is required in order that an echo can return to the receiver prior to the transmission of the next pulse. At the shorter range scale settings, the shorter pulse length provides better range resolution and shorter minimum ranges, the higher power of the longer pulse not being required. Also, the higher pulse repetition rates at the shorter range scale settings provide more frequent repainting of the pips and, thus, sharper pips on the PPI desirable for short range observation.

On other radar sets the pulse length and PRR must be changed by manual operation of controls. On some of these sets pulse length and PRR can be changed independently. The pulse lengths and PRR's of radar sets installed aboard merchant ships usually are changed automatically with the range scale settings.

LIGHTING AND BRIGHTNESS CONTROLS

Reflection Plotter

The illumination levels of the reflection plotter and the bearing dials are adjusted by a control, labeled PLOTTER DIMMER.

The reflection plotter lighting must be turned on in order to see reflected images of the grease pencil plot on the PPI. With yellowish-green fluorescence, yellow and orange grease pencil markings provide the clearest images on the PPI; with orange fluorescence, black grease pencil markings provide the clearest images.

Heading Flash

The brightness of the heading flash is adjusted by a control, labeled FLASHER INTENSITY CONTROL. The brightness should be kept at a low level to avoid masking a small pip on the PPI. The heading flash should be turned off periodically for the same reason.

Electronic Bearing Cursor

The brightness of the electronic bearing cursor is adjusted by a control for this purpose. Unless the electronic bearing cursor appears as a dashed or dotted line, the brightness levels of the electronic bearing cursor and the heading flash should be different to serve as an aid to their identification. Radar indicators are now equipped with a spring-loaded switch to temporarily disable the flash.

Fixed Range Markers

The brightness of the fixed range markers is adjusted by a control, labeled FIXED RANGE MARK INTENSITY CONTROL. The fixed range markers should be turned off periodically to avoid the possibility of their masking a small pip on the PPI.

Variable Range Marker

The brightness of the variable range marker is adjusted by the control labeled VARIABLE RANGE MARK INTENSITY CONTROL. This control is adjusted so that the ring described by the VRM is sharp and clear but not too bright.

Panel Lighting

The illumination of the panel is adjusted by the control labeled PANEL CONTROL.

MEASUREMENT AND ALIGNMENT CONTROLS

Range

Usually, ranges are measured by means of the variable range marker (VRM). On some radars the VRM can be used to measure ranges up to only 20 miles although the maximum range scale setting is 40 miles. For distances greater than 20 miles, the fixed range rings must be used.

The radar indicators designed for merchant ship installation have range counter readings in miles and tenths of miles. According to the range calibration, the readings may be either statute or nautical miles. The range counter has three digits, the last or third digit indicating the range in tenths of a mile. As the VRM setting is adjusted, the range is read in steps of tenths of a mile. The VRM control may have coarse and fine settings. The coarse setting permits rapid changes in the range setting of the VRM. The fine setting permits the operator to make small adjustments of the VRM more readily. For accurate range measurements, the circle described by the VRM should be adjusted so that it just touches the inside edge of the pip.

Bearing

On most radar indicators bearings are measured by setting the mechanical bearing cursor to bisect the target pip and reading the bearing on the bearing dial.

With unstabilized Heading-Upward displays, true bearings are read on the outer, rotatable dial which is set either manually or automatically to ship's true heading.

With stabilized North-Upward displays, true bearings are read on the fixed dial. With loss of compass input to the indicator, the bearings as read on the latter dial are relative. Some radar indicators designed for stabilized North-Upward displays have rotatable relative bearing dials, the zero graduations of which can be set to the heading flash for reading relative bearings.

Some radar indicators, especially those having true motion displays, may have an electronic bearing cursor and associated bearing indicator. The electronic cursor is particularly useful when the display is off-centered.

Sweep Centering

For accurate bearing measurement by the mechanical bearing cursor, the sweep origin must be placed at the center of the PPI. Some radar indicators have panel controls which can be used for horizontal and vertical shifting of the sweep origin to place it at the center of the PPI and, thus, at the pivot point of the mechanical bearing cursor. On other radar indicators not having panel controls for centering the sweep origin, the sweep must be centered by making those adjustments inside the indicator cabinet as are prescribed in the manufacturer's instruction manual.

Center Expansion

Some radar indicators have a CENTER EXPAND SWITCH which is used to displace zero range from the center of the PPI on the shortest range scale setting. With the switch in the ON position, there is distortion in range but no distortion in the bearings of the pips displayed because the expansion is radial. Using center expansion, there is greater separation between pips near the center of the PPI and, thus, better bearing resolution. Also, bearing accuracy is improved because centering errors have lesser effect on accuracy with greater displacement of pips from the PPI center. When center expansion is used, the fixed range rings expand with the center. However, the range must be measured from the inner circle as opposed to the center of the PPI.

The use of the center expansion can be helpful in anti-clutter adjustment.

Heading Flash Alignment

For accurate bearing measurements, the alignment of the heading flash with the PPI display must be such that radar bearings are in close agreement with relatively accurate visual bearings observed from near the radar antenna.

On some radar indicators, the heading flash must be set by a PICTURE-ROTATE CONTROL according to the type of display desired. Should there be any appreciable difference between radar and visual bearings, adjustment of the heading flash contacts is indicated. The latter adjustment should be made in accordance with the procedure prescribed in the manufacturer's instruction manual. However, the following procedures should prove helpful in obtaining an accurate adjustment:

(1) Adjust the centering controls to place the sweep origin at the center of the PPI as accurately as is possible.

(2) In selecting an object for simultaneous visual and radar bearing measurements, select an object having a small and distinct pip on the PPI.

(3) Select an object which lies near the maximum range of the scale in use. This object should be not less than 2 nautical miles away.

(4) Observe the visual bearings from a position as close to the radar antenna as is possible.

(5) Use as the bearing error the average of the differences of several simultaneous radar and visual observations.

(6) After any heading flash adjustment, check the accuracy of the adjustment by simultaneous radar and visual observations.

Range Calibration

The range calibration of the indicator should be checked at least once each watch, before any event requiring high accuracy, and more often if there is any reason to doubt the accuracy of the calibration. A calibration check made within a few minutes after a radar set has been turned on should be checked again 30 minutes later, or after the set has warmed up thoroughly.

The calibration check is simply the comparison of VRM and fixed range ring ranges at various range scale settings. In this check the assumptions are that the calibration of the fixed range rings is more accurate than that of the VRM, and that the calibration of the fixed range rings is relatively stable. One indication of the accuracy of the range ring calibration is the linearity of the sweep or time base. Since range rings are produced by brightening the electron beam at regular intervals during the radial sweep of this beam, equal spacing of the range rings is indicative of the linearity of the time base.

Representative maximum errors in calibrated fixed range rings are 75 yards or 1.5 percent of the maximum range of the range scale in use, whichever is greater. Thus, on a 6-mile range scale setting the error in the range of a pip just touching a range ring may be about 180 yards or about 0.1 nautical mile. Since fixed range rings are the most accurate means generally available for determining range when the leading edge of the target pip is at the range ring, it follows that ranging by radar is less accurate than many may assume. One should not expect the accuracy of navigational radar to be better than plus or minus 50 yards under the best conditions.

Each range calibration check is made by setting the VRM to the leading edge of a fixed range ring and comparing the VRM range counter reading with the range represented by the fixed range ring. The VRM reading should not differ from the fixed range ring value by more than 1 percent of the maximum range of the scale in use. For example, with the radar indicator set on the 40-mile range scale and the VRM set at the 20-mile range ring, the VRM range counter reading should be between 19.6 and 20.4 miles.

TRUE MOTION CONTROLS

The following controls are representative of those additional controls used in the true motion mode of operation. If the true motion radar set design includes provision for ground stabilization of the display, this stabilization may be effected through use of either set and drift or speed and course-made-good controls.

Operating Mode

Since true motion radars are designed for operation in true motion and relative motion modes, there is a control on the indicator panel for selecting the desired mode.

Normal Reset Control

Since own ship is not fixed at the center of the PPI in the true motion mode, own ship's position must be reset periodically on the PPI. Own ship's position may be reset manually or automatically. Automatic reset is performed at definite distances from the PPI center, according to the radar set design. With the normal reset control actuated, reset may be performed automatically when own ship has reached a position beyond the PPI center about two thirds the radius of the PPI. Whether own ship's position is reset automatically or manually, own ship's position is reset to an off-center position on the PPI, usually at a position from which the heading flash passes through the center of the PPI. This off-center position provides more time before resetting is required than would be the case if own ship's position were reset to the center of the PPI.

Delayed Reset Control

With the delayed reset control actuated, reset is performed automatically when own ship has reached a position closer to the edge of the PPI than with normal reset. With either the normal or delayed reset control actuated, there is an alarm signal which gives about 10 seconds forewarning of automatic resetting.

Manual Reset Control

The manual reset control permits the resetting of own ship's position at any desired time.

Manual Override Control

The manual override control when actuated prevents automatic resetting of own ship's position. This control is particularly useful if a critical situation should develop just prior to the time of automatic resetting. Shifting from normal to delayed reset can also provide more time for evaluating a situation before resetting occurs.

Ship's Speed Input Selector Control

Own ship's speed and course being necessary inputs to the true motion radar computer, the ship's speed input selector control permits either manual input of ship's speed or automatic input of speed from a speed log. With the control in the manual position, ship's speed in knots and tenths of knots can be set in steps of tenths of knots.

Set and Drift Controls

Set and drift controls, or their equivalent, provide means for ground stabilization of the true motion display. When there is accurate compensation for set and drift, there is no movement of stationary objects on the PPI. Without such compensation, slight movements of stationary objects may be detected on the PPI. The set control may be labeled DRIFT DIRECTION; the drift control may be labeled DRIFT SPEED.

Speed and Course Made Good Controls

The radar set design may include speed and course made good controls in lieu of set and drift controls to effect ground stabilization of the true motion display. The course made good control permits the input of a correction, within limits of about 25° to the course input to the radar set. The speed control permits the input of a correction to the speed input from the underwater speed log or from an artificial (dummy) log.

Zero Speed Control

In the ZERO position, the zero speed control stops the movement of own ship on the PPI; in the TRUE position own ship moves on the PPI at a rate set by the speed input.

CHAPTER 3 — COLLISION AVOIDANCE

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 also 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 3.1, ship A, at geographic position A1, on true course 000˚ at 15 knots initially observes ship B on the 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 position 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 ships A and B.

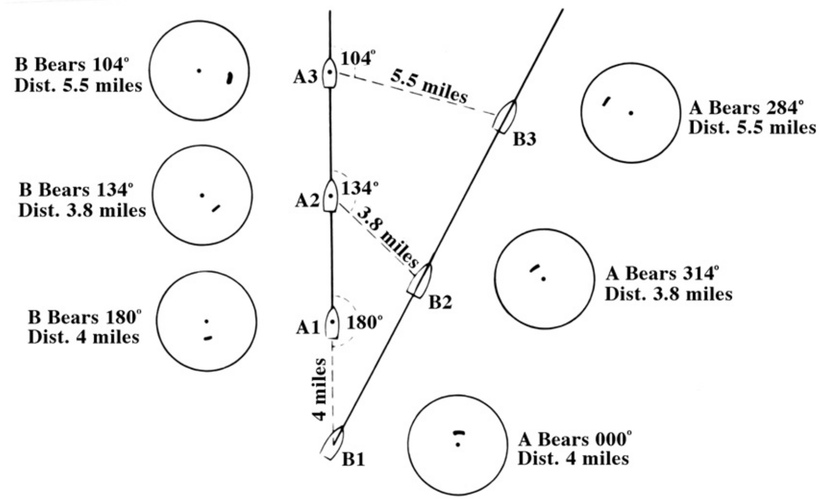


Figure 3.1 - Relative motion between two ships.

If the radar observer aboard ship A plots the 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 3.2.

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 illustrated in figure 3.3. The radar observer aboard ship A will determine that the Direction of Relative Movement (DRM) of ship B is 064˚ whereas the radar observer aboard ship B will determine that the DRM of ship A is 244˚.

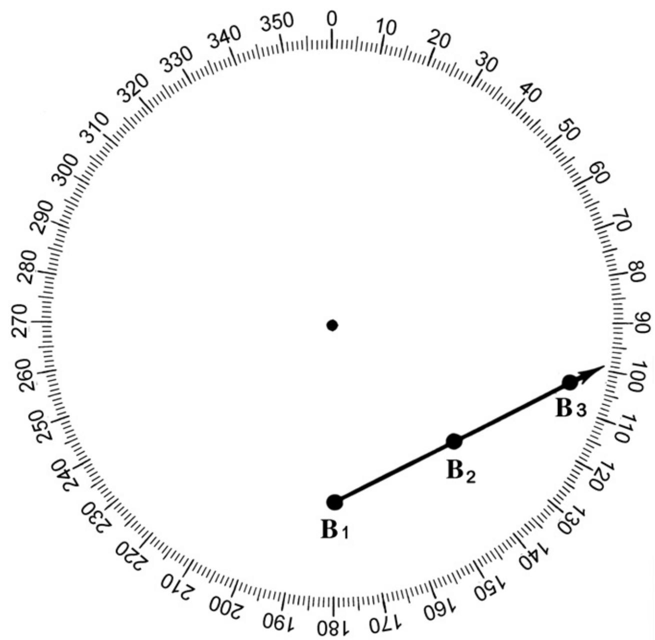


Figure 3.2 - Motion of ship B relative to ship A.

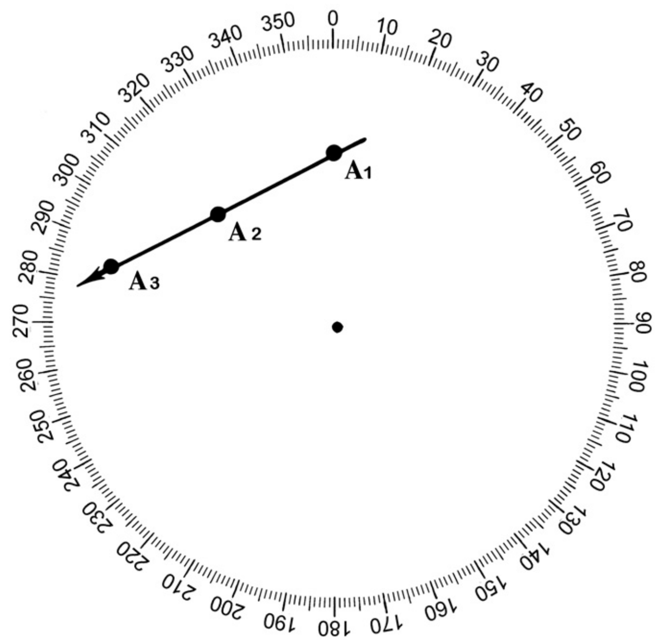


Figure 3.3 - Motion of ship A relative to ship B.

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 3.4 illustrates the actual heading of ship B superimposed upon the relative plot obtained by ship A. *Relative motion displays do not indicate the aspects of ship targets.* 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.

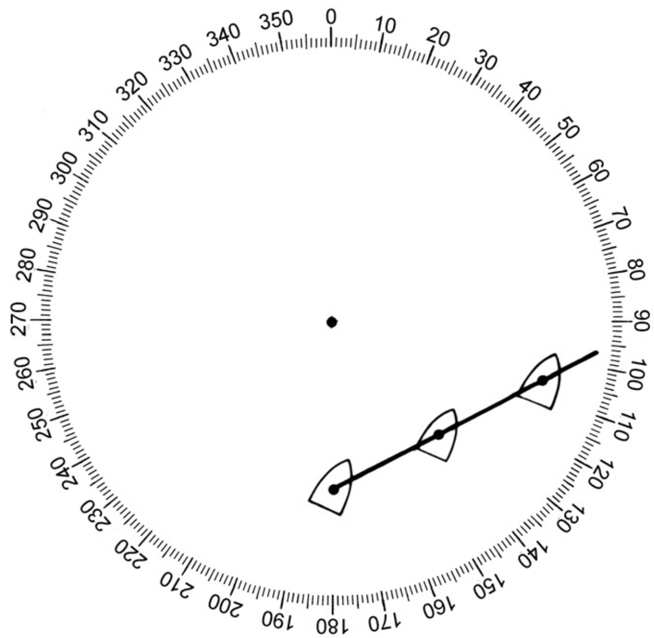


Figure 3.4 - The actual heading of ship B.

Figure 3.5 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.

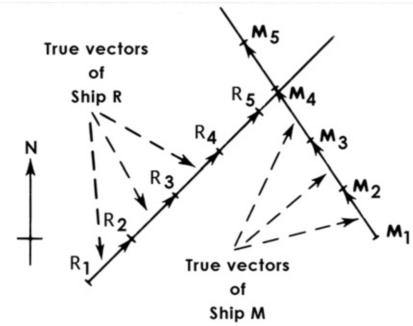


Figure 3.5 - True velocity vectors.

Figure 3.6 illustrates a modification of figure 3.5 in which the true bearing lines and ranges of other ship M from own 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 own 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.

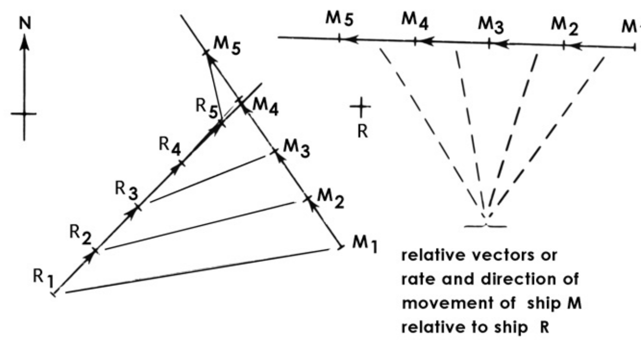


Figure 3.6 - Relative velocity vectors.

The true velocity vector depicting own ship's true motion is called *own ship's true (course-speed) vector*; the true velocity vector depicting the other ship's true motion is called *other ship's true (course-speed) vector*; the relative velocity vector depicting the *relative motion* between own ship and the other ship is called the *relative* (DRM-SRM) *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, own ship's true (course-speed) vector magnitude 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.

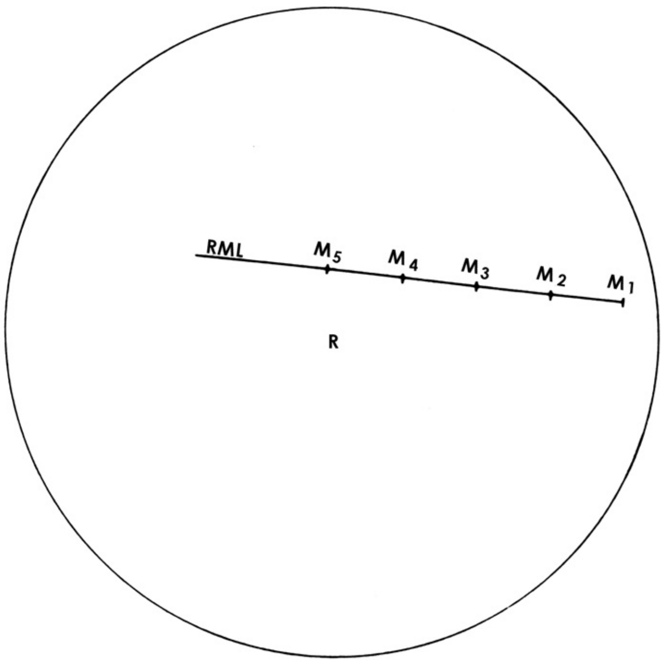


Figure 3.7 - Relative Plot.

A plot of the successive positions of other ship M in the same situation on a relative motion display on the PPI of the radar set aboard own ship R would appear as in figure 3.7. 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 plot, called the RELATIVE PLOT or RELATIVE MOTION PLOT, is the plot of the true bearings and distances of ship M from own ship R. If the plots were not timed, vector magnitude would not be indicated. In such cases the relative plot would be related to the (DRM-SRM) vector in direction only.

Figure 3.8 illustrates the same situation as figure 3.7 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.

Figure 3.8 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.

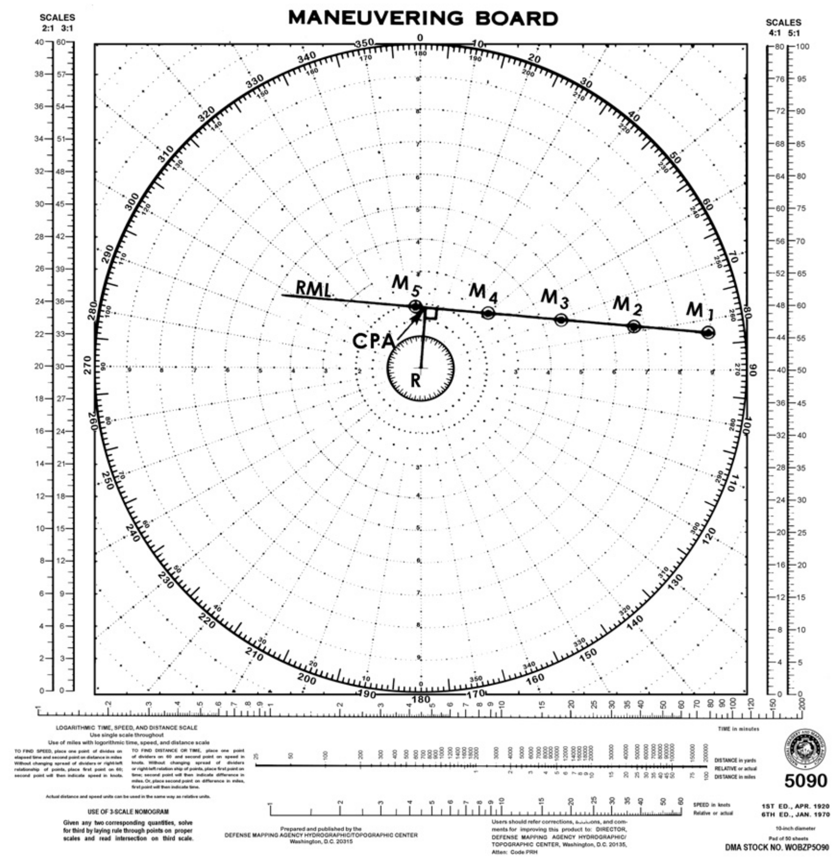


Figure 3.8 - Relative Plot on the Maneuvering Board.

THE VECTOR TRIANGLE

In the foregoing discussion, the relative motion of other ship M with respect to own 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 the other ship M, knowing own ship's true motion (true course and speed) and, through plotting, determining the motion of ship M relative to own ship R.

The vector triangle 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 other ship M, the true (course-speed) vector of own ship R is added to the relative (DRM-SRM) vector derived from the relative plot, or the timed motion of other ship M relative to own 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 own ship's true (course-speed) vector or own ship's true (course-speed) vector 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 own ship's true (course-speed) vector, unless otherwise specified.

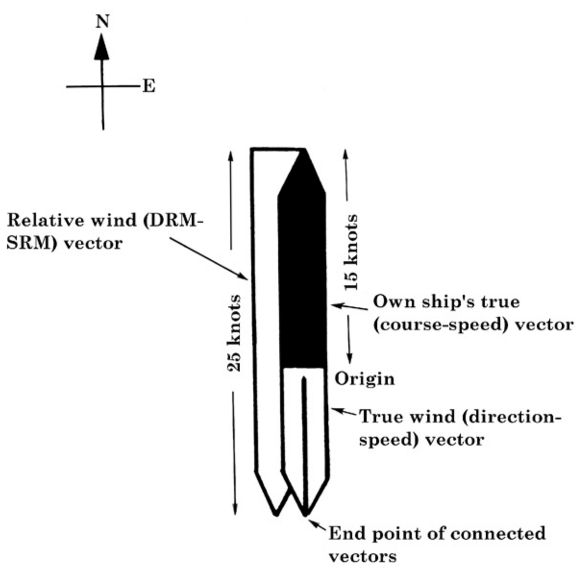


Figure 3.9 - Relative and true wind vectors.

The resultant vector, the true (course-speed) vector of other ship M, 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 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 3.9.

In figure 3.9, 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 3.10).

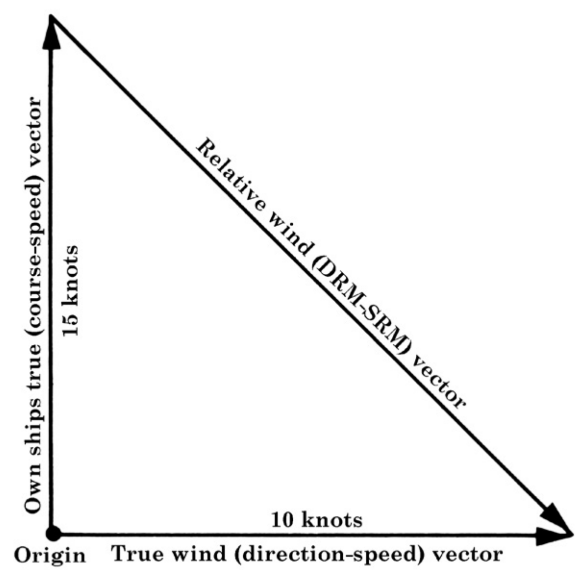


Figure 3.10 - Wind vector triangle.

Returning now to the problem of relative motion between ships and using the same situation as in figure 3.7, a *timed* plot of the motion of other ship M relative to own ship R is made on the PPI as illustrated in figure 3.11.

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

The vectors are laid end to end, while maintaining their respective directions and magnitudes. The resultant vector, the true (course-speed) vector of other ship, is found by drawing a vector from the origin of the two connected (added) vectors to their end point.

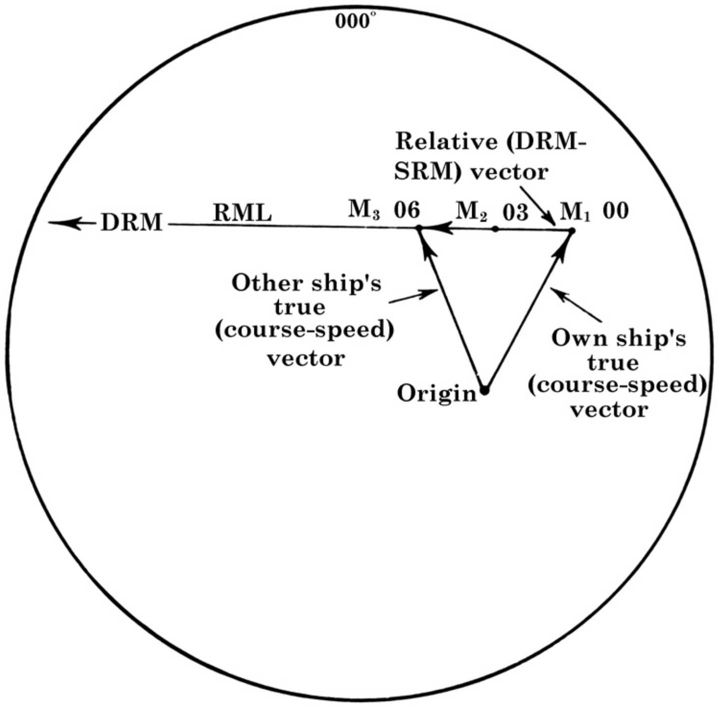


Figure 3.11 - Vector triangle on PPI.

VECTOR EQUATIONS

Where:

em is other ship's true (course-speed) vector.

er is own ship's true (course-speed) vector.

rm is relative (DRM-SRM) vector.

em = er + rm

er = em - rm

rm = em - er

(See figure 3.12)

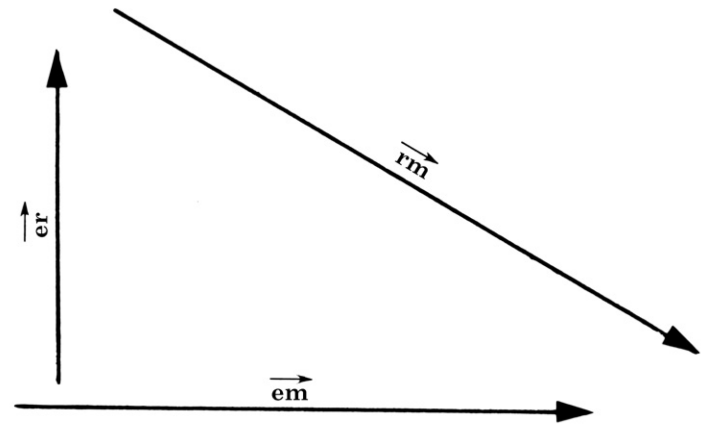


Figure 3.12 - True and relative vectors.

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 3.13).

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 3.14).

To determine vector *rm* from vectors *em* and *er*, vector *er* is subtracted from vector *em* by laying vector *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 3.15).

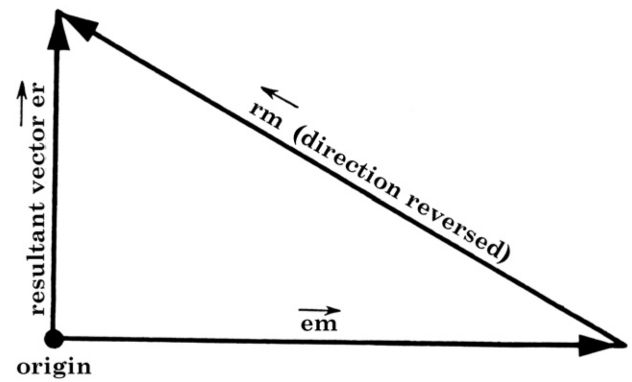


Figure 3.14 - Subtraction of the relative (DRM-SRM) vector from other ship's true (course-speed) vector to find own ship's true (course-speed) vector.

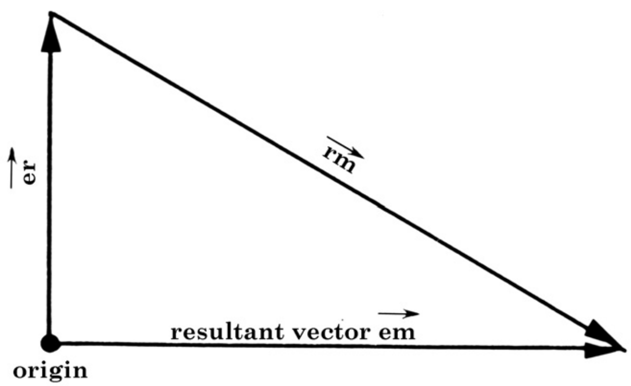


Figure 3.13 - Addition of own ship's true (course-speed) vector and the relative (DRM-SRM) vector to find the true (course-speed) vector of the other ship.

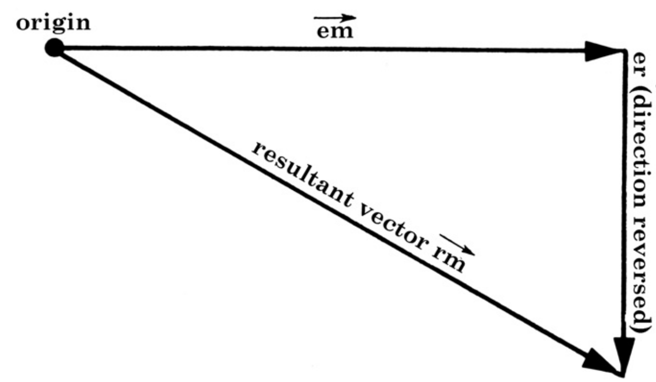


Figure 3.15 - Subtraction of own ship's true (course-speed) vector from other ship's true (course-speed) vector to find the relative (DRM-SRM) vector.

MANEUVERING BOARD FORMAT

The Maneuvering Board is a diagram which can be used in the solution of relative motion problems. Printed in green on white, it is issued in two sizes, 10 inches and 20 inches, charts 5090 and 5091, respectively.

Chart 5090, illustrated in figure 3.16, consists primarily of a polar diagram having equally spaced radials and concentric circles. The radials are printed as dotted lines at 10˚ intervals. The 10 concentric circles are also dotted except for the inner circle and the outer complete circle, which has a 10-inch diameter. Dotted radials and arcs of concentric circles are also printed in the area of the corners of the 10-inch square framing the polar diagram.

The 10-inch circle is graduated from 0˚ at the top, through 360˚ with the graduations at each 10˚ coinciding with the radials.

The radials between concentric circles are subdivided into 10 equal parts by the dots and small crosses from which they are formed. Except for the inner circle, the arcs of the concentric circles between radials are subdivided into 10 equal parts by the dots and small crosses from which they are formed. The inner circle is graduated at 5˚ intervals.

Thus, except for the inner circle, all concentric circles and the arcs of concentric circles beyond the outer complete circle are graduated at one-degree intervals.

In the labeling of the outer complete circle at 10˚ intervals, the reciprocal values are printed inside this circle. For example, the radial labeled as 0˚ is also labeled as 180˚.

In the left-hand margin there are two vertical scales (2:1 and 3:1); in the right-hand margin there are two vertical scales (4:1 and 5:1).

A logarithmic time-speed-distance scale and instructions for its use are printed at the bottom.

Chart 5090 is identical to chart 5091 except for size.

PLOTTING ON MANEUVERING BOARD

If radar targets to be plotted lie within 10 miles of own ship and the distances to these targets are measured in miles, and tenths of miles, the Maneuvering Board format is particularly advantageous for relatively rapid transfer plotting, i.e., plotting target (radar contact) information transferred from the radarscope.

The extension of the dotted radials and arcs of concentric circles into the corners of the Maneuvering Board permits plotting with the same facility when the distances to the targets are just beyond 10 miles and their bearings correspond to these regions.

In plotting the ranges and bearings of radar targets on the Maneuvering Board, the radar observer generally must select an optimum distance scale. For radar targets at distances between 10 and 20 miles, the 2:1 scale is the best selection, unless the targets can be plotted within the corners of the Maneuvering Board using the 1:1 scale. The objective is to provide as much separation between individual plots as is possible for both clarity and accuracy of plotting.

While generally either the 1:1 or 2:1 scale is suitable for plotting the relative positions of the radar contacts in collision avoidance applications when the ranges are measured in miles, the radar observer also must select a suitable scale for the graphical construction of the vector triangles when the sides of these triangles are scaled in knots.

To avoid confusion between scales being used for distance and speed in knots, the radar observer should make a notation on the Maneuvering Board as to which scale is being used for distance and which scale is being used for speed in knots. However, rapid radar plotting techniques, within the scope of using a selected portion of the relative plot directly as the relative (course-speed) vector, may be employed with the Maneuvering Board.

As illustrated in figure 3.18, the plotting of relative positions on the Maneuvering Board requires the use of a straightedge and a pair of dividers. The distance scale is selected in accordance with the radar range setting. To avoid mistakes, the distance scale used should be circled.

As illustrated in figure 3.19, the construction of own ships true (course-speed) vector scaled in knots and originating from the center of the Maneuvering Board also requires the use of a straightedge and pair of dividers.

In the use of a separate relative plot and vector triangle scaled in knots, the direction of the relative (DRM-SRM) vector must be transferred from the relative plot by parallel rules or by sliding one triangle against another.

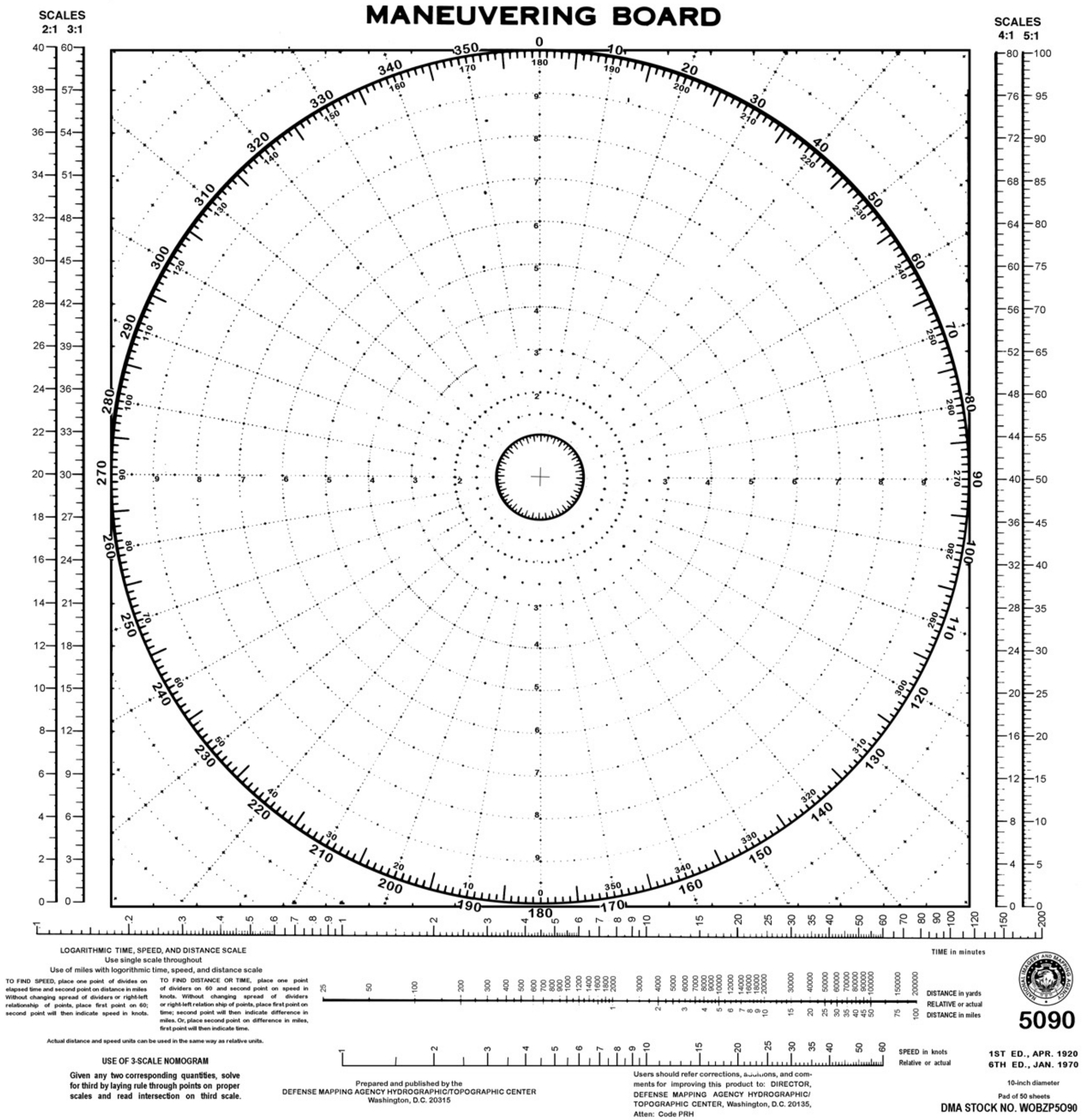


Figure 3.16 - Maneuvering Board.

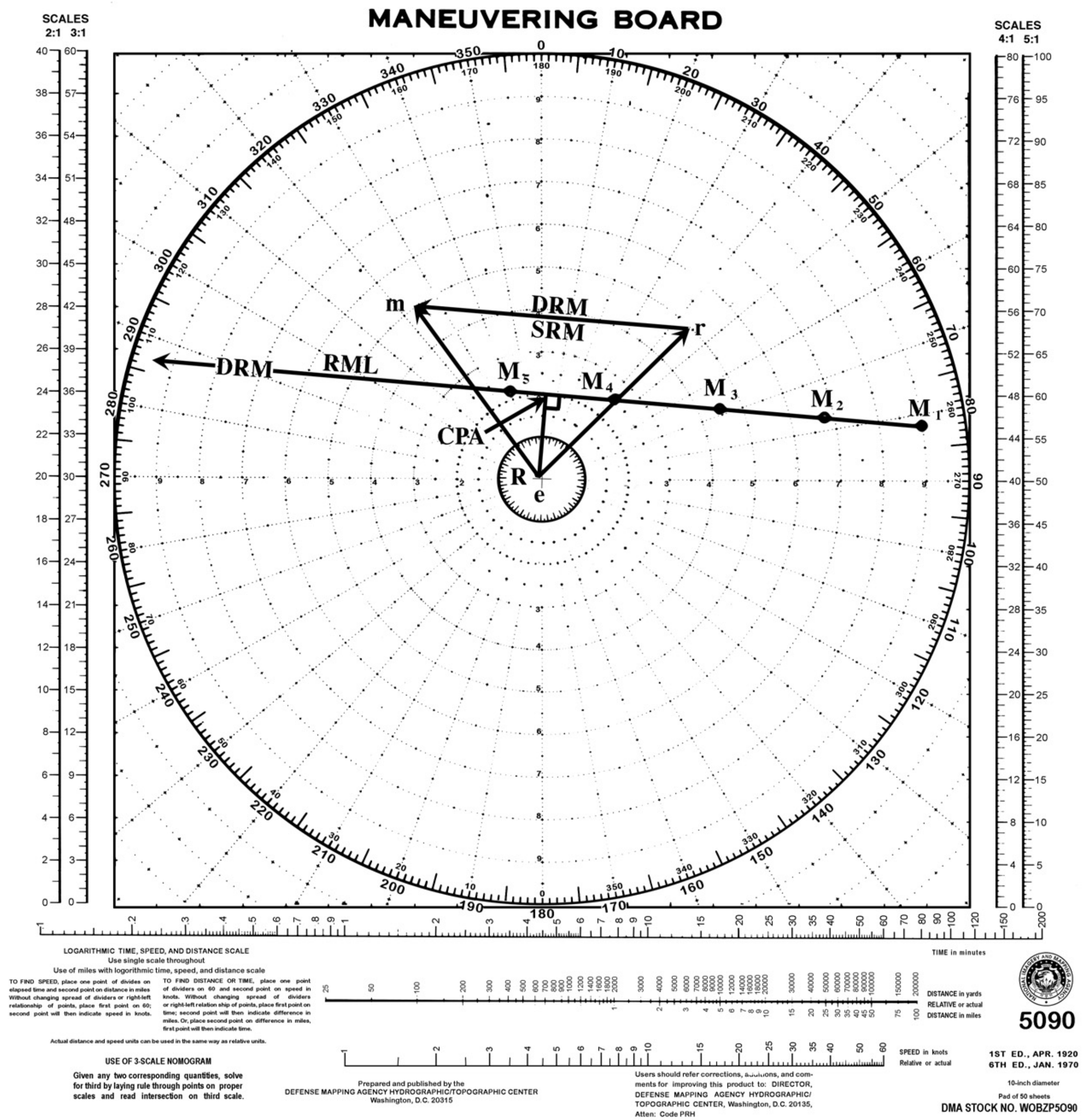


Figure 3.17 - Speed triangle and relative plot on the Maneuvering Board.

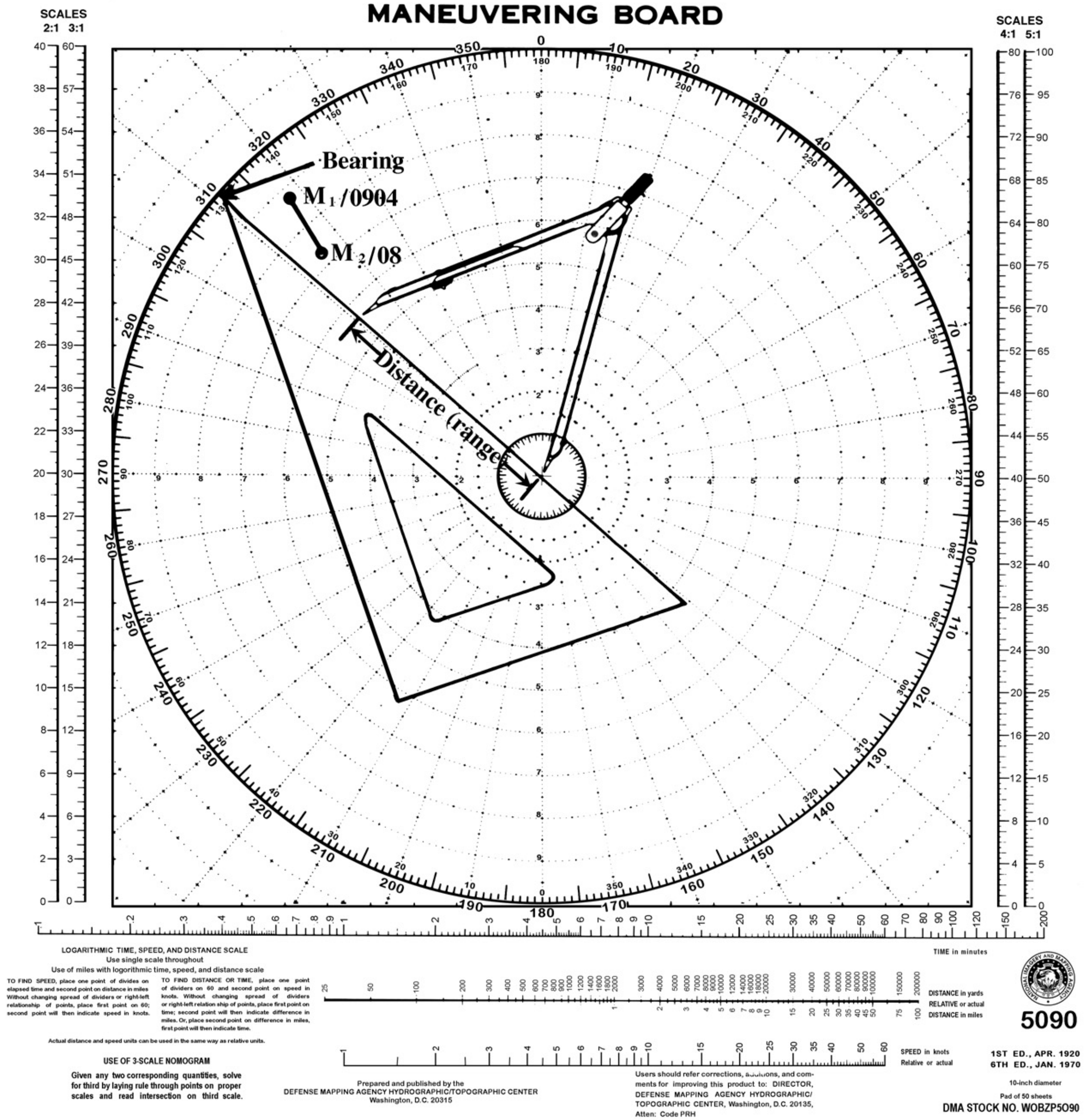


Figure 3.18 - Plotting relative positions on the Maneuvering Board.

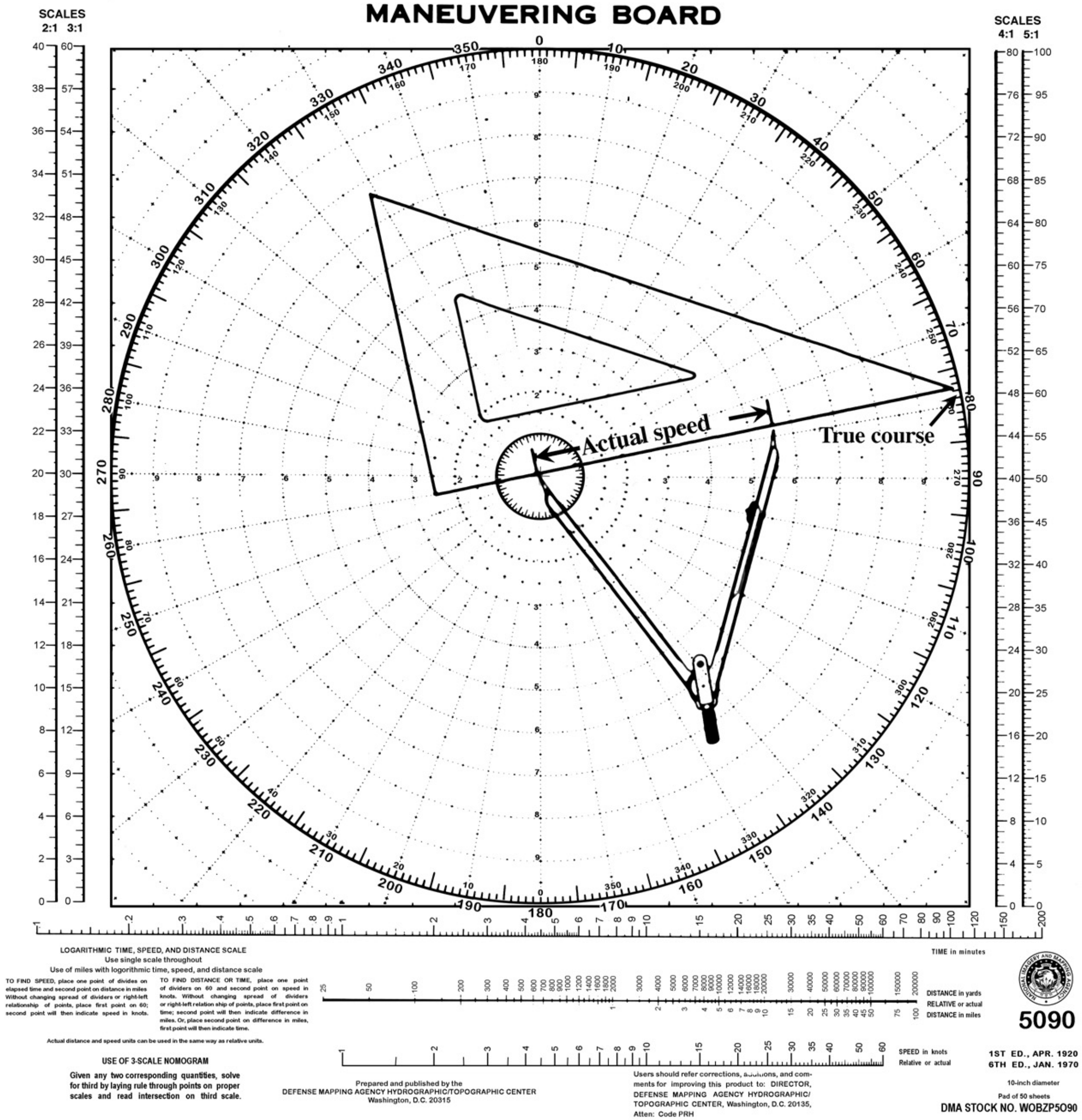


Figure 3.19 - Constructing a true vector on the Maneuvering Board.

Relative Movement Problems

Relative movement problems may be divided into two general categories:

(1) Tracking: from observed relative movement data, determining the actual motion of the ship or ships being observed.

(2) 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).

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 3.20 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 3.20 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.

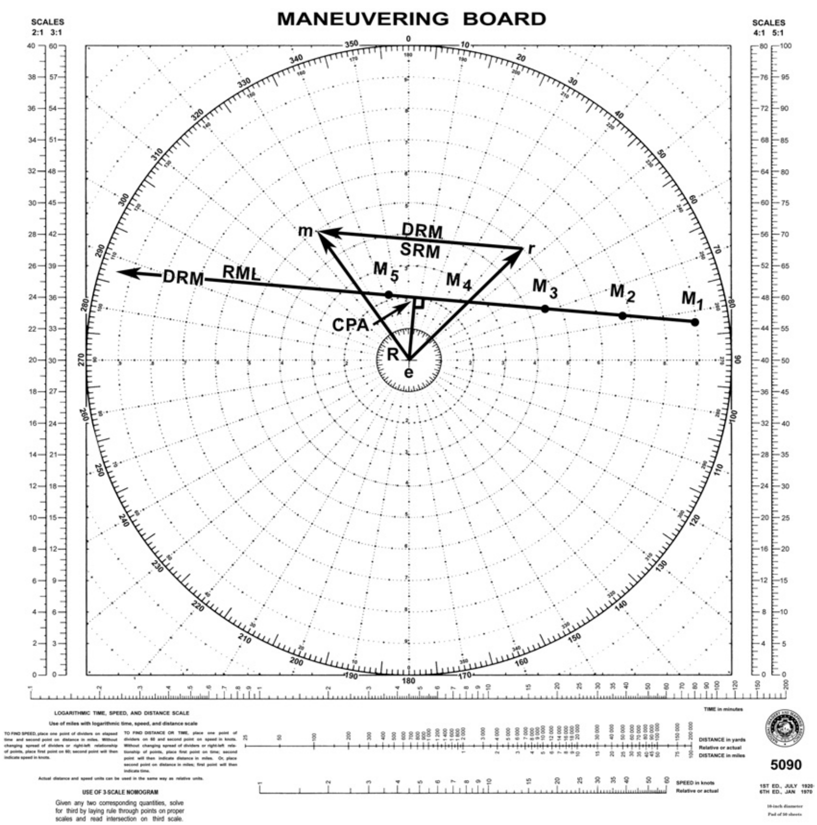


Figure 3.20 - Speed triangle and relative plot.

If in figure 3.20 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 3.20 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 3.20 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 3.21 and 3.22(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 3.22(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.

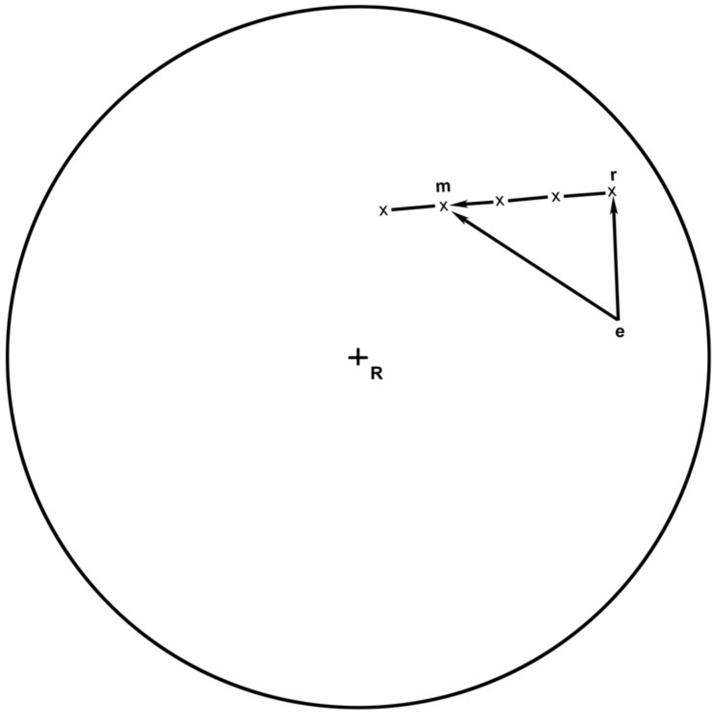


Figure 3.21 - Vector diagram.

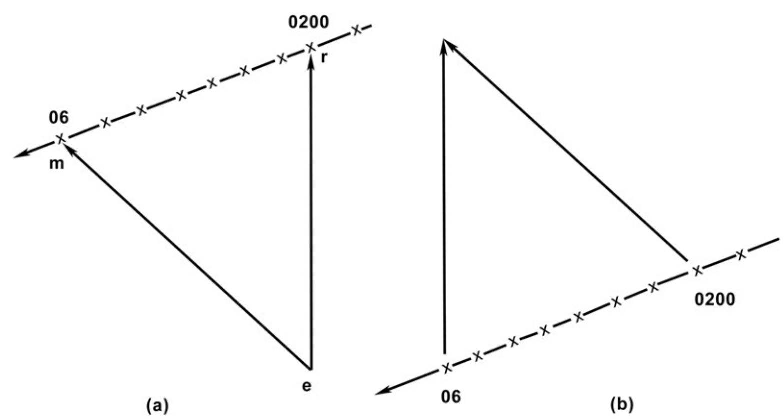


Figure 3.22 - Vector diagrams.

Figure 3.23 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.

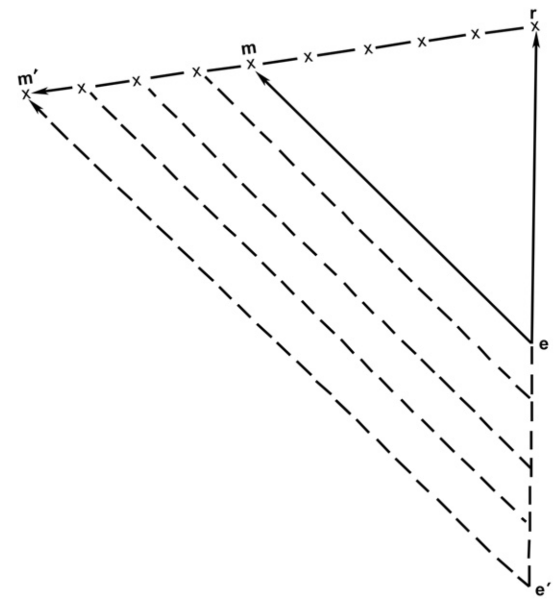


Figure 3.23 - Vector diagram.

THE LOGARITHMIC TIME-SPEED-DISTANCE NOMOGRAM

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

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

Distance = Speed x 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 3.24 illustrates a solution for speed when a distance of 4 miles is traveled in 11 minutes. 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. Because the upper scale is larger, its use for this purpose is preferred for obtaining greater accuracy.

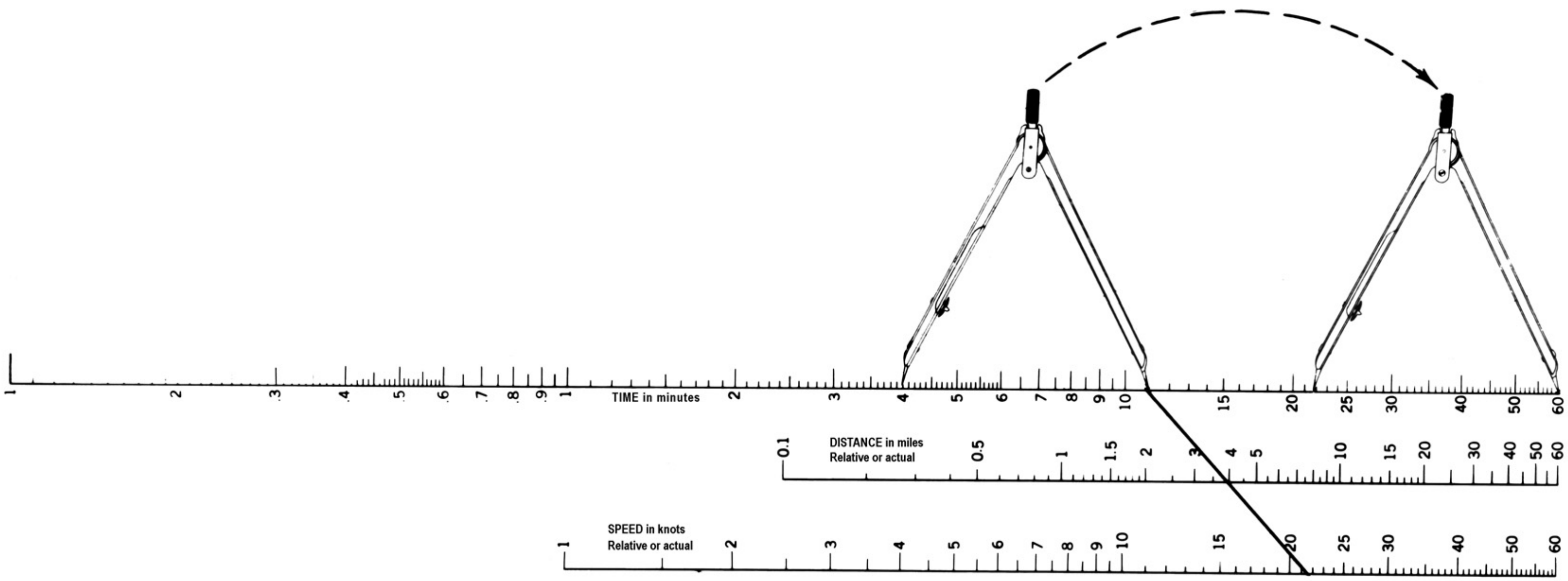


Figure 3.24 - Logarithmic time-speed-distance nomogram.

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 3.24 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. One point of a pair of dividers is set at the time in minutes, 11, and the second point 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.

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 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.

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 rather than 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.

For speeds of less than 60 knots and when using a logarithmic scale which increases from left to right, the distance graduation always lies to the left of the time in minutes graduation; the speed in knots graduation always lies to the left of the 60 graduation.

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 half 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:

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

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.

NAUTICAL SLIDE RULES

Several slide rules have been designed for the solution of time, speed, and distance problems. The circular slide rule illustrated in figure 3.25 has distance graduations in both nautical miles and yards. One nautical mile is assumed to be equal to 2,000 yards. On setting two known values to their respective arrowheads, the value sought is found at the third arrowhead. Thus, there is relatively little chance for error in the use of this slide rule. While the nautical miles and yards graduations are differentiated clearly by their numbering, the nautical miles graduations are green and the yards graduations are black. There is a notation on the base of the slide rule with respect to this color code.

There are straight slide rules designed specifically for the solution of time, speed, and distance problems. The fixed and sliding scales are labeled so as to avoid blunders in their use.

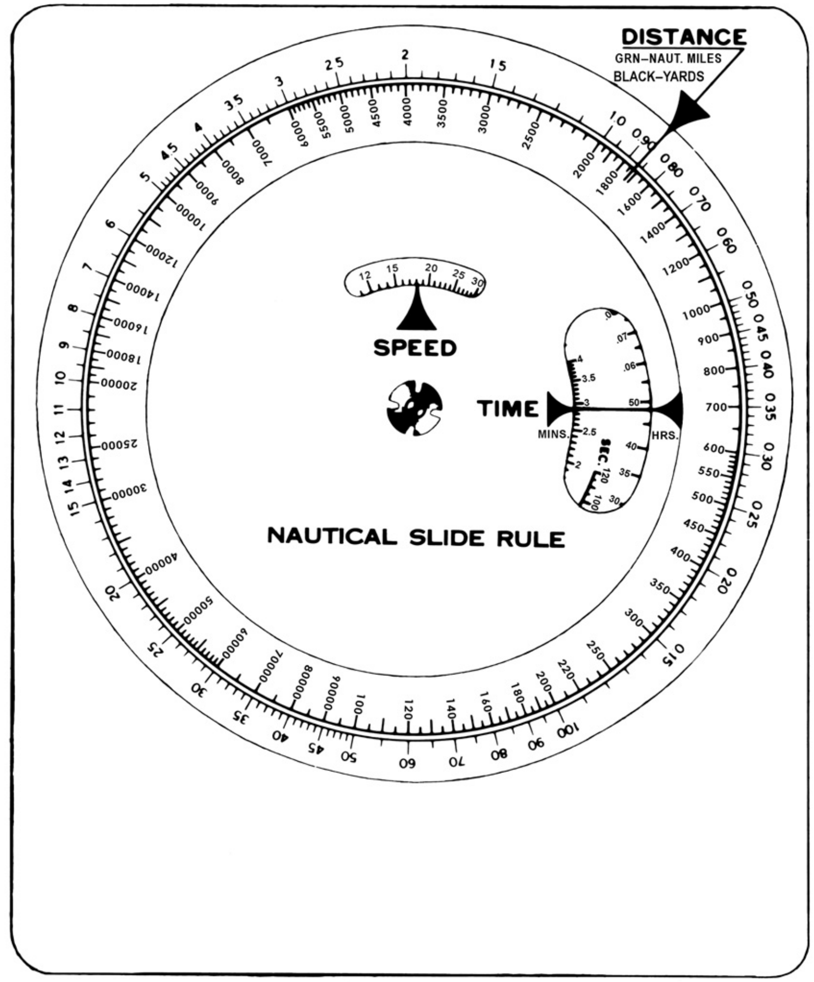


Figure 3.25 - Nautical slide rule.

GRAPHICAL RELATIVE MOTION SOLUTIONS

This section provides example solutions of typical relative motion problems encountered while avoiding collision at sea. The solutions to these problems may be derived from radar plots made on the PPI, a reflection plotter mounted on the PPI, or from radar plot information transferred to a separate polar plotting diagram such as the Maneuvering Board.

Until recently, transfer plotting techniques or the transfer of radar plot information to a separate polar plotting diagram were given primary emphasis in the training of radar observers. Studies of the increasing numbers of collisions among radar-equipped ships have directed attention to the fact that too many mariners, usually trained only in transfer plotting techniques, were not making effective use of their radars because of a number of factors, including:

(1) Their performance of multiple duties aboard merchant ships with little if any assistance.

(2) The problems inherent to transfer plotting, such as the time lag in measuring the ranges and bearings and transferring this data to a separate plot, and the possibility of error in transferring the data.

(3) Their attention being directed away from the radar indicator and the subsequent movements of the targets and the appearance of new targets on the PPI while recording, plotting, and constructing graphical solutions on a separate plotting diagram.

(4) In a multiple radar contact situation, the confusion and greater probability for blunders associated with the construction of overlapping vector triangles, the vectors of which must be related to separate relative plots.

(5) The general lack of capability of competent radar observers to determine expeditiously initial relative motion solutions for more than about two or three radar contacts imposing possible danger at one time while using conventional transfer plotting techniques. The latter capability generally requires the use of at least two competent radar observers. Evasive action by one or more of the radar contacts may result in an extremely confusing situation, the timely solution of which may not be practicable by means of transfer plotting techniques.

RAPID RADAR PLOTTING

The expression RAPID RADAR PLOTTING is descriptive of techniques used to obtain solutions to relative motion problems by making the required graphical constructions on the PPI or reflection plotter as opposed to the use of a separate plotting diagram for these constructions. These techniques make *direct* use of the *timed* relative motion plot on the PPI as the relative (DRM-SRM) vector. The other two vectors of the vector triangle are scaled in accordance with the scale of the relative (DRM-SRM) vector. Thus, the magnitudes of all vectors are governed by the same interval of time, the distance scale of the radar range setting, and the respective rates of movement.

The direct use of the timed relative motion plot as the relative (DRM-SRM) vector eliminates the necessity for making measurements of the bearings and ranges of the radar targets for plotting on a separate diagram.

This information is obtained simply by marking the target pips on the PPI by grease pencil. Thus, rapid radar plotting techniques, when feasible, permit the radar observer to employ simpler procedures while being able to devote more time to radar observation.

TRANSFER PLOTTING

Relative motion solutions derived from radar data transferred to a plotting diagram can be determined through the direct use of a timed segment of the relative plot as the relative (DRM-SRM) vector of the vector triangle as in rapid radar plotting. Usually, however, the vector triangle is scaled in knots with the origin of each true vector at the center of the plotting diagram. In this transfer plotting technique, the separate relative plot and vector triangle are related in that the relative (DRM-SRM) vector of the vector triangle scaled in knots is derived from the relative plot.

As illustrated in figure 3.26, own ship's true (course-speed) vector *er* is constructed from the center of the Maneuvering Board in the direction of own ship's true course (090˚) with its magnitude scaled in knots. The 2:1 scale in the left margin is used for scaling the vectors of the vector triangle (speed triangle) in knots. Using a pair of dividers, own ship's speed of 12 knots is picked off the 2:1 scale to determine the length of vector *er*.

Using the distance scale on which the relative plot is based, i.e., the 2:1 scale (circled as an aid in avoiding the subsequent use of the wrong distance scale), the relative distance between timed plots M_1/0720 and M_2/29 is measured as 3.3 miles. With other ship M having moved 3.3 miles in 9 minutes relative to own ship R, the speed of relative movement (SRM) is 22 knots.

Since the direction of the relative (DRM-SRM) vector is that of the direction of relative movement (DRM), i.e., the direction along the relative movement line (RML) from M1 to M2, all information needed for constructing the relative (DRM-SRM) vector is available.

Transferring the DRM from the relative plot by parallel rulers or other means, a line is drawn from the extremity of own ship's true (course-speed) vector *er* in the same direction as the DRM. The length of the relative vector *rm* is taken from the 2:1 scale used in constructing own ship's true vector *er*. The true (course-speed) vector of other ship M, vector *em*, is found by completing the triangle. The speed of other ship M in knots is found by setting the length of the vector *em* to the 2:1 scale.

SELECTION OF PLOTTING TECHNIQUES

The primary advantage of transfer plotting is the higher accuracy afforded by the large vector triangles scaled in knots. Also, the plotting diagrams used provide a permanent record. For a specific situation, the selection of the basic technique to be used should be based upon the relative advantages and disadvantages of each technique as they pertain to that situation. While the individual's skill in the use of a particular technique is a legitimate factor in technique selection, the competent radar observer should be skilled in the use of both basic techniques, i.e., transfer plotting and rapid radar plotting.

During daylight when the hood must be mounted over the PPI, the rapid radar plotting technique generally is not practical. Even with hand access holes in the hood, direct plotting generally is too awkward to be feasible for reasonably accurate solutions. However, the use of a blackout curtain instead of a hood enables the use of the rapid radar plotting technique during daylight as long as the curtain adequately shields the PPI from ambient light. Since most hood designs do not permit more than one observer to view the radarscope at one time, blackout curtain arrangements which permit more than one observer to view the radarscope at one time should enable safer radar observation than hood designs which limit observation to one observer.

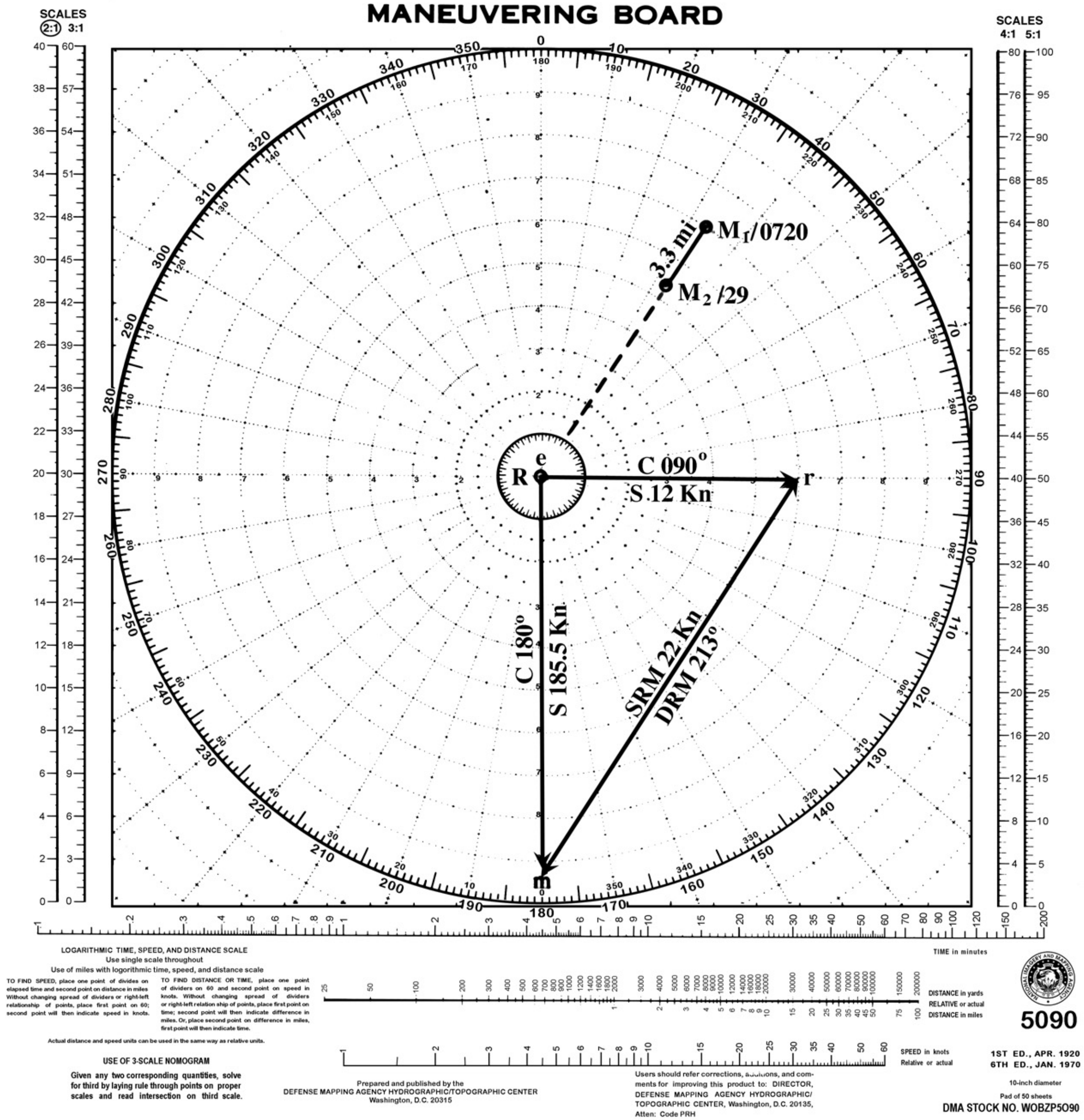


Figure 3.26 - Determining the true course and speed of the other ship by transfer plotting.

Rapid radar plotting techniques are particularly valuable when rapid, approximate solutions have higher priority than more accurate solutions derived from time consuming measurement of radar information and transfer of this information to separate plotting sheets for graphical constructions thereon. The feasibility of the rapid radar plotting techniques is enhanced when used with reflection plotters mounted on the larger sizes of PPI's. The feasibility is enhanced further at the lower radar range scale settings. With the larger PPI's and at the lower range scale settings, larger vector triangles are formed for a particular plotting interval. These larger triangles provide more accurate solutions. Plotting and graphical construction errors associated with the use of the grease pencil have lesser effects on the accuracy of the solution when the display is such that larger vector triangles are formed.

In many situations it is preferable to obtain an approximate solution rapidly on which to base early and substantial evasive action rather than wait for a more accurate solution. In the use of rapidly obtained approximate solutions, the radar observer should, of course, incorporate in his solution a larger safety factor than would be the case with more tedious and accurate solutions. Should the radar observer employ more time consuming and accurate techniques, there is always the possibility that evasive action by the other ship will nullify his solution. The same is true for early and approximate solutions, but such would have the advantage of being acted upon while the ships are at greater distances from one another. It is far better that any misunderstandings as to the intentions and actions of the ship be incurred while the ships are farther apart.

Figure 3.27 illustrates a transfer plotting solution for only two contacts initially imposing danger. From this illustration it should be readily apparent that a competent radar observer having multiple responsibilities on the navigation bridge with little, if any, assistance would have to direct his attention primarily to the transfer plotting task. Particularly if there were three radar contacts initially imposing danger, the probability for solution mistakes generally would be significantly greater because of the greater possibility of confusion associated with the overlapping vectors. If one or more of the contacts should change course or speed during the solution, evaluation of the situation could become quite difficult.

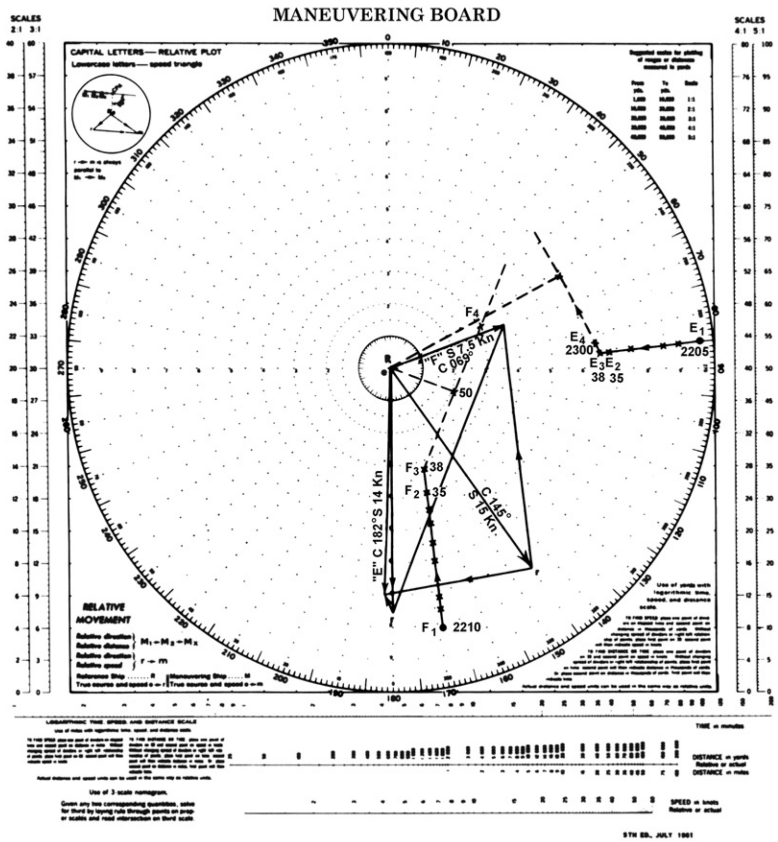


Figure 3.27 - Multiple-contact solution by transfer plotting.

The use of rapid radar plotting techniques in a multiple radar contact situation should tend to reduce solution mistakes or blunders because of the usual separation of the vector triangles. Through constructing the vector triangles directly on the PPI or reflection plotter, the probability of timely detection of new contacts and any maneuvers of contacts being plotted should be greater while using rapid radar plotting techniques than while using transfer plotting.

Should the radar observer choose to use a separate plotting sheet for each of the contacts in a multiple radar contact situation to avoid any overlapping of vector triangles in transfer plotting, this multiple usage of plotting sheets can introduce some difficulty in relating each graphical solution to the PPI display. Through constructing the vector triangles directly on the PPI display, the graphical solutions can be related more readily to the PPI display. Also, the direct plotting is compatible with a technique which can be used to evaluate the effect of any planned evasive action on the relative movements of radar contacts for which true course and speed solutions have not been obtained.

The foregoing discussion of the comparative advantages of rapid radar plotting over transfer plotting in a multiple radar contact situation does not mean to imply that rapid radar plotting techniques always should be used whenever feasible. Each basic technique has its individual merits. In some situations, the more accurate solutions afforded by transfer plotting may justify the greater time required for problem solution. However, the radar observer should recognize that the small observational and plotting errors normally incurred can introduce significant error in an apparently accurate transfer plotting solution. A transfer plotting solution may indicate that a contact on a course nearly opposite to that of own ship will pass to starboard while the actual situation is that each ship will pass port to port if no evasive action is taken. If in this situation own ship’s course is changed to the left to increase the CPA to starboard, the course of the other ship may be changed to its right to increase the CPA of a correctly evaluated port passing. Such action taken by own ship could result in a collision.

RADAR PLOTTING SYMBOLS

(See Alternative Radar Plotting Symbols)

RELATIVE PLOT

Symbol	Meaning
R	Own Ship.
M	Other Ship.
M_1	First plotted position of other ship.
M_2, M_3	Later positions of other ship.
M_x	Position of other ship on RML at planned time of evasive action; point of execution.
NRML	New relative movement line.
RML	Relative movement line.
DRM	Direction of relative movement; always in the direction of $M_1 \rightarrow M_2 \rightarrow M_3$........
SRM	Speed of relative movement.
MRM	Miles of relative movement; relative distance traveled.
CPA	Closed point of approach.

VECTOR TRIANGLE

Symbol	Meaning
e	The origin of any ship's true (course-speed) vector; fixed with respect to the earth.
r	The end of own ship's true (course-speed) vector, *er*; the origin of the relative (DRM-SRM) vector, *rm*.
r_1, r_2	The ends of alternative true (course-speed) vectors for own ship.
er	Own ship's true (course-speed) vector.
m	The end of other ship's true (course-speed) vector, *em*; the end of the relative (DRM-SRM) vector, *rm*.
em	Other ship's true (course-speed) vector.
rm	The relative (DRM-SRM) vector; always in the direction of $M_1 \rightarrow M_2 \rightarrow M_3$........

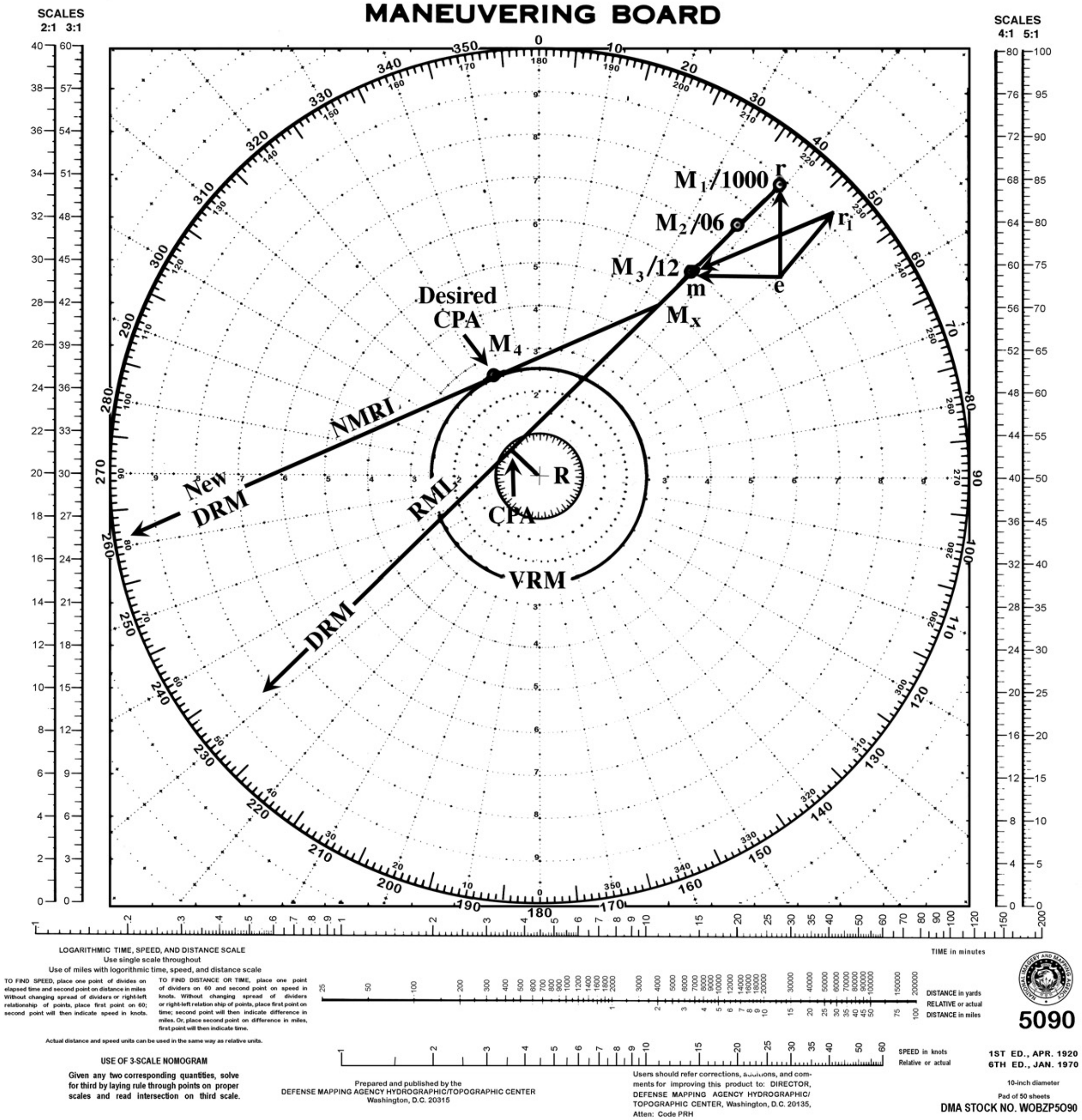


Figure 3.28 - Examples of use of radar plotting symbols.

CLOSEST POINT OF APPROACH

To determine the closest point of approach (CPA) of a contact by graphical solution on the reflection plotter, follow the procedure given below.

(1) Plot at least three relative positions of the contact. If the relative positions lie in a straight or nearly straight line, fair a line through the relative positions. Extend this relative movement line (RML) past the center of the PPI.

(2) Crank out the variable range marker (VRM) until the ring described by it is tangent to the RML as shown in figure 3.29. The point of tangency is the CPA.

(3) The range at CPA is the reading of the VRM counter; the bearing at CPA is determined by means of the mechanical bearing cursor, parallel-line cursor, or other means for bearing measurement from the center of the PPI.

Note: The RML should be reconstructed if the contact does not continue to plot on the RML as originally constructed.

TRUE COURSE AND SPEED OF CONTACT

To determine the true course and speed of a contact by graphical solution on the reflection plotter, follow the procedure given below.

(1) As soon as possible after a contact appears on the PPI, plot its relative position on the reflection plotter. Label the position with the time of the observation as shown in figure 3.29. When there is no doubt with respect to the hour of the plot, it is only necessary to show the last two digits, i.e., the minutes after the hour. In those instances where an unduly long wait would not be required it might be advantageous to delay starting the *timed* plot until the time is some tenth of an hour..., 6 minutes, 12 minutes, 18 minutes, etc., after the hour. This timing could simplify the use of the 6-minute plotting interval normally used with the rapid radar plotting technique.

(2) Examine the relative plot to determine whether the contact is on a steady course at constant speed. If so, the relative positions plot in a straight or nearly straight line; the relative positions are equally

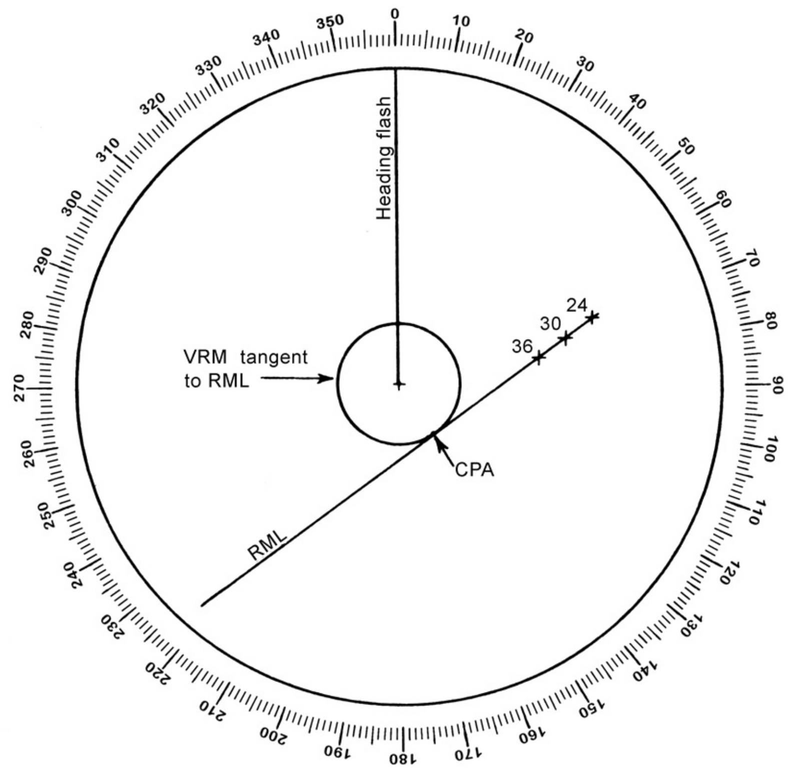


Figure 3.29 - Closest point of approach.

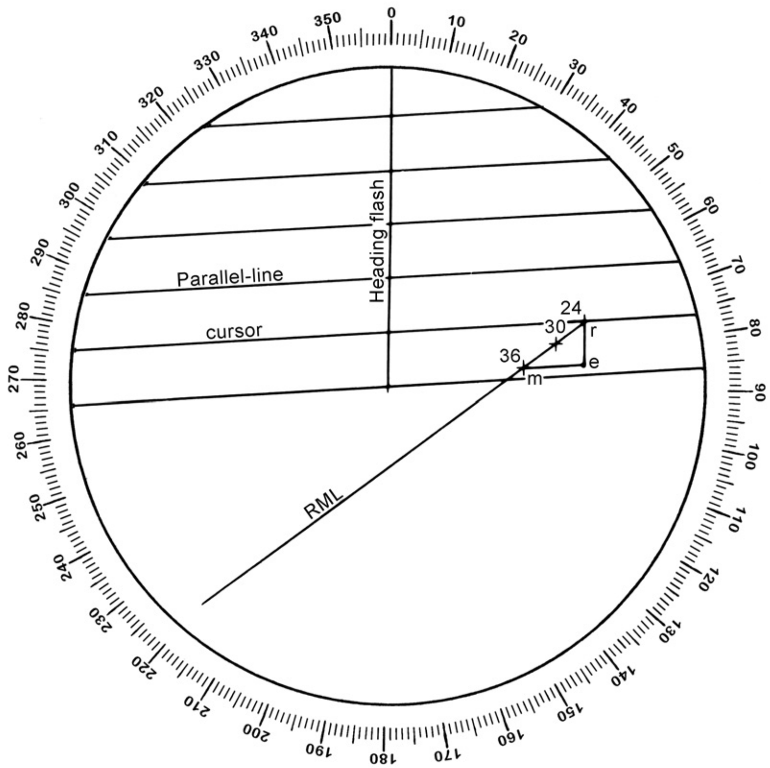


Figure 3.30 - Use of the notched plastic rule.

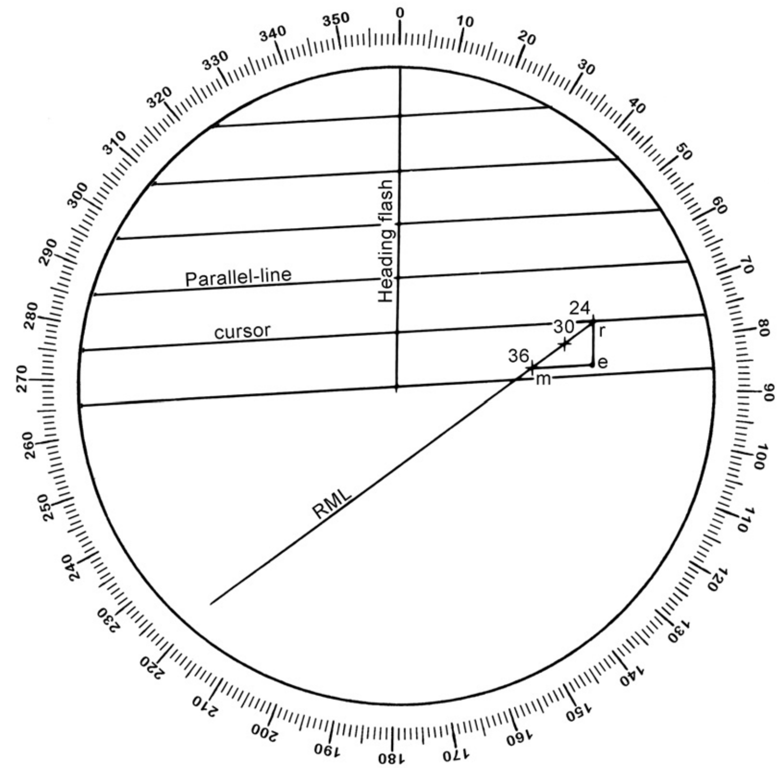


Figure 3.31 - Use of parallel-line cursor to find true course of contact.

(3) With the contact on a steady course at constant speed, select a suitable relative position as the origin of the relative speed (DRM-SRM) vector; label this plot *r* as shown in figure 3.30.

(4) Crank the parallel-line cursor until its lines are parallel to the heading flash. As shown in figure 3.30, place the appropriate plastic rule so that one notch is at *r* and its straightedge is parallel to the lines of the cursor and the heading flash. The rule is scaled for a 6-minute run between notches.

(5) Select the time interval for the solution, 12 minutes for example. Accordingly, the origin *e* of own ship's true (course-speed) vector *er* is at the second notch from *r*; *m*, the head of the contact's true (course-speed) vector, is at the plot 12 minutes beyond *r* in the direction of relative movement.

(6) Construct the contact's true (course-speed) vector *em*.

(7) Crank the parallel-line cursor so that its lines are parallel to vector *em* as shown in figure 3.31. The contact's true course is read on the true bearing dial using the radial line of the parallel-line cursor; the contact's true speed is estimated by visual comparison with own ship's true vector *er*. For example if *em* is about two-thirds the length of *er*, the contact's speed is about two-thirds own ship's speed. Or, the notched rule can be used to determine the speed corresponding to the length of *em*.

COURSE TO PASS AT SPECIFIED CPA

The procedure for determining own ship's new course and/or speed to reduce the risk of collision is given below.

(1) Continuing with the plot used in finding the true course and speed of the contact, mark the point of execution (Mx) on the RML as shown in figure 3.32. Mx is the position of the contact on the RML at the planned time of evasive action. This action may be taken at a specific clock time or when the range to the contact has decreased to a specified value.

(2) Crank the VRM to the desired distance at CPA. This is normally the distance specified for the **danger** or **buffer zone**. If the fixed range rings are displayed and one range ring is equal to this distance, it will not be necessary to use the VRM.

(3) From Mx draw the new RML tangent to the VRM circle. Two lines can be drawn tangent to the circle, but the line drawn in figure 3.32 fulfills the requirement that the contact pass ahead of own ship. If the new RML crosses the heading flash, the contact will pass ahead.

To avoid parallax, the appropriate sector of the VRM may be marked on the reflection plotter and the new RML drawn to it rather than attempting to draw the new RML tangent to the VRM directly.

(4) Using the parallel-line cursor, draw a line parallel to the new RML through *m* or the final plot (relative position) used in determining the course and speed of the contact. This line is drawn from *m* in a direction opposite to the new DRM because the new relative speed (DRM-SRM) vector will be parallel to the new RML and the head (*m*) of the new vector (*r′m*) will lie in the new DRM away from the origin, *r′*.

(5) Avoiding by course change only, the magnitude of own's true (course-speed) vector remains constant. Therefore, the same number of notches on the plastic rule used for own ship's true vector for the contact's course and speed solution are used for own ship's new true vector *er′*. With one notch set at *e*, the ruler is adjusted so that the third notch away intersects the line drawn parallel to the new RML. As shown in figure 3.32, the intersection at *r′* is the head of the required new true vector for own ship (*er′*); it is the origin of the new relative speed vector, *r′m*.

The previously described use of the plastic ruler, in effect, rotates vector *er* about its origin; the head of the vector describes an arc which intersects the line drawn parallel to the new RLM at *r′*.

If the speed of the contact were greater than own ship's speed, there would be two intersections and, thus, two courses available to produce the desired distance at CPA. Generally, the preferred course is that which results in the higher relative speed (the longer relative speed vector) in order to expedite safe passing.

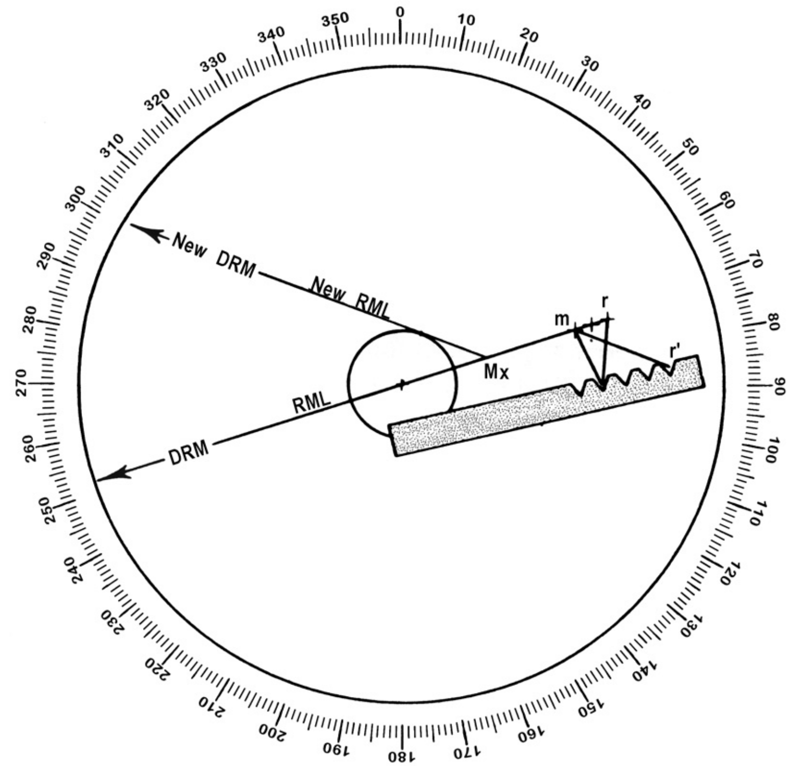


Figure 3.32 - Evasive action.

SPECIAL CASES

In situations where contacts are on courses opposite to own ship's course or are on the same course as own ship but at slower or higher speeds, the relative movement lines are parallel to own ship's course line. If a contact has the same course and speed as own ship, there is no relative movement line; all relative positions lie at one point at a constant true bearing and distance from own ship. If a contact is stationary or dead in the water, the relative vector *rm* and own ship's true vector *er* are equal and opposite, and coincident. With *e* and *m* coincident, there is no vector *em*.

The solutions of these special cases can be effected in the same manner as those cases resulting in the conventional vector triangle. However, no vector triangle is formed; the vectors lie in a straight line and are coincident.

In figure 3.33 contacts A, B, C, and D are plotted for a 12-minute interval; own ship's true vector *er* is scaled in accordance with this time. Inspection of the plot for contact A reveals that the DRM is opposite to own ship's course; the relative speed is equal to own ship's speed plus the contact's speed. The contact is on a course opposite to own ship's course at about the same speed.

Inspection of the plot for contact B reveals that the DRM is opposite to own ship's course; the relative speed is equal to own ship's speed minus the contact's speed. The contact is on the same course as own ship at about one-half own ship's speed.

Inspection of the plot for contact C reveals that the DRM is opposite to own ship's course; the relative speed is equal to own ship's speed plus the contact's speed. The contact is on a course opposite to own ship's course at about the same speed.

Inspection of the plot for contact D reveals that the DRM is the same as own ship's course; the relative speed is equal to the contact's speed minus own ship's speed. The contact is on the same course as own ship at about twice own ship's speed.

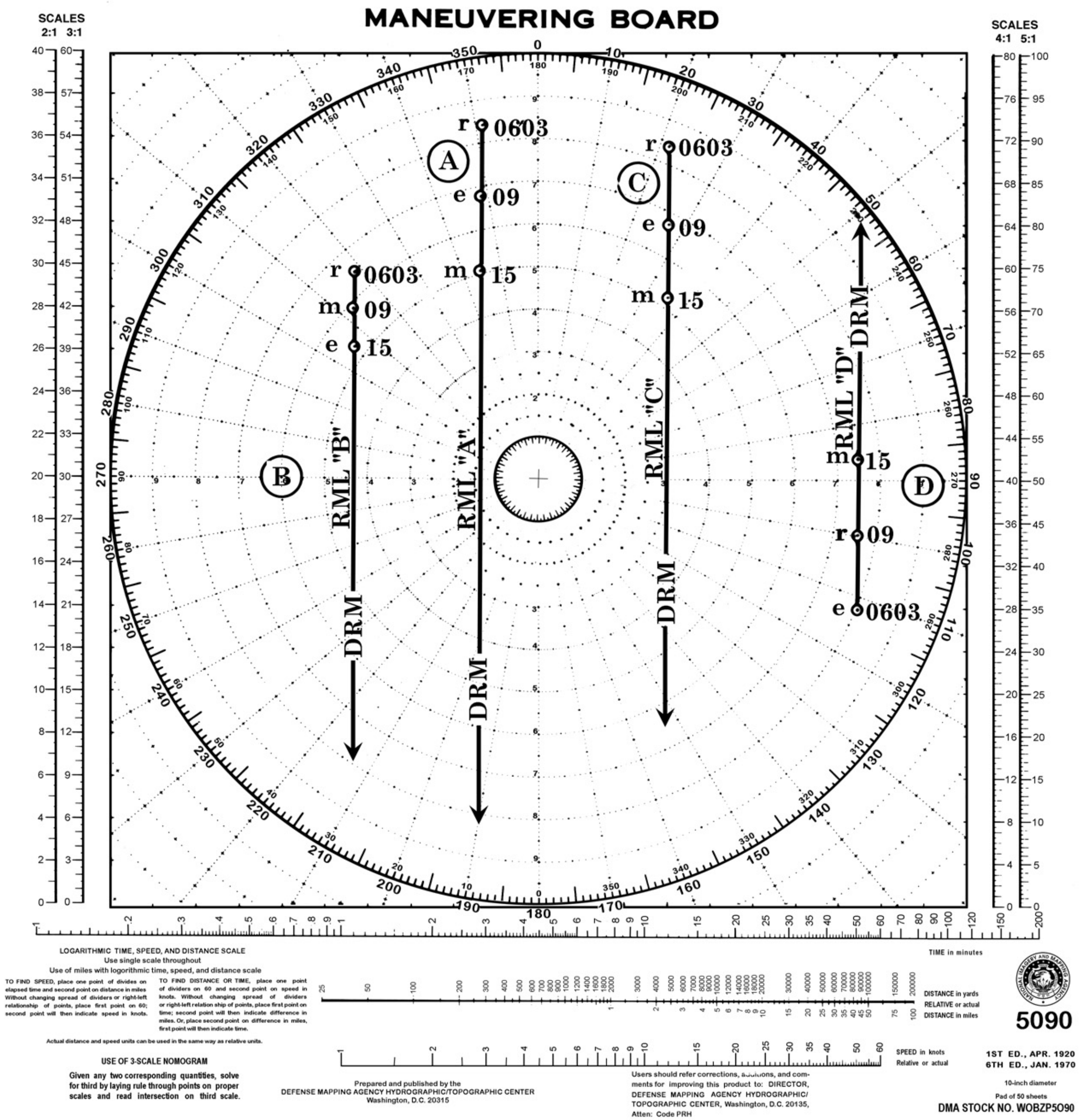


Figure 3.33 - Special cases.

CONSTRUCTING THE PLASTIC RULE USED WITH RAPID RADAR PLOTTING

When plotting by the rapid radar plotting technique, a colored 6 to 8-inch flexible plastic straightedge is normally used to construct the vectors and other line segments on the reflection plotter. The following procedure can be used to construct the desired scale for vector magnitudes on the straightedge.

(1) Switch the radar indicator to an appropriate plotting range, 24 miles for example.
(2) Crank out the variable range marker (VRM) to an integral value of range, 5 miles for example. Mark the reflection plotter at the intersection of the VRM and the heading flash as shown in figure 3.34. This point will represent zero on the scale to be constructed for subsequent transfer to the plastic strip.
(3) Compute the distance own ship will travel in 6 minutes at a speed expected to be used in collision avoidance. At a speed of 21 knots, own ship will travel 2.1 miles in 6 minutes.
(4) Since the zero mark is at 5 miles on the PPI, crank out the VRM to 7.1 miles and mark the reflection plotter at the intersection of the VRM and the heading flash to obtain the scale spacing for 2.1 miles. Repeat this procedure with the VRM set at 9.2, 11.3, and 13.4 miles to obtain other scale graduations 2.1 miles apart. The length between scale marks at 5.0 and 7.1 miles provides the magnitude of 6-minute vectors at 21 knots; the length between scale marks at 5.0 and 9.2 provides the magnitudes of 12-minute vectors at 21 knots, etc.
(5) As shown in figure 3.35, lay the plastic strip adjacent to the graduation marks on the reflection plotter and parallel to the heading flash. Extend the grease pencil marks onto the plastic strip. With the scale transferred to the plastic strip, a permanent rule is made by notching the scale on the plastic strip. The notches in the rule shown in figure 3.35 have been drawn large and angular for illustration purposes only. They should be about the size and shape of the cross-section of the lead used in the grease pencil.
(6) Several rules are normally used, each graduated for a particular range scale setting and own ship speed. The range and speed should be prominently marked on each rule.

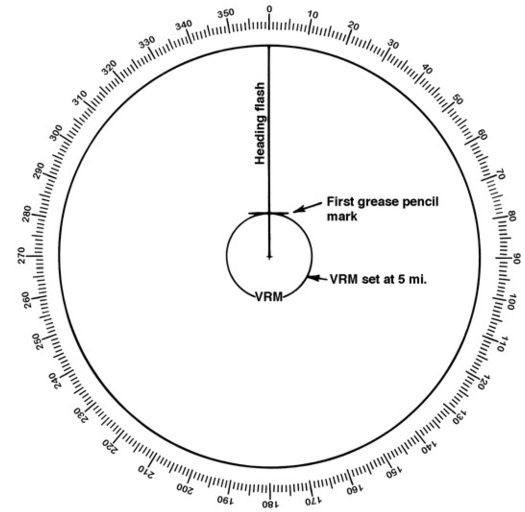


Figure 3.34 - Constructing the scale.

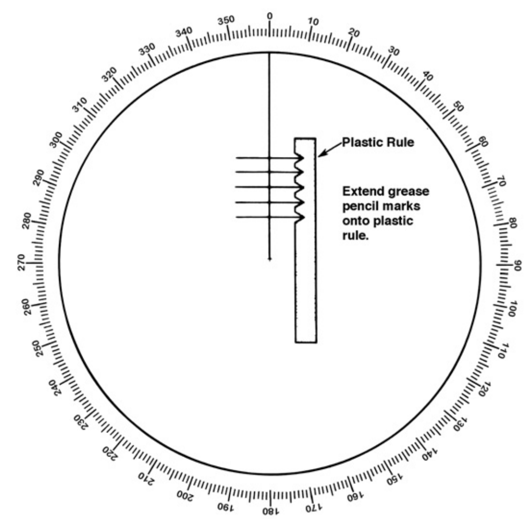


Figure 3.35 - Graduating the rule.

EXAMPLES

e-r-m TRIANGLE

EXAMPLE 1 . DETERMINATION OF CLOSEST POINT OF APPROACH (CPA)

EXAMPLE 2 . COURSE AND SPEED OF A RADAR CONTACT

EXAMPLE 3 . COURSE AND SPEED OF RADAR CONTACT BY THE LADDER METHOD

EXAMPLE 4 . COURSE TO PASS A SHIP AT A SPECIFIED CPA
Own Ship's Speed is Greater Than That of Other Ship

EXAMPLE 5 . COURSE TO PASS A SHIP AT A SPECIFIED CPA
Own Ship's Speed is Less Than That of Other Ship

EXAMPLE 6 . VERIFICATION OF FIXED OBJECTS OR RADAR CONTACTS DEAD IN THE WATER

EXAMPLE 7 . AVOIDANCE OF MULTIPLE CONTACTS WITHOUT FIRST DETERMINING TRUE COURSES AND SPEEDS OF THE CONTACTS

EXAMPLE 8 . DETERMINING THE CLOSEST POINT OF APPROACH FROM THE GEOGRAPHICAL PLOT

EXAMPLE 1

DETERMINATION OF CLOSEST POINT OF APPROACH (CPA)

Situation:

With own ship on course 070˚ and the radar set on the 12-mile range scale, other ship M is observed as follows:

Time	*Bearing*	*Range (miles)*	*Rel. position*
1000	050˚	9.0	M1
1006	049˚	7.5	M2
1012	047˚	6.0	M3

Required:

(1) Direction of relative movement (DRM).
(2) Speed of relative movement (SRM).
(3) Bearing and range at closest point of approach (CPA).
(4) Estimated time of arrival at CPA.

Solution:

(1) Plot and label the relative positions, M_1, M_2, and M_3, using the 1:1 scale; fair a line through the relative positions; extend this line, the *relative movement line (RML)*, beyond the center of the Maneuvering Board.

(2) The direction of the RML from the initial plot M_1, is the direction of relative movement (DRM): 236˚.

(3) Measure the relative distance (MRM) between any two timed plots on the RML, preferably between the two best plots with the greatest time separation. In this instance, measure the distance between M_1 and M_3: 3.0 miles. Using the corresponding time interval (1000 - 1012 = 12m), obtain the speed of relative movement (SRM) from the Logarithmic Time-Speed-Distance Scale at the bottom of the Maneuvering Board: 15 knots.

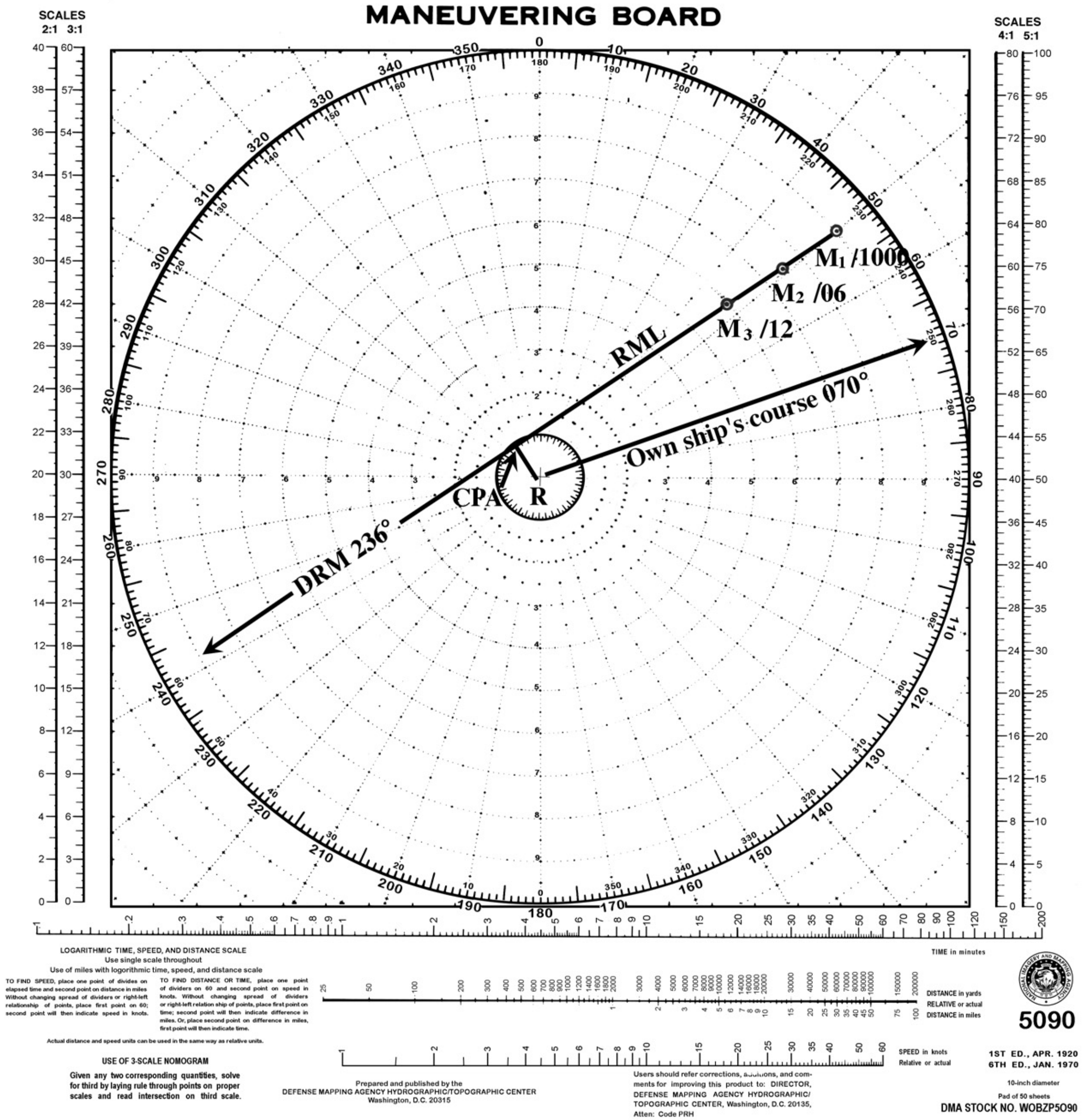
(4) From the center of the radar plotting sheet, R, draw a line perpendicular to the RML; label the intersection CPA. The direction of the CPA from the center of the plotting sheet, i.e., own ship's position, is the bearing of the CPA: 326˚; the distance from the center or own ship is the range at CPA: 0.9 mile.

(5) Measure the distance from M_3 to CPA: 6.0 miles. Using this distance and the speed of relative movement (SRM): 15 knots, obtain the time interval from 1012 (the time of plot M_3) by means of the Time-Speed-Distance Scale: 24^m. The estimated time of arrival at CPA is 1012 + 24^m = 1036.

Answers:

(1) DRM 236˚; (2) SRM 15 knots; (3) CPA 326˚, 0.9 mile; (4) ETA at CPA 1036.

EXAMPLE 1



Notes:

1. There should be sufficient plots to insure accurate construction of the RML faired through the plots. Should only two plots be made, there would be no means of detecting course or speed changes by the other ship. The solution is valid only if the other ship maintains course and speed constant. Preferably, the timed plots should be made at equal time intervals. Equal spacing of the plots timed at regular intervals and the successive plotting of the relative positions in a straight line indicate that the other ship is maintaining constant course and speed.

2. This transfer plotting solution required individual measurements and recording of the ranges and bearings of the relative position of ship M at intervals of time. It also entailed the normal requirement of plotting the relative positions on the PPI or reflection plotter. Visualizing the concentric circles of the Maneuvering Board as the fixed range rings of the PPI, a faster solution may be obtained by fairing a line through the grease pencil plot on the PPI and adjusting the VRM so that the circle described is tangent to or just touches the RML. The range at CPA is the setting of the VRM; the bearing at CPA and the DRM may be found by use of the parallel-line cursor (parallel index). The time of the CPA can be determined with reasonable accuracy through visual inspection, i.e., the length along the RML from M_3 to CPA by quick visual inspection is about twice the length between M_1 and M_3 representing about 24 minutes.

EXAMPLE 2

COURSE AND SPEED OF A RADAR CONTACT

Situation:

Own ship R is on course 340°, speed 15 knots. The radar is set on the 12-mile range scale. A radar contact, ship M, is observed to be changing course, and possibly speed, between times 0953 and 1000. While keeping a close watch of the relative movement, the relative positions of M are marked at frequent intervals on the reflection plotter by grease pencil.

Required:

(1) Course and speed of ship M when M has steadied on course and speed.

Solution:

(1) With the decision made that the solution will be obtained by rapid radar plotting, the solution is started while M is still maneuvering through determining: (a) the distance own ship will travel through the water during a time lapse of 6 minutes and (b) the length of such distance on the PPI at the range setting in use.

(i) The distance traveled by own ship in 6 minutes is one-tenth of the speed in knots, or 1.5 nautical miles.

(ii) The length of 1.5 nautical miles on the PPI may be found through use of the variable range marker (VRM). Crank the VRM out to a convenient starting point, 6 miles for instance.

Mark the intersection of the VRM and the heading flash. Crank the VRM out to 7.5 miles and mark the intersection of the VRM and the heading flash. The length between the two marks (1.5 mi.) is transferred to a short plastic rule.

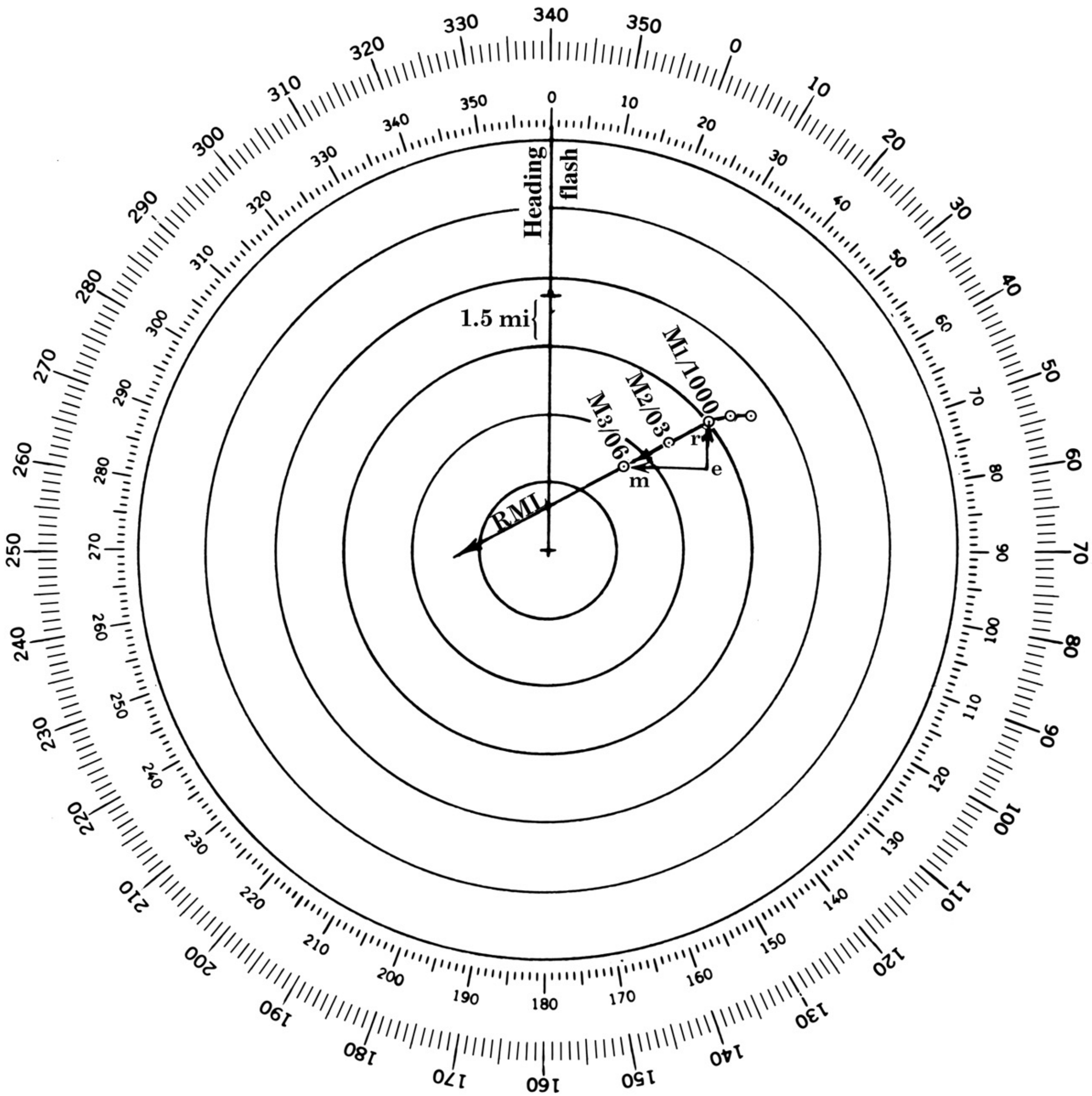
(2) Observation of the PPI reveals that between 1000 and 1006, M is on a steady course at constant speed (successive plots form a straight line on the scope; plots for equal time intervals are equally spaced). Draw the relative movement line (RML) from the 1000 plot (M_1) through the 1006 plot (M_3), extending beyond the center of the PPI.

(3) Set center line of parallel-line cursor to heading flash. At the 1000 plot (M_1) place the plastic rule, marked for the 6-minute run of own ship, parallel to the cursor lines. In the *direction of own ship's course*, draw a line of 1.5 miles length which ends at the 1000 plot. Two sides of the vector triangle have been formed (*er* and *rm*). The solution is obtained by completing the triangle to form true (course-speed) vector *em*.

(4) On completing the triangle, the third side, vector *em*, represents the true course and rate of movement of M. The true course may be read by adjusting the parallel-line cursor parallel to the third side, true vector *em*. The speed of M in knots may be estimated by comparing the length of *em* with the length of *er*, the true (course-speed) vector of own ship R, the speed of which in knots is known.

Answers:

(1) Course 252°, speed 25 knots.



EXAMPLE 2

Heading-Upward Unstabilized PPI Display with Stabilized True Bearing Dial

Scale: 12-mile range setting

Note:
In some cases it may be desirable to construct own ship's true vector originating at the end of the segment of the relative plot used directly as the relative vector *rm*. If applied to this case, the 6-minute run of own ship would be drawn *from* the 1006 plot *in the direction of own ship's course*. On completing the triangle, the third side would represent the true course and rate of movement of M.

EXAMPLE 3

COURSE AND SPEED OF RADAR CONTACT BY THE LADDER METHOD

Situation:

Own ship R is on course 120°, speed 15 knots. The radar is set on the 6-mile range scale because small wooden vessels are expected to be encountered. The range scale setting is being shifted periodically to longer ranges for possible detection of distant targets. A radar contact is being plotted on the reflection plotter. Inspection of the plot reveals that the contact is on steady course at constant speed (see solution step (2) of example 2).

Required:

(1) Course and speed of the radar contact.

Solution:

(1) With the decision made that the solutions will be obtained by rapid radar plotting, the radar observer further elects to use the Ladder Method in order to be able to *refine* the solution as the relative plot for the contact develops with time.

(2) For a 6-minute interval of time, own ship at 15 knots runs 1.5 nautical miles through the water; the run for 12 minutes is 3.0 nautical miles.

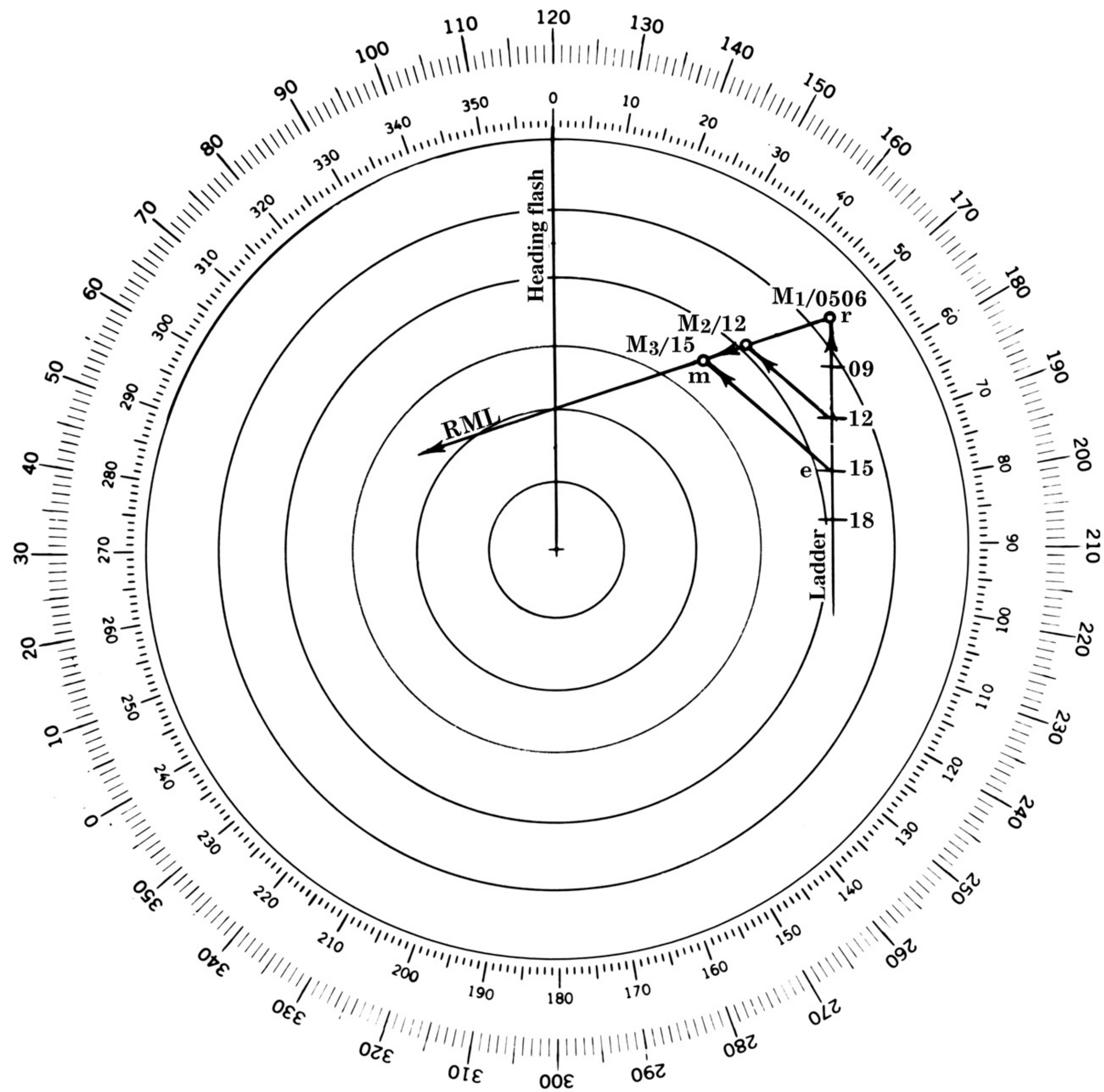
(3) Draw own ship's true (course-speed) vector *er in the direction of own ship's true course*, with the head of the vector at the 0506 plot; the length of this vector is drawn in multiples of 6-minute runs of own ship and subsequently subdivided by eye to form a ladder. Since the *timed* plot on the relative movement line starts at 0506, the starting point of the 6-minute run of own ship is labeled 12; the starting point of the 12-minute run is labeled 18.

(4) The first solution is obtained at time 0512 by drawing a line from the 12-graduation or rung on the ladder to the 0512 plot on the RML. This line, which completes the vector triangle for a 6-minute run, represents the true course and rate of movement of the contact. The true course and speed of the contact is obtained as in solution step (4) of Example 2.

(5) The second solution is obtained at time 0515 by drawing a line from the 15-graduation or rung on the ladder to the 0515 plot on the RML. This line, which completes the vector triangle for a 9-minute run, represents the true course and rate of movement of the contact.

Answers:

(1) Course 072°, Speed 17 knots.



EXAMPLE 3

Heading-Upward Unstabilized PPI Display with Stabilized True Bearing Dial

Scale: 6-mile range setting

Notes:

1. Using the ladder method, the radar observer is able to obtain an approximate solution quickly and then refine the solution as the plot develops.
2. This solution was simplified by starting the timed plot at some tenth of an hour after the hour.

EXAMPLE 4

COURSE TO PASS A SHIP AT A SPECIFIED CPA
(Own ship's speed is greater than that of other ship)

Situation:

Own ship R is on course 188˚, speed 18 knots. The radar is set on the 12-mile range scale. Other ship M, having been observed and plotted between times 1730 and 1736, is on course 258˚ at 12 knots. Ships M and R are on collision courses. Visibility is 2.0 nautical miles.

Required:

(1) Course of own ship R at 18 knots to pass ahead of other ship M with a CPA of 3.0 nautical miles if course is changed to the right when the range is 6.5 nautical miles.

Solution:

(1) Continuing with the plot on the PPI used in finding the true course and speed of other ship M, plot M_x bearing 153˚, 6.5 nautical miles from R. Adjust the VRM to 3.0 nautical miles, the desired distance at CPA. From M_x draw a line tangent to the VRM circle at M_3. From M_x two lines can be drawn tangent to the circle, but the point of tangency at M_3 fulfills the requirement that own ship pass ahead of the other ship or that other ship M pass astern of own ship R.

(2) From the origin of the true vectors of the vector triangle used in finding the true course and speed of ship M, point *e,* describe an arc of radius 1.8 nautical miles. Since own ship R will not change speed in the maneuver, the distance and corresponding PPI length of own ship's true vector (1.8 nautical miles for a 6-minute run of own ship at 18 knots) is used as the radius of the arc.

(3) Using the parallel-line cursor, draw a line through M_2 parallel to the new RML (M_x M_3) to intersect the arc drawn in (2).

(4) The intersection of the arc with the line through M_2 parallel to the new RML establishes the head of the own ship's new true (course-speed) vector drawn from point *e*. Therefore, own ship's new course when other ship M reaches relative position M_x is represented by the true vector drawn from point e to the intersection at r_1.

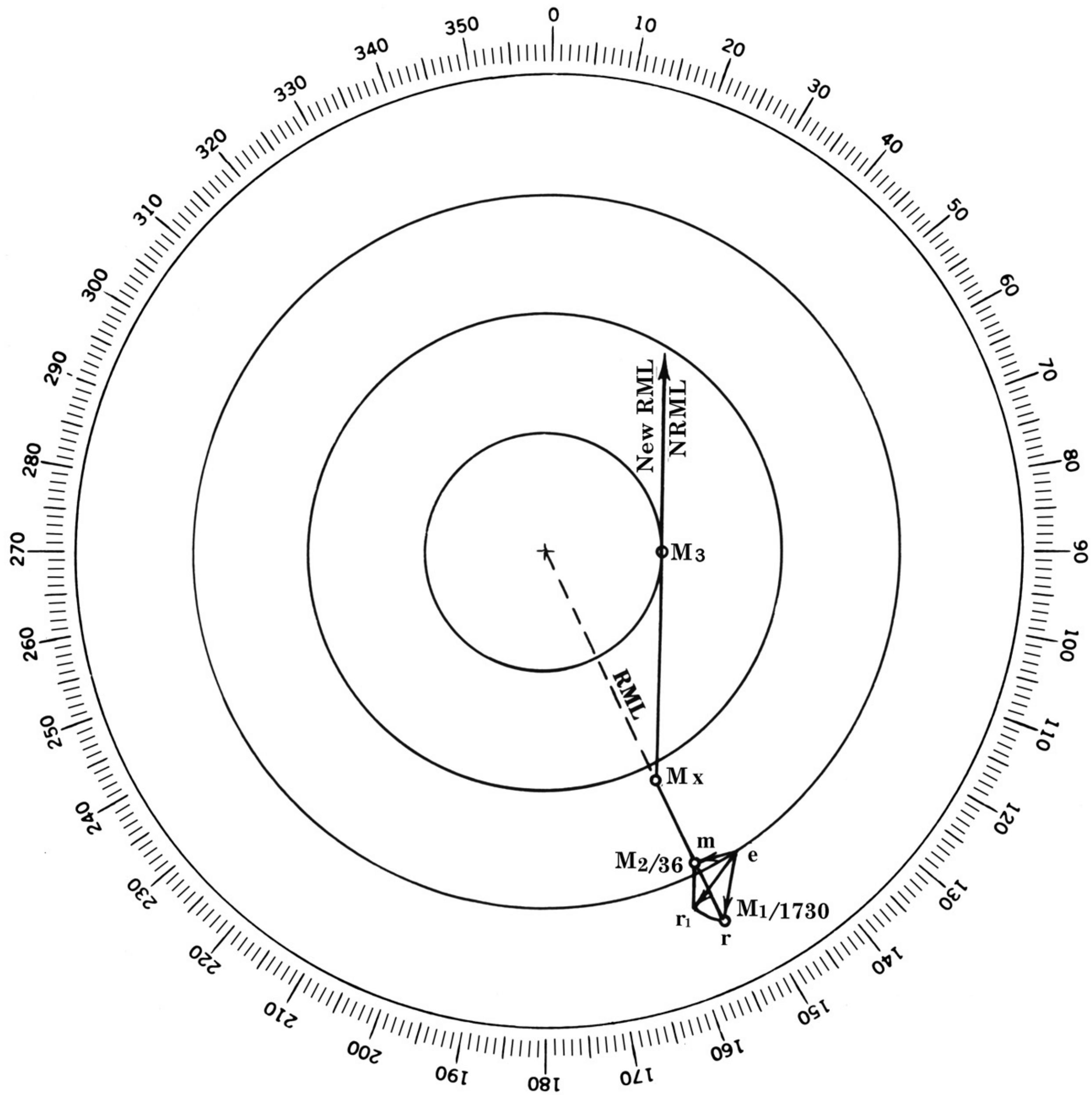
Answers:

(1) Course 218˚.

Notes:

1. Actually the arc intersecting the line drawn M_2 in a direction opposite to the new DRM would also intersect the same line if extended in the new DRM. But a new course of own ship based upon this intersection would reverse the new DRM or reverse the direction the other ship would plot on the new RML.

2. If the speed of other ship M were greater than own ship R, there would be two courses available at 18 knots to produce the desired distance at CPA. Generally, the preferred course is that which results in the highest relative speed in order to expedite the safe passing.



EXAMPLE 4

North-Upward Stabilized PPI Display

Scale: 12-mile range setting

Notes: (Continued)

3. After own ship's course has been changed, other ship R should plot approximately along the new RML, as drawn and in the desired direction of relative movement. This continuity of the plot following a course change by own ship is one of the primary advantages of a stabilized display. Immediately following any evasive action, one should inspect the PPI to determine whether the target's bearing is changing sufficiently and in the desired direction. With the stabilized display, the answer is before the radar observer's eyes.

EXAMPLE 5

COURSE TO PASS SHIP AT A SPECIFIED CPA
(Own ship's speed is less than that of other ship)

Situation:

Own ship R is on course 340˚, speed 15 knots. The radar is set on the 12-mile range scale. Other ship M, having been observed and plotted between times 0300 and 0306, is on course 249˚ at 25 knots. Since the CPA will be 1.5 nautical miles at 310˚ if both ships maintain their courses and speeds until they have passed, the distance at CPA is considered too short for adequate safety.

Required:

(1) Course of own ship R at 15 knots to pass astern of other ship M with a CPA of 3.0 nautical miles if course is changed to the right when the range to ship M is 6.0 nautical miles.

Solution:

(1) Continuing with the plot on the PPI used in finding the true course, speed, and CPA of ship M, plot M_x on the RML 6.0 nautical miles from own ship R. Set the VRM to 3.0 nautical miles, the desired distance at CPA (in this case the VRM setting is coincident with the first fixed range ring). From M_x two lines can be drawn tangent to the VRM circle, but the point of tangency at M_3 fulfills the requirement that own ship pass astern of other ship M.

(2) From the origin of the true vectors of the vector triangle used in finding the true course and speed of ship M, point *e*, describe an arc of radius 1.5 nautical miles. Since own ship will not change speed in the maneuver, the distance and corresponding PPI length of own ship's true vector (1.5 nautical miles for a 6-minute run of own ship at 15 knots) is used as the radius of the arc.

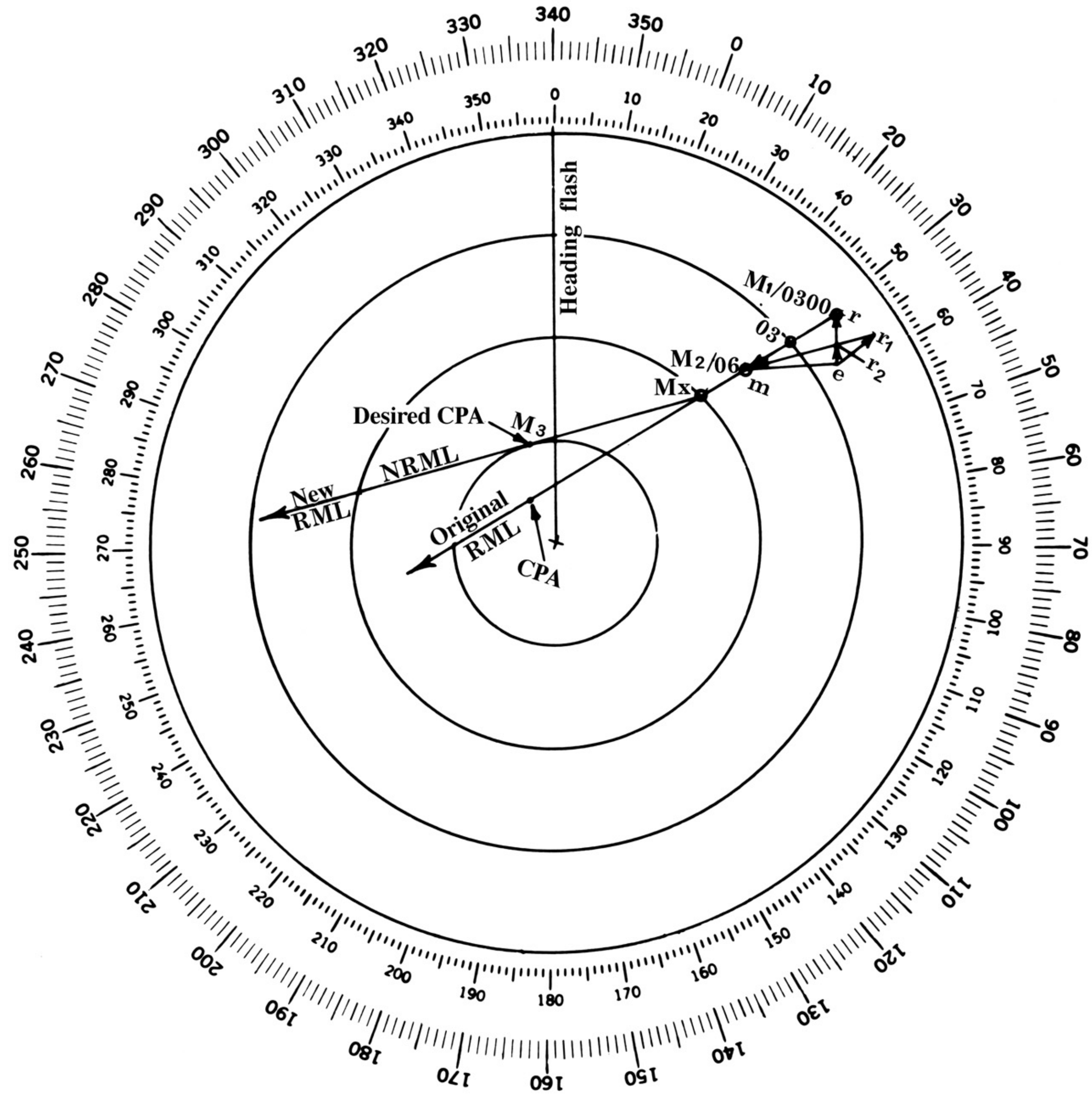
(3) Using the parallel-line cursor, draw a line through M_2 parallel to the new RML (M_x M_3) to intersect the arc drawn in (2).

(4) Since the speed of other ship M is greater than that of own ship R, the arc intersects the line through M_2 at two points. Each intersection establishes a head of a possible new own ship's true vector. Of the two possible vectors one provides a higher speed of relative movement than the other. Generally, the true vector which provides the higher SRM or longer relative vector is chosen to expedite the passing. However, in this example a course change to the right is specified. This requires the use of vector er_1, which provides the higher SRM.

(5) With this unstabilized, Heading-Upward PPI display, there is a complication arising from the plot shifting equal and opposite to the amount and direction of the course change. Some reflection plotter designs have provisions for either manual or automatic shifting of their plotting surfaces to compensate for the shifting of the plot. Without this capability, there is no continuity in the grease pencil plot following course changes by own ship. Consequently, it is necessary to erase the plot and replot the other ship's relative position when own ship steadies on course. With the VRM set to 3.0 miles, the new RML must be drawn tangent to the circle described by the VRM. The other ship must be watched closely to insure that its relative movement conforms with the new RML.

Answers:

(1) Course 030˚.



EXAMPLE 5

Heading–Upward Unstabilized PPI Display with Stabilized True Bearing Dial

Scale: 12-mile range setting

Note:

Examination of the plot reveals that if own ship R maintains its original true course (340˚), the intersection of the original true vector *er* of own ship with the line drawn through M_2 parallel to the new RML provides the head of the vector er_2 required to effect the desired CPA without course change. Since the length of vector er_2 is approximately half that of the original vector *er*, an instantaneous change to approximately half the original speed would produce the desired results. A lesser change of course to the right in conjunction with a speed reduction could be used to compensate for deceleration.

EXAMPLE 6

VERIFICATION OF FIXED OBJECTS OR RADAR CONTACTS DEAD IN THE WATER

Situation:

Own ship R is on course 340˚, speed 20 knots. The radar is set at the 24-mile range scale. Radar observations are made as follows:

Time	*Bearing*	*Range (miles)*	*Rel. position*
1200	017˚	22.8	M_1
1218	029˚	17.4	M_2
1236	046˚	14.4	M_3

The RML is parallel to and the DRM is opposite to own ship's course, 340˚.

Required:

Course and speed of M in order to verify whether M is dead in the water or a terrestrial object.

Solution:

(1) On the PPI, preferably a reflection plotter mounted thereon, plot M_1, M_2, M_3. Draw the relative movement line (RML) through the relative positions, M_1, M_2, M_3.

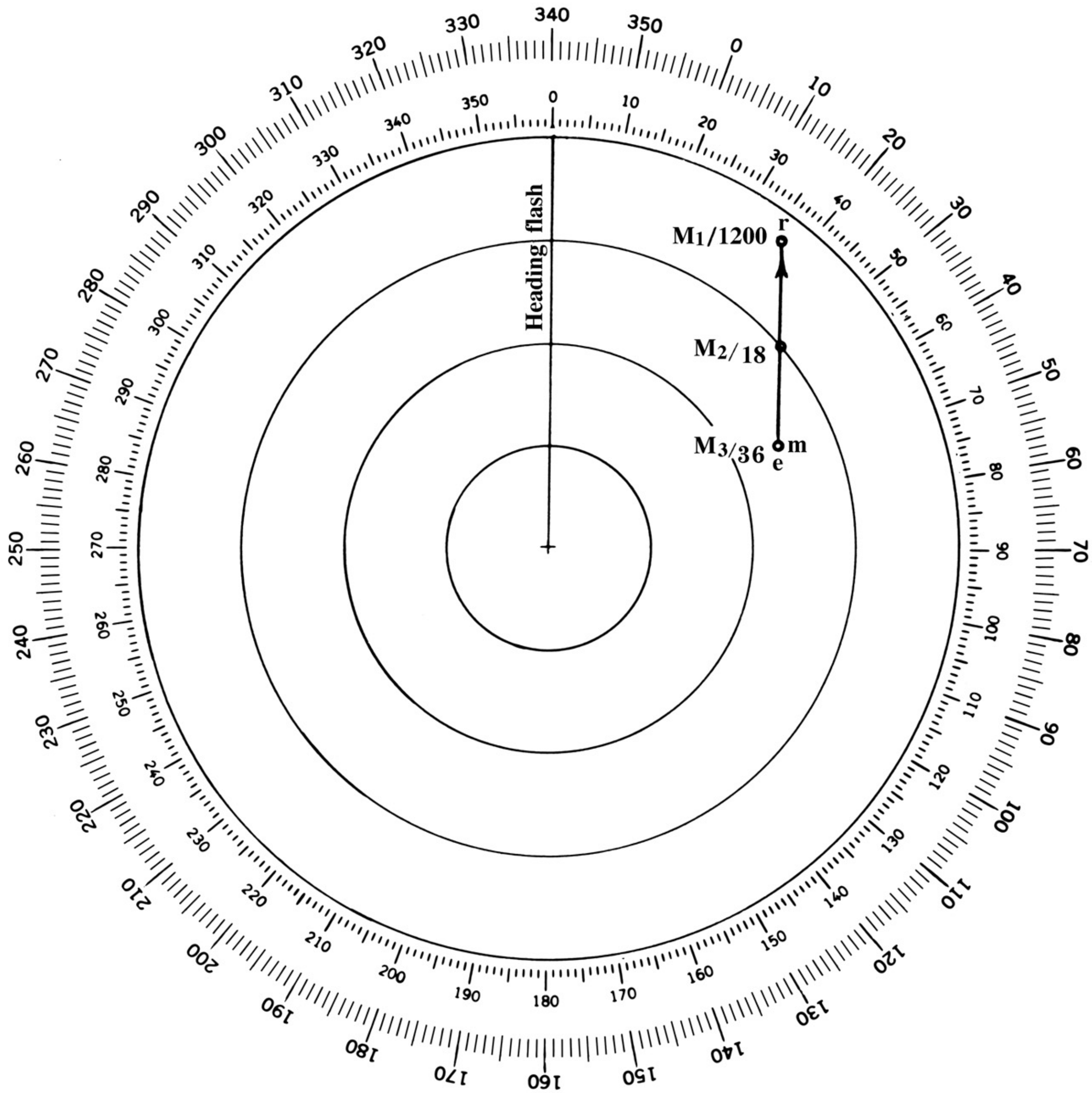
(2) Using the same distance scale as the radar range setting, determine the length of the true (course-speed) vector *er* of own ship R for a time interval of 36 minutes: 12 miles.

(3) Draw true vector *er in the direction of own ship's course* with its head at relative position M_1. If, after such graphical construction, the vector origin *e* lies over relative position M_3, the length of the *em* vector would be zero. Thus, the true speed of the observed contact would be zero. Even if the observed target is dead in the water or a fixed object, small observational and plotting errors will frequently indicate a small value of true speed for the contact.

EXAMPLE 6

Heading-Upward Unstabilized PPI Display with Stabilized True Bearing Dial

Scale: 24-mile range setting



EXAMPLE 7

AVOIDANCE OF MULTIPLE CONTACTS WITHOUT FIRST DETERMINING THE TRUE COURSES AND SPEEDS OF THE CONTACTS

Situation:

Own ship R is on course 000˚, speed 20 knots. With the stabilized relative motion display radar set at the 12-mile range setting, radar contacts A, B, and C are observed and plotted directly on the PPI or reflection plotter. The plots at time 1000 are considered as the initial plots in the solution.

Required:

(1) Determine the new relative movement lines for contacts A, B, and C which would result from own ship changing course to 065˚ and speed to 15 knots at time 1006.

(2) Determine whether such course and speed change will result in desirable or acceptable CPA's for all contacts.

Solution:

(1) With the center of the PPI as their origin, draw own ship's true vectors *er* and *er′* for the course and speed in effect or to be put in effect at times 1000 and 1006, respectively. Using the distance scale of the radar presentation, draw each vector of length equal to the distance own ship R will travel through the water during the time interval of the relative plot (relative vector), 6 minutes. Vector *er*, having a speed of 20 knots, is drawn 2.0 miles in length in true direction 000˚; vector *er′*, having a speed of 15 knots, is drawn 1.5 miles in length in true direction 065˚.

(2) Draw a dashed line between *r* and *r′*.

(3) For contacts A, B, and C, offset the initial plots (A_1, B_1, and C_1) in the same direction and distance as the dashed line *r-r′*; label each such offset plot *r′*.

(4) In each relative plot, draw a straight line from the offset initial plot, *r′*, through the final plot (A_2 or B_2 or C_2). The lines *r′* A_2, *r′* B_2, and *r′* C_2 represent the new RML's which would result from a course change to 065˚ and speed change to 15 knots at time 1006.

Answers:

(1) New RML of contact A-DRM 280˚
New RML of contact B-DRM 051˚
New RML of contact C-DRM 028˚

(2) Inspection of the new relative movement lines for all contacts indicates that if all contacts maintain course and speed, all contacts will plot along their respective relative movement lines at a safe distances from own ship R on course 065˚, speed 15 knots.

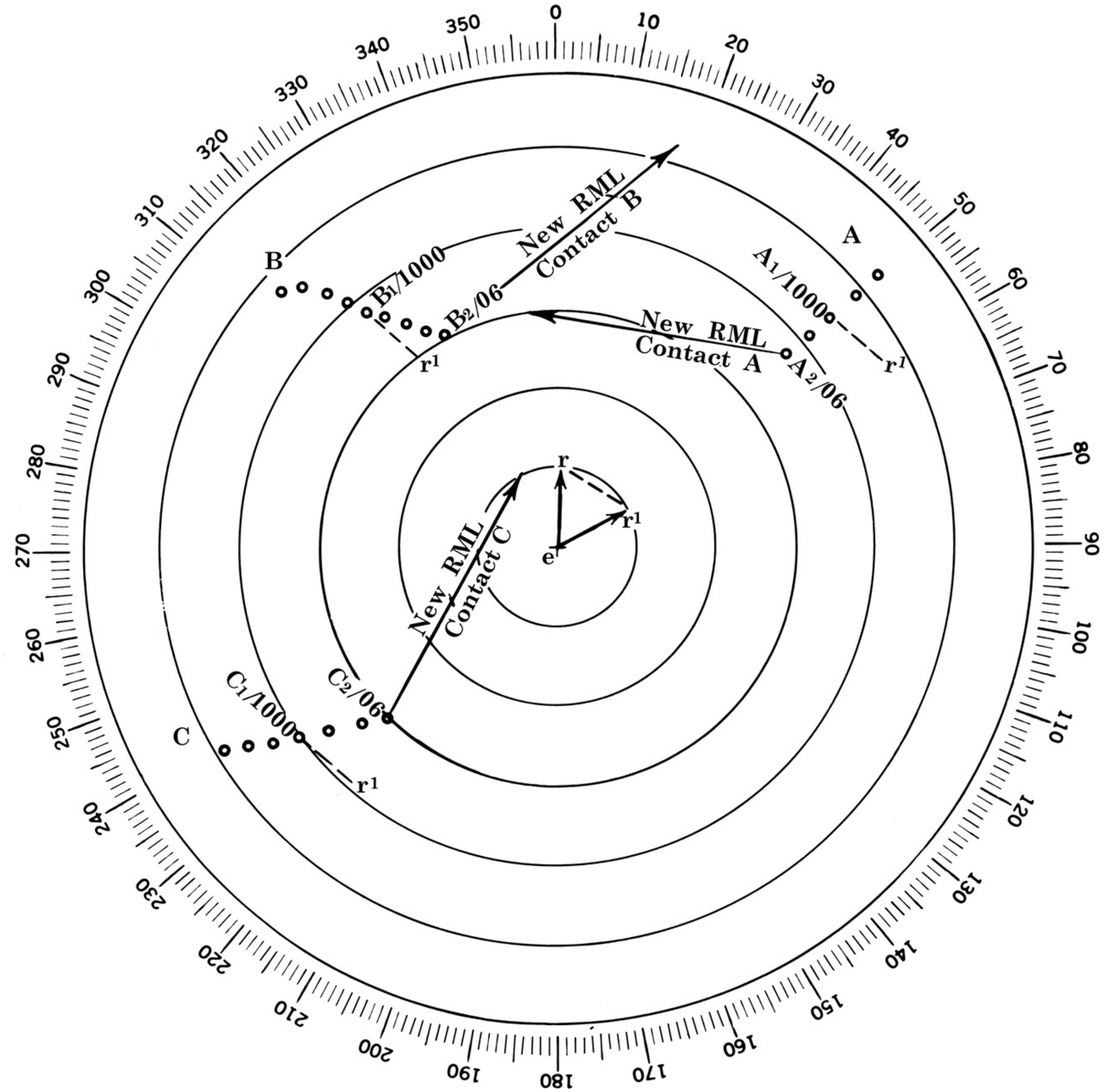
Explanation:

The solution is based upon the use of the relative plot as the relative vector. With each contact maintaining true course and speed, the *em* vector for each contact remains static while own ship's *er′* vector is rotated about *e* to the new course and changed in magnitude corresponding to the new speed.

EXAMPLE 7

North-Upward
Stabilized PPI Display

Scale: 12-mile range setting



EXAMPLE 8

DETERMINING THE CLOSEST POINT OF APPROACH FROM THE GEOGRAPHICAL PLOT

Situation:

Own ship R is on course 000˚, speed 10 knots. The true bearings and ranges of another ship are plotted from own ship's successive positions to form a geographical (navigational) plot:

Time	*Bearing*	*Range (miles)*	*Rel. position*
0200	074˚	7.3	T_1
0206	071˚	6.3	T_2
0212	067˚	5.3	T_3

Required:

(1) Determine the closest point of approach.

Solution:

(1) Since the successive *timed* positions of each ship of the geographical plot indicate rate of movement and true direction of travel for each ship, each line segment between successive plots represents a true velocity vector. Equal spacing of the plots timed at regular intervals and the successive plotting of the true positions in a straight line indicate that the other ship is maintaining constant course and speed.

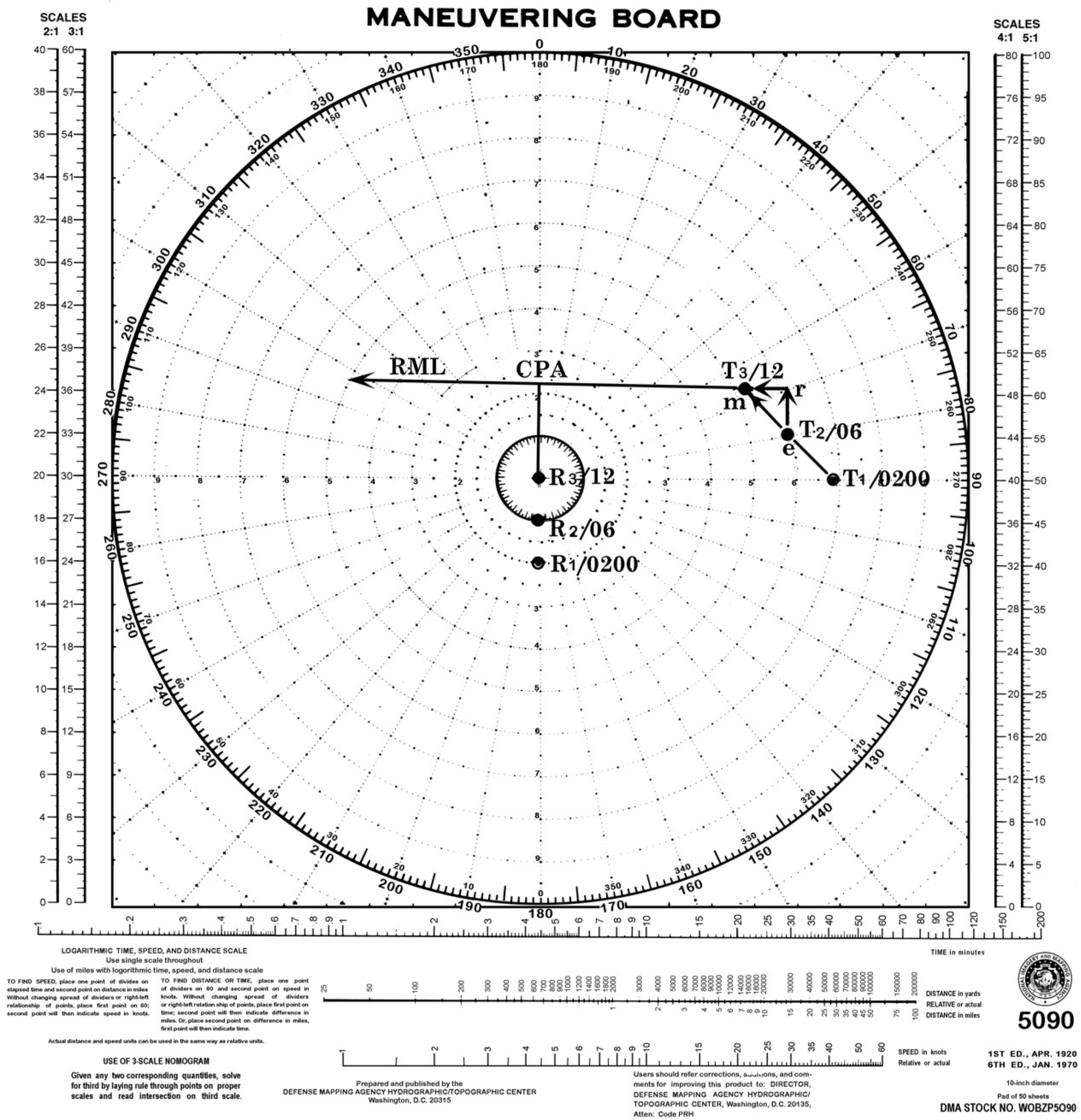
(2) The solution is essentially a reversal of the procedure in relative motion solutions in which, from the relative plot and own ship's true vector, the true vector of the other ship is determined. Accordingly, the true vectors from the two true plots for the same time interval, 0206-0212 for example, are subtracted to obtain the relative vector ($rm = em - er$).

(3) The relative (DRM-SRM) vector *rm* is extended beyond own ship's 0212 position to form the relative movement line (RML).

(4) The closest point of approach (CPA) is found by drawing a line from own ship's 0212 plot perpendicular to the relative movement line.

Answers:

(1) CPA 001˚, 2.2 miles.



EXAMPLE 8

Note:

Either the time 0200, 0206, or 0212 plots of the other ship can be used as the origin of the true vectors of the vector diagram. Using the time 0200 plot as the origin and a time interval of 6 minutes for vector magnitude, the line perpendicular to the extended relative movement line would be drawn from the time 0206 plot of own ship.

While the Maneuvering Board has been used in illustrating the solution, the technique is applicable to solutions for CPA on true motion displays. See PRACTICAL SOLUTION FOR CPA IN TRUE MOTION MODE.

ALTERNATIVE RADAR PLOTTING SYMBOLS

The alternative radar plotting symbols described in this section were derived from those used in *Real Time Method of Radar Plotting* by Max H. Carpenter and Captain Wayne M. Waldo of the Maritime Institute of Technology and Graduate Studies, Linthicum Heights, Maryland. The above manual should be referred to for a more complete explanation of the symbols and their use in radar plotting.

The explanation of the alternative symbols as given here follows an approach different from that used by Carpenter and Waldo. The two approaches should be helpful to the student.

The alternative symbols are deemed to provide simpler and more representational symbology for Rapid Radar Plotting than does the *Maneuvering Board* symbology, which has value for relative motion solutions of greater variety than those normally associated with collision avoidance. Greater simplicity is afforded by using the same symbols for the relative motion plot and the corresponding side of the vector diagram (triangle). The symbols are deemed to be more representational in that the symbols suggest their meaning.

As shown in figure 3.36, the relative motion plot is labeled *R-M*; the true motion plot is labeled *T-M*. In the relative motion case, the first plot is at *R*; the second plot (or the plot for the time interval to be used in the solution) is labeled *M*. Thus, *R-M* is descriptive of the relative motion plotted. Likewise with the first plot being labeled *T* in the true motion case, *T-M* is descriptive of the true motion plotted.

As is also shown in figure 3.36, the plots are annotated with time in two digits (for minutes of time). Preferably the first plot is for zero time rather than clock time. Such practice is enhanced with the use of a suitable timer which can be readily reset as required. Such practice, which is followed here, facilitates plotting at desired intervals and also enables more accurate timing of the plot.

When using this symbology in textual references, time interval from zero time is indicated as a subscript of a symbol when appropriate. For example, the relative plot (or relative vector) for plotting interval 3 minutes may be shown as

$$\mathbf{R_{00}—M_{03}}$$

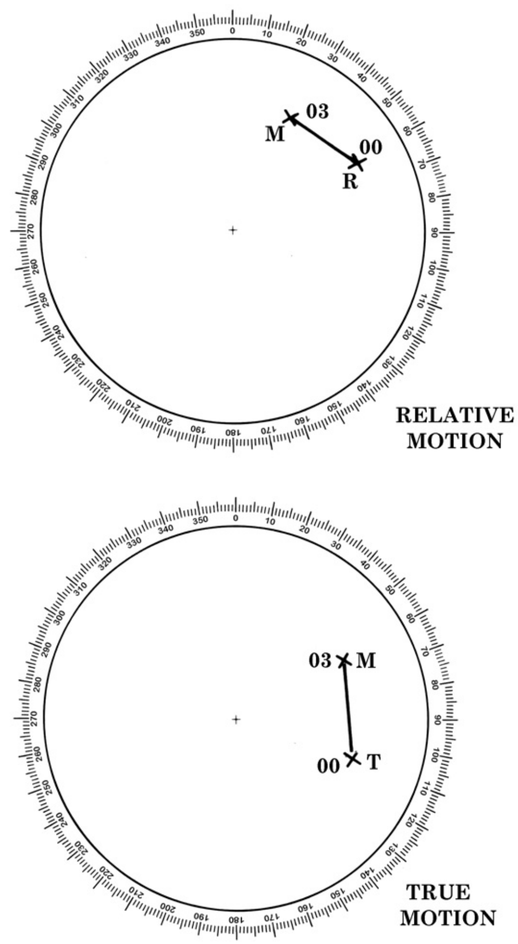


Figure 3.36 - Relative and true motion plots.

In actual plotting on the reflection plotter, the placement of the time annotation is affected by practical considerations, including clutter.

With consideration at this point that Rapid Radar Plotting makes direct use of the relative plot as the relative vector of the vector diagram (triangle), the symbols for the other two vectors or sides of the triangle are now described.

Since the other two vectors are *true* vectors, the symbol *T* is used to indicate the origin of both vectors at a common point. One of the true vectors must end at *R*, the other at *M*. The true vector *T-R* is own ship's (reference ship *R* in the other symbology) true (course-speed) vector; the other true vector *T-M* is the other ship's (other ship *M* in the other symbology) true (course-speed) vector.

Own ship's true vector *T-R* being suggestive of the abbreviation *TR* for track, in turn suggests true course and speed. Or, using a combination of symbologies, the symbol *T-R* suggests true vector for reference ship *R* (own ship).

The other ship's true vector *T-M* is suggestive of true motion (of the other ship, or of other ship M, using a combination of symbologies). See figure 3.37 for the R-T-M triangle.

Now thinking in terms of true motion rather than true course and speed of the other ship, the abbreviations DTM and STM are used to indicate direction of true motion and speed of true motion, respectively.

In brief the vectors are comprised of the following elements:

R-M: DRM & SRM
T-R: Course & Speed (of own ship)
T-M: DTM & STM (of other ship)

Abbreviations common to both symbologies are CPA (Closest Point Approach), DRM (Direction of Relative Movement), SRM (Speed of Relative Movement) and NRML (New Relative Movement Line). In addition to DTM (Direction of Contact's True Motion) and STM (Speed of Contact's True Motion), the alternative symbology uses MCPA for minutes to CPA. The symbol R is used to indicate the head of own ship's true vector following a change of course or speed or both to obtain a new RML. The symbol M is also used to indicate the point of execution.

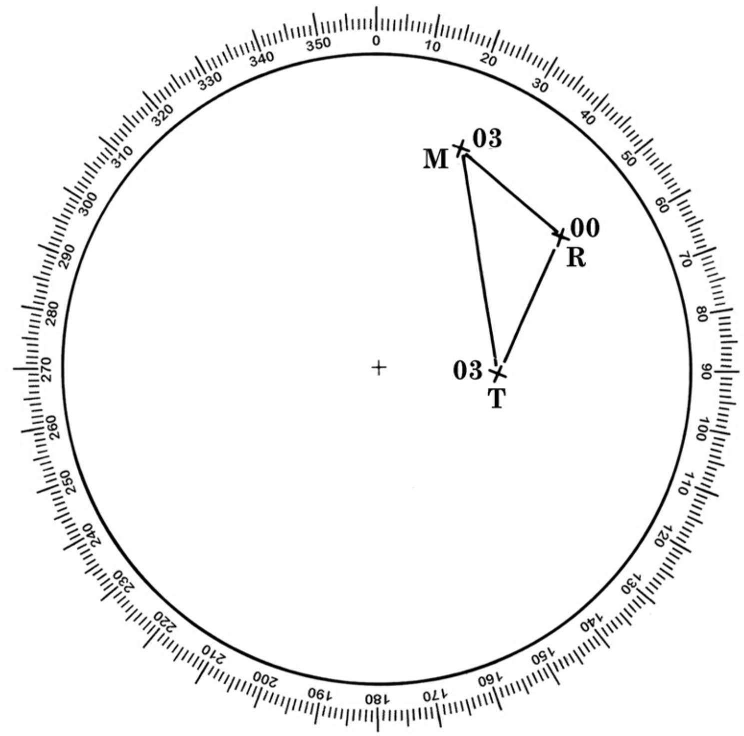


Figure 3.37 - *R-T-M* triangle.

The following is an alternative presentation of the *R-T-M* triangle which does not use vector terminology.

By examining the combination geographic (true) and relative plot in figure 3.38, it can be seen that *T-M* of the triangle is the path actually followed by the other ship at the rate of its actual speed. At the time of the first observation from *T′*, the other ship was actually at *T*, not *R*. Also own ship was at *T′*, not *R′*. However, at the end of the plotting interval, the other ship was actually at *M* and own ship was actually at *R′*. But all observations of the other ship were actually plotted from *R′*. Thus, the first observation placed the other ship at *R*; successive observations place the other ship at points along *R-M* until *M* was reached at the end of the plotting interval.

In the above presentation the true motion of the other ship is given. But in the normal course of radar observation for collision avoidance purposes, this motion must be determined. With *R-M* derived by plotting, it can be seen by inspection that *T* of the triangle can be located by constructing *T-R* in the direction of own ship's course and scaled according to the distance own ship travels during the plotting interval. After such construction, the triangle is completed to find *T-M* (DTM & STM).

STANDARD PLOTTING PERIOD

A standard plotting period, which varies in a simple, easily remembered relationship with the range scale setting, can be used to facilitate scaling *T-R* or determining STM from *T-M*. The use of standard plotting period is enhanced when the PPI has six fixed range rings and the range scales are $1^1/_2$, 3, 6, 12, 24, and 48 miles.

The standard plotting period enables the direct use of the range ring separation as the speed scale as shown below. On a given properly adjusted (for linearity) PPI with six range rings, the ring separation is 5 centimeters. On the 6-mile scale, this separation (5 centimeters) represents 1 nautical mile. On the 12-mile scale, the same separation between rings (5 centimeters) represents 2 nautical miles; and on the 24-mile scale, 4 nautical miles, etc. With distance in miles traveled in 6 minutes being numerically equal to one-tenth of the speed in knots, at 20 knots a vessel travels 2 miles in 6 minutes. Thus, on the frequently used 12-mile scale, a vessel steaming at 20 knots (relative or true) travels a distance (relative or true) equal to the range ring separation (5 centimeters or 2 nautical miles) in the number of minutes (6) equal to one half of the range scale in miles (12). With the range scale changed to 6 miles, a vessel at 20 knots (relative or true) still travels a distance (relative or true) equal to the range ring separation (5 centimeters now corresponding to 1 nautical mile) during the number of minutes (3) equal to one half of the range scale in miles (6).

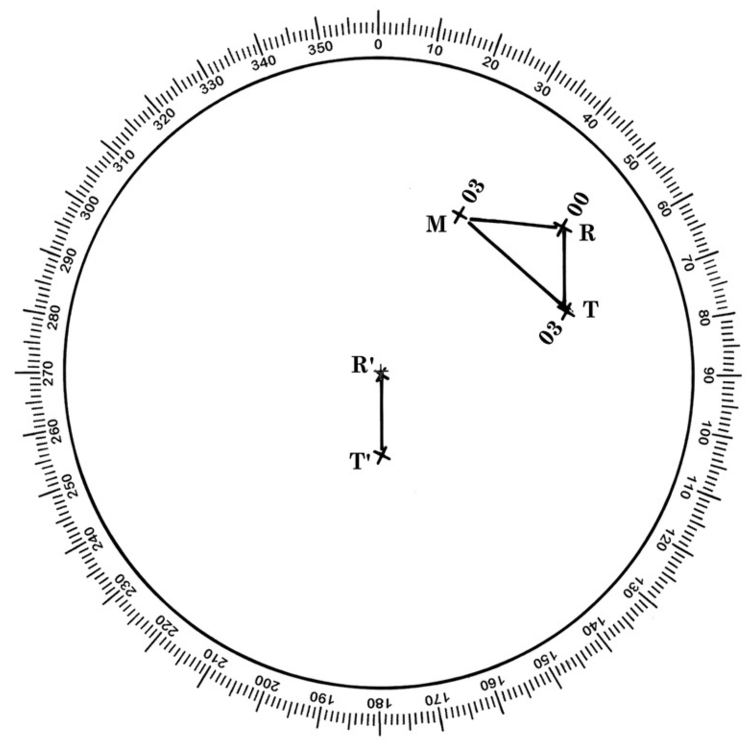


Figure 3.38 - Combination geographic (true) and relative plot.

Whatever the speed of own ship or of the other ship may be, for the six-ring PPI having the scales as described above, the standard plotting period remains: *a period in minutes equal to one half of the range scale in miles*. For example on the 12-mile scale and using the associated 6-minute standard plotting period, a vessel at 20 knots travels one ring separation (5 centimeters) during the plotting period; at 10 knots the vessel travels one half of the ring separation during the same period. Thus a single speed scale can be calibrated linearly for use with different range scales. But the associated standard plotting period must be used with each range scale.

In summary, the standard plotting period makes one range ring separation equal to 20 knots whatever the range scale setting may be. Multiples and sub-multiples of this one range ring separation for 20 knots establish other speeds as shown in figure 3.39.

The standard plotting intervals based upon the six-ring PPI and range scales described above and upon one range ring separation corresponding to 20 knots are summarized as follows:

Range Scale (miles)	*Standard Plotting Period*
12	6 min.
6	3 min.
3	90 sec.
1.5	45 sec.

If the PPI has four fixed range rings, standard plotting periods can be established in like manner for one range ring separation equal to 20 knots. As with the six-ring PPI, the standard plotting period doubles as the range scale doubles. The only difference is that the standard plotting period is three-fourths of the range scale setting, instead of one-half.

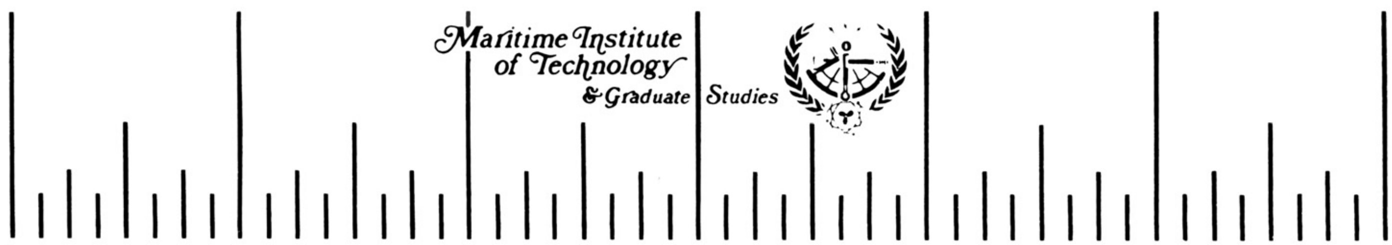


Figure 3.39 - Standard plotting period scale. Under "black light" illumination a plastic scale of chartreuse color has been found to be most useful.

SUMMARY OF ALTERNATIVE PLOTTING SYMBOLS
R-T-M TRIANGLE

RELATIVE PLOT

Symbol	Meaning
R_{00}	First plotted position of other ship; plotted position of other ship at time 00.
M_{03}, M_{06}	Plotted positions of other ship at times 03 and 06, respectively.
M_x	Position of other ship on RML at planned time of evasive action; point of execution.
RML	Relative movement line.
NRML	New relative movement line.
DRM	Direction of relative movement; always in the direction of $R_{00} \rightarrow M_{03} \rightarrow M_{06}$........
SRM	Speed of relative movement.
CPA	Closest point of approach.
MCPA	Minutes to CPA.
TCPA	Time to CPA.

VECTOR TRIANGLE

Symbol	Meaning
T_{03}	The origin of any ship's true (course-speed) vector; fixed with respect to the earth. The subscript is the plotting period used to construct the triangle.
R_{00}	The head of own ship's true (course-speed) vector, T_{03}-R_{00}; the origin of the relative (DRM-SRM) vector, R_{00}-M_{03}.
T_{03}-R_{00}	Own ship's true (course-speed) vector.
T_{03}-M_{03}	Other ship's true (course-speed) vector. The subscript is the plotting period used to construct the triangle.
DTM	Direction of other ship's true motion.
STM	Speed of other ships true motion.
R_{00}-M_{03}	The relative (DRM-SRM) vector; always in the direction of $R_{00} \rightarrow M_{03} \rightarrow M_{06}$........
R_c	The head of own ship's true (course-speed) vector following course or speed change or both to obtain a new RML.
R_c-M_{03}	The relative (DRM-SRM) vector; always in the direction of the new RML (M_x M_{x+3} M_{x+6}...).
T_{03}-R_c	Own ship's true (course-speed) vector required to obtain new RML.

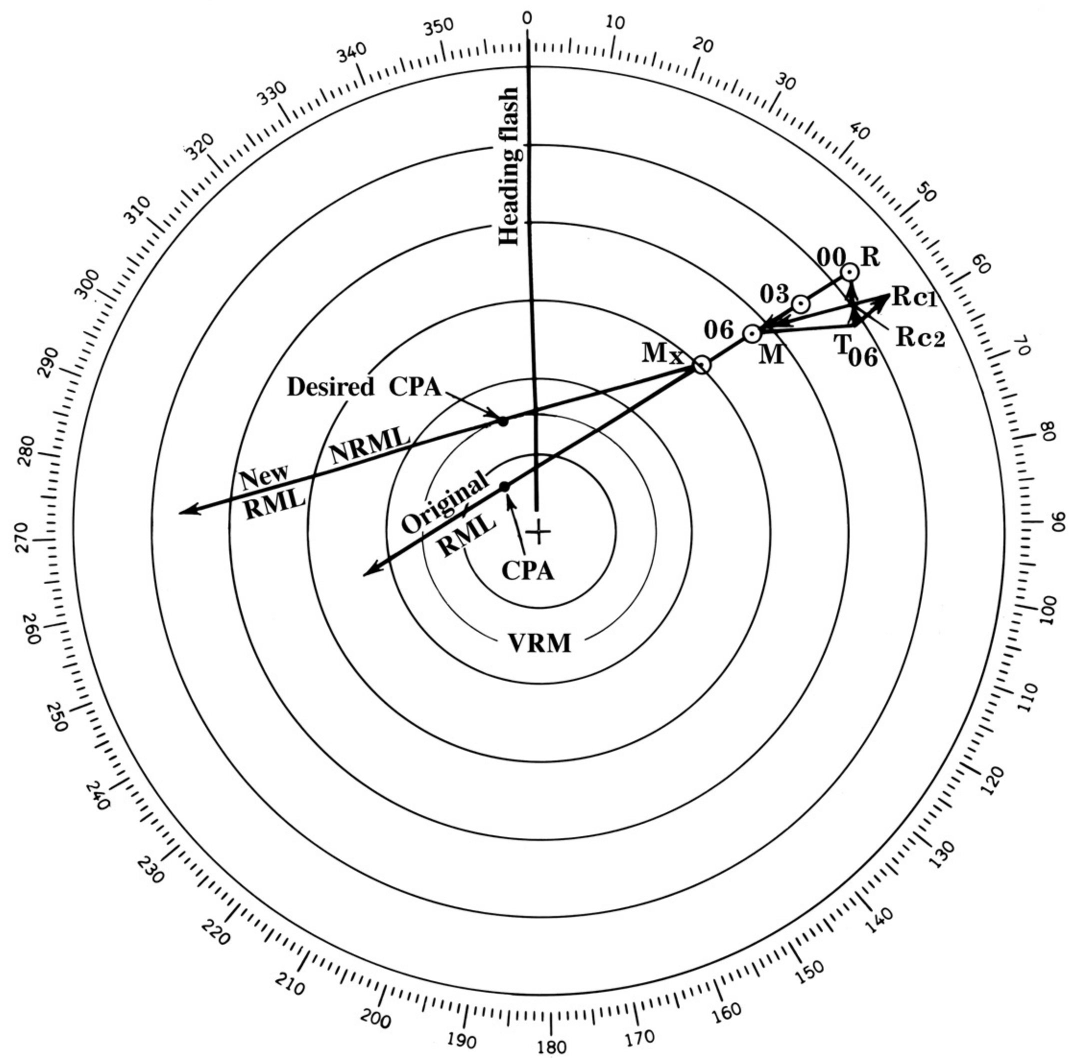


Figure 3.40 - Alternative plotting symbols.

ALTERNATIVE GRAPHICAL SOLUTIONS ON THE REFLECTION PLOTTER

R-T-M TRIANGLE

CLOSEST POINT OF APPROACH

To determine the closest point of approach (CPA) of a contact by graphical solution on the reflection plotter, follow the procedure given below.

(1) Plot at least three relative positions of the contact. If the relative positions lie in a straight or nearly straight line, fair a line through the relative positions. Extend this relative movement line (RML) past the center of the PPI.

(2) Crank out the variable range marker (VRM) until the ring described by it is tangent to the RML as shown in figure 3.41. The point of tangency is the CPA.

(3) The range at CPA is the reading of the VRM counter; the bearing at CPA is determined by means of the mechanical bearing cursor, parallel-line cursor, or other means for bearing measurement from the center of the PPI.

Note: The RML should be reconstructed if the contact does not continue to plot on the RML as originally constructed.

TRUE COURSE AND SPEED OF CONTACT

To determine the true course and speed of a contact by graphical solution on the reflection plotter, follow the procedure given below.

(1) As soon as possible after a contact appears on the PPI, plot its relative position on the reflection plotter. Label the position with the time of the observation as shown in figure 3.41. As recommended in Alternative Plotting Symbols, the first plot is labeled as time zero. Subsequent relative positions are plotted and labeled at 3-minute intervals, preferably using a suitable timing device which can be reset to zero time when desired.

(2) Examine the relative plot to determine whether the contact is on a steady course at constant speed. If so, the relative positions plot in a straight or nearly straight line; the relative positions are equally spaced for equal time intervals as shown in figure 3.41.

(3) With the contact on a steady course at constant speed, R_{00}, the plot for zero time, is the origin of the relative (DRM-SRM) vector. At plot time 03, this vector is R_{00}-M_{03}; at plot time 06, this vector is R_{00}-M_{06}. Note that the relative motion and relative vector are always in the direction of $R_{00}M_{03}M_{06}$.

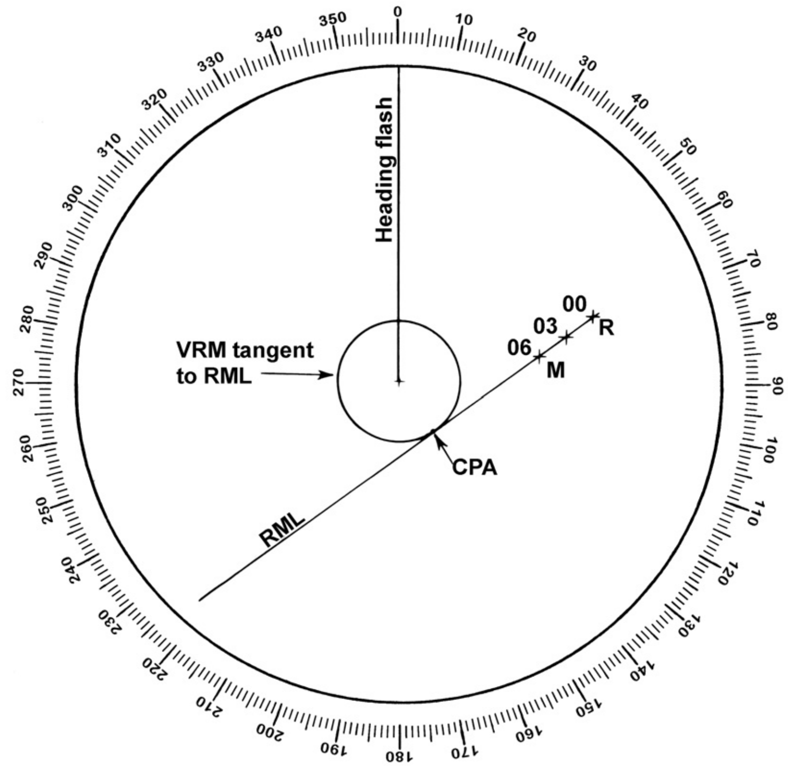


Figure 3.41 - Closest point of approach.

(4) Crank the parallel-line cursor until its lines are parallel to the heading flash. As shown in figure 3.42, place the standard plotting period scale so that its straightedge is parallel to the lines of the cursor and the heading flash and the zero speed graduation is at R_{00}.

(5) Given that own ship is on course 000˚ at 30 knots and the range scale setting is 12 miles, the standard plotting period is 6 minutes; the 30-knot graduation on the scale corresponds to T_{06}. The head of the other ship's true (course-speed) vector is at M_{06} beyond R_{00} in the direction of relative movement (DRM).

(6) Construct the other ship's true (course-speed) vector T_{06}-M_{06}.

(7) Crank the parallel-line cursor so that its lines are parallel to vector T_{06}-M_{06} as shown in figure 3.43. The other ship's direction of true motion (DTM) is read on the true bearing dial using the radial line of the parallel-line cursor; the other ship's speed of true motion (STM) is measured by the standard plotting period scale or estimated by visual comparison with own ship's true vector T_{06}-R_{00}. For example, if T_{00}-M_{06} is about two-thirds the length of T_{06}-R_{00}, the other ship's speed of true motion is about two-thirds own ship's speed.

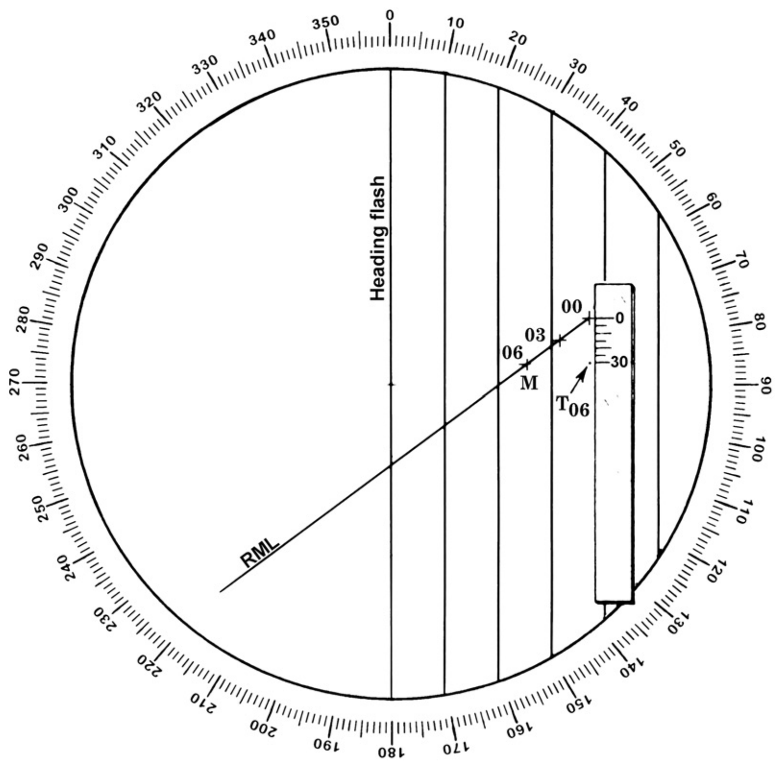


Figure 3.42 - Use of the standard plotting period scale.

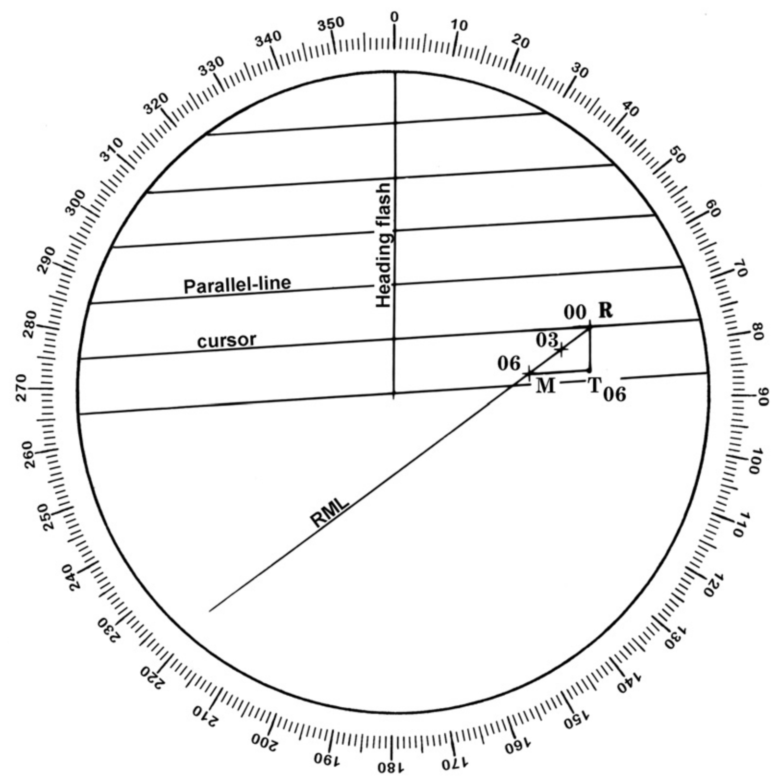


Figure 3.43 - Use of parallel-line cursor to find true course of contact.

COURSE TO PASS AT SPECIFIED CPA

The procedure for determining own ship's new course and/or speed to reduce the risk of collision is given below.

(1) Continuing with the plot used in finding the true course and speed of the other ship, mark the point of execution (M_x) on the RML as shown in figure 3.44. M_x is the position of the contact on the RML at the planned time of evasive action. This action may be taken at a specific clock time or when the range to the other ship has decreased to a specified value.

(2) Crank the VRM to the desired distance at CPA. This is normally the distance specified for the **danger** or **buffer zone**. If the fixed range rings are displayed and one range ring is equal to this distance, it will not be necessary to use the VRM.

(3) From M_x draw the new RML tangent to the VRM circle. Two lines can be drawn tangent to the circle, but the line drawn in figure 3.44 fulfills the requirement that the other ship pass ahead of own ship. If the new RML crosses the heading flash, the other ship will pass ahead.

(4) Using the parallel-line cursor, draw a line parallel to the new RML through M_{06} or the final plot (relative position) used in determining the course and speed of the contact. This line is drawn from M_{06} in a direction opposite to the new DRM because the new relative speed (DRM-SRM) vector will be parallel to the new RML and the head (M_{06}) of the new vector (R_cM_{06}) will lie in the new DRM away from the origin, R_c.

(5) Avoiding by course change only, the magnitude of own ship's true (course-speed) vector remains constant. Therefore, the same speed graduation on the standard plotting interval scale used to construct T_{06}-R_{00} is set at T_{06}. The scale is then adjusted so that its zero graduation intersects the line drawn parallel to the new RML. As shown in figure 3.44, the intersection at R_c is the head of the required new true (course-speed) vector for own ship, T_{06}-R_c.

The previously described use of the plastic ruler, in effect, rotates vector T_{06}-R_c about its origin; the head of the vector describes an arc which intersects the line drawn parallel to the new RML at R_c.

If the speed of the contact were greater than own ship's speed, there would be two intersections and, thus, two courses available to produce the desired distance at CPA. Generally, the preferred course is that which results in the higher relative speed (the longer relative speed vector) in order to expedite safe passing.

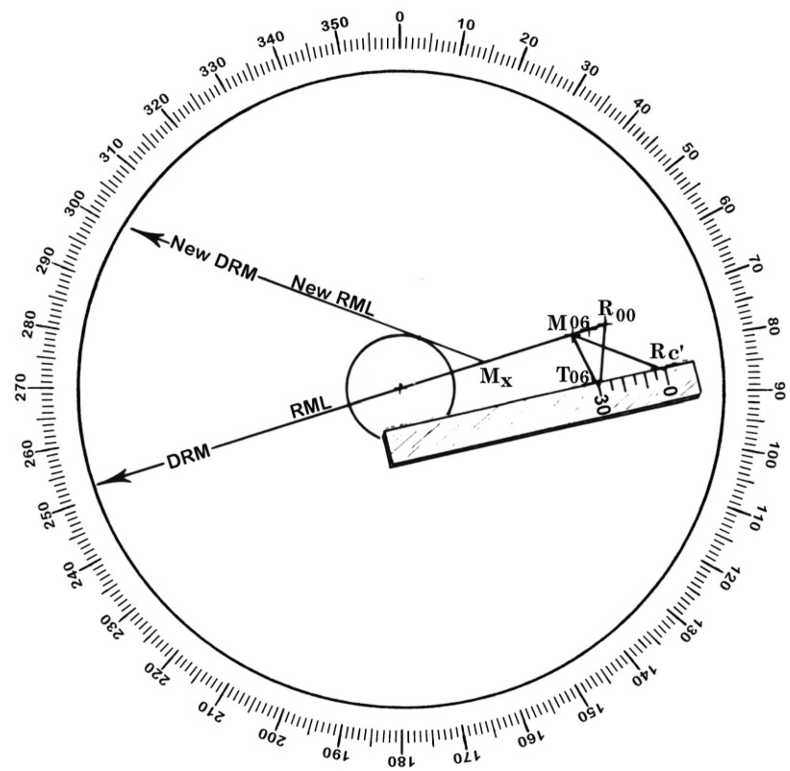


Figure 3.44 - Evasive action.

SPECIAL CASES

In situations where contacts are on courses opposite to own ship's course or are on the same course as own ship but at slower or higher speeds, the relative movement lines are parallel to own ship's course line. If a contact has the same course and speed as own ship, there is no relative movement line; all relative positions lie at one point at a constant true bearing and distance from own ship. If a contact is stationary or dead in the water, the relative vector *R-M* and own ship's true vector *T-R* are equal and opposite, and coincident. With *T* and *M* coincident, there is no vector *T-M*.

The solutions of these special cases can be effected in the same manner as those cases resulting in the conventional vector triangle. However, no vector triangle is formed; the vectors lie in a straight line and are coincident.

In figure 3.45 contacts A, B, C, and D are plotted for a 12-minute interval; own ship's true vector T_{12}-R_{00} is scaled in accordance with this time. Inspection of the plot for contact A reveals that the DRM is opposite to own ship's course; the relative speed is equal to own ship's speed plus the contact's speed. The contact is on a course opposite to own ship's course at about the same speed.

Inspection of the plot for contact B reveals that the DRM is opposite to own ship's course; the relative speed is equal to own ship's speed minus the contact's speed. The contact is on the same course as own ship at about one-half own ship's speed.

Inspection of the plot for contact C reveals that the DRM is opposite to own ship's course; the relative speed is equal to own ship's speed plus the contact's speed. The contact is on a course opposite to own ship's course at about the same speed.

Inspection of the plot for contact D reveals that the DRM is the same as own ship's course; the relative speed is equal to the contact's speed minus own ship's speed. The contact is on the same course as own ship at about twice own ship's speed.

BLACK LIGHT ILLUMINATION

"Black light" illumination of the reflection plotter permits the use of the standard plotting period scale without the use of notches in the scale that would otherwise be required. However, when this type of illumination is used to facilitate scaling by means of a graduated scale, such illumination should be used only while scaling because it tends to make the video on the PPI less visible. Therefore, means should be readily available to extinguish this illumination when it is not required.

The shaft of the grease pencil as well as the standard plotting period scale should be fluorescent.

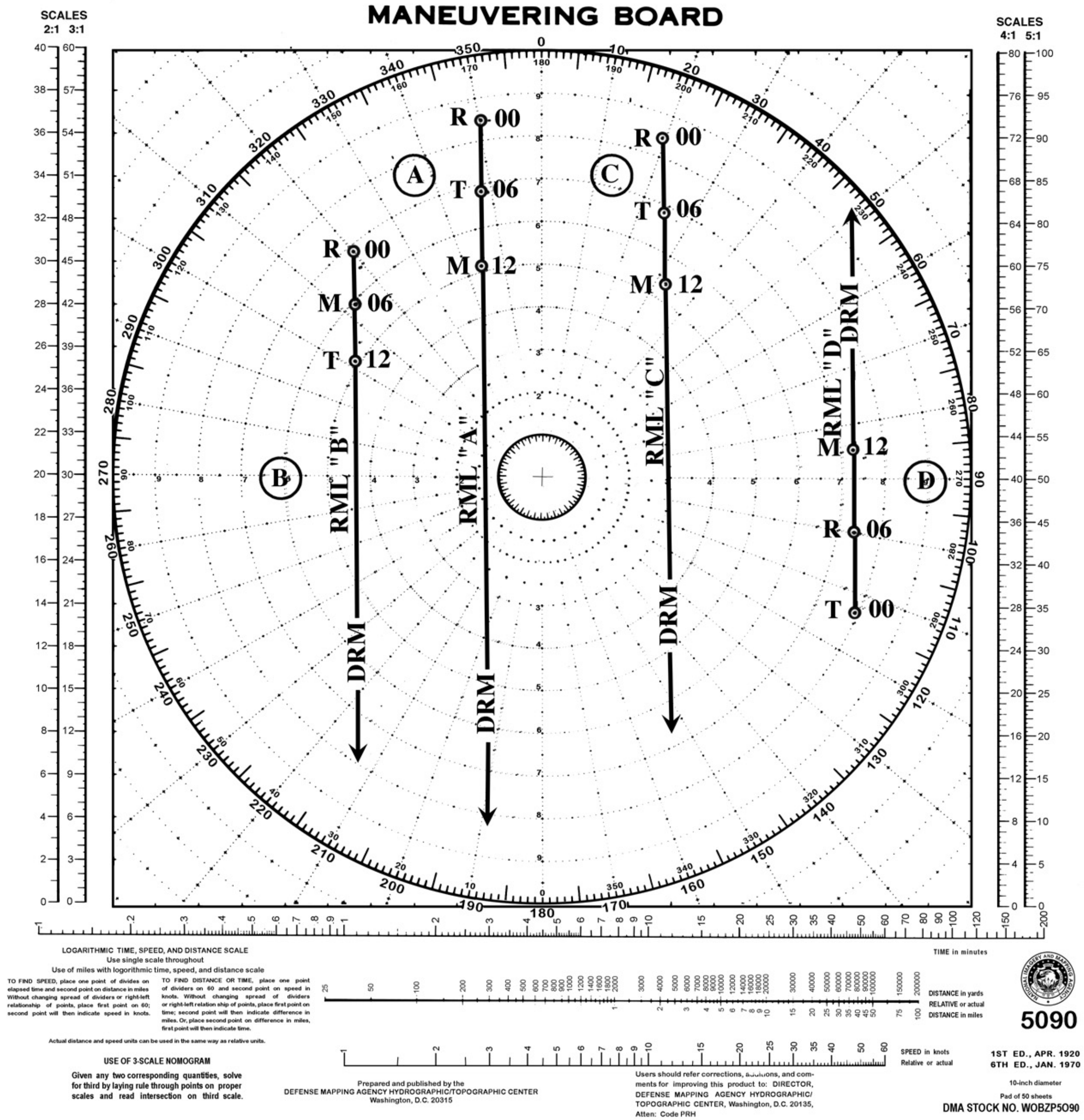


Figure 3.45 - Special cases.

EXAMPLES

R-T-M TRIANGLE

EXAMPLE 9

DETERMINATION OF CLOSEST POINT OF APPROACH (CPA)

Situation:

With own ship on course 070° and the radar set on the 12-mile range scale, the other ship is observed as follows:

Time	*Bearing*	*Range (miles)*	*Rel. position*
1000	050°	9.0	R00
1006	049°	7.5	M06
1012	047°	6.0	M12

Required:

(1) Direction of relative movement. (DRM)
(2) Speed of relative movement. (SRM)
(3) Bearing and range at closest point of approach. (CPA)
(4) Estimated time of arrival at CPA.

Solution:

(1) Plot and label the relative positions, R_{00}, M_{06}, and M_{12}, using the 1:1 scale; fair a line through the relative positions; extend this line, the *relative movement line (RML)*, beyond the center of the Maneuvering Board.

(2) The direction of the RML from the initial plot R_{00} is the direction of relative movement (DRM): 236°.

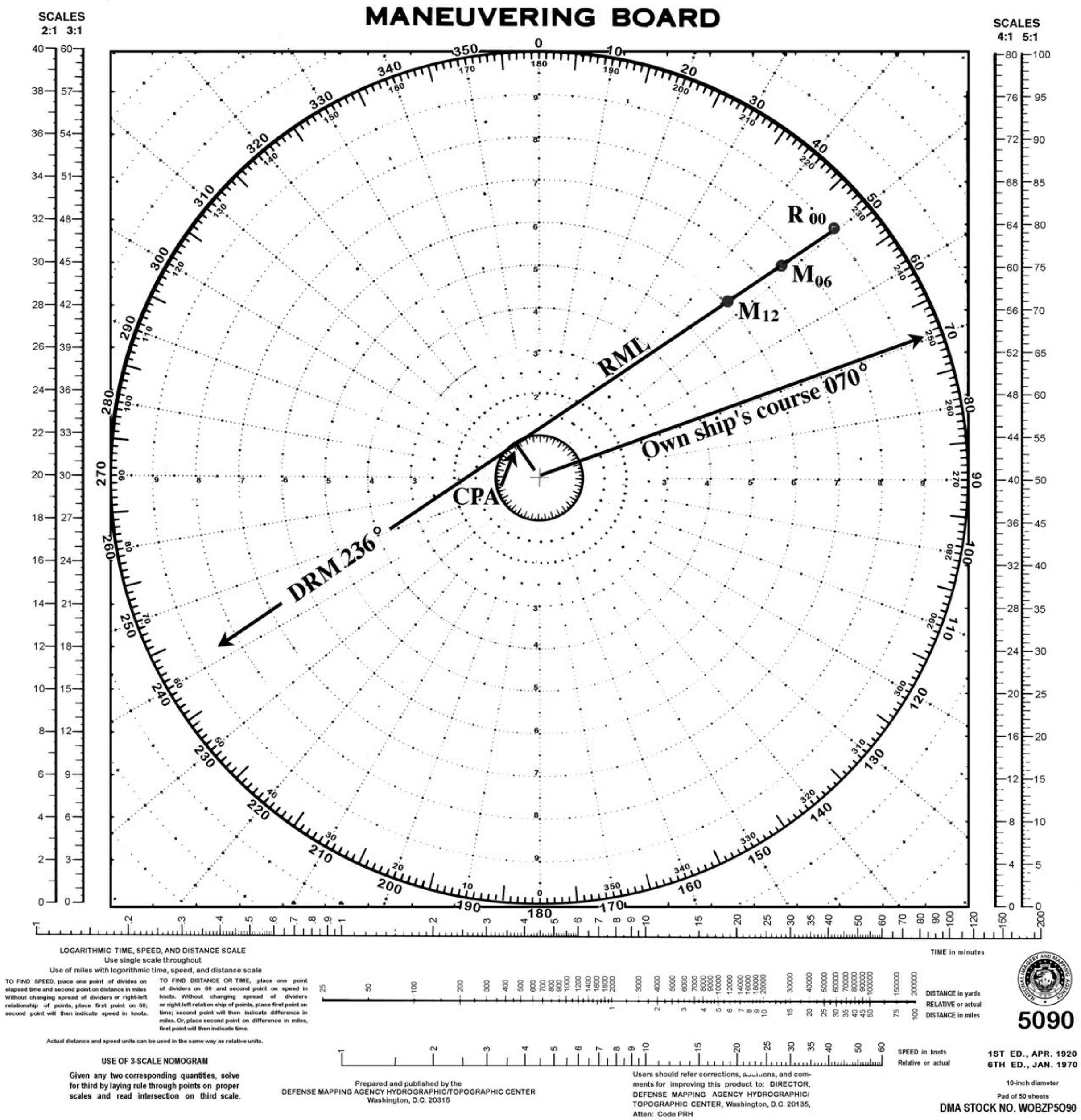
(3) Measure the relative distance between any two timed plots on the RML, preferably between the two best plots with the greatest time separation. In this instance, measure the distance between R_{00} and M_{12}: 3.0 miles. Using the corresponding time interval (1000 - 1012 = 12^m), obtain the speed of relative movement (SRM) from the Logarithmic Time-Speed-Distance Scale at the bottom of the Maneuvering Board: 15 knots.

(4) From the center of the Maneuvering Board, draw a line perpendicular to the RML; label the intersection CPA. The direction of the CPA from the center of the plotting sheet, i.e., own ship's position, is the bearing of the CPA: 326°; the distance from the center or own ship is the range at CPA: 0.9 mile.

(5) Measure the distance from M_{12} to CPA: 6.0 miles. Using this distance and the speed of relative movement (SRM): 15 knots, obtain the minutes to CPA (MCPA) from 1012 (the time of plot M_{12}) by means of the Time-Speed-Distance Scale: 24m. The estimated time of arrival at CPA is 1012 + 24^m = 1036.

Answers:

(1) DRM 236° (2) SRM 15 knots; (3) CPA 326°, 0.9 mile; (4) ETA at CPA 1036.



EXAMPLE 9

Notes:

1. There should be sufficient plots to insure accurate construction of the RML faired through the plots. Should only two plots be made, there would be no means of detecting course or speed changes by the other ship. The solution is valid only if the other ship maintains course and speed constant. Preferably, the timed plots should be made at equal time intervals. Equal spacing of the plots timed at regular intervals and the successive plotting of the relative positions in a straight line indicate that the other ship is maintaining constant course and speed.

2. This transfer plotting solution required individual measurements and recording of the ranges and bearings of the relative position of ship M at intervals of time. It also entailed the normal requirement of plotting the relative positions on the PPI or reflection plotter. Visualizing the concentric circles of the Maneuvering Board as the fixed range rings of the PPI, a faster solution may be obtained by fairing a line through the grease pencil plot on the PPI and adjusting the VRM so that the circle described is tangent to or just touches the RML. The range at CPA is the setting of the VRM; the bearing at CPA and the DRM may be found by use of the parallel-line cursor (parallel index). The time of the CPA can be determined with reasonable accuracy through visual inspection, i.e., the length along the RML from M_{12} to CPA by quick visual inspection is about twice the length between R_{00} and M_{12}, representing about 24 minutes.

EXAMPLE 10

COURSE AND SPEED OF A RADAR CONTACT

Situation:

Own ship is on course 340˚, speed 15 knots. The radar is set on the 12-mile range scale. A radar contact is observed to be changing course, and possibly speed, between times 0953 and 1000. While keeping a close watch of the relative movement, the relative positions of the contact are marked at frequent intervals on the reflection plotter by grease pencil.

Required:

(1) Course and speed of the contact when it has steadied on course and speed.

Solution:

(1) The solution is started before the contact steadies on course and speed through planning:

(a) Since the contact is being observed on the 12-mile range scale, the standard plotting period for use with the six fixed range rings is 6 minutes.

(b) The observer anticipates that after the contact has been observed to be on a steady course at constant speed for 6 minutes he will be able to obtain a rapid solution by using the spacing between range rings as a speed scale.

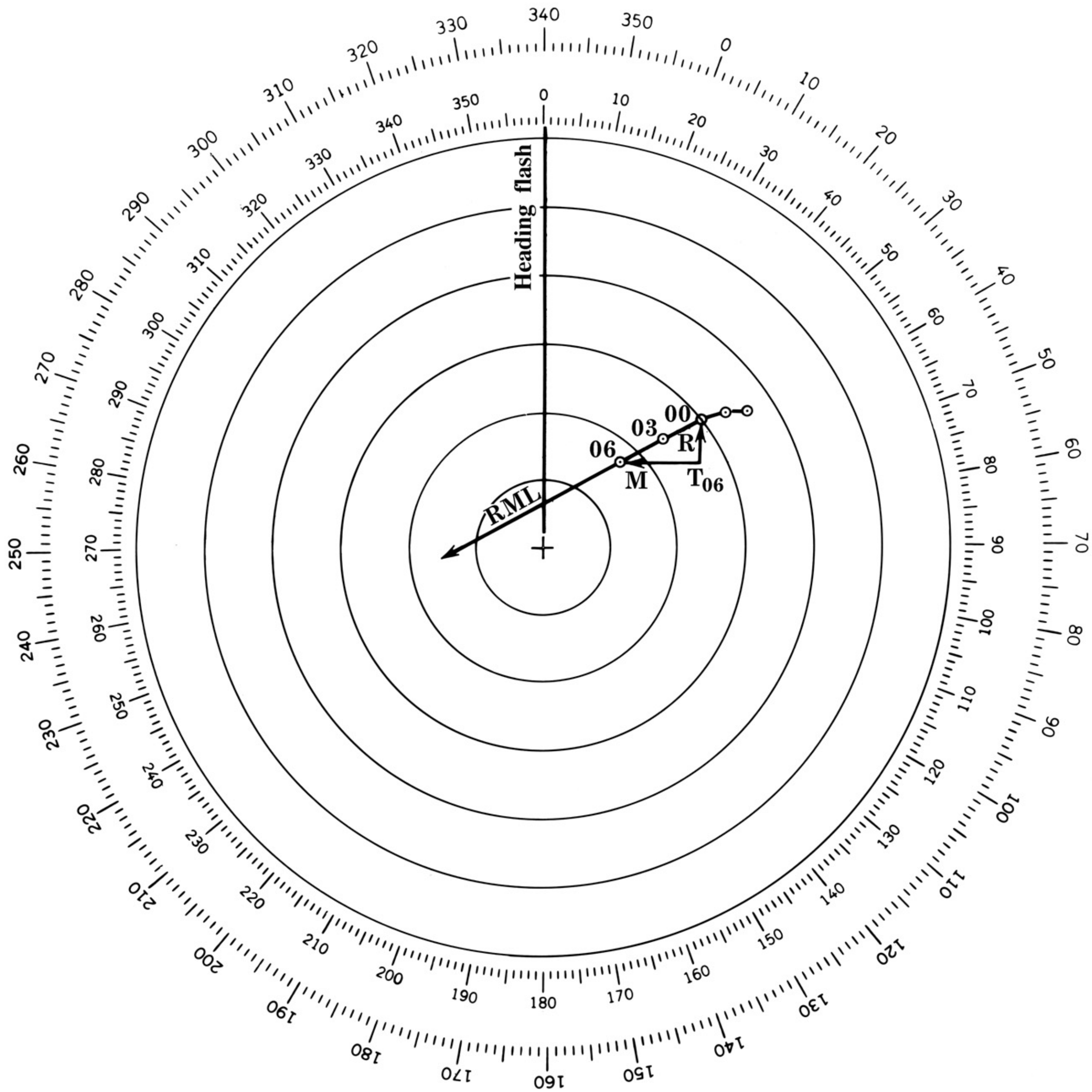
(2) Observation of the PPI reveals that between 1000 and 1006, the contact is on a steady course at constant speed (successive plots form a straight line on the scope; plots for equal time intervals are equally spaced). Draw the relative movement line (RML) from the 1000 plot (R_{00}) through the 1006 plot (M_{06}), extending beyond the center of the PPI.

(3) Set center line of parallel-line cursor to heading flash. Place the standard plotting period scale parallel to the lines on the cursor and with its zero graduation at R_{00}. The 15-knot graduation on the scale corresponds to T_{06}. Two sides of the vector diagram (triangle) have been formed: T_{06}-R_{00} and R_{00}-M_{06}. The solution is obtained by completing the triangle to form the contact's true (course-speed) vector T_{06}-M_{06}.

(4) The direction of the contact's true motion (DMT) can be read by adjusting the parallel-line cursor parallel to T_{06}-M_{06}. After such adjustment, the radial line of the cursor indicates the DTM or true course of the contact. The speed of the contact's true motion (STM) can be measured by the standard plotting period scale, or it can be estimated by comparing the length of T_{06}-M_{06} with T_{06}-R_{00}, the speed of which in knots is known.

Answers:

(1) Course 252˚, speed 25 knots.



EXAMPLE 10

Heading-Upward Unstabilized PPI Display with Stabilized True Bearing Dial

Scale: 12-mile range setting

Notes:

1. In this example with the contact observed to be changing course, and possibly speed, between times 0953 and 1000, it was necessary to delay construction of own ship's true vector (T_{06}-R_{00}) until after 1000. However, when it is not known that the contact is on other than a steady course at constant speed, the solution can often be expedited by constructing T_{06}-R_{00} soon after the initial observation and then determining whether the contact is on a steady course at constant speed. If such is the case, the triangle is completed at time 06.

2. With the display of the fixed range rings, a practical solution can be obtained without the use of the standard plotting period scale by visualizing the vector diagram (triangle) using the spacing between range rings as the speed scale.

EXAMPLE 11

COURSE AND SPEED OF RADAR CONTACT BY THE LADDER METHOD

Situation:

Own ship is on course 120˚, speed 20 knots. The radar is set on the 6-mile range scale because small wooden vessels are expected to be encountered. The range scale setting is being shifted periodically to longer ranges for possible detection of distant targets. A radar contact is being plotted on the reflection plotter. Inspection of the plot reveals that the contact is on steady course at constant speed (see solution step (2) of example 10).

Required:

(1) Course and speed of the radar contact.

Solution:

(1) With the decision made that the solutions will be obtained by rapid radar plotting, the radar observer further elects to use the Ladder Method in order to be able to *refine* the solution as the relative plot for the contact develops with time.

(2) Since the contact is being observed on the 6-mile range scale, the standard plotting period for use with the six fixed range rings is 3 minutes.

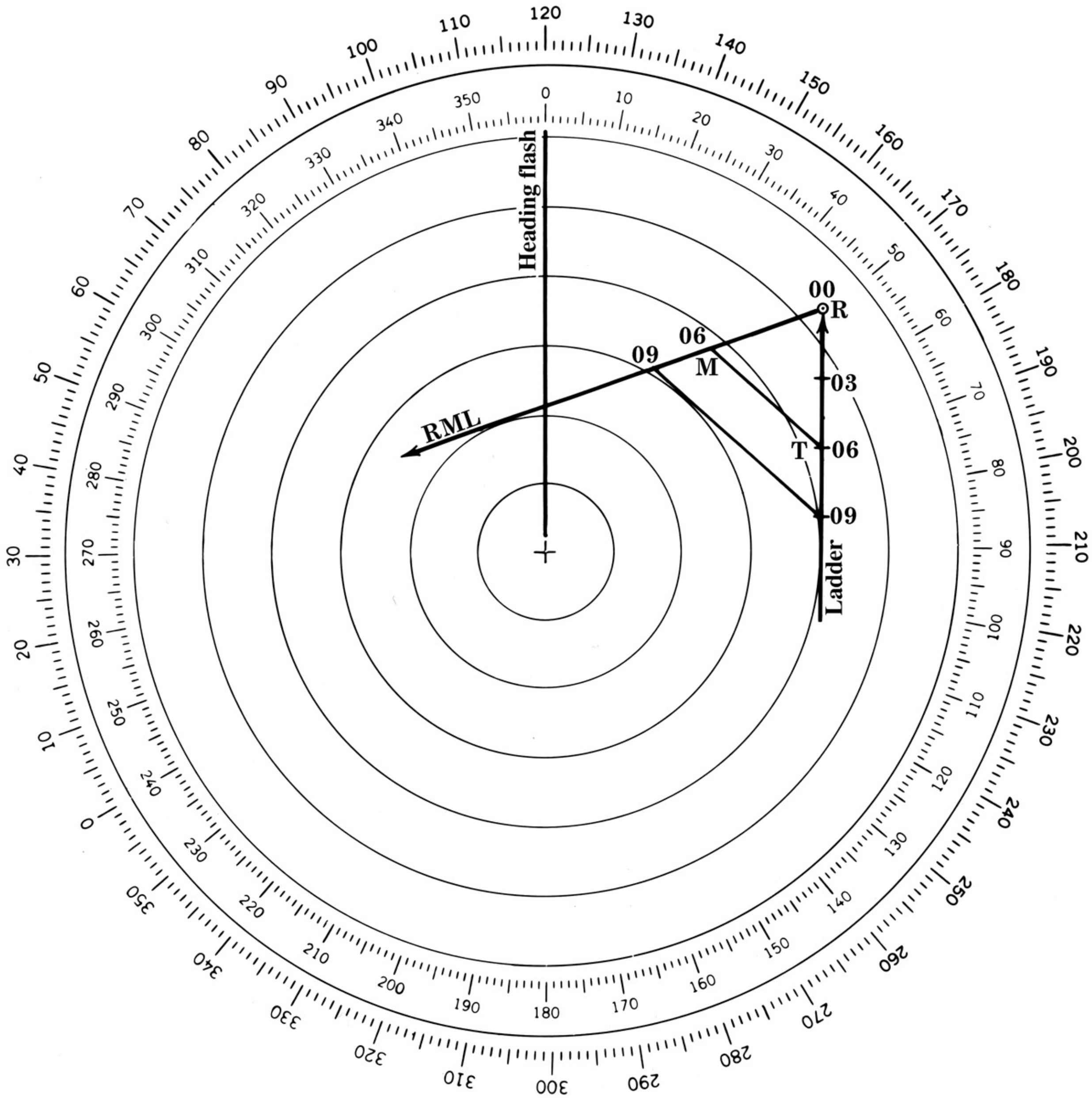
(3) Set the center line of the parallel-line cursor to heading flash. Place the standard plotting period scale parallel to the lines of the cursor and with its zero graduation at R_{00}. The 20-knot graduation on the scale corresponds to T_{03}. The ladder is drawn in multiples and sub-multiples to T_{03}-R_{00}: The 40-knot graduation corresponds to T_{06}; the 30-knot graduation corresponds to $T_{4.5}$; and the 10-knot graduation corresponds to $T_{1.5}$.

(4) With the assumption that the contact is on a steady course at constant speed, the first solution is obtained at time 1.5 (90 seconds) by constructing vector $T_{1.5}$-$M_{1.5}$. At time 03 it is seen that the contact is on a steady course at constant speed. The solution obtained at time 03 by completing vector T_{03}-M_{03} is a refinement of the earlier solution. Assuming that the contact maintains course and speed, solutions obtained at later times should be of increasing accuracy.

(5) The direction of the contact's true motion (DTM) at time 06 can be read by adjusting the parallel-line cursor parallel to T_{06}-M_{06}. After such adjustment, the radial line of the cursor indicates the DTM or true course of the contact. The speed of the contact's true motion (STM) can be measured by the standard plotting period scale, or it can be estimated by comparing the length of T_{06}-M_{06} with T_{06}-R_{00}, the speed of which in knots (20) is known. Note that although the 40-knot graduation on the standard plotting period scale corresponds to time 06, vectors $T_{1.5}$-R_{00}, T_{03}-R_{00}, $T_{4.5}$-R_{00}, and T_{06}-R_{00} are all 20-knot vectors.

Answers:

(1) Course 072˚, Speed 22 knots.



EXAMPLE 11

Heading-Upward Unstabilized PPI Display with Stabilized True Bearing Dial

Scale: 6-mile range setting

Notes:

1. Using the ladder method, the radar observer is able to obtain an approximate solution quickly and then refine the solution as the plot develops.
2. This solution was simplified by starting the timed plot at some tenth of an hour after the hour.

EXAMPLE 12

COURSE TO PASS A SHIP AT A SPECIFIED CPA
(Own ship's speed is greater than that of other ship)

Situation:

Own ship is on course 188˚, speed 18 knots. The radar is set on the 12-mile range scale. Between times 1730 and 1736 a ship has been observed to be on a collision course with own ship. By rapid radar plotting, it is found to be on course 258˚ at 12 knots. The visibility is 2.0 nautical miles.

Required:

(1) Course of own ship at 18 knots to pass ahead of the other ship with a CPA of 3.0 nautical miles if course is changed to the right when the range is 6.5 nautical miles.

Solution:

(1) Continuing with the plot on the PPI used in finding the true course and speed of the other ship, plot M_x on the RML 6.5 nautical miles from own ship. Adjust the VRM to 3.0 nautical miles, the desired distance at CPA. From M_x draw a line tangent to the VRM circle. From M_x two lines can be drawn tangent to the circle, but the line as drawn fulfills the requirement that own ship pass ahead of the other ship or that the other ship pass astern of own ship.

(2) From the origin of the true vectors of the vector triangle used in finding the DTM and STM of the other ship, T_{06}, describe an arc of radius equal to the length of T_{06}-R_{00}.

(3) With the aid of the parallel-line cursor, draw a line through M_{06} parallel to the new RML to intersect the arc drawn in (2).

(4) The intersection of the arc with the line through M_{06} parallel to the new RML establishes the head of vector T_{06}-R_c, own ship's true (course-speed) vector required to obtain new RML.

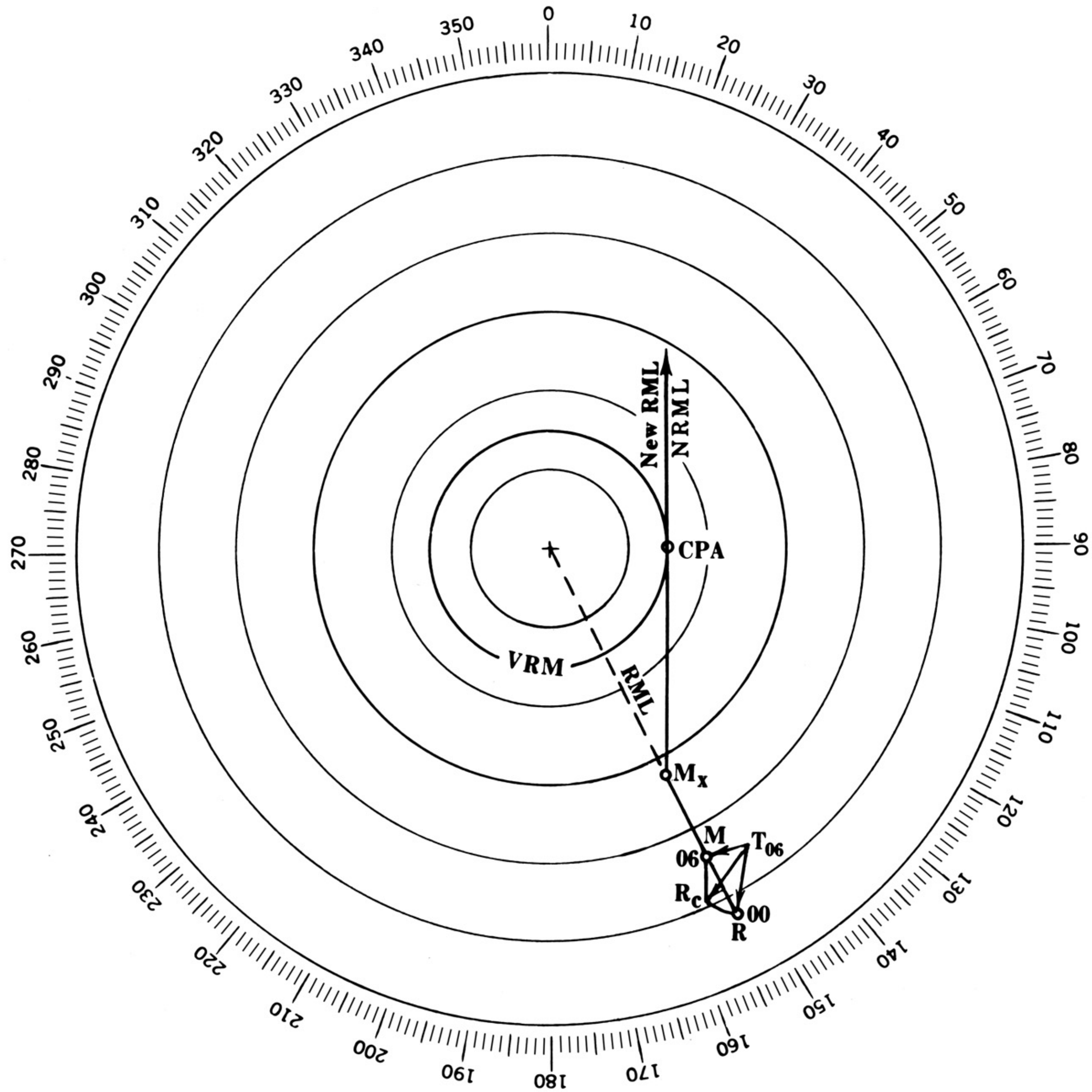
Answers:

(1) Course 218˚.

Notes:

1. Actually the arc intersecting the line drawn from M_{06} in a direction opposite to the new DRM would also intersect the same line if extended in the new DRM. But a new course of own ship based upon this intersection would reverse the new DRM or reverse the direction the other ship would plot on the new RML.

2. If the speed of the other ship were greater than that of own ship, there would be two courses available at 18 knots to produce the desired distance at CPA.



EXAMPLE 12

North-Upward Stabilized PPI Display

Scale: 12-mile range setting

Notes: (continued)

Generally, the preferred course is that which results in the highest relative speed in order to expedite the safe passing.

3. After own ship's course has been changed, the other ship should plot approximately along the new RML, as drawn and in the desired direction of relative movement. This continuity of the plot following a course change by own ship is one of the primary advantages of a stabilized display. Immediately following any evasive action, one should inspect the PPI to determine whether the target's bearing is changing sufficiently and in the desired direction. With the stabilized display, the answer is before the radar observer's eyes.

EXAMPLE 13

COURSE TO PASS SHIP AT A SPECIFIED CPA
(Own ship's speed is less than that of other ship)

Situation:

Own ship is on course 340˚, speed 15 knots. The radar is set on the 12-mile range scale. Between times 0300 and 0306, a ship has been observed to be on a collision course with own ship. By rapid radar plotting, it is found to be on course 249˚ at 25 knots. The visibility is 2.0 nautical miles.

Required:

(1) Course of own ship at 15 knots to pass astern of the other ship with CPA of 3.0 nautical miles if course is changed to the right when the range is 6.0 nautical miles.

Solution:

(1) Continuing with the plot on the PPI used in finding the true course, speed, and CPA of the other ship, plot M_x on the RML 6.0 nautical miles from own ship. Adjust the VRM to 3.0 nautical miles, the desired distance at CPA. From M_x two lines can be drawn tangent to the VRM circle, but the line as drawn fulfills the requirement that own ship pass astern of the other ship.

(2) From the origin of the true vectors of the vector triangle used in finding the DTM and STM of the other ship, T_{06}, describe an arc of radius equal to T_{06}-R_{00}.

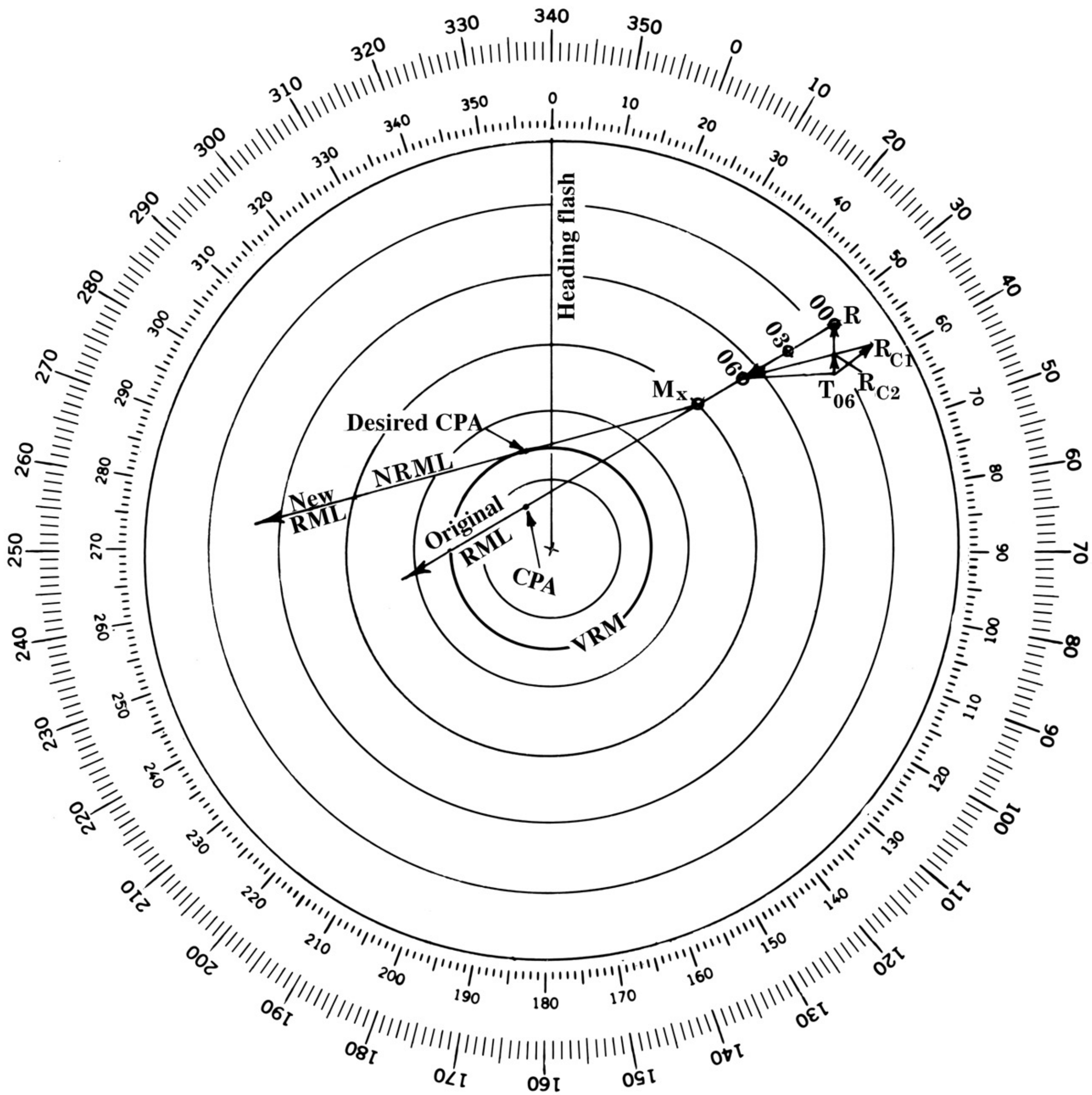
(3) With the aid of the parallel-line cursor, draw a line through M_{06} parallel to the new RML to intersect the arc drawn in (2).

(4) Since the speed of the other ship is greater than that of own ship, the arc intersects the line through M_{06} at two points. Each intersection establishes a head of a possible new own ship's true vector. Of the two possible vectors one provides a higher speed of relative movement than the other. Generally, true vector which provides the higher SRM or longer relative vector is chosen to expedite the passing. However, in this example a course change to the right is specified. This requires the use of vector T_{06}-R_{c1}, which provides the higher SRM.

(5) With this unstabilized, Heading-Upward PPI display, there is a complication arising from the plot shifting equal and opposite to the amount and direction of the course change. Some reflection plotter designs have provisions for either manual or automatic shifting of their plotting surfaces to compensate for the shifting of the plot. Without this capability, there is no continuity in the grease pencil plot following course changes of own ship. Consequently, it is necessary to erase the plot and replot the other ship's relative position when own ship steadies on course. With the VRM set to 3.0 miles, the new RML must be drawn tangent to the circle described by the VRM. The other ship must be watched closely to insure that its movement conforms with the new RML.

Answers:

(1) Course 030˚.



EXAMPLE 13

Heading-Upward Unstabilized PPI Display with Stabilized True Bearing Dial

Scale: 12-mile range setting

Note:

Examination of the plot reveals that if own ship maintains its original true course (340˚), the intersection of the original true vector T_{06}-R_{00} of own ship with the line drawn through M_{06} parallel to the new RML provides the head of the vector T_{06}-R_{C2} required to effect the desired CPA without course change. Since the length of vector T_{06}-R_{C2} is approximately half that of the original vector T_{06}-R_{00}, an instantaneous change to approximately half the original speed would produce the desired results. A lesser change of course to the right in conjunction with a speed reduction could be used to compensate for deceleration.

EXAMPLE 14

VERIFICATION OF FIXED OBJECTS OR RADAR CONTACTS DEAD IN THE WATER

Situation:

Own ship is on course 340˚, speed 20 knots. The radar is set at the 24-mile range scale. Radar observations are made as follows:

Time	*Bearing*	*Range (miles)*	*Rel. position*
1200	017˚	22.8	R00
1218	029˚	17.4	M18
1236	046˚	14.4	M36

The RML is parallel to and the DRM is opposite to own ship's course, 340˚.

Required:

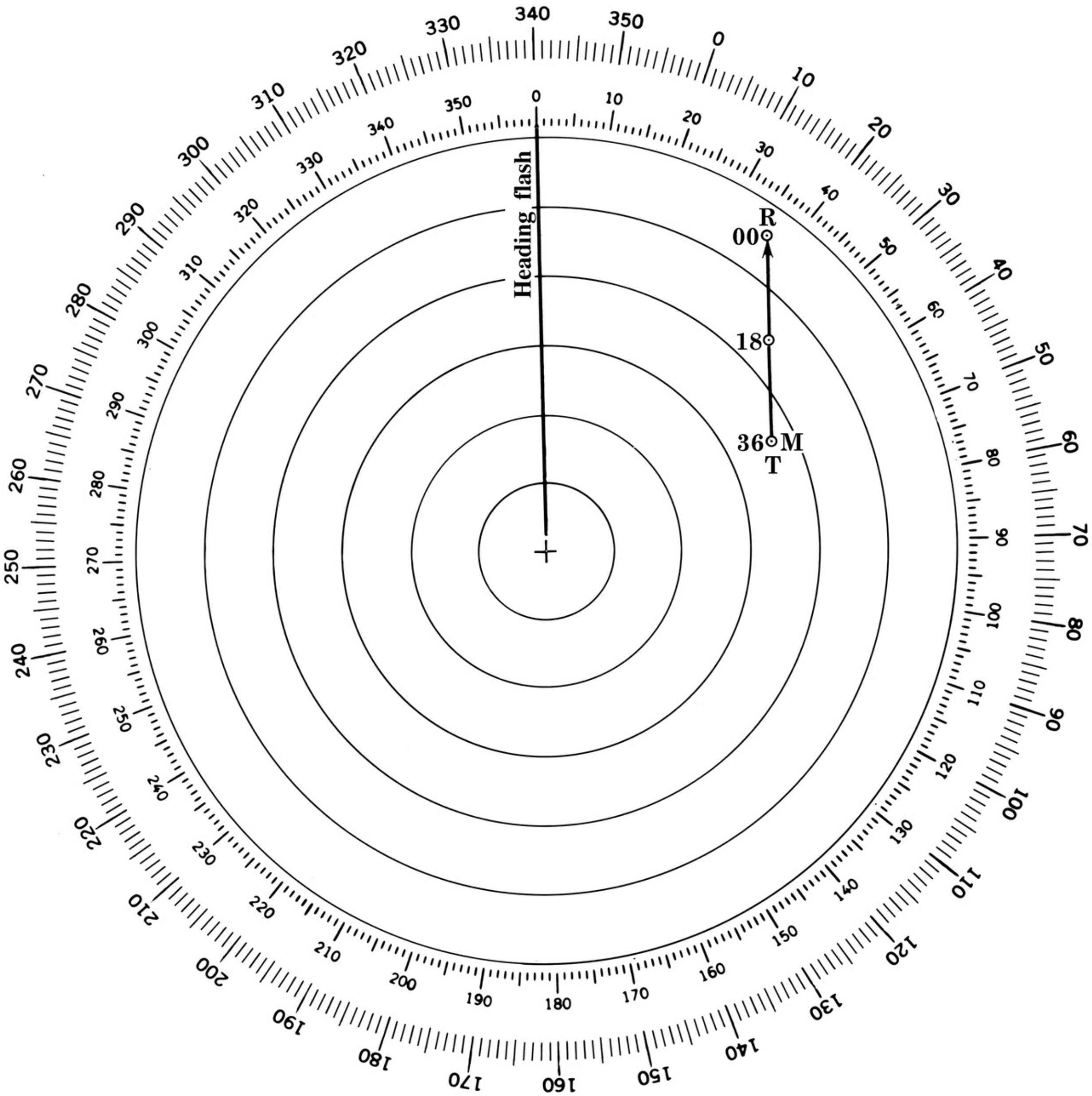
Course and speed of contact in order to verify whether it is dead in the water or a terrestrial object.

Solution:

(1) On the PPI, preferably one with a reflection plotter mounted thereon, plot R_{00}, M_{18}, M_{36}. Draw the relative movement line (RML) through these relative positions.

(2) Using the same distance scale as the radar range setting, determine the length of the true (course-speed) vector *T-R* of own ship for a time interval of 36 minutes: 12 miles.

(3) Draw true vector T_{36}-R_{00} *in the direction of own ship's course* with its head at relative position R_{00}. If after such graphical construction, the vector origin lies over relative position M_{36}, the length of the T_{36}-M_{36} vector would be zero. Thus, the true speed of the observed contact would be zero. Even if the observed target is dead in the water or a fixed object, small observational and plotting errors will frequently indicate a small value of true speed for the contact.



EXAMPLE 14

Heading-Upward Unstabilized PPI Display with Stabilized True Bearing Dial

Scale: 24-mile range setting

EXAMPLE 15

AVOIDANCE OF MULTIPLE CONTACTS WITHOUT FIRST DETERMINING THE TRUE COURSES AND SPEEDS OF THE CONTACTS

Situation:

Own ship is on course 000˚, speed 20 knots. With the stabilized relative motion display radar set at the 12-mile range setting, radar contacts A, B, and C are observed and plotted directly on the PPI or reflection plotter. The plots at time 1000 are considered as the initial plots in the solution.

Required:

(1) Determine the new relative movement lines for contacts A, B, and C which would result from own ship changing course to 065˚ and speed to 15 knots at time 1006.

(2) Determine whether such course and speed change will result in desirable or acceptable CPA's for all contacts.

Solution:

(1) With the center of the PPI as their origin, draw own ship's true vectors T-R and T-R_c for the course and speed in effect or to be put in effect at times 1000 and 1006, respectively. Using the distance scale of the radar presentation, draw each vector of length equal to the distance own ship will travel through the water during the time interval of the relative plot (relative vector), 6 minutes. Vector T-R, having a speed of 20 knots, is drawn 2.0 miles in length in true direction 000˚; vector T-R_c, having a speed of 15 knots, is drawn 1.5 miles in length in true direction 065˚.

(2) Draw a broken line between R and R_c.

(3) For contacts A, B, and C, offset the initial plots (A_1, B_1, and C_1) in the same direction and distance as the broken line R-R_c; *label each such offset plot* R_c.

(4) In each relative plot, draw a straight line from the offset initial plot R_c, through the final plot (A_2 or B_2 or C_2). The lines $R_c\,A_2$, $R_c\,B_2$, and $R_c\,C_2$ represent the new RML's which would result from a course change to 065˚ and speed change to 15 knots at time 1006.

Answers:

(1) New RML of contact A—DRM 280˚
New RML of contact B—DRM 051˚
New RML of contact C—DRM 028˚

(2) Inspection of the new relative movement lines for all contacts indicates that if all contacts maintain course and speed, all contacts will plot along their respective relative movement lines at safe distances from own ship on course 065˚, speed 15 knots.

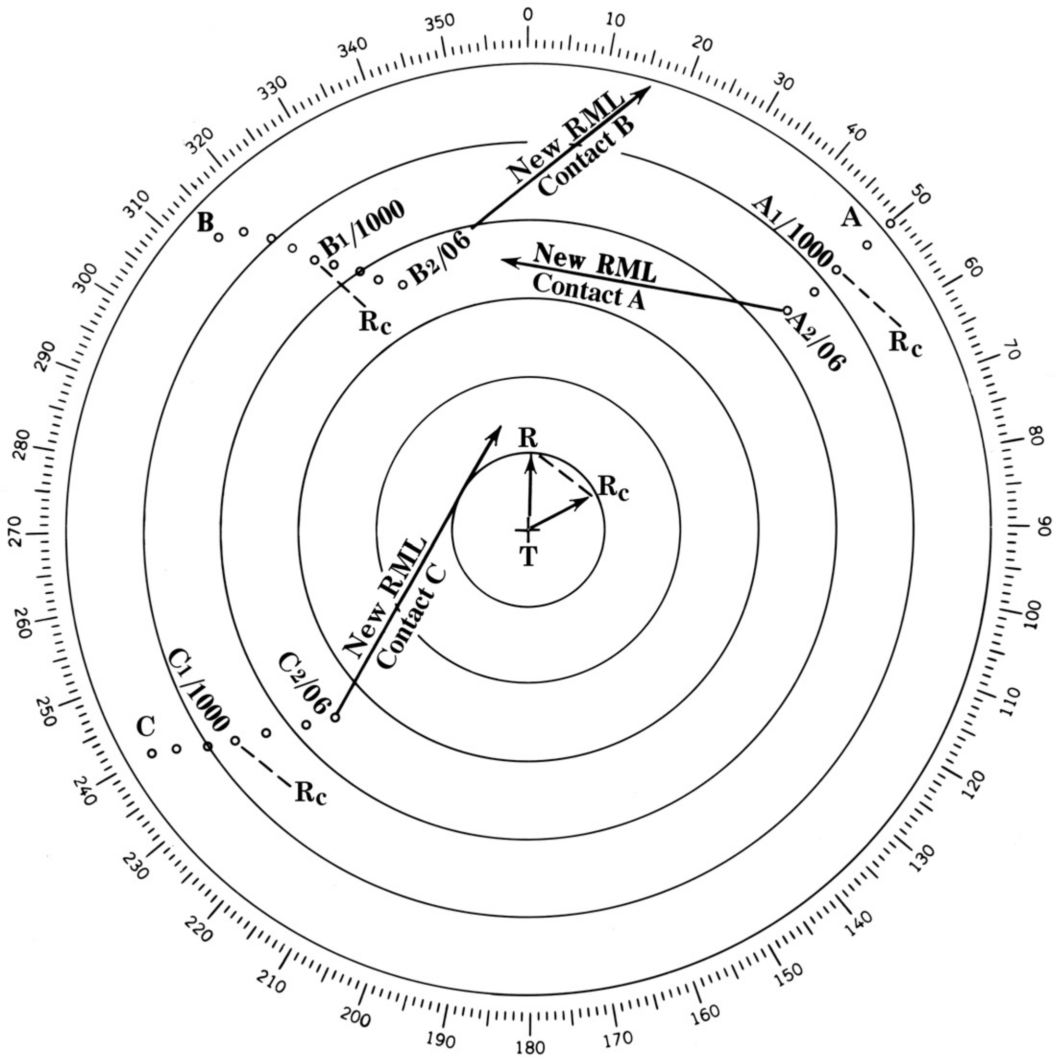
Explanation:

The solution is based upon the use of the relative plot as the relative vector. With each contact maintaining true course and speed, the true vector for each contact remains static while own ship's true vector is rotated about its origin T to the new course and changed in magnitude corresponding to the new speed.

EXAMPLE 15

North-Upward
Stabilized PPI Display

Scale: 12-mile range setting



PRACTICAL SOLUTION FOR CPA IN TRUE MOTION MODE

A practical solution for CPA in the true motion mode is dependent upon a feature normally provided with a true motion radar: some form of electronic bearing line (EBL) that can hold the range and bearing to which set. With the EBL originating at own ship moving in true motion on the PPI, it follows that if the EBL is held at an initial setting, the *end* of the EBL moves at the same speed as own ship along a parallel path. Or the *end* of the EBL follows own ship in true motion.

The true motions of own ship and of a contact are shown in figure 3.46 after observation for about 3 minutes. With own ship (at the center of the range rings) on course 000˚ at 20 knots, its tail has a length about equal to the 1-mile range ring interval, 1 mile being the distance own ship travels in 3 minutes at 20 knots. The tail of the contact bearing 045˚ at 4 miles indicates that the contact is on true course 280˚ at 30 knots. At this point it should be noted that the accuracy of the true motion displayed is dependent upon the accuracies of own ship course and speed inputs, particularly the speed input, and other errors associated with dead reckoning, such as those due to currents. Therefore, true motion solutions should be considered more approximate than those derived from stabilized relative motion displays.

Due to the fact that unlike relative motion, the true motion is not actually observed but is deduced from observed relative motion and *estimated* own ship course and speed over ground inputs, the true motion displayed on the PPI is better called *deduced* true motion.

Figure 3.47 shows the EBL set at the contact at the initial position (time 00), which is labeled T_{00}. Own ship's position at this time is also labeled 00. If own ship is dead reckoned to the time 03 position as shown in figure 3.48, with the EBL holding the range and bearing to which set at time 00, the end of the EBL, moving in parallel motion at the same rate as the true motion of ship, arrives at R_{03} at the same time as own ship reaches the time 03 dead reckoning position. During this time the contact moves in deduced true motion from its initial position, T_{00} to M_{03} as shown in figure 3.48. With the motions of own ship and of the contact producing the two true vectors of the *R-T-M* triangle, the triangle is completed to provide the relative vector R_{03}-M_{03}, the extension of which provides the RML, by means of which the CPA is determined. See figure 3.49.

With the EBL holding the initial range and bearing, it follows that the motions of the contact and of the end of the EBL from the initial position continuously generate the *R-T-M* triangle. Therefore the *R-T-M* triangle can be completed at any time between times 00 and 03 by constructing the relative vector from the end of the EBL to the position the contact occupies at the same time. Figure 3.50 shows the completion of the *R-T-M* triangle at times 01, 02, and 03. However, as indicated above, the triangle can be completed at any time. The relative vector and the RML can be obtained without any direct consideration of plot time. This fact enhances the practicality of the solution. It enables real-time visualization of the RML through observation of the current position of the contact in relation to the end of the moving EBL. This, in turn, enables the observer to determine the CPA very quickly.

Should the CPA be less than desired, a procedure similar to obtaining a desired CPA on a relative motion display (see examples 12 and 13) can be used. As shown in figure 3.51, the CPA is increased by course change only. The CPA is measured from the position own ship occupies on the PPI at plot time 03.

This practical solution for CPA in the true motion mode was devised by Captain Wayne M. Waldo, Head, All-weather Navigation Department, Maritime Institute of Technology and Graduate Studies, Linthicum Heights, Maryland.

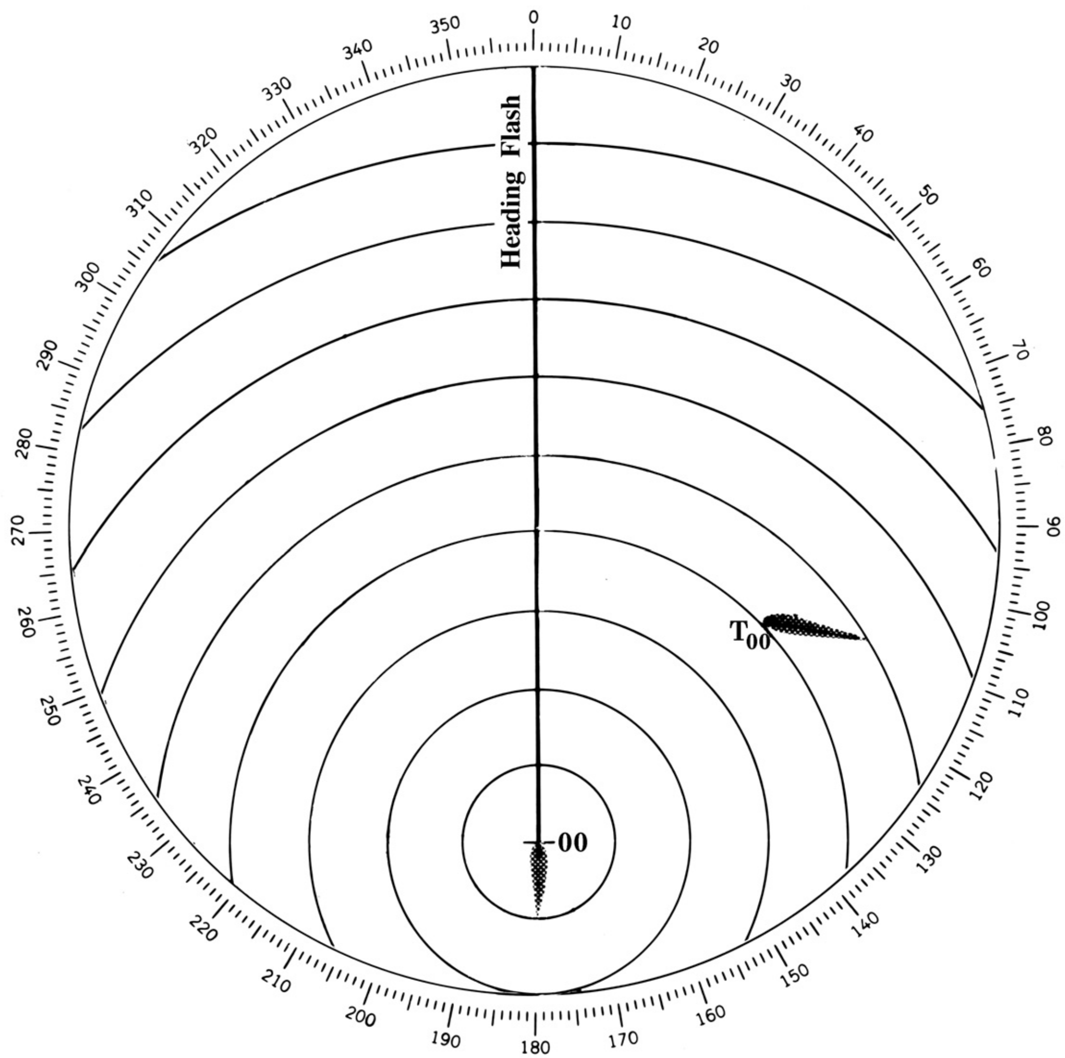
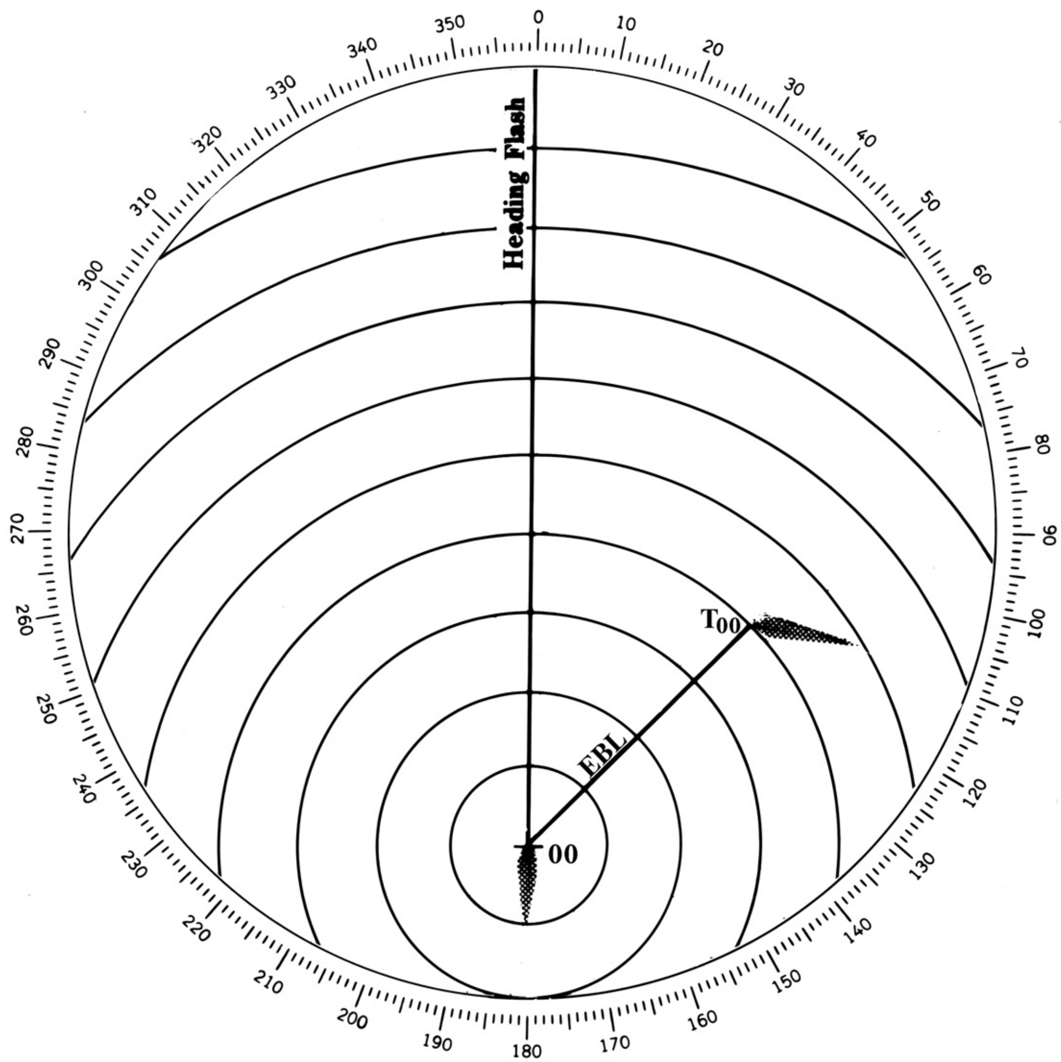


Figure 3.46 - True motion display

Own ship's course 000˚
speed 20 knots

Contact's course 280˚
speed 30 knots

Range-ring interval: 1 mile

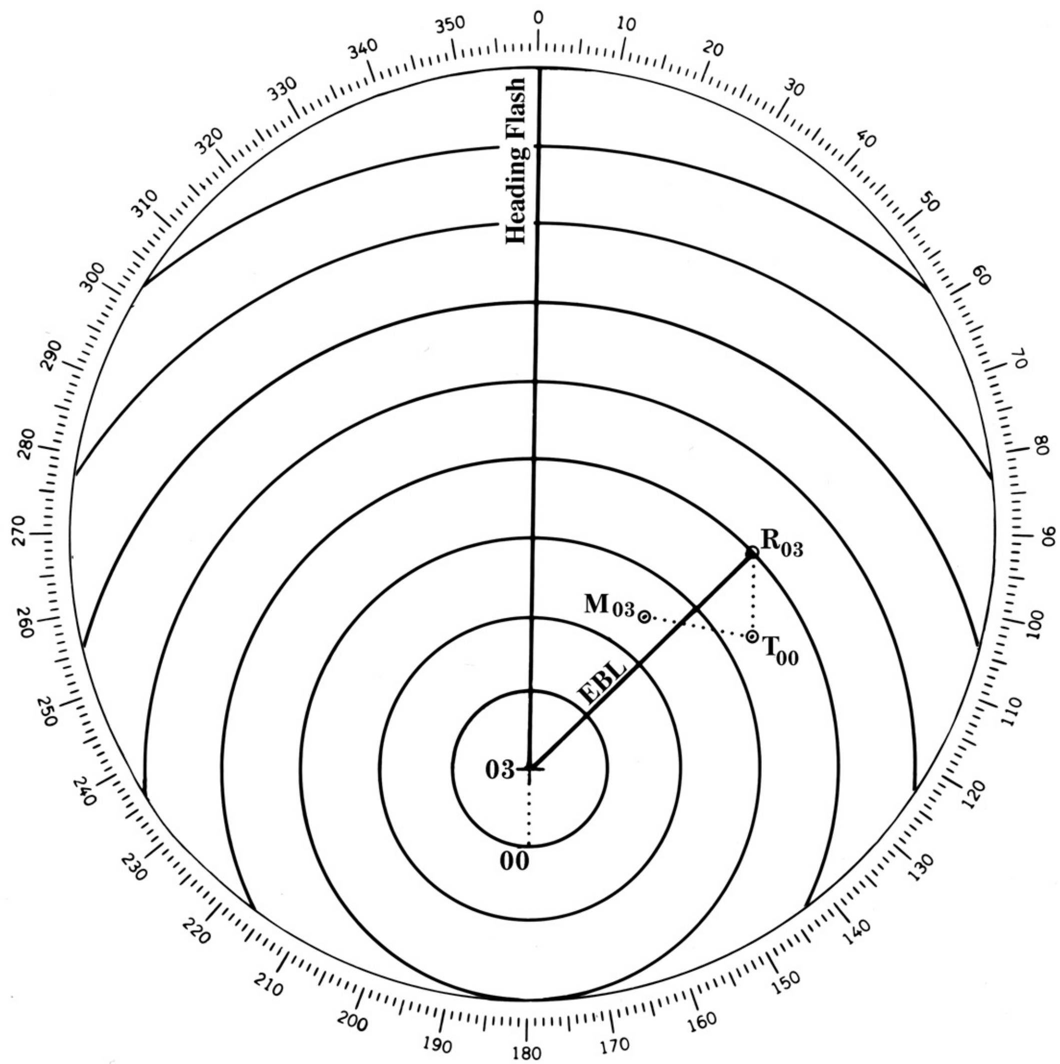


Own ship's course 000˚
speed 20 knots

Contact's course 280˚
speed 30 knots

Range-ring interval: 1 mile

Figure 3.47 - Electronic bearing line set at initial time position of contact moving in true motion.

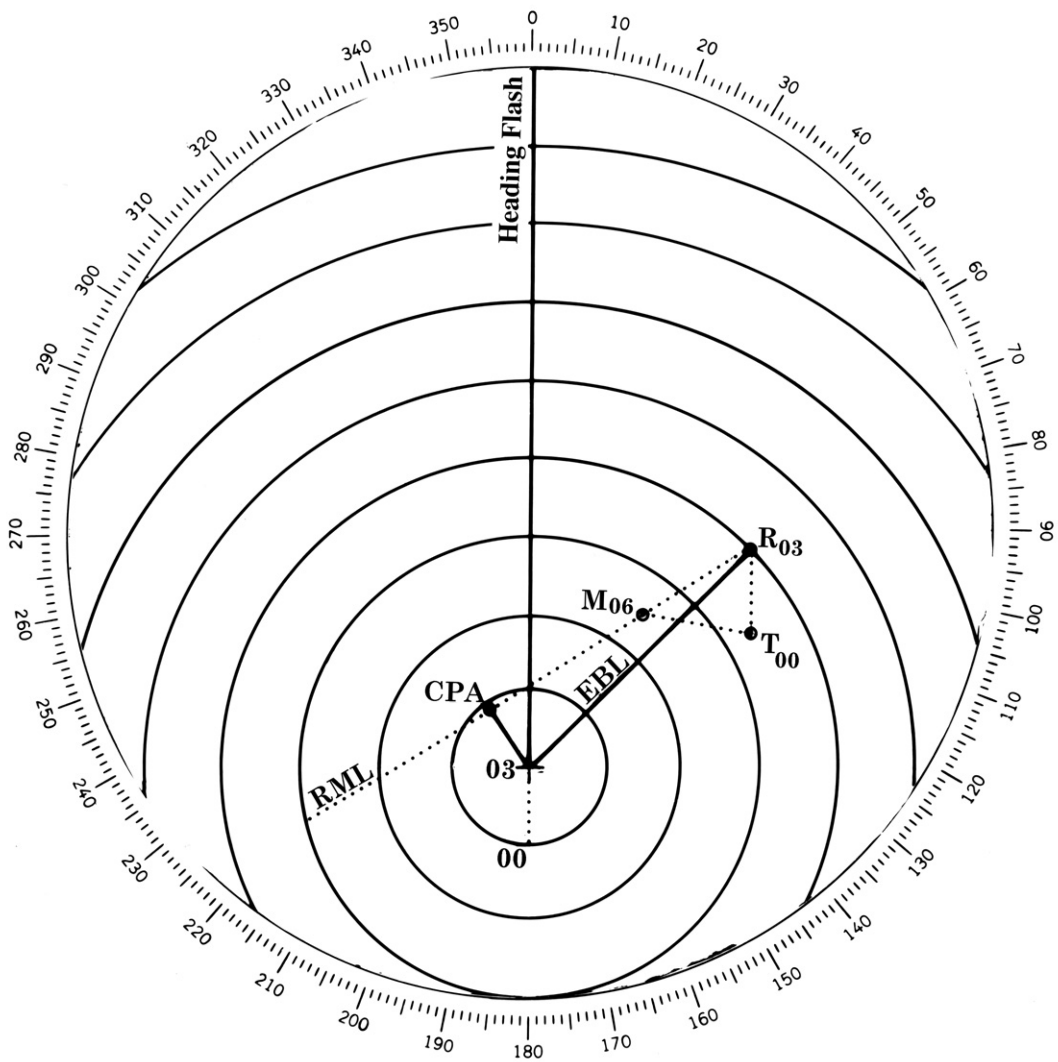


Own ship's course 000˚
speed 20 knots

Contact's course 280˚
speed 30 knots

Range-ring interval: 1 mile

Figure 3.48 - True motion display with electronic bearing line holding the bearing and range at which initially set.

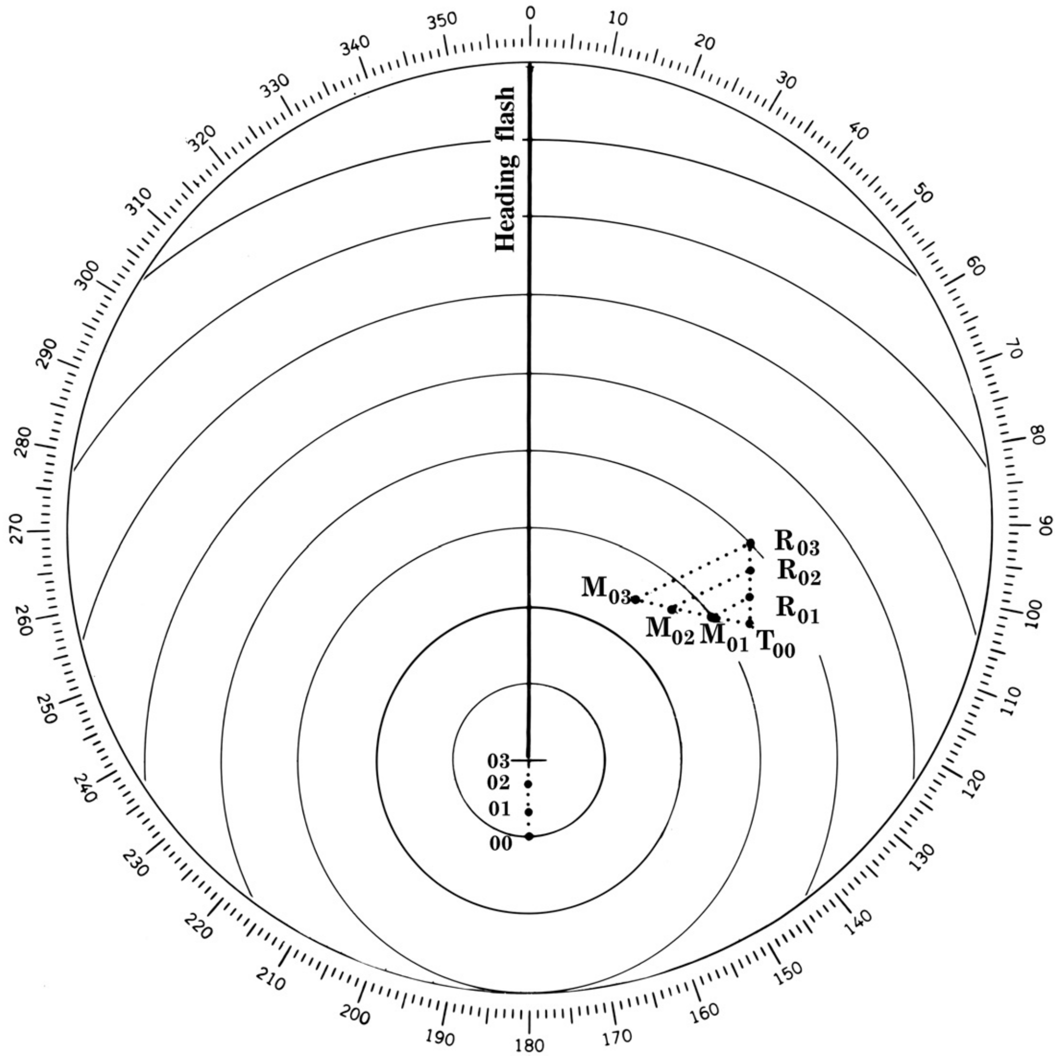


Own ship's course 000˚
speed 20 knots

Contact's course 280˚
speed 30 knots

Range-ring interval: 1 mile

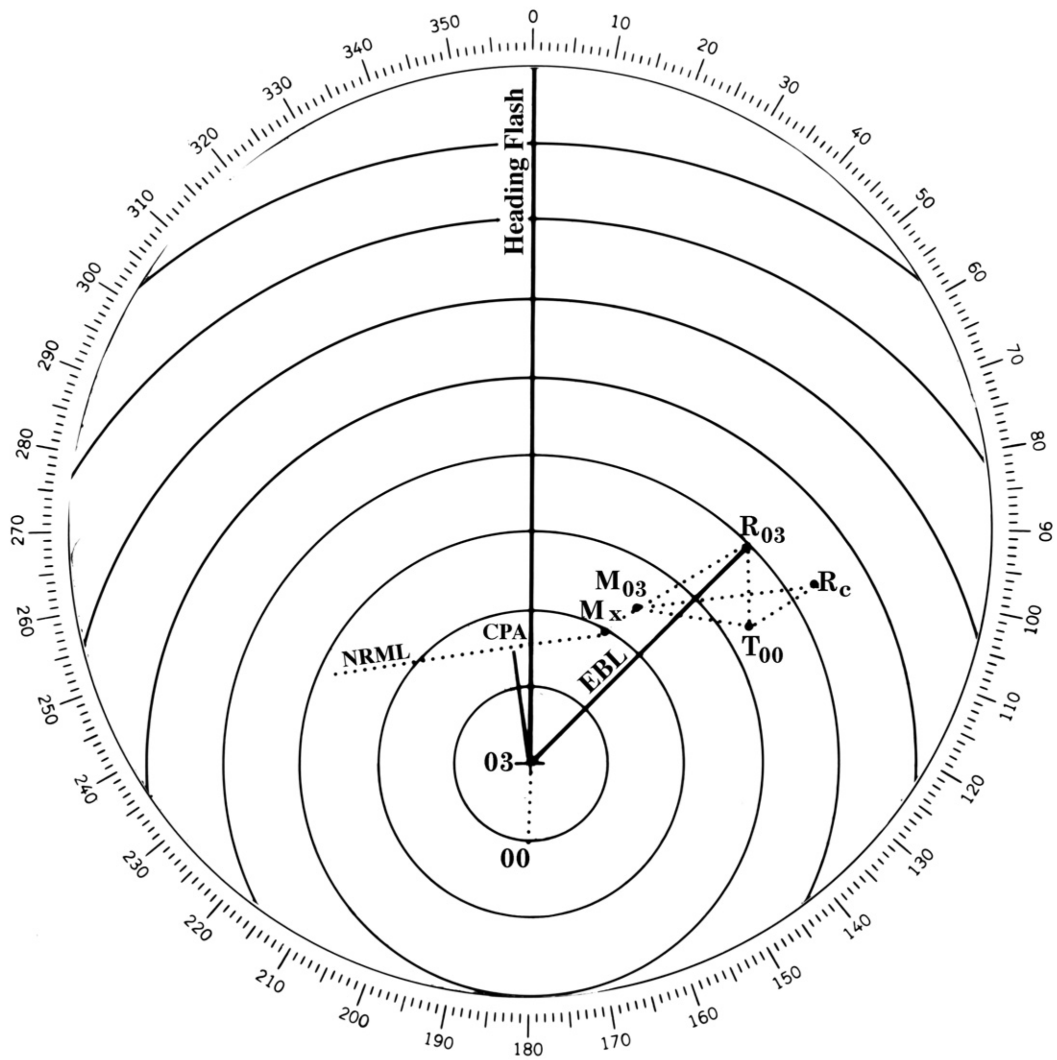
Figure 3.49 - Solution for CPA on true motion display.



Own ship's course 000˚
speed 20 knots

Contact's course 280˚
speed 30 knots

Figure 3.50 - Construction of *R-T-M* triangle at any time.



Own ship's course 000˚
speed 20 knots

Contact's course 280˚
speed 30 knots

Range-ring interval: 1 mile

Desired CPA: 1.5 miles

Figure 3.51 - Solution for desired CPA.

SITUATION RECOGNITION

INTRODUCTION

The rules for Situation Recognition were developed by Mr. Max H. Carpenter and Captain Wayne M. Waldo, former members of the faculty for the Maritime Institute of Technology and Graduate Studies, Linthicum Heights, Maryland. The following information is printed from Section VII of the *Real Time Method of Radar Plotting*.

As your RTM plotting skills increase so will your ability to instantly recognize dangerous situations without a plot. This skill can be described as Situation Recognition, and makes use of everything you have learned and practiced thus far.

This ability to recognize a situation as you view it on radar will mark you as an exceptionally competent mariner.

In a risk of collision situation, the *true* or *compass* direction of relative movement must be changed. Simple rules for rapid prediction of the change in the compass direction of relative movement (DRM) of a radar contact resulting from a course or speed change by own ship can be invaluable, particularly in confusing multiple-contact situations.

The rules can be used only when using a *stabilized relative motion* display. Attempting to apply these rules using an unstabilized radar display could be very dangerous since a high degree of compass orientation is required to discover and avoid the risk of collision. Preferably, the radarscope should have high persistence.

Situation Recognition can be thought as a two-step procedure. The first is to ascertain the risk of collision as required by the Rules of the road. The second is to recognize those actions you can take which will reduce the risk of collision, i.e. increase the passing distance

Step one; is relatively simple provided you obey the instruction given in the Steering and sailing Rules and ascertain the risk of collision, by “carefully watching the <u>compass</u> bearing of an approaching vessel. Therefore, your radar must give you the compass reference you need to recognize risk of collision. This means that the situation at a glance requires a gyro stabilized display. Unless your radar is so equipped that you can, at a glance, observe the compass bearing change of all approaching vessels you are seriously handicapped. There is no way you can, at a glance, determine the risk of collision by observing the relative bearings of approaching vessels. To repeat: there is only one method that is 100% reliable in determining risk of collision either visually or by radar, and that is the one given in the Steering and Sailing Rules. In this game of collision avoidance if you cannot satisfactorily answer the requirements of step one, it is impossible to evaluate the actions required in step two.

Step two; consists of deciding which of the four basic collision avoidance maneuvers will best increase the passing distance (turn left, turn right, speed up, slow down). This is relatively easy for you have been making these same decisions all your life. If while you are moving you visually observe an object coming towards you, you can very quickly decide how best to avoid a collision by either turning right or left, speeding up or slowing down. You do exactly the same thing using a radar to observe contacts coming towards the center of the scope.

RULES FOR SPEED CHANGE

The following rules provide predictions of how a contact's relative motion changes with a speed change by own ship. The predictions are valid irrespective of the position of the contact in range and bearing.

Reduced Speed

The relative plot moves up-the-scope when own ship reduces speed or stops.

Increased Speed

The relative plot moves down-the-scope when own ship increases speed.

Speed of Relative Motion (SRM)

The effectiveness of a turning maneuver depends, in part, upon the SRM of the radar target. A target whose SRM is high will show less change in relative motion than a similarly located contact with a low SRM.

Assume two contacts on collision courses approaching the observer's vessel at the same speed, with one contact 40˚ on the observer's port bow and the other 40˚ to starboard. A right turn will result in a small change in the DRM of the contact to starboard and a much larger change in the one to port. The difference is explained by the fact that the turn toward the starboard contact raised its SRM, making it more difficult to change. The port contact's SRM was reduced. As a result, the amount of DRM change was greater.

Thus, the effectiveness of a turn to avoid a contact is enhanced by turning away from the contact. This is illustrated in Figure 3.52.

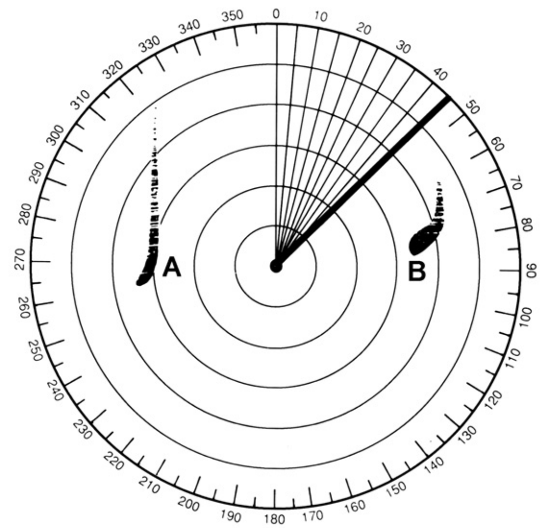


Figure 3.52 - Effects of a course change against targets with different speeds of relative motion.

SITUATION DISPLAYS

The series of illustrations which follow, shows various steps in evaluating the results of own ship's maneuvers using only the direction of relative motion as presented, and demonstrates the immediate readability of information sufficient to make risk of collision assessment and maneuver. These photographs were taken of a 16 inch stabilized north up relative motion radar, the range setting is 6 miles. Views A and B show the situation up to the decision time of 3 minutes. Views C thru J show the results of four simulator runs demonstrating each basic maneuver.

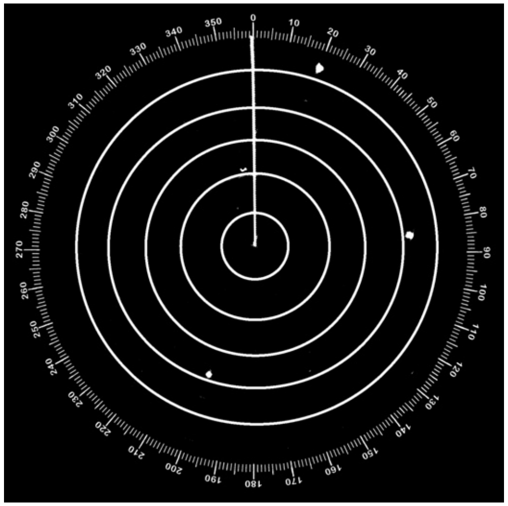
These illustrations show that it is possible for the maneuvering officer to have instantaneous, readily available, at-a-glance information which will "hang in" when the going gets rough and when orientation seems to be the most threatened. This is important, for it is difficult to assess a maneuver by reading a list of numbers concerning the threat and then mentally trying to associate those numbers with what own ship is doing.

APPLICATION

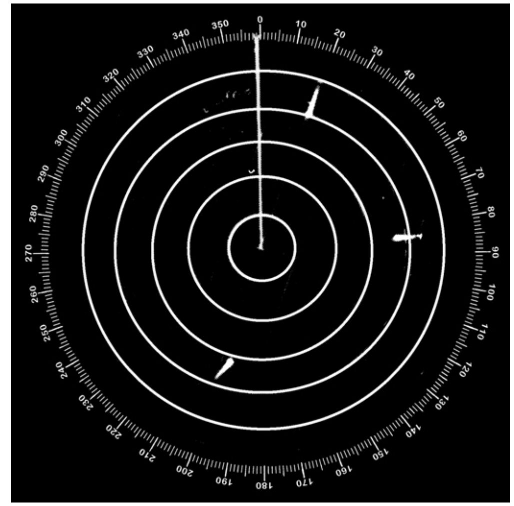
Figures 3.53 to 3.56 illustrate the use of the rules in evaluating the effects of evasive action by own ship.

When the contact is faster than own ship, the effect of own ship's evasive action on the compass direction of relative movement is generally less than it would be if own ship were the faster ship. Note that the contact is *always faster* than own ship in the up-the-scope and across-the-scope cases.

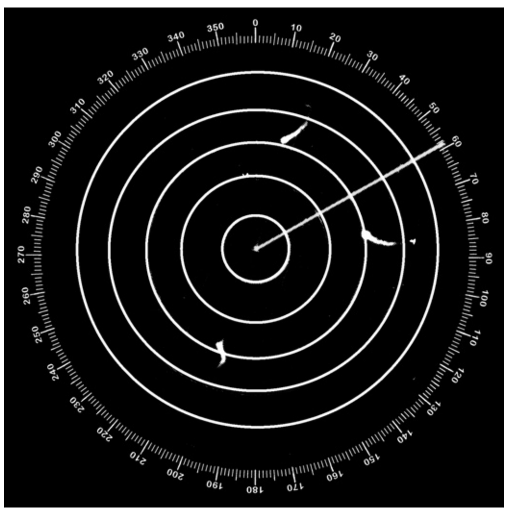
In making maneuvering decisions using the DRM technique, speed information on a ratio basis is adequate. The observer need only know whether the contact's speed is about one-half, three-fourths, or twice own ship's speed for example.



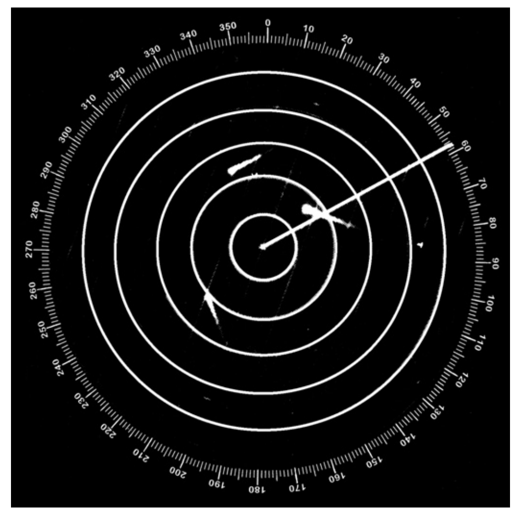
View A Upon switching from standby to on, we discover 3 contacts. No risk of collision is available therefore no maneuver decision can be made.



View B After the end of 3 minutes the direction of relative motion reveals that risk of collision exists with contacts on the starboard bow and beam. In other words the compass bearing is not changing on these two contacts.

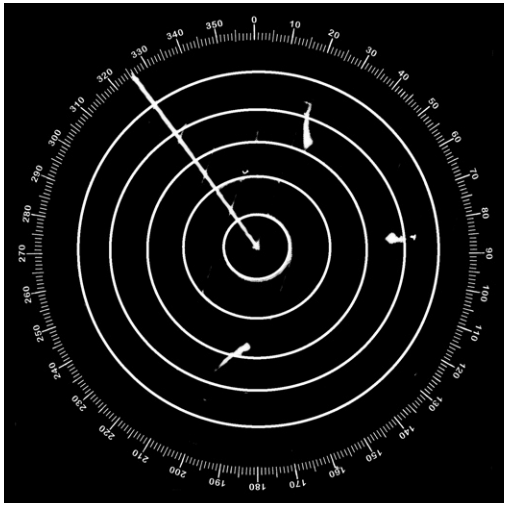


View C At the end of 5 minutes a decision to turn right 60° has resulted in a change in DRM of all contacts. The contact astern has changed his DRM from up to across category.

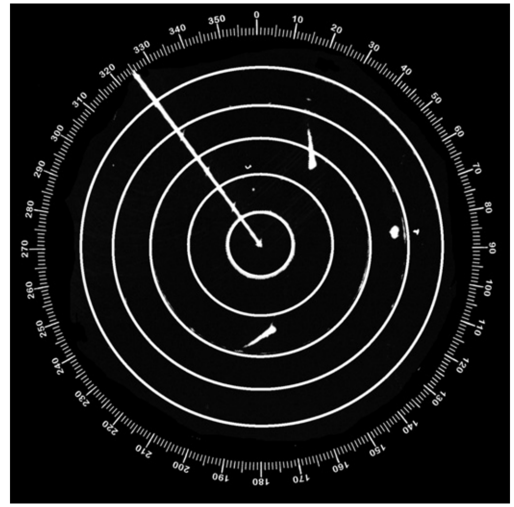


View D Approximately 10 minutes from the start the Master can begin coming back to base course expecting to achieve 1.5 mile CPA on all targets.

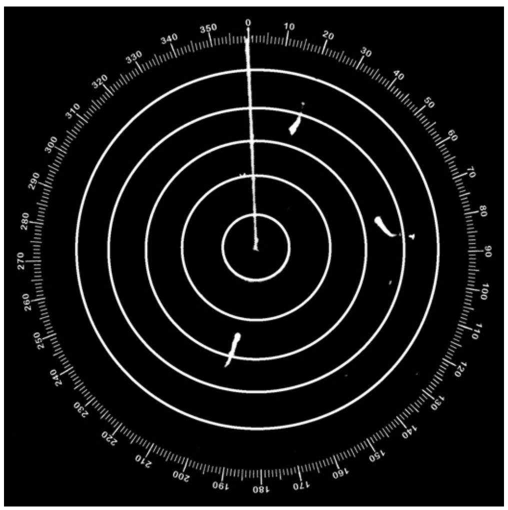
Figure 3.53 - Predicting effects of evasive action.



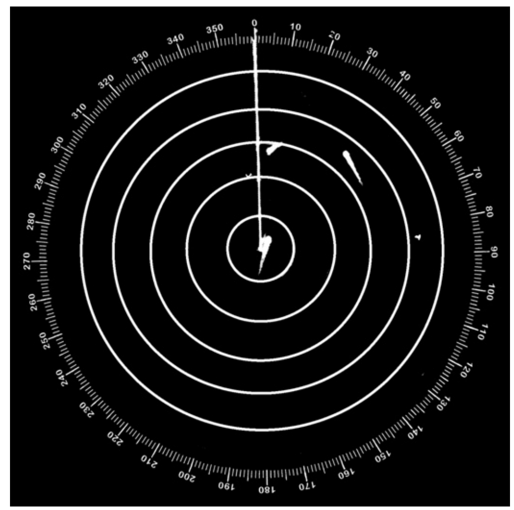
View E Same situation as Fig. 3 at five minutes, but with a 35 deg. left turn. Note “down” contact has moved to his left, “up” contact to his right.



View F The decision nine minutes from first observation for 35 deg. left projects a 1.5 mile CPA. Notice the beam contact has lost most of its relative motion, thus revealing his course and speed to be about the same as own ship’s at this instant.

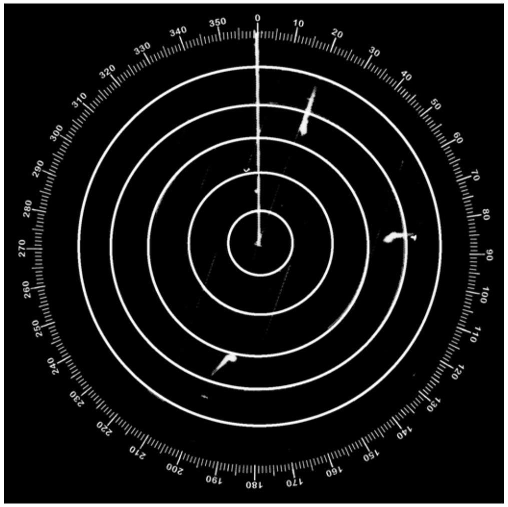


View G This is the original situation plus five minutes. The Master in this instance decided to stop. Note that all DRM is swinging forward.

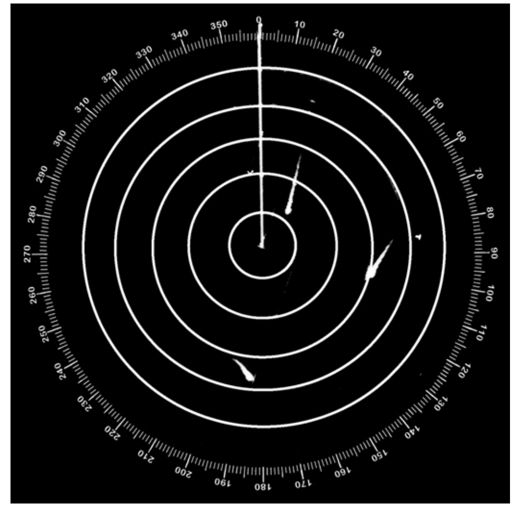


View H After 11 minutes, the action to stop has resulted in a close quarters situation.

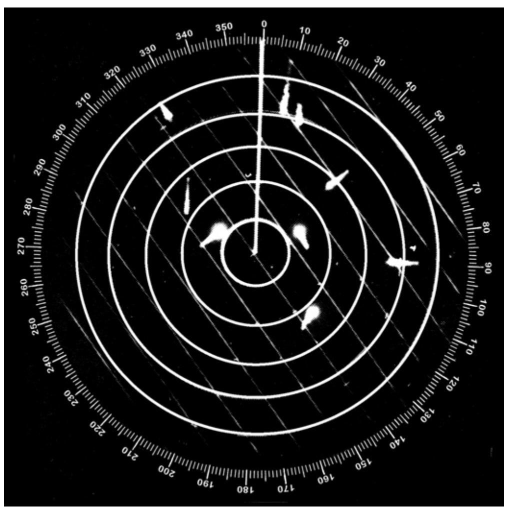
Figure 3.54 - Predicting effects of evasive action.



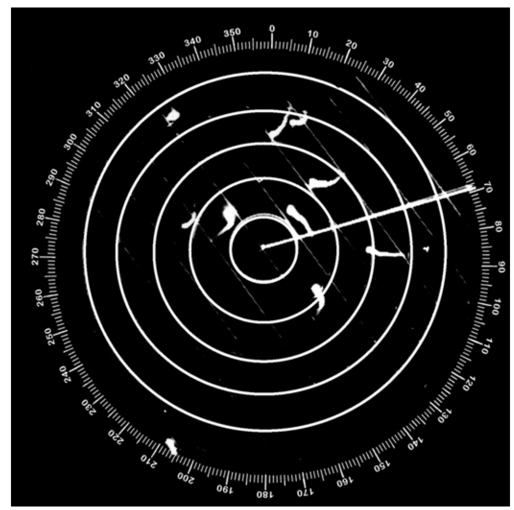
View I **At five minutes the decision to increase speed from half to full ahead results in a swing of all DRM aft. It is apparent that vessel whose DRM is 195 deg. will pass close but clear.**



View J **After 10 minutes it is obvious that all contacts will pass clear, but contact whose DRM is 195˚ will clear by only one-half mile.**



View K **A high density situation.**



View L **Trying for a 1-mile CPA in the high density situation illustrated in View K the conning officer comes to course 060˚. After 2 minutes he notes that the contact bearing 125˚ will pass too close. Therefore, he starts to come to course 125˚.**

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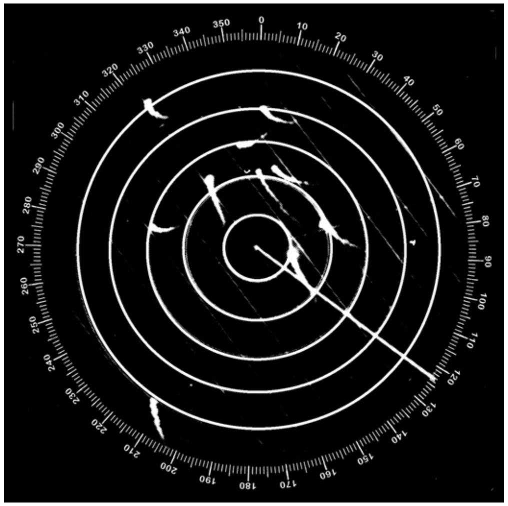
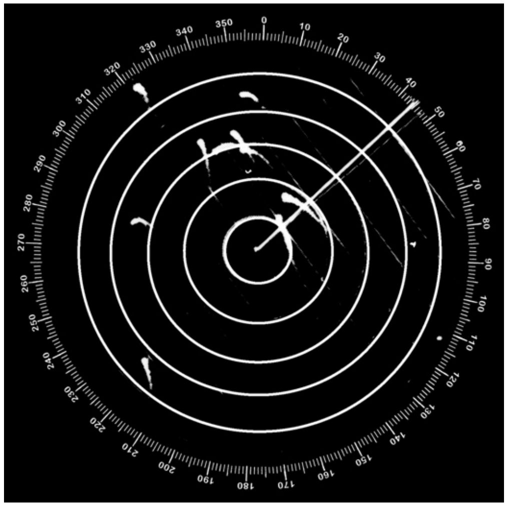
Figure 3.55 - Predicting effects of evasive action.



View M **The relative plots of all contacts are changing according to the rules.**



View N **After 6 minutes the conning officer can resume his original course.**

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Figure 3.56 - Predicting effects of evasive action.

RULES FOR MANEUVERING

To maneuver using the information from “situation recognition” requires a technique whose effectiveness has been demonstrated in the radar laboratory and is currently being used at sea. This technique makes use of the “natural” ability we all have in avoiding collision with moving objects in daily life. This ability is, an understanding of relative motion. In this technique we use the Direction of Relative Motion (DRM) as the key to the whole thing.

In considering this key, let’s remember that any collision avoidance system requires, as a minimum, a stabilized radar which has the high persistence phosphor C.R.T. With this we have a display from which we can obtain the information on the DRM almost at a glance. With a few simple rules concerning this direction of relative motion, and a Deck Officer with maneuvering experience, we now have a competent marine collision avoidance system.

In viewing any radar scope, the direction in which the ship’s heading flasher is pointing can be described as “up the scope”. The reciprocal of it is a direction opposite to the heading flasher, or “down the scope”. A contact moving at right angles to the heading flasher anywhere on the scope would be described as “across the scope”.

The rules we use to show that DRM is the “key” are based solely on the relationship of DRM with reference to own ship’s heading flasher. These rules alert the deck officer to the expected effect on DRM as a result of any collision avoidance action, such as any course or speed change. We have three specific rules concerning course change, two specific rules concerning speed change, and two subordinate rules which apply to the technique described therein.

Rule number one: Any contact appearing on the scope, regardless of position in range and bearing whose direction of relative motion is up-the-scope, from a few degrees up, to parallel to the heading flasher, when own ship turns right, the direction of relative motion of the observed threat will turn to its left.

Rule number two: Any contact whose direction of relative motion is down-the-scope, that is, anywhere from a few degrees down, to parallel to the heading flasher but in the opposite direction, when own ship turns right, the direction of relative motion will turn to its right. (Views A-D) This rule also applies in the case of a left turn as shown in (Views E and F).

Rule number three: Any contact whose DRM is across-the-scope is in “limbo”. Changing of own ship’s course left or right will have very little effect on the crossing contacts DRM until it’s category is changed to either a “down contact” or “up contact”, and then the contact will follow rules One or Two as stated previously (View F).

Rule number four: If own ship reduces speed or stops, all relative motion observed on your scope will swing forward or “up-the-scope”, no matter where they are. (View G).

Rule number five: Conversely, if own ship increases speed, all relative motion will swing aft, or down the scope. (View I).

The experienced mariner of course knows that any contact whose relative motion is up-the-scope is a faster ship. this fact also applies to contacts whose direction of relative motion is at right angles to the heading flasher as in rule three contacts.

Though specific speed is not available in using the DRM technique, the speed information is adequate for making decisions in maneuvering. The experienced officer usually handles speed on the basis of a ratio. Is the threat’s relative speed faster or slower than own ship’s speed?

Rule number six: If contact’s relative speed is high, the effect of own ship’s avoiding action is low.

Rule number seven: If contact’s relative speed is low, the effect of own ship’s avoiding action is high.

To state Rules 6 and 7 in another way, if the contact is faster than own ship, it is likely to be harder to maneuver against. If it is slower, then own ship essentially is in command of the situation.

CHAPTER 4 — RADAR NAVIGATION

RADARSCOPE INTERPRETATION

In its position finding or navigational application, radar may serve the navigator as a very valuable tool if its characteristics and limitations are understood. While determining position through observation of the range and bearing of a charted, isolated, and well defined object having good reflecting properties is relatively simple, this task still requires that the navigator have an understanding of the characteristics and limitations of his radar. The more general task of using radar in observing a shoreline where the radar targets are not so obvious or well defined requires considerable expertise which may be gained only through an adequate understanding of the characteristics and limitations of the radar being used.

While the plan position indicator does provide a chartlike presentation when a landmass is being scanned, the image painted by the sweep is not a true representation of the shoreline. The width of the radar beam and the length of the transmitted pulse are factors which act to distort the image painted on the scope. Briefly, the width of the radar beam acts to distort the shoreline features in bearing; the pulse length may act to cause offshore features to appear as part of the landmass.

The major problem is that of determining which features in the vicinity of the shoreline are actually reflecting the echoes painted on the scope. Particularly in cases where a low lying shore is being scanned, there may be considerable uncertainty.

An associated problem is the fact that certain features on the shore will not return echoes, even if they have good reflecting properties, simply because they are blocked from the radar beam by other physical features or obstructions. This factor in turn causes the chartlike image painted on the scope to differ from the chart of the area.

If the navigator is to be able to interpret the chartlike presentation on his radarscope, he must have at least an elementary understanding of the characteristics of radar propagation, the characteristics of his radar set, the reflecting properties of different types of radar targets, and the ability to analyze his chart to make an estimate of just which charted features are most likely to reflect the transmitted pulses or to be blocked from the radar beam. While contour lines on the chart topography aid the navigator materially in the latter task, experience gained during clear weather comparison of the visual cross-bearing plot and the radarscope presentation is invaluable.

LAND TARGETS

On relative and true motion displays, landmasses are readily recognizable because of the generally steady brilliance of the relatively large areas painted on the PPI. Also land should be at positions expected from knowledge of the ship's navigational position. On relative motion displays, landmasses move in directions and at rates opposite and equal to the actual motion of the observer's ship. Individual pips do not move relative to one another. On true motion displays, landmasses do not move on the PPI if there is accurate compensation for set and drift. Without such compensation, i.e., when the true motion display is sea-stabilized, only slight movements of landmasses may be detected on the PPI.

While landmasses are readily recognizable, the primary problem is the identification of specific features so that such features can be used for fixing the position of the observer's ship. Identification of specific features can be quite difficult because of various factors, including distortion resulting from beam width and pulse length and uncertainty as to just which charted features are reflecting the echoes. The following hints may be used as an aid in identification:

(a) Sandspits and smooth, clear beaches normally do not appear on the PPI at ranges beyond 1 or 2 miles because these targets have almost no area that can reflect energy back to the radar. Ranges determined from these targets are not reliable. If waves are breaking over a sandbar, echoes may be returned from the surf. Waves may, however, break well out from the actual shoreline, so that ranging on the surf may be misleading when a radar position is being determined relative to shoreline.

(b) Mud flats and marshes normally reflect radar pulses only a little better than a sandspit. The weak echoes received at low tide disappear at high tide. Mangroves and other thick growth may produce a strong echo. Areas that are indicated as swamps on a chart, therefore, may return either strong or weak echoes, depending on the density and size of the vegetation growing in the area.

(c) When sand dunes are covered with vegetation and are well back from a low, smooth beach, the apparent shoreline determined by radar appears as the line of the dunes rather than the true shoreline. Under some conditions, sand dunes may return strong echo signals because the combination of the vertical surface of the vegetation and the horizontal beach may form a sort of corner reflector.

(d) Lagoons and inland lakes usually appear as blank areas on a PPI because the smooth water surface returns no energy to the radar antenna. In some instances, the sandbar or reef surrounding the lagoon may not appear on the PPI because it lies too low in the water.

(e) Coral atolls and long chains of islands may produce long lines of echoes when the radar beam is directed perpendicular to the line of the islands. This indication is especially true when the islands are closely spaced. The reason is that the spreading resulting from the width of the radar beam causes the echoes to blend into continuous lines. When the chain of islands is viewed lengthwise, or obliquely, however, each island may produce a separate pip. Surf breaking on a reef around an atoll produces a ragged, variable line of echoes.

(f) Submerged objects do not produce radar echoes. One or two rocks projecting above the surface of the water, or waves breaking over a reef, may appear on the PPI. When an object is submerged entirely and the sea is smooth over it, no indication is seen on the PPI.

(g) If the land rises in a gradual, regular manner from the shoreline, no part of the terrain produces an echo that is stronger than the echo from any other part. As a result, a general haze of echoes appears on the PPI, and it is difficult to ascertain the range to any particular part of the land.

Land can be recognized by plotting the contact. Care must be exercised when plotting because, as a ship approaches or goes away from a shore behind which the land rises gradually, a plot of the ranges and bearings to the land may show an “apparent course and speed. This phenomenon is demonstrated in figure 4.1. In view A the ship is 50 miles from the land, but because the radar beam strikes at point 1, well up on the slope, the indicated range is 60 miles. In view B where the ship is 10 miles closer to land, the indicated range is 46 miles because the radar echo is now returned from point 2. In view C where the ship is another 10 miles closer, the radar beam strikes at point 3, even lower on the slope, so that the indicated range is 32 miles. If these ranges are plotted, the land will appear to be moving toward the ship.

In figure 4.1, a smooth, gradual slope is assumed, so that a consistent plot is obtained. In practice, however, the slope of the ground usually is irregular and the plot erratic, making it hard to assign a definite speed to the land contact. The steeper the slope of the land, the less is its apparent speed. Furthermore, because the slope of the land does not always fall off in the direction from which the ship approaches, the apparent course of the contact

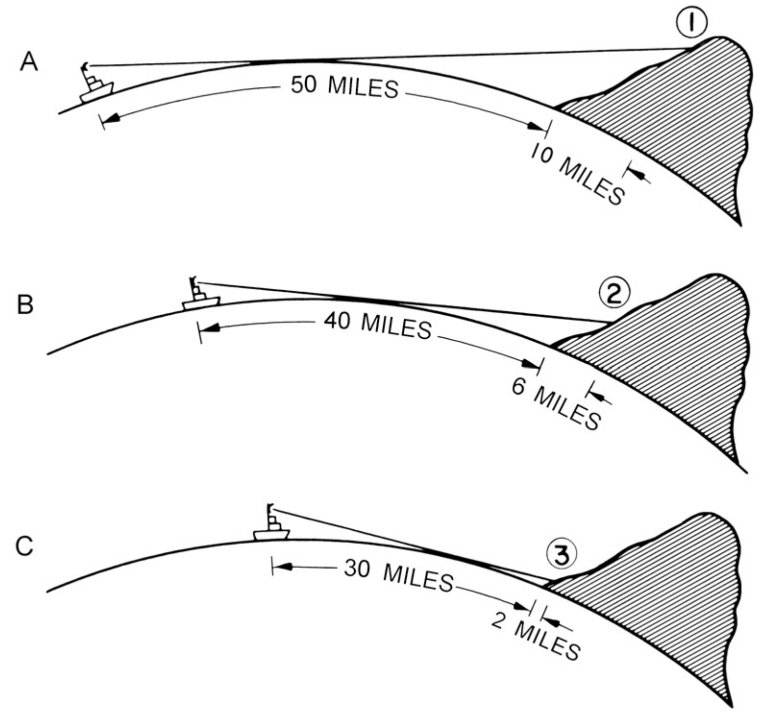

Figure 4.1 - Apparent course and speed of land target.

need not always be the opposite of the course of the ship, as assumed in this simple demonstration.

(h) Blotchy signals are returned from hilly ground because the crest of each hill returns a good echo although the valley beyond is in a shadow. If high receiver gain is used, the pattern may become solid except for the very deep shadows.

(i) Low islands ordinarily produce small echoes. When thick palm trees or other foliage grow on the island, strong echoes often are produced because the horizontal surface of the water around the island forms a sort of corner reflector with the vertical surfaces of the trees. As a result, wooded islands give good echoes and can be detected at a much greater range than barren islands.

SHIP TARGETS

With the appearance of a small pip on the PPI, its identification as a ship can be aided by a process of elimination. A check of the navigational position can overrule the possibility of land. The size of the pip can be used to overrule the possibility of land or precipitation, both usually having a massive appearance on the PPI. The rate of movement of the pip on the PPI can overrule the possibility of aircraft.

Having eliminated the foregoing possibilities, the appearance of the pip at a medium range as a bright, steady, and clearly defined image on the PPI indicates a high probability that the target is a steel ship.

The pip of a ship target may brighten at times and then slowly decrease in brightness. Normally, the pip of a ship target fades from the PPI only when the range becomes too great.

RADAR SHADOW

While PPI displays are approximately chartlike when landmasses are being scanned by the radar beam, there may be sizable areas missing from the display because of certain features being blocked from the radar beam by other features. A shoreline which is continuous on the PPI display when the ship is at one position may not be continuous when the ship is at another position and scanning the same shoreline. The radar beam may be blocked from a segment of this shoreline by an obstruction such as a promontory. An indentation in the shoreline, such as a cove or bay, appearing on the PPI when the ship is at one position may not appear when the ship is at another position nearby. Thus, radar shadow alone can cause considerable differences between the PPI display and the chart presentation. This effect in conjunction with the beam width and pulse length distortion of the PPI display can cause even greater differences.

BEAM WIDTH AND PULSE LENGTH DISTORTION

The pips of ships, rocks, and other targets close to shore may merge with the shoreline image on the PPI. This merging is due to the distortion effects of horizontal beam width and pulse length. Target images on the PPI always are distorted angularly by an amount equal to the effective horizontal beam width. Also, the target images always are distorted radially by an amount at least equal to one-half the pulse length (164 yards per microsecond of pulse length).

Figure 4.2 illustrates the effects of ship’s position, beam width, and pulse length on the radar shoreline. Because of beam width distortion, a straight, or nearly straight, shoreline often appears crescent-shaped on the PPI. This effect is greater with the wider beam widths. Note that this distortion increases as the angle between the beam axis and the shoreline decreases.

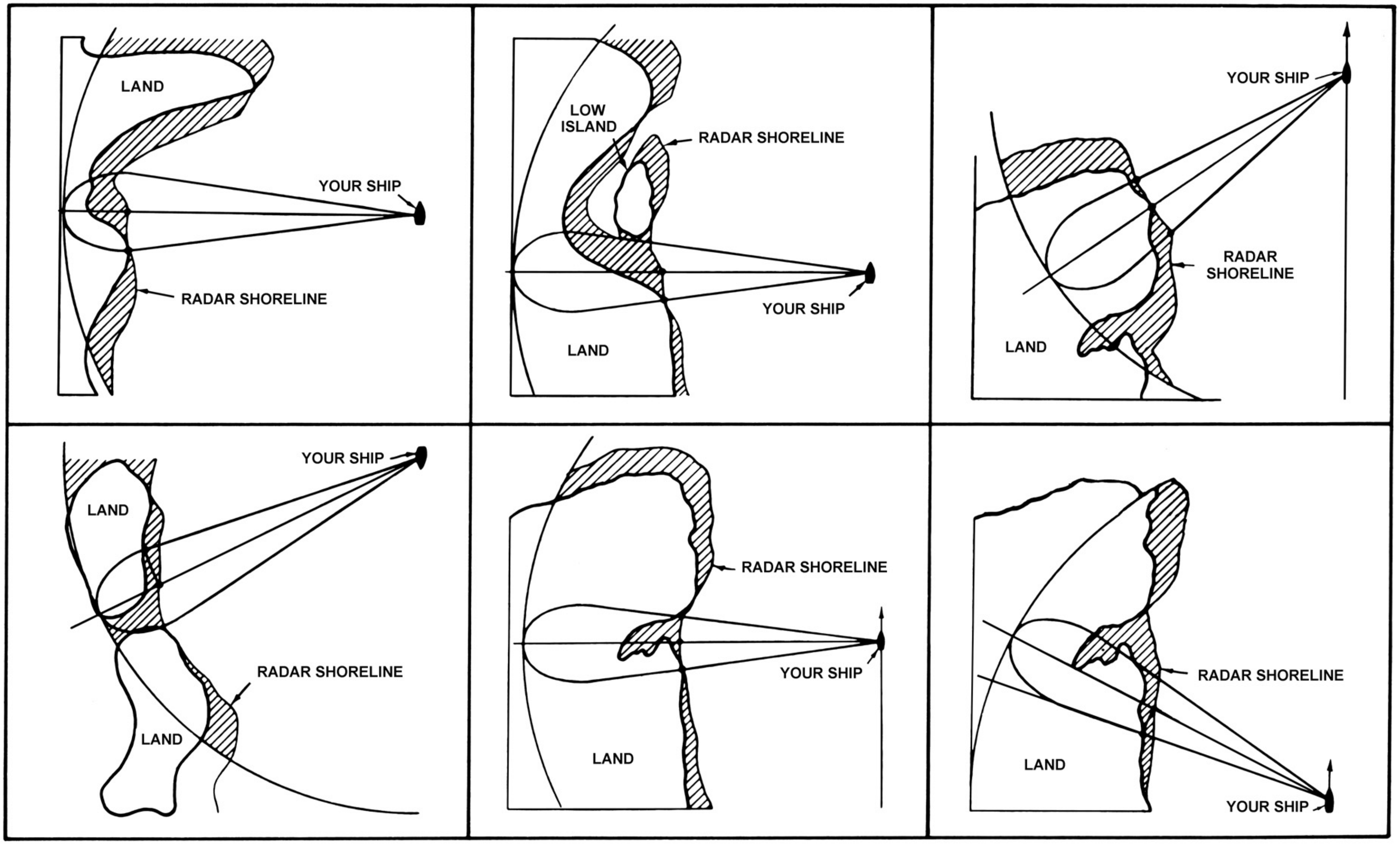

Figure 4.2 - Effects of ship's position, beam width, and pulse length on radar shoreline.

SUMMARY OF DISTORTIONS

Figure 4.3 illustrates the distortion effects of radar shadow, beam width, and pulse length. View A shows the actual shape of the shoreline and the land behind it. Note the steel tower on the low sand beach and the two ships at anchor close to shore. The heavy line in view B represents the shoreline on the PPI. The dotted lines represent the actual position and shape of all targets. Note in particular:

(a) The low sand beach is not detected by the radar.

(b) The tower on the low beach is detected, but it looks like a ship in a cove. At closer range the land would be detected and the cove-shaped area would begin to fill in; then the tower could not be seen without reducing the receiver gain.

(c) The radar shadow behind both mountains. Distortion owing to radar shadows is responsible for more confusion than any other cause. The small island does not appear because it is in the radar shadow.

(d) The spreading of the land in bearing caused by beam width distortion. Look at the upper shore of the peninsula. The shoreline distortion is greater to the west because the angle between the radar beam and the shore is smaller as the beam seeks out the more westerly shore.

(e) Ship No. 1 appears as a small peninsula. Her pip has merged with the land because of the beam width distortion.

(f) Ship No. 2 also merges with the shoreline and forms a bump. This bump is caused by pulse length and beam width distortion. Reducing receiver gain might cause the ship to separate from land, provided the ship is not too close to the shore. The FTC could also be used to attempt to separate the ship from land.

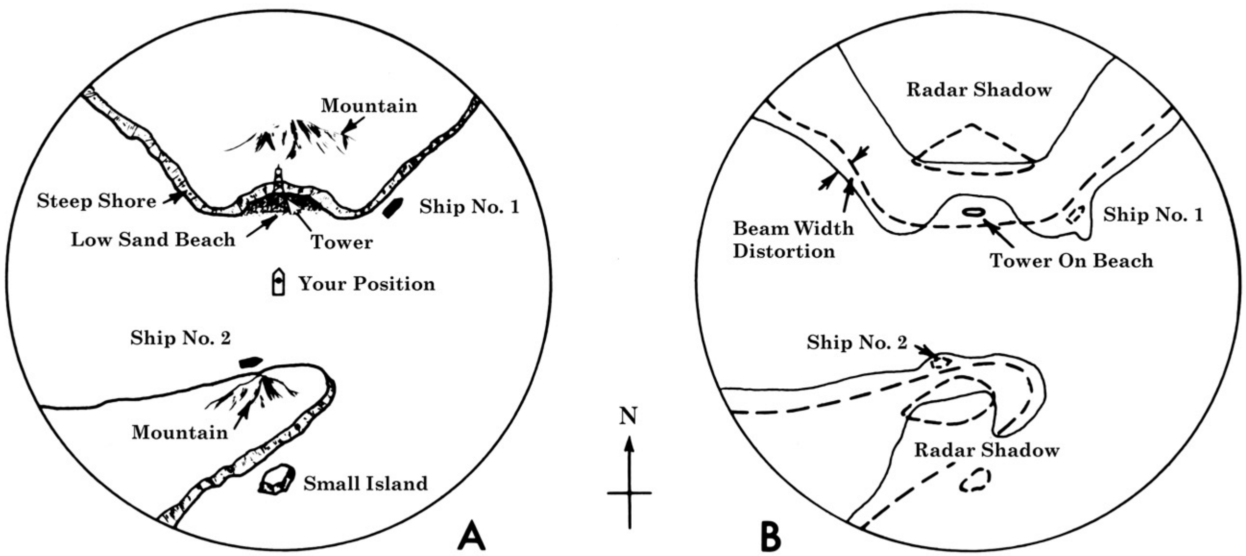

Figure 4.3 - Distortion effects of radar shadow, beam width, and pulse length.

RECOGNITION OF UNWANTED ECHOES AND EFFECTS

The navigator must be able to recognize various abnormal echoes and effects on the radarscope so as not to be confused by their presence.

Indirect (False) Echoes

Indirect or false echoes are caused by reflection of the main lobe of the radar beam off ship's structures such as stacks and kingposts. When such reflection does occur, the echo will return from a legitimate radar contact to the antenna by the same indirect path. Consequently, the echo will appear on the PPI at the bearing of the reflecting surface. This indirect echo will appear on the PPI at the same range as the direct echo received, assuming that the additional distance by the indirect path is negligible (see figure 4.4).

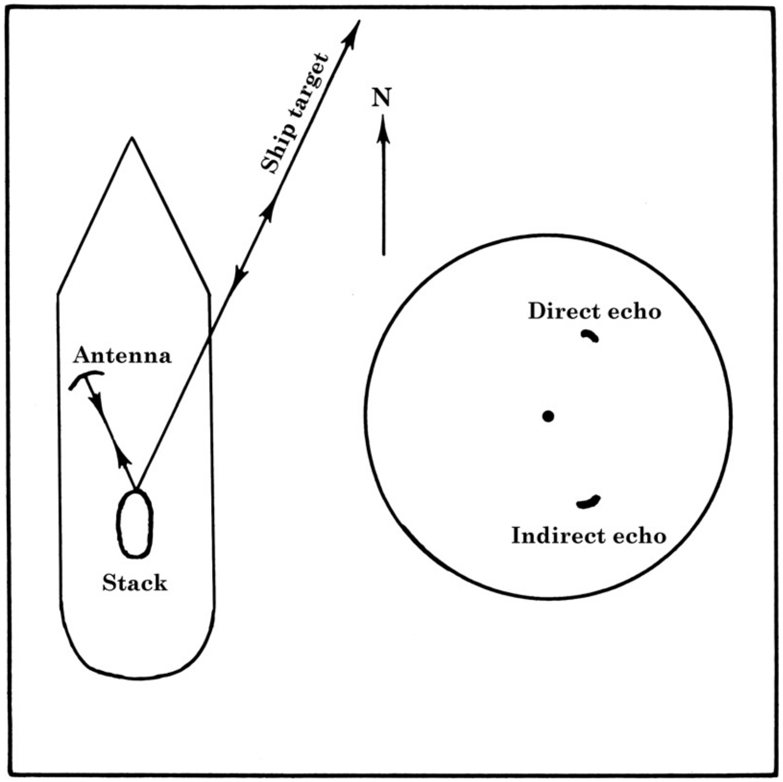

Figure 4.4 - Indirect echo.

Characteristics by which indirect echoes may be recognized are summarized as follows:

(1) The indirect echoes will usually occur in shadow sectors.

(2) They are received on substantially constant bearings although the true bearing of the radar contact may change appreciably.

(3) They appear at the same ranges as the corresponding direct echoes.

(4) When plotted, their movements are usually abnormal.

(5) Their shapes may indicate that they are not direct echoes.

Figure 4.5 illustrates a massive indirect echo such as may be reflected by a landmass.

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Figure 4.5 - Indirect echo reflected by a landmass.

Side-lobe Effects

Side-lobe effects are readily recognized in that they produce a series of echoes on each side of the main lobe echo at the same range as the latter. Semi-circles or even complete circles may be produced. Because of the low energy of the side-lobes, these effects will normally occur only at the shorter ranges. The effects may be minimized or eliminated through use of the gain and anticlutter controls. Slotted wave guide antennas have largely eliminated the side-lobe problem (see figure 4.6).

Multiple Echoes

Multiple echoes may occur when a strong echo is received from another ship at close range. A second or third or more echoes may be observed on the radarscope at double, triple, or other multiples of the actual range of the radar contact (see figure 4.7).

Second-Trace (Multiple-Trace) Echoes

Second-trace echoes (multiple-trace echoes) are echoes received from a contact at an actual range greater than the radar range setting. If an echo from a distant target is received after the following pulse has been transmitted, the echo will appear on the radarscope at the correct bearing but not at the true range. Second-trace echoes are unusual except under abnormal atmospheric conditions, or conditions under which super-refraction is present. Second-trace echoes may be recognized through changes in their positions on the radarscope on changing the pulse repetition rate (PRR); their hazy, streaky, or distorted shape; and their erratic movements on plotting.

As illustrated in figure 4.8, a target pip is detected on a true bearing of 090˚ at a distance of 7.5 miles. On changing the PRR from 2000 to 1800 pulses per second, the same target is detected on a bearing of 090˚ at a distance of 3 miles (see figure 4.9). The change in the position of the pip indicates that the pip is a second-trace echo. The actual distance of the target is the distance as indicated on the PPI plus half the distance the radar wave travels between pulses.

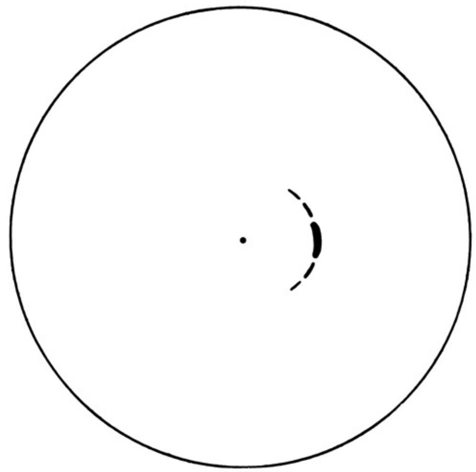

Figure 4.6 - Side-lobe effects.

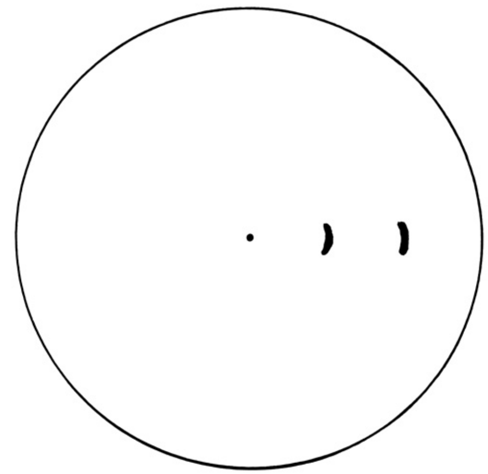

Figure 4.7 - Multiple echoes.

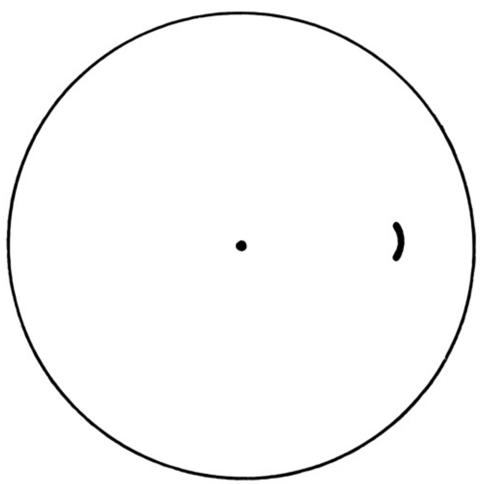

Figure 4.8 - Second-trace echo on 12-mile range scale.

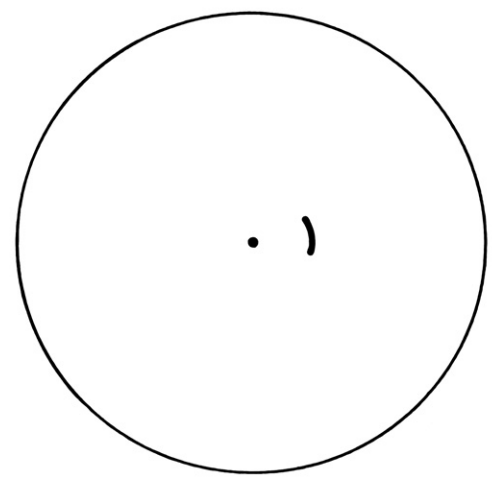

Figure 4.9 - Position of second-trace echo on 12-mile range scale after changing PRR.

Figure 4.10 - Normal, indirect, multiple, and side echoes.

Figure 4.10 illustrates normal, indirect, multiple, and side echoes on a PPI with an accompanying annotated sketch.

Electronic Interference Effects

Electronic interference effects, such as may occur when in the vicinity of another radar operating in the same frequency band as that of the observer's ship, is usually seen on the PPI as a large number of bright dots either scattered at random or in the form of dotted lines extending from the center to the edge of the PPI.

Interference effects are greater at the longer radar range scale settings. The interference effects can be distinguished easily from normal echoes because they do not appear in the same places on successive rotations of the antenna.

Blind and Shadow Sectors

Stacks, masts, samson posts, and other structures may cause a reduction in the intensity of the radar beam beyond these obstructions, especially if they are close to the radar antenna. If the angle at the antenna subtended by the obstruction is more than a few degrees, the reduction of the intensity of the radar beam beyond the obstruction may be such that a blind sector is produced. With lesser reduction in the intensity of the beam beyond the obstructions, shadow sectors, as illustrated in figure 4.11, can be produced. Within these shadow sectors, small targets at close range may not be detected while larger targets at much greater ranges may be detected.

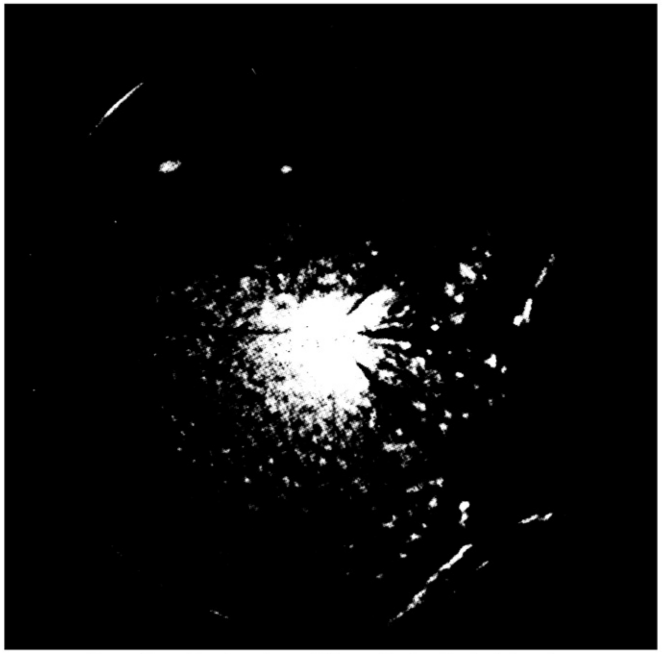

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Figure 4.11 - Shadow sectors.

Spoking

Spoking appears on the PPI as a number of spokes or radial lines. Spoking is easily distinguished from interference effects because the lines are straight on all range-scale settings and are lines rather than a series of dots.

The spokes may appear all around the PPI, or they may be confined to a sector. Should the spoking be confined to a narrow sector, the effect can be distinguished from a ramark signal of similar appearance through observation of the steady relative bearing of the spoke in a situation where the bearing of the ramark signal should change. The appearance of spoking is indicative of need for equipment maintenance.

Sectoring

The PPI display may appear as alternately normal and dark sectors. This phenomenon is usually due to the automatic frequency control being out of adjustment.

Serrated Range Rings

The appearance of serrated range rings is indicative of need for equipment maintenance.

PPI Display Distortion

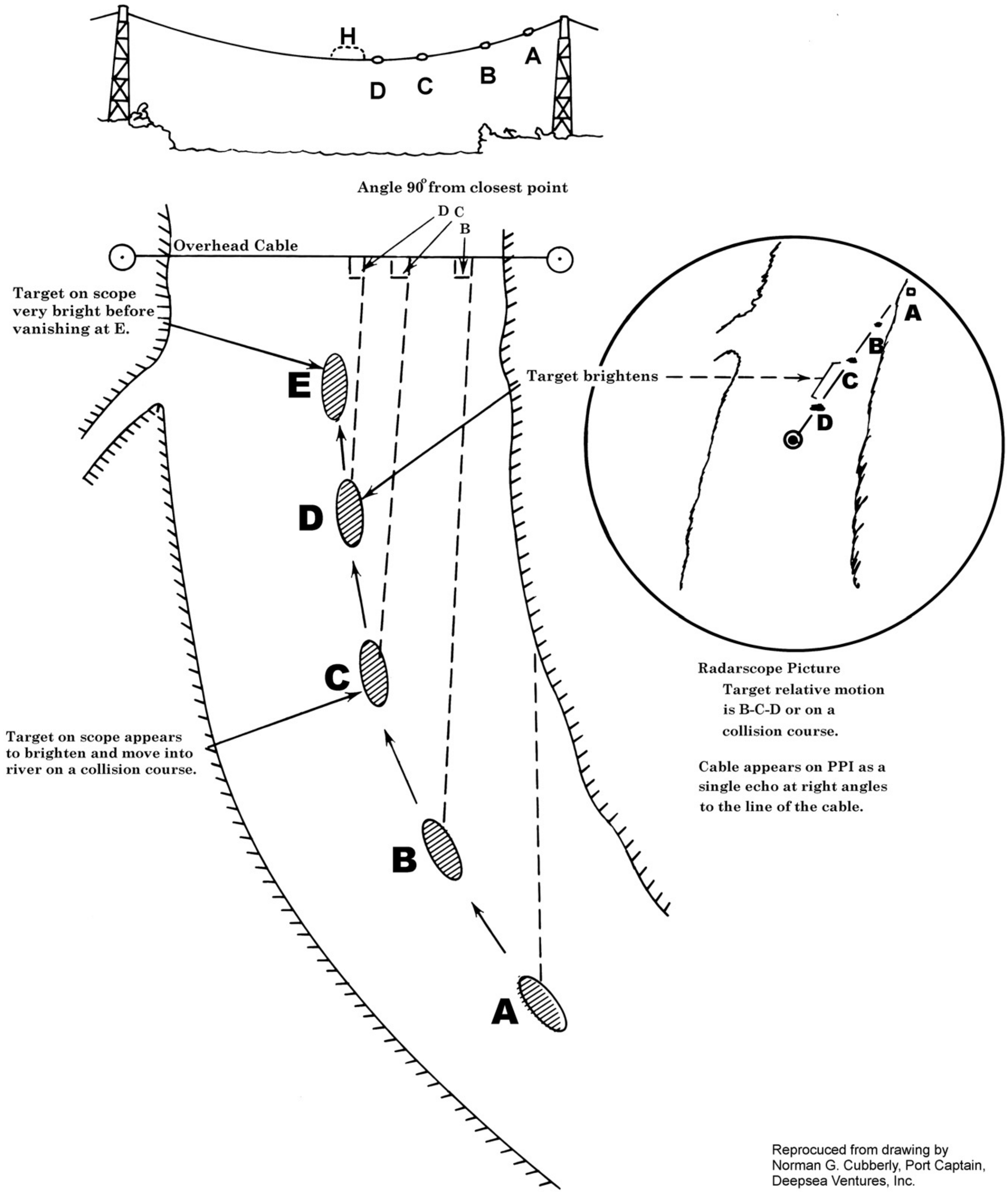
After the radar set has been turned on, the display may not spread immediately to the whole of the PPI because of static electricity inside the CRT. Usually, this static electricity effect, which produces a distorted PPI display, lasts no longer than a few minutes.

Hour-Glass Effect

Hour-glass effect appears as either a constriction or expansion of the display near the center of the PPI. The expansion effect is similar in appearance to the expanded center display. This effect, which can be caused by a nonlinear time base or the sweep not starting on the indicator at the same instant as the transmission of the pulse, is most apparent when in narrow rivers or close to shore.

Overhead Cable Effect

The echo from an overhead power cable appears on the PPI as a single echo always at right angles to the line of the cable. If this phenomenon is not recognized, the echo can be wrongly identified as the echo from a ship on a steady bearing. Avoiding action results in the echo remaining on a constant bearing and moving to the same side of the channel as the ship altering course. This phenomenon is particularly apparent for the power cable spanning the Straits of Messina. See figure 4.12 for display of overhead cable effect.



Reprocuced from drawing by
Norman G. Cubberly, Port Captain,
Deepsea Ventures, Inc.

Figure 4.12 - Overhead cable effect.

AIDS TO RADAR NAVIGATION

Various aids to radar navigation have been developed to aid the navigator in identifying radar targets and for increasing the strength of the echoes received from objects which otherwise are poor radar targets.

RADAR REFLECTORS

Buoys and small boats, particularly those boats constructed of wood, are poor radar targets. Weak fluctuating echoes received from these targets are easily lost in the sea clutter on the radarscope. To aid in the detection of these targets, radar reflectors, of the corner reflector type, may be used. The corner reflectors may be mounted on the tops of buoys or the body of the buoy may be shaped as a corner reflector, as illustrated in figure 4.13.

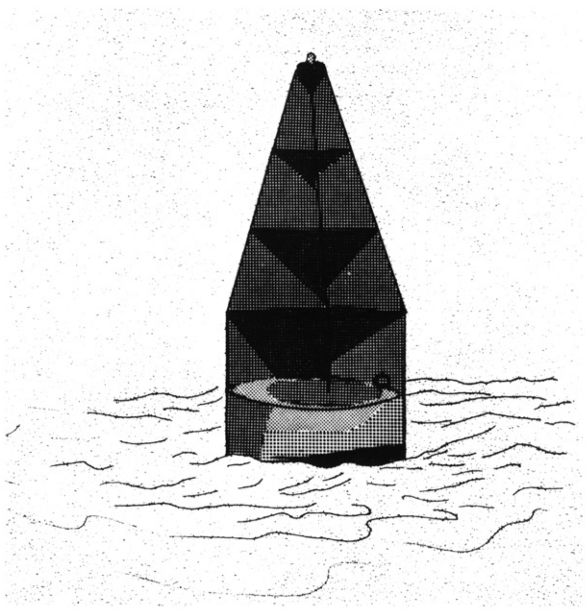


Figure 4.13 - Radar reflector buoy.

Each corner reflector illustrated in figure 4.14 consists of three mutually perpendicular flat metal surfaces.

A radar wave on striking any of the metal surfaces or plates will be reflected back in the direction of its source, i.e., the radar antenna. Maximum energy will be reflected back to the antenna if the axis of the radar beam makes equal angles with all the metal surfaces. Frequently corner reflectors are assembled in clusters to insure receiving strong echoes at the antenna.

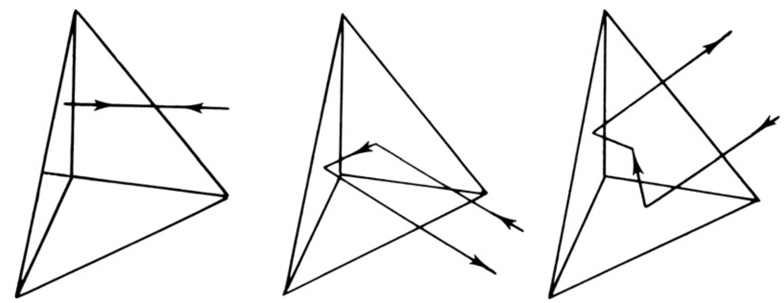


Figure 4.14 - Corner reflectors.

RADAR BEACONS

While radar reflectors are used to obtain stronger echoes from radar targets, other means are required for more positive identification of radar targets. Radar beacons are transmitters operating in the marine radar frequency band which produce distinctive indications on the radarscopes of ships within range of these beacons. There are two general classes of these beacons: *racon* which provides both bearing and range information to the target and *ramark* which provides bearing information only. However, if the ramark installation is detected as an echo on the radarscope, the range will be available also.

From The Use of Radar at Sea, 4th Ed. Copyright 1968, The Institute of Navigation, London.
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Figure 4.15 - Racon signal.

Racon

Racon is a radar transponder which emits a characteristic signal when triggered by a ship's radar. The signal may be emitted on the same frequency as that of the triggering radar, in which case it is automatically superimposed on the ship's radar display. The signal may be emitted on a separate frequency, in which case to receive the signal the ship's radar receiver must be capable of being tuned to the beacon frequency or a special receiver must be used. In either case, the PPI will be blank except for the beacon signal.

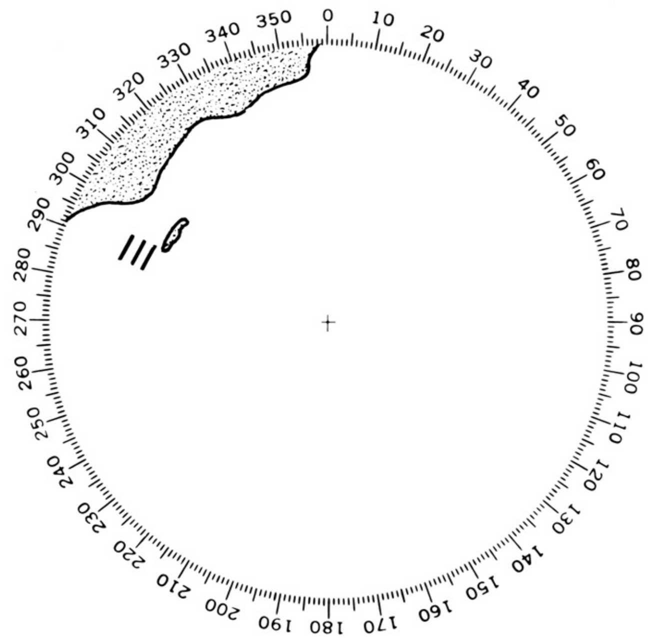


Figure 4.16 - Coded racon signal.

"Frequency agile" racons are now in widespread use. They respond to both 3 and 10 centimeter radars.

The racon signal appears on the PPI as a radial line originating at a point just beyond the position of the radar beacon or as a Morse code signal displayed radially from just beyond the beacon (see figures 4.15 and 4.16).

Racons are being used as ranges or leading lines. The range is formed by two racons set up behind each other with a separation in the order of 2 to 4 nautical miles. On the PPI scope the "paint" received from the front and rear racons form the range.

Some bridges are now equipped with racons which are suspended under the bridge to provide guidance for safe passage.

The maximum range for racon reception is limited by line of sight.

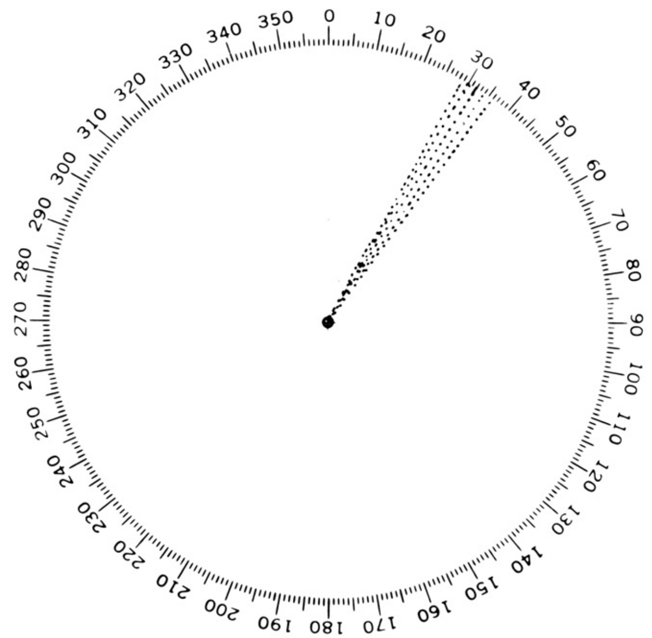


Figure 4.17 - Ramark signal appearing as a dotted line.

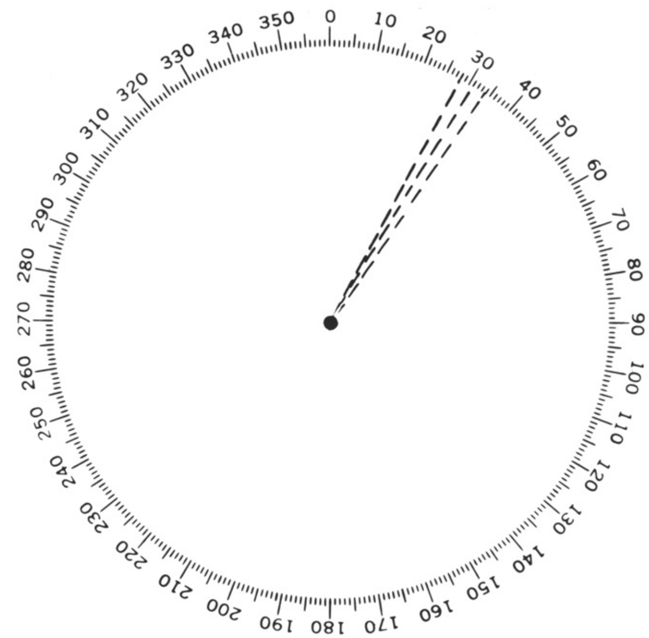


Figure 4.18 - Ramark signal appearing as a dashed line.

Ramark

Ramark is a radar beacon which transmits either continuously or at intervals. The latter method of transmission is used so that the PPI can be inspected without any clutter introduced by the ramark signal on the scope. The ramark signal as it appears on the PPI is a radial line from the center. The radial line may be a continuous narrow line, a series of dashes, a series of dots, or a series of dots and dashes (see figures 4.17 and 4.18).

RADAR FIXING METHODS

RANGE AND BEARING TO A SINGLE OBJECT

Preferably, radar fixes obtained through measuring the range and bearing to a single object should be limited to small, isolated fixed objects which can be identified with reasonable certainty. In many situations, this method may be the only reliable method which can be employed. If possible, the fix should be based upon a radar range and visual gyro bearing because radar bearings are less accurate than visual gyro bearings. A primary advantage of the method is the rapidity with which a fix can be obtained. A disadvantage is that the fix is based upon only two intersecting position lines, a bearing line and a range arc, obtained from observations of the same object. Identification mistakes can lead to disaster.

TWO OR MORE BEARINGS

Generally, fixes obtained from radar bearings are less accurate than those obtained from intersecting range arcs. The accuracy of fixing by this method is greater when the center bearings of small, isolated, radar-conspicuous objects can be observed.

Because of the rapidity of the method, the method affords a means for initially determining an approximate position for subsequent use in more reliable identification of objects for fixing by means of two or more ranges.

TANGENT BEARINGS

Fixing by tangent bearings is one of the least accurate methods. The use of tangent bearings with a range measurement can provide a fix of reasonably good accuracy.

As illustrated in figure 4.19, the tangent bearing lines intersect at a range from the island observed less than the range as measured because of beam width distortion. Right tangent bearings should be decreased by an estimate of half the horizontal beam width. Left tangent bearings should be increased by the same amount. The fix is taken as that point on the range arc midway between the bearing lines.

It is frequently quite difficult to correlate the left and right extremities of the island as charted with the island image on the PPI. Therefore, even with compensation for half of the beam width, the bearing lines usually will not intersect at the range arc.

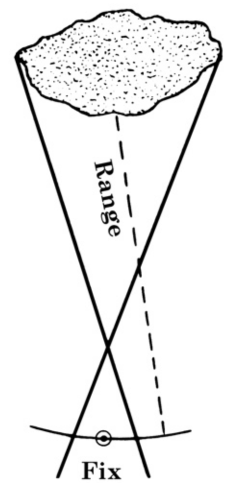


Figure 4.19 - Fixing by tangent bearings and radar range.

TWO OR MORE RANGES

In many situations, the more accurate radar fixes are determined from nearly simultaneous measurements of the ranges to two or more fixed objects. Preferably, at least three ranges should be used for the fix. The number of ranges which it is feasible to use in a particular situation is dependent upon the time required for identification and range measurements. In many situations, the use of more than three range arcs for the fix may introduce excessive error because of the time lag between measurements.

If the most rapidly changing range is measured first, the plot will indicate less progress along the intended track than if it were measured last. Thus, less lag in the radar plot from the ship's actual position is obtained through measuring the most rapidly changing ranges last.

Similar to a visual cross-bearing fix, the accuracy of the radar fix is dependent upon the angles of cut of the intersecting position lines (range arcs). For greater accuracy, the objects selected should provide range arcs with angles of cut as close to 90˚ as is possible. In cases where two identifiable objects lie in opposite or nearly opposite directions, their range arcs, even though they may intersect at a small angle of cut or may not actually intersect, in combination with another range arc intersecting them at an angle approaching 90˚, may provide a fix of high accuracy (see figure 4.20). The near tangency of the two range arcs indicates accurate measurements and good reliability of the fix with respect to the distance off the land to port and starboard.

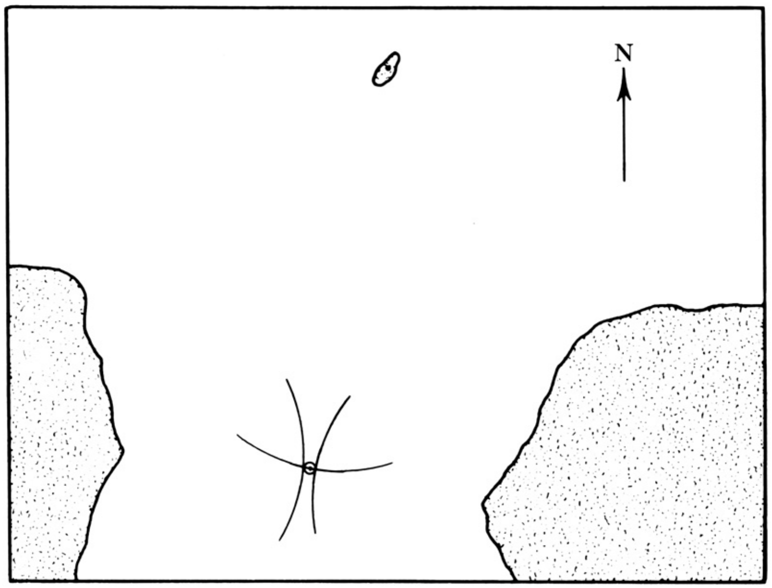


Figure 4.20 - Radar fix.

Small, isolated, radar-conspicuous fixed objects afford the most reliable and accurate means for radar fixing when they are so situated that their associated range arcs intersect at angles approaching 90˚.

Figure 4.21 illustrates a fix obtained by measuring the ranges to three well situated radar-conspicuous objects. The fix is based solely upon range measurements in that radar ranges are more accurate than radar bearings even when small objects are observed. Note that in this rather ideal situation, a point fix was not obtained. Because of inherent radar errors, any point fix should be treated as an accident dependent upon plotting errors, the scale of the chart, etc.

While observed radar bearings were not used in establishing the fix as such, the bearings were useful in the identification of the radar-conspicuous objects.

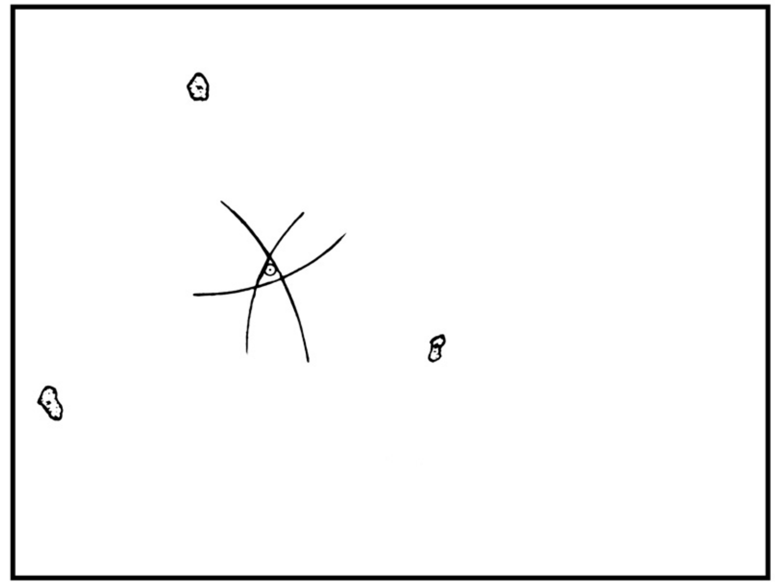


Figure 4.21 - Fix by small, isolated radar-conspicuous objects.

As the ship travels along its track, the three radar-conspicuous objects still afford good fixing capability until such time as the angles of cut of the range arcs have degraded appreciably. At such time, other radar-conspicuous objects should be selected to provide better angles of cut. Preferably, the first new object should be selected and observed before the angles of cut have degraded appreciably. Incorporating the range arc of the new object with range arcs of objects which have provided reliable fixes affords more positive identification of the new object.

MIXED METHODS

While fixing by means of intersecting range arcs, the usual case is that two or more small, isolated, and conspicuous objects, which are well situated to provide good angles of cut, are not available. The navigator must exercise considerable skill in radarscope interpretation to estimate which charted features are actually displayed. If initially there are no well defined features displayed and there is considerable uncertainty as to the ship's position, the navigator may observe the radar bearings of features tentatively identified as a step towards their more positive identification. If the cross-bearing fix does indicate that the features have been identified with some degree of accuracy, the estimate of the ship's position obtained from the cross-bearing fix can be used as an aid in subsequent interpretation of the radar display. With better knowledge of the ship's position, the factors affecting the distortion of the radar display can be used more intelligently in the course of more accurate interpretation of the radar display.

Frequently there is at least one object available which, if correctly identified, can enable fixing by the range and bearing to a single object method. A fix so obtained can be used as an aid in radarscope interpretation for fixing by two or more intersecting range arcs.

The difficulties which may be encountered in radarscope interpretation during a transit may be so great that accurate fixing by means of range arcs is not obtainable. In such circumstances, range arcs having some degree of accuracy can be used to aid in the identification of objects used with the range and bearing method.

With correct identification of the object observed, the accuracy of the fix obtained by the range and bearing to a single object method usually can be improved through the use of a visual gyro bearing instead of the radar bearing. Particularly during periods of low visibility, the navigator should be alert for visual bearings of opportunity.

While the best method or combination of methods for a particular situation must be left to the good judgment of the experienced navigator, factors affecting method selection include:

(1) The general need for redundancy—but not to such extent that too much is attempted with too little aid or means in too little time.

(2) The characteristics of the radar set.

(3) Individual skills.

(4) The navigational situation, including the shipping situation.

(5) The difficulties associated with radarscope interpretation.

(6) Angles of cut of the position lines.

PRECONSTRUCTION OF RANGE ARCS

Small, isolated, radar-conspicuous objects permit preconstruction of range arcs on the chart to expedite radar fixing. This preconstruction is possible because the range can be measured to the same point on each object, or nearly so, as the aspect changes during the transit. With fixed radar targets of lesser conspicuous, the navigator, generally, must continually change the centers of the range arcs in accordance with his interpretation of the radarscope.

To expedite plotting further, the navigator may also preconstruct a series of bearing lines to the radar-conspicuous objects. The degree of preconstruction of range arcs and bearing lines is dependent upon acceptable chart clutter resulting from the arcs and lines added to the chart. Usually, preconstruction is limited to a critical part of a passage or to the approach to an anchorage.

CONTOUR METHOD

The contour method of radar navigation consists of constructing a land contour on a transparent template according to a series of radar ranges and bearings and then fitting the template to the chart. The point of origin of the ranges and bearings defines the fix.

This method may provide means for fixing when it is difficult to correlate the landmass image on the PPI with the chart because of a lack of features along the shoreline which can be identified individually. The accuracy of the method is dependent upon the navigator's ability to estimate the contours of the land most likely to be reflecting the echoes forming the landmass image on the PPI. Even with considerable skill in radarscope interpretation, the navigator can usually obtain only an approximate fit of the template contour with the estimated land contour. There may be relatively large gaps in the fit caused by radar shadow effects. Thus, there may be considerable uncertainty with respect to the accuracy of the point fix. The contour method is most feasible when the land rises steeply at or near the shoreline, thus enabling a more accurate estimate of the reflecting surfaces.

Figure 4.22 illustrates a rectangular template on the bottom side of which radials are drawn at 5-degree intervals. The radials are drawn from a small hole, which is the position of the radar fix when the template is fitted to the chart.

In making preparation for use of the template, the template is tacked to the range (distance) scale of the chart. As the ranges and bearings to shore are measured at 5 or 10-degree intervals, the template is rotated about the zero-distance graduation and marked accordingly. A contour line is faired through the marks on each radial.

On initially fitting the contour template to the chart, the template should be oriented to true north. Because of normal bearing errors in radar observations, the template will not necessarily be aligned with true north when the best fit is obtained subsequently.

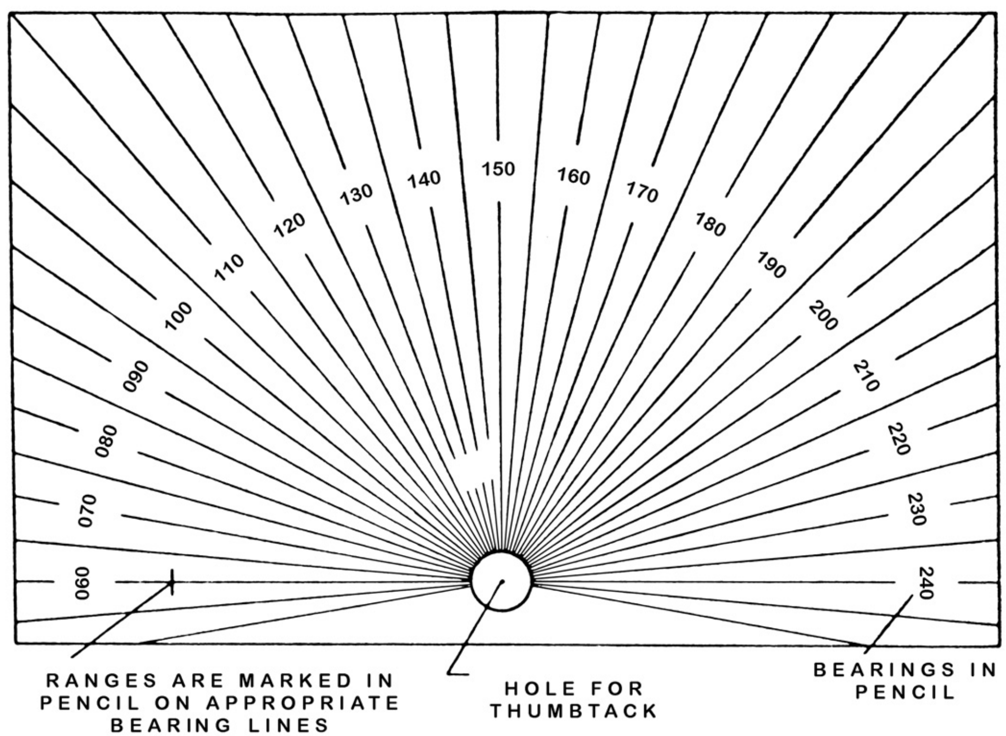


Figure 4.22 - Transparent template used with contour method.

IDENTIFYING A RADAR-INCONSPICUOUS OBJECT

Situation:

There is doubt that a pip on the PPI represents the echo from a buoy, a radar-inconspicuous object. On the chart there is a radar-conspicuous object, a rock, in the vicinity of the buoy. The pip of the rock is identified readily on the PPI.

Required:

Identify the pip which is in doubt.

Solution:

(1) Measure the bearing and distance of the buoy from the rock on the chart.
(2) Determine the length of this distance on the PPI according to the range scale setting.
(3) Rotate the parallel-line cursor to the bearing of the buoy from the rock (see figure 4.23).
(4) With rubber-tipped dividers set to the appropriate PPI length, set one point over the pip of the rock; using the parallel lines of the cursor as a guide, set the second point in the direction of the bearing of the buoy from the rock.
(5) With the dividers so set, the second point lies over the unidentified pip. Subject to the accuracy limitations of the measurements and normal prudence, the pip may be evaluated as the echo received from the buoy.

NOTE: During low visibility a radar-conspicuous object can be used similarly to determine whether another ship is fouling an anchorage berth.

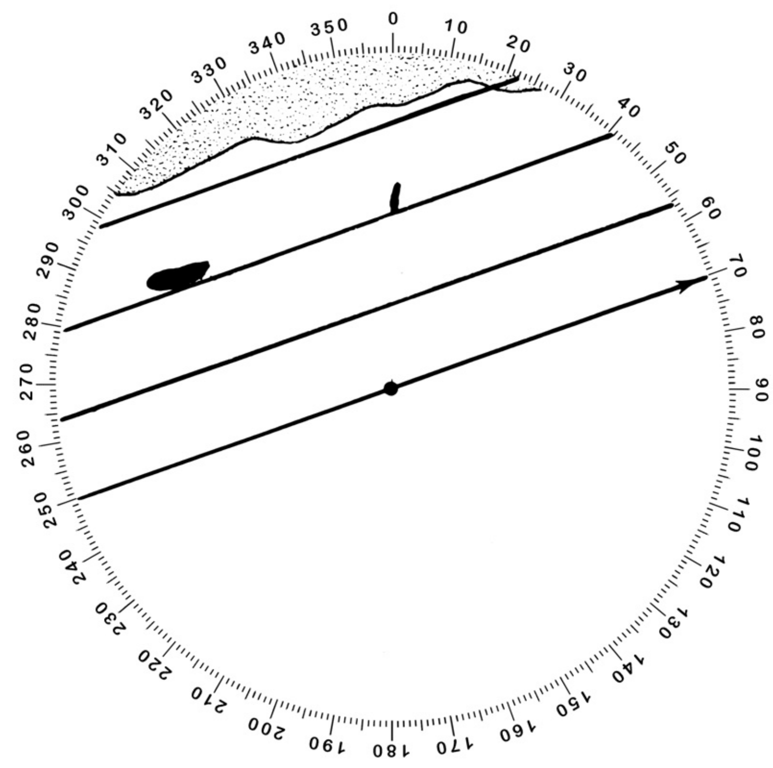


Figure 4.23 - Use of parallel-line cursor to identify radar-inconspicuous object.

FINDING COURSE AND SPEED MADE GOOD BY PARALLEL-LINE CURSOR

Situation:

A ship steaming in fog detects a prominent rock by radar. Because of the unknown effects of current and other factors, the navigator is uncertain of the course and speed being made good.

Required:

To determine the course and speed being made good.

Solution:

(1) Make a timed plot of the rock on the reflection plotter.
(2) Align the parallel-line cursor with the plot to determine the course being made good, which is in a direction opposite to the relative movement (see figure 4.24).
(3) Measure the distance between the first and last plots and using the time interval, determine the speed of relative movement. Since the rock is stationary, the relative speed is equal to that of the ship.

NOTE: This basic technique is useful for determining whether the ship is being set off the intended track in pilot waters. Observing a radar-conspicuous object and using the parallel-line cursor, a line is drawn through the radar-conspicuous object in a direction opposite to own ship's course.

By observing the successive positions of the radar-conspicuous object relative to this line, the navigator can determine whether the ship is being set to the left or right of the intended track.

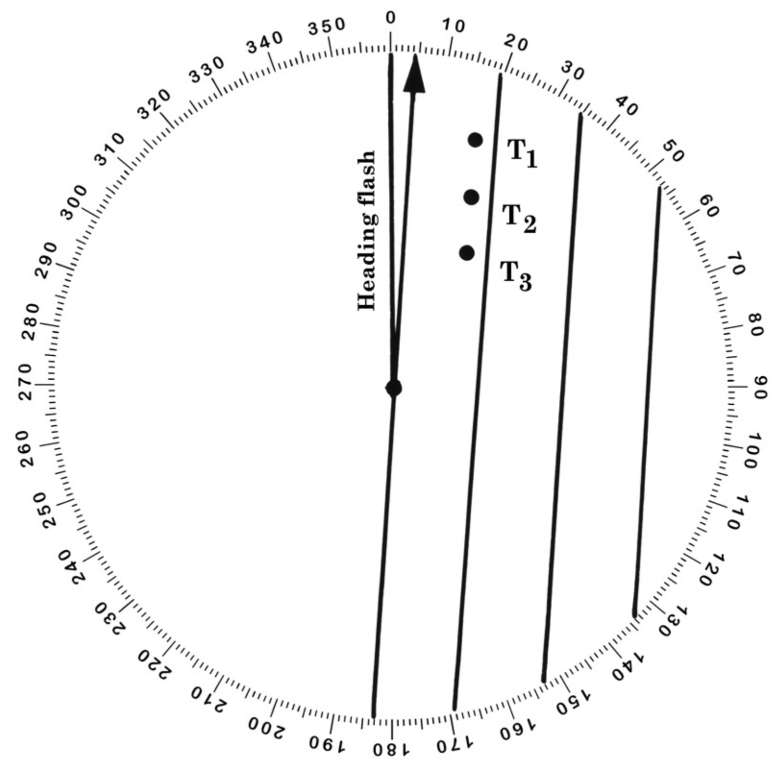


Figure 4.24 - Use of parallel-line cursor to find course and speed made good.

USE OF PARALLEL-LINE CURSOR FOR ANCHORING

Situation:

A ship is making an approach to an anchorage on course 290˚. The direction of the intended track to the anchorage is 290˚. Allowing for the radius of the letting go circle, the anchor will be let go when a radar-conspicuous islet is 1.0 mile ahead of the ship on the intended track. A decision is made to use a parallel-line cursor technique to keep the ship on the intended track during the last mile of the approach to the anchorage and to determine the time for letting go. Before the latter decision was made, the navigator's interpretation of the stabilized relative motion display revealed that, even with change in aspect, the radar image of a jetty to starboard could be used to keep the ship on the intended track.

Required:

Make the approach to the anchorage on the intended track and let the anchor go when the islet is 1.0 mile ahead along the intended track.

Solution:

(1) From the chart determine the distance at which the head of the jetty will be passed abeam when the ship is on course and on the intended track.
(2) Align the parallel-line cursor with the direction of the intended track, 290˚ (see figure 4.25).
(3) Using the parallel lines of the cursor as a guide, draw, at a distance from the center of the PPI as determined in step (2), the relative movement line for the head of the jetty in a direction opposite to the direction of the intended track.
(4) Make a mark at 290˚ and 1.0 mile from the center of the PPI; label this mark "LG" for letting go.
(5) Make another mark at 290˚ and 1.0 mile beyond the LG mark; label this mark "1".
(6) Subdivide the radial between the marks made in steps (4) and (5). This subdivision may be limited to 0.1 mile increments from the LG mark to the 0.5 mile graduation.
(7) If the ship is on the intended track, the RML should extend from the radar image of the head of the jetty. If the ship keeps on the intended track, the image of the jetty will move along the RML. If the ship deviates from the intended track, the image of the jetty will move away from the RML. Corrective action is taken to keep the image of the jetty on the RML.
(8) With the ship being kept on the intended track by keeping the image of the jetty on the RML, the graduations of the radial in the direction of the intended track provide distances to go. When the mark labeled "1" just touches the leading edge of the pip of the islet ahead, there is 1 mile to go. When the mark label ".5" just touches the leading edge of the latter pip, there is 0.5 mile to go, etc. The anchor should be let go when the mark labeled "LG" just touches the leading edge of the pip of the islet.

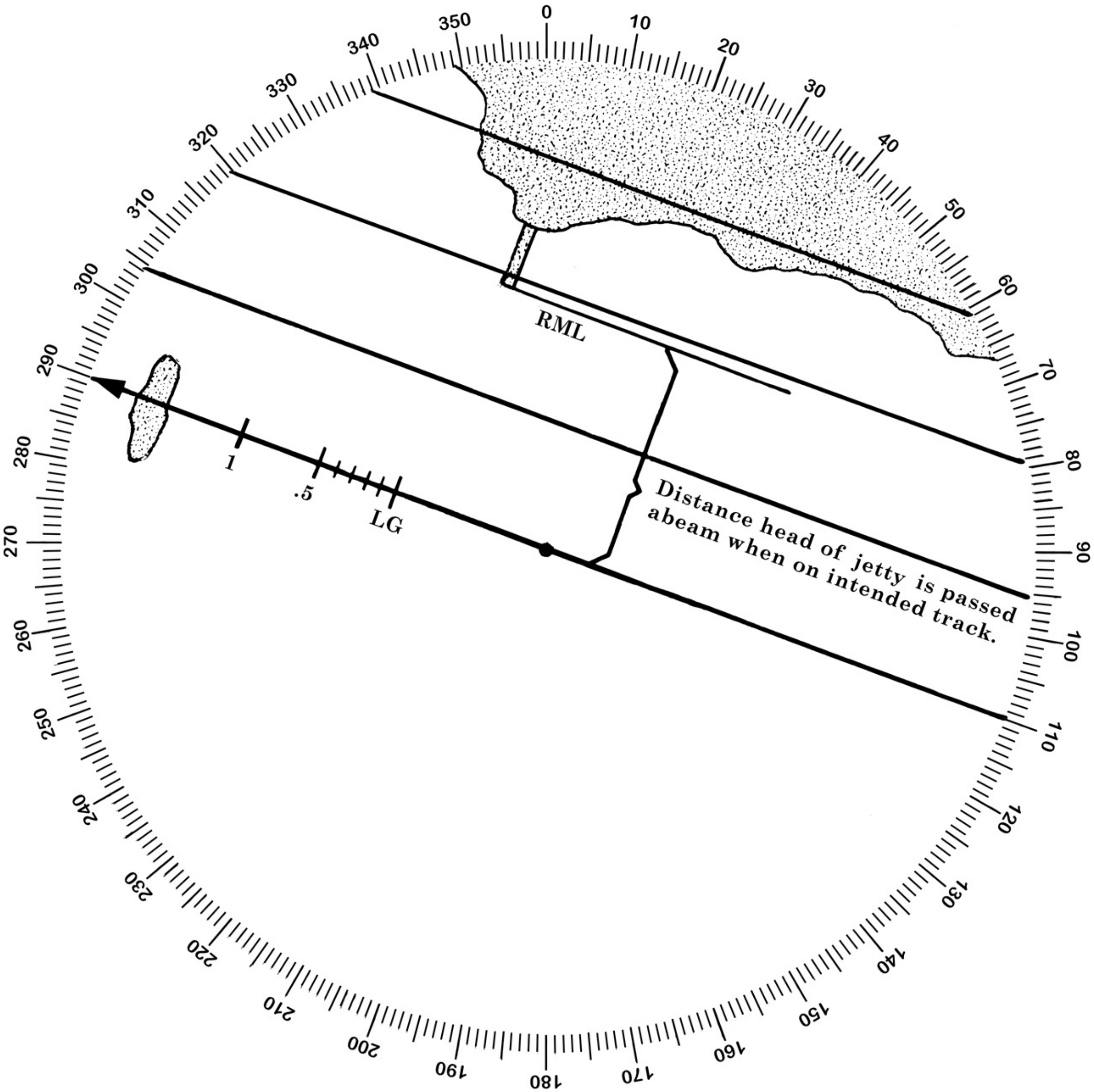


Figure 4.25 - Use of parallel-line cursor for anchoring.

PARALLEL INDEXING

Parallel Indexing has been used for many years. It was defined by William Burger in the *Radar Observers Handbook* (1957, page. 98) as equidistantly spaced parallel lines engraved on a transparent screen which fits on the PPI and can be rotated. This concept of using parallel lines to assist in navigation has been extensively used in Europe to assist in maintaining a specified track, altering course and anchoring. It is best suited for use with a stabilized radar. When using an unstabilized radar, it can pose some danger to an individual that is unaware of problems inherent in this type of display.

With the advent of ARPA with movable EBLs (Electronic Bearing Lines) and Navigation Lines, parallel indexing on screen can be accomplished with greater accuracy. Index lines that are at exact bearings and distances off can be displayed with greater ease. A number of diagrams are included on the pages that follow to explain the use of parallel indexing techniques as well as its misuse.

Cross Index Range (“C”)

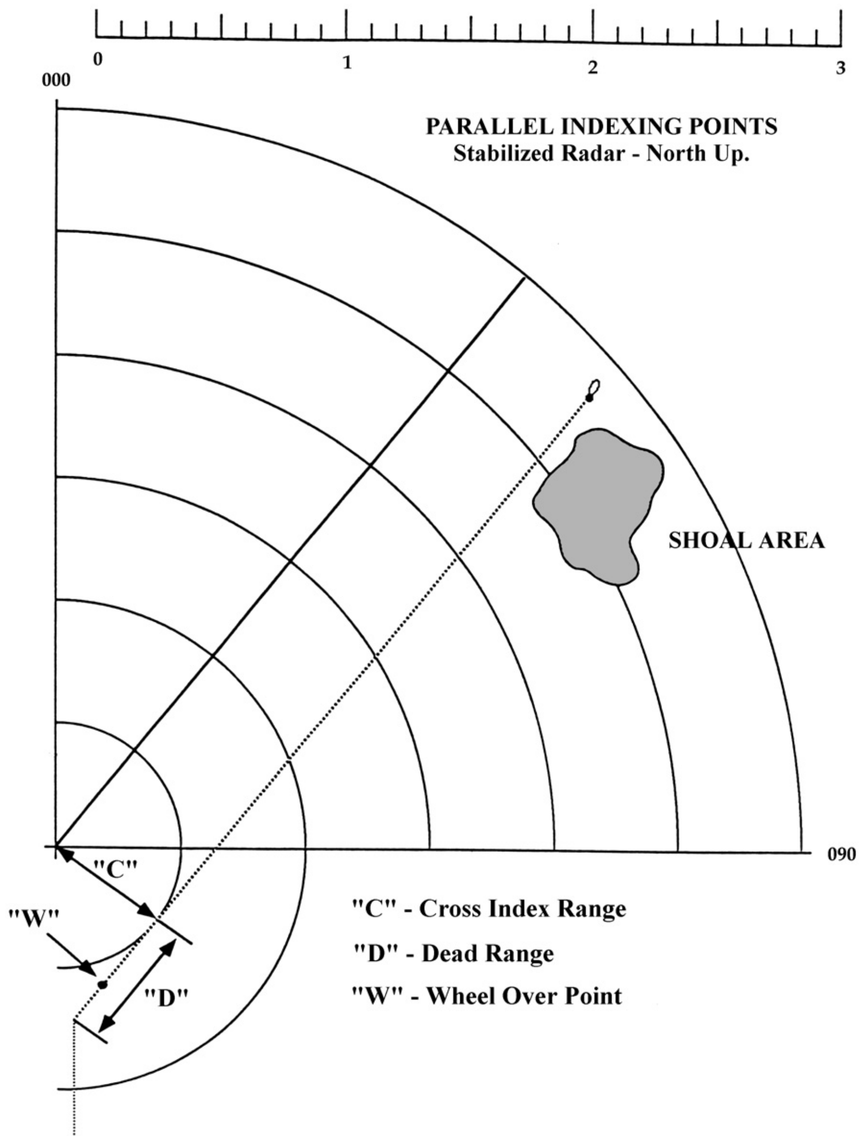
The distance of an object when abeam if the vessel was to pass the navigation mark. A parallel line is drawn through this mark. The perpendicular distance from the center of the display to this parallel line is the *Cross Index Range* (1964, Admiralty Manual of Navigation).

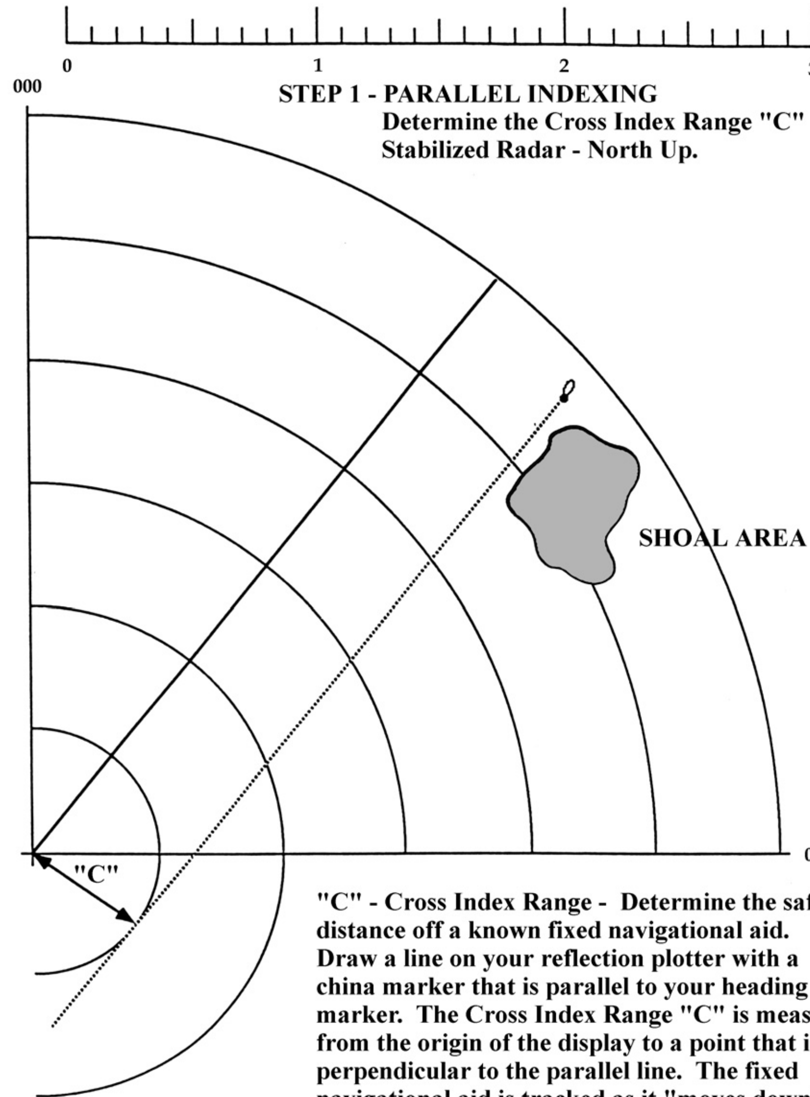
Dead Range (“D”)

The distance at which an object tracking on a parallel line would be on a new track line (ahead of or behind the beam bearing of the object).

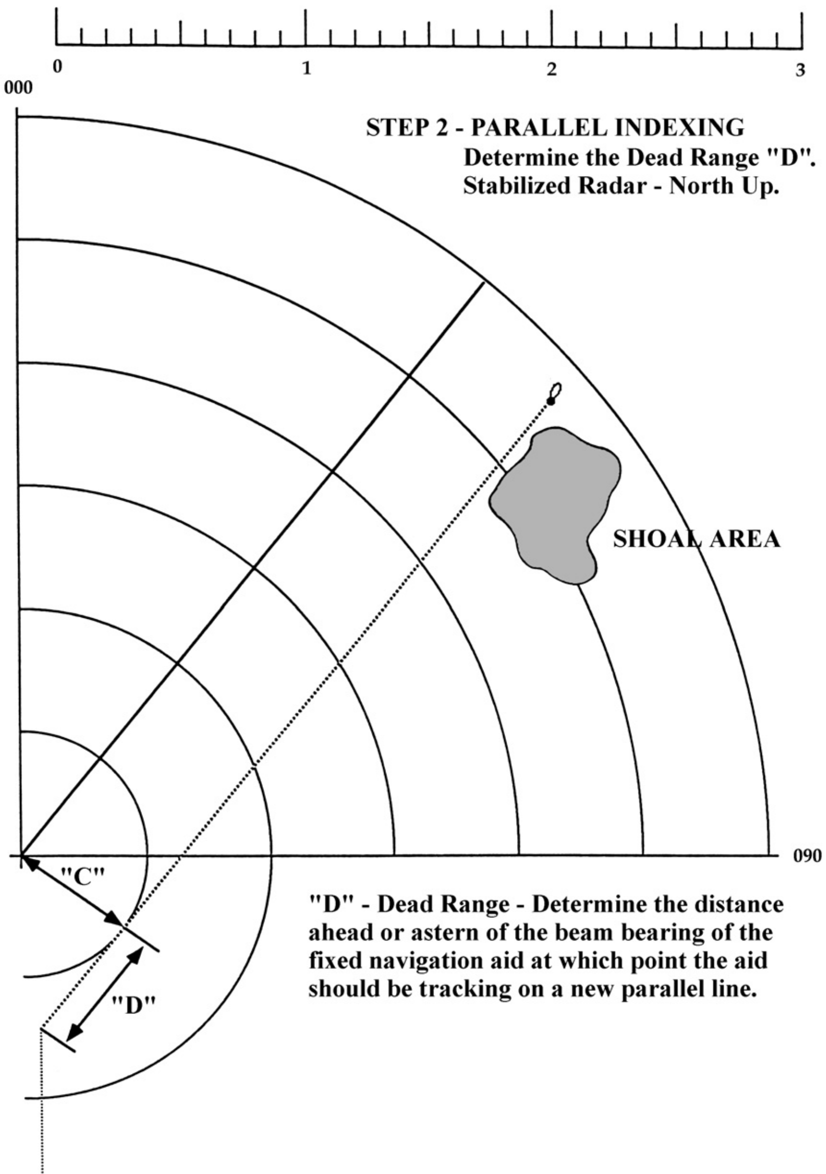
Wheel Over Point (“W”)

The point at which the actual maneuver is made to insure that the object being “indexed” is on the new track line taking into account the advance and transfer of the vessel.



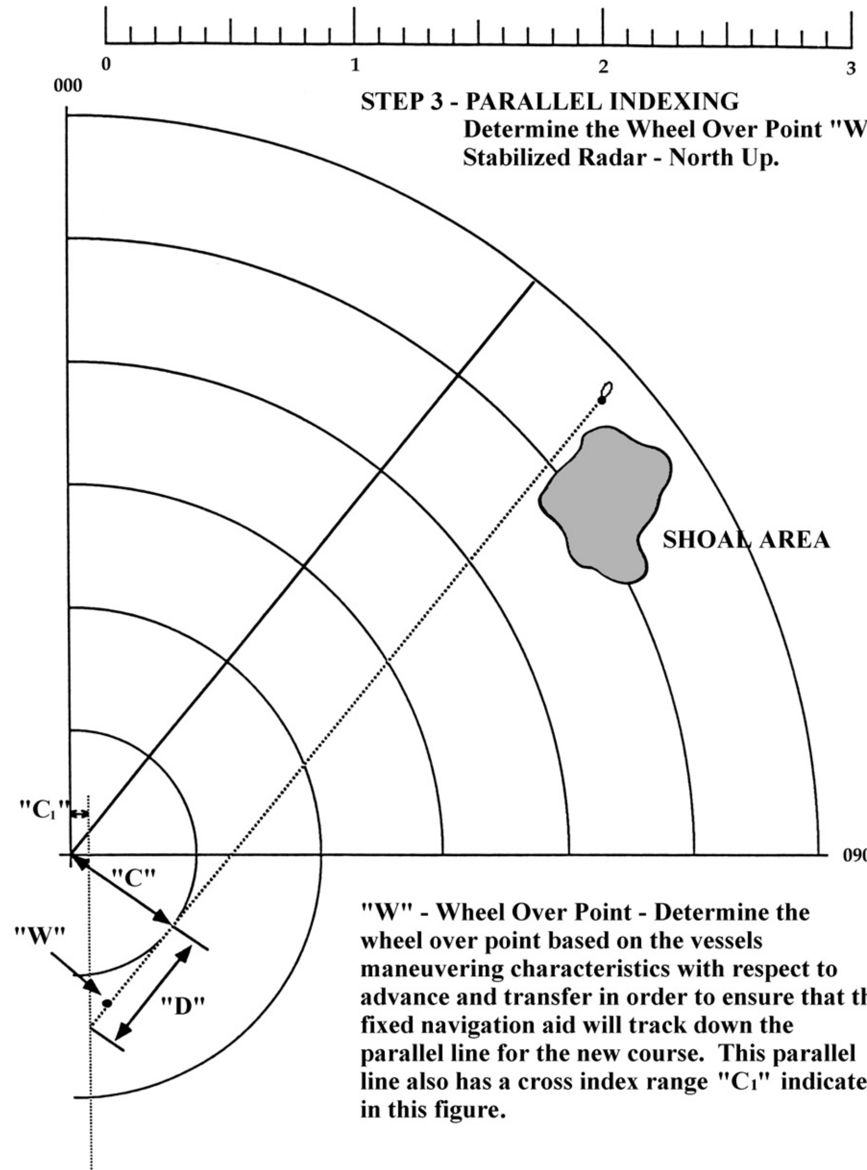


"C" - Cross Index Range - Determine the safe distance off a known fixed navigational aid. Draw a line on your reflection plotter with a china marker that is parallel to your heading marker. The Cross Index Range "C" is measured from the origin of the display to a point that is perpendicular to the parallel line. The fixed navigational aid is tracked as it "moves down" the parallel line. If the navigational aid moves off the parallel line, there is a set and drift present.



STEP 2 - PARALLEL INDEXING
Determine the Dead Range "D".
Stabilized Radar - North Up.

"D" - Dead Range - Determine the distance ahead or astern of the beam bearing of the fixed navigation aid at which point the aid should be tracking on a new parallel line.

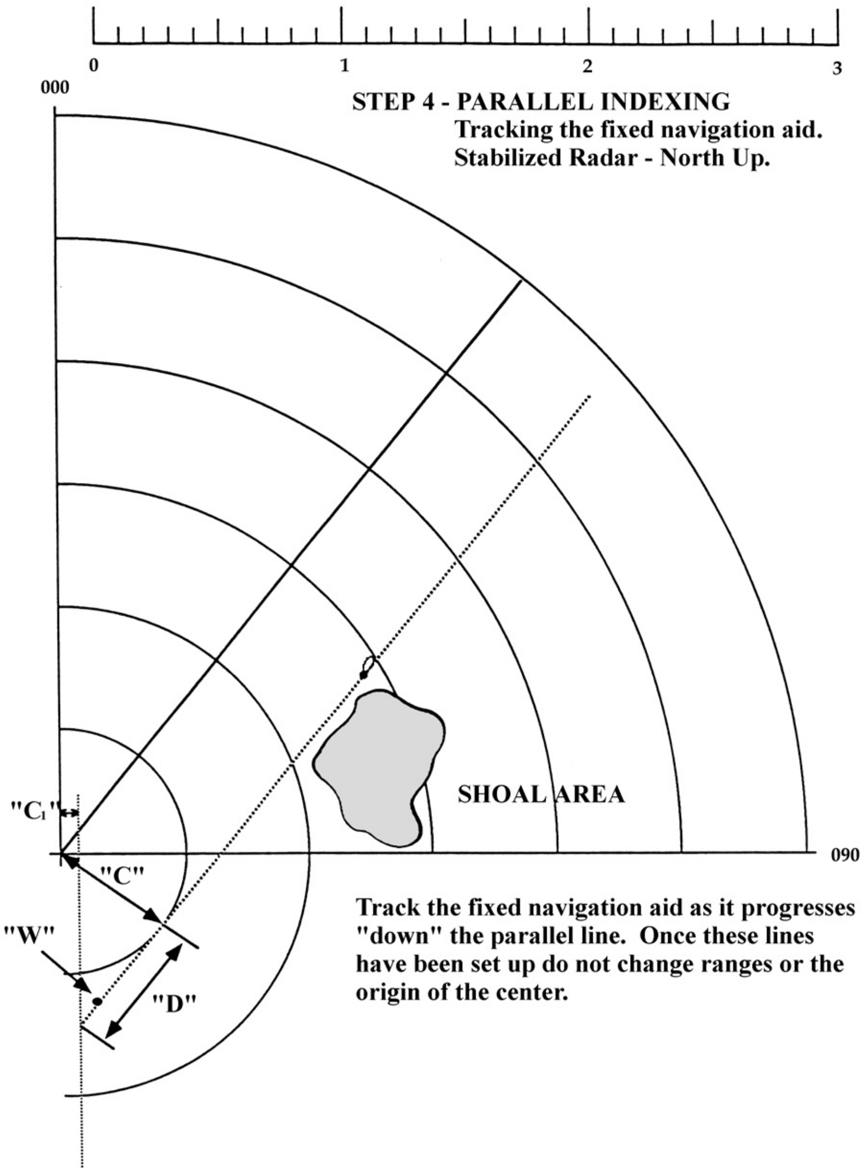


STEP 3 - PARALLEL INDEXING
Determine the Wheel Over Point "W".
Stabilized Radar - North Up.

"W" - Wheel Over Point - Determine the wheel over point based on the vessels maneuvering characteristics with respect to advance and transfer in order to ensure that the fixed navigation aid will track down the parallel line for the new course. This parallel line also has a cross index range "C_1" indicated in this figure.

STEP 4 - PARALLEL INDEXING

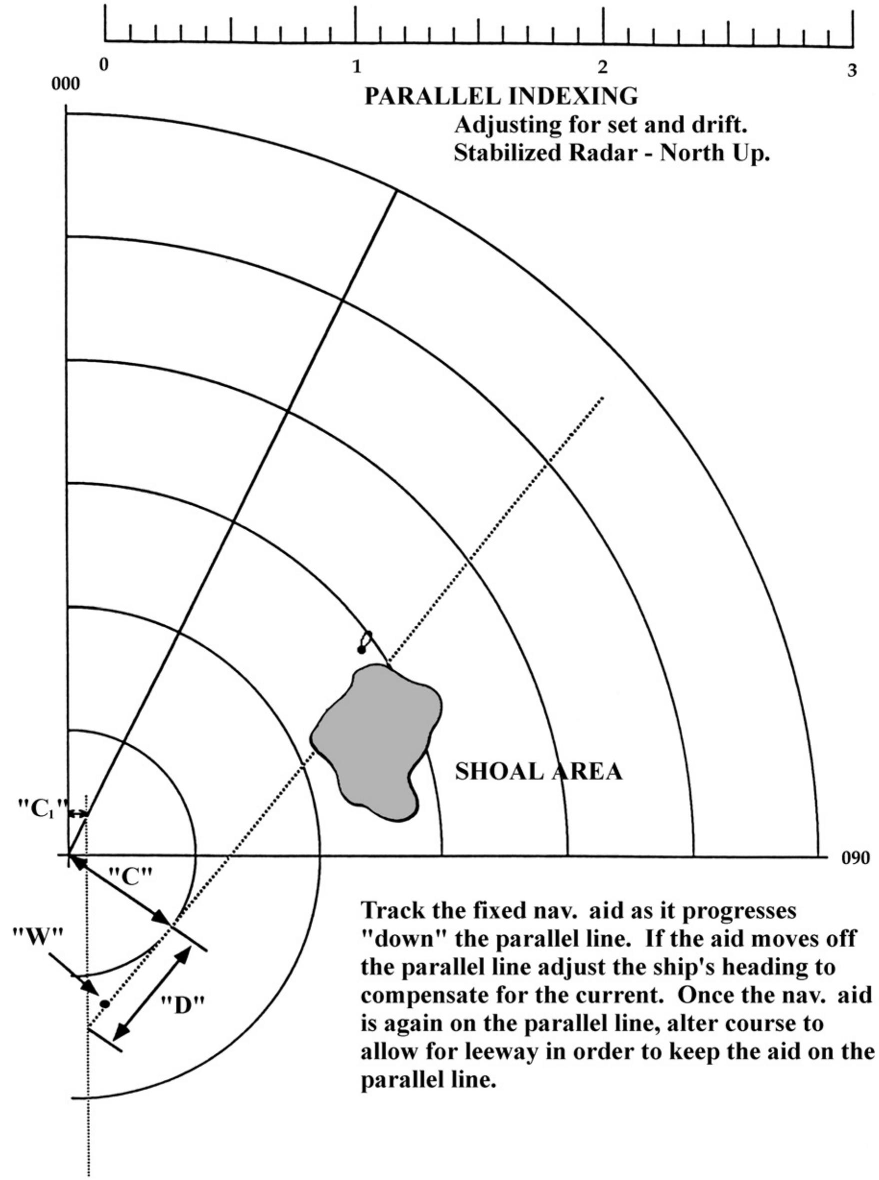
Tracking the fixed navigation aid.
Stabilized Radar - North Up.



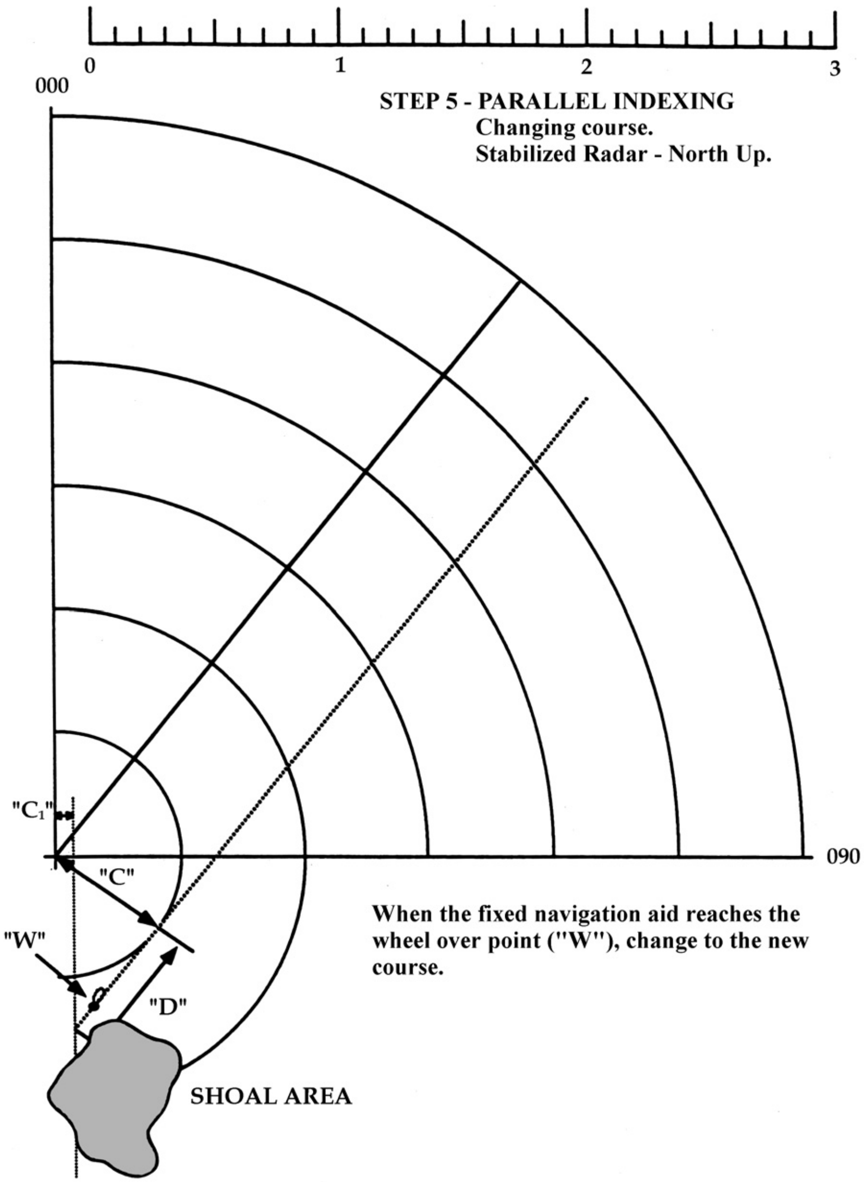
Track the fixed navigation aid as it progresses "down" the parallel line. Once these lines have been set up do not change ranges or the origin of the center.

PARALLEL INDEXING

Adjusting for set and drift.
Stabilized Radar - North Up.

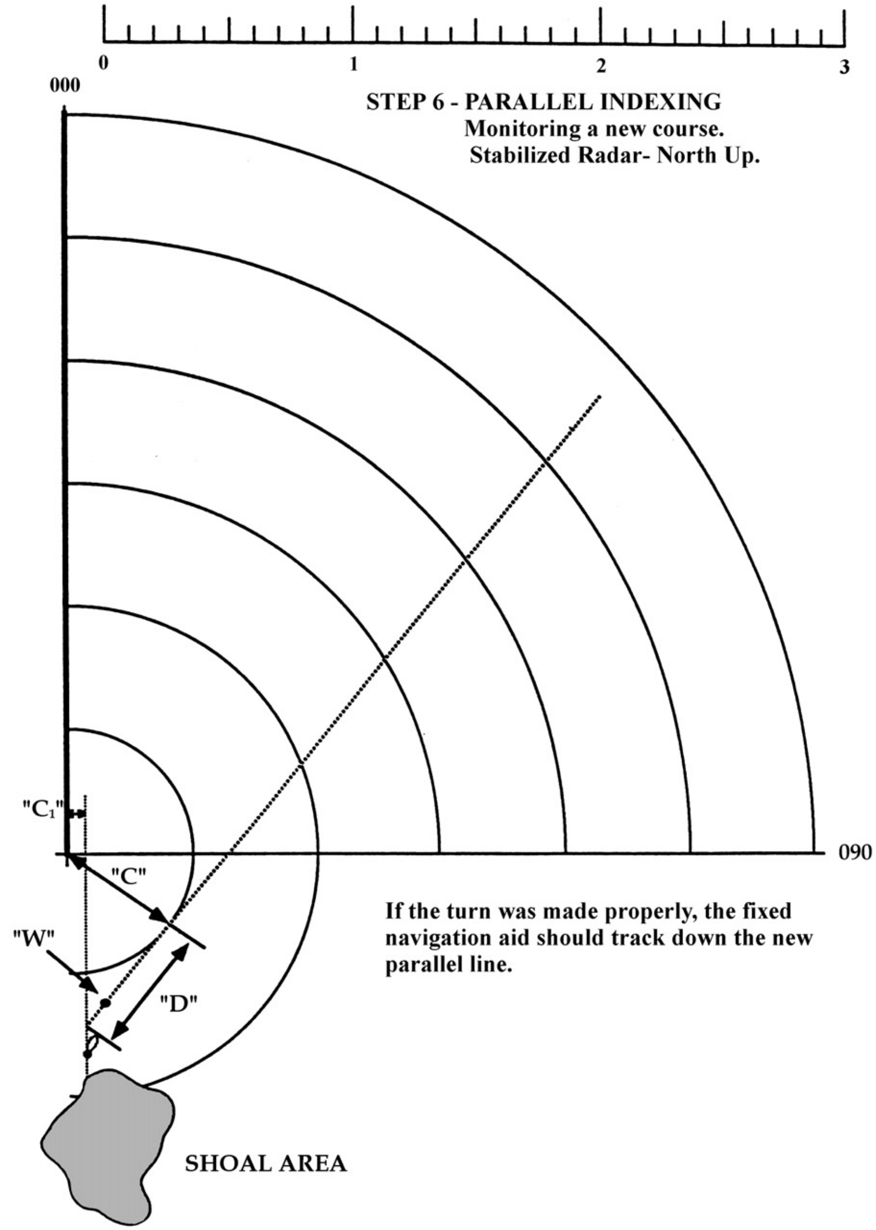


Track the fixed nav. aid as it progresses "down" the parallel line. If the aid moves off the parallel line adjust the ship's heading to compensate for the current. Once the nav. aid is again on the parallel line, alter course to allow for leeway in order to keep the aid on the parallel line.



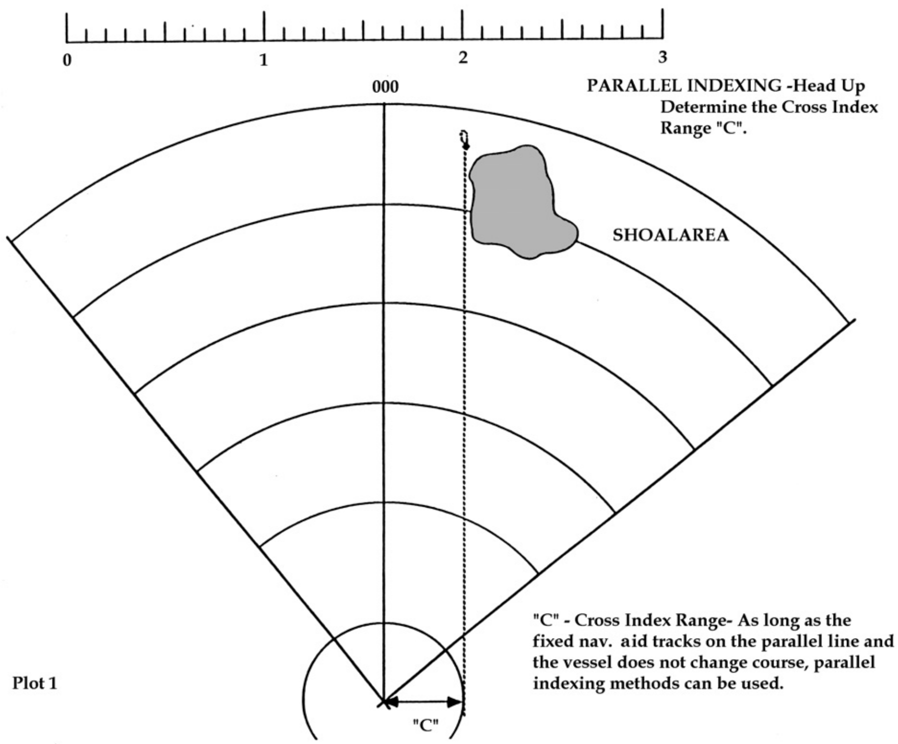
STEP 5 - PARALLEL INDEXING
Changing course.
Stabilized Radar - North Up.

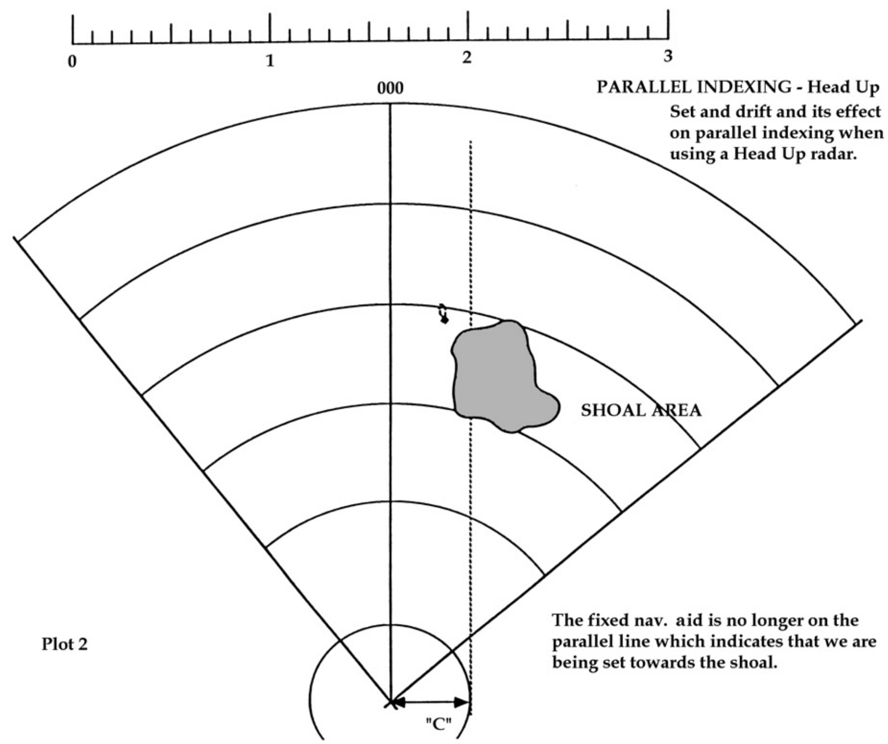
When the fixed navigation aid reaches the wheel over point ("W"), change to the new course.

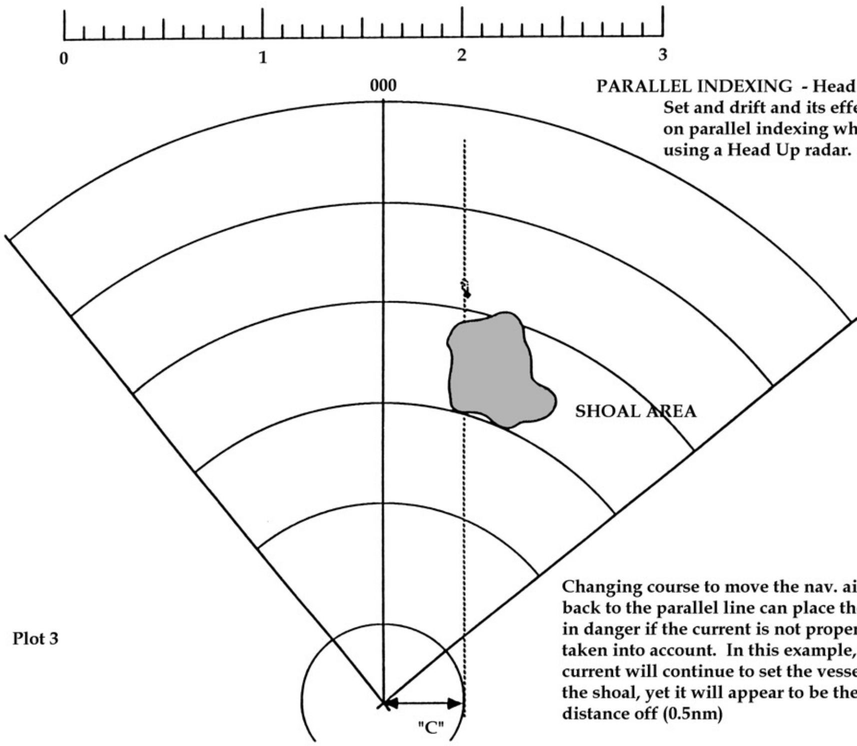


STEP 6 - PARALLEL INDEXING
Monitoring a new course.
Stabilized Radar- North Up.

If the turn was made properly, the fixed navigation aid should track down the new parallel line.


0
1
2
3
000
PARALLEL INDEXING -Head Up
Determine the Cross Index Range "C".
SHOALAREA
"C" - Cross Index Range- As long as the fixed nav. aid tracks on the parallel line and the vessel does not change course, parallel indexing methods can be used.
Plot 1
"C"

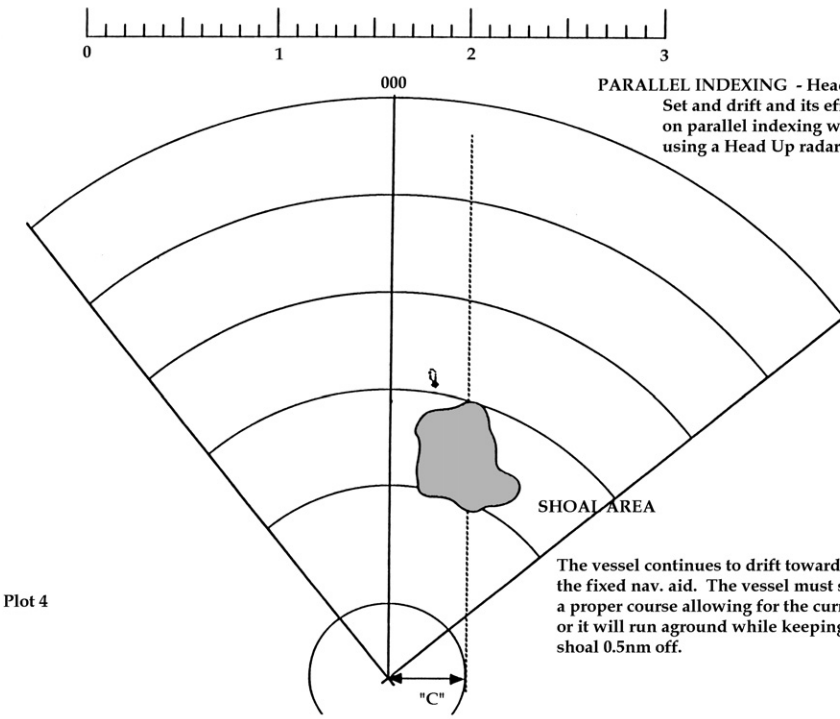

0
1
2
3
000
PARALLEL INDEXING - Head Up
Set and drift and its effect on parallel indexing when using a Head Up radar.
SHOAL AREA
Plot 2
The fixed nav. aid is no longer on the parallel line which indicates that we are being set towards the shoal.
"C"



PARALLEL INDEXING - Head Up
Set and drift and its effect on parallel indexing when using a Head Up radar.

Plot 3

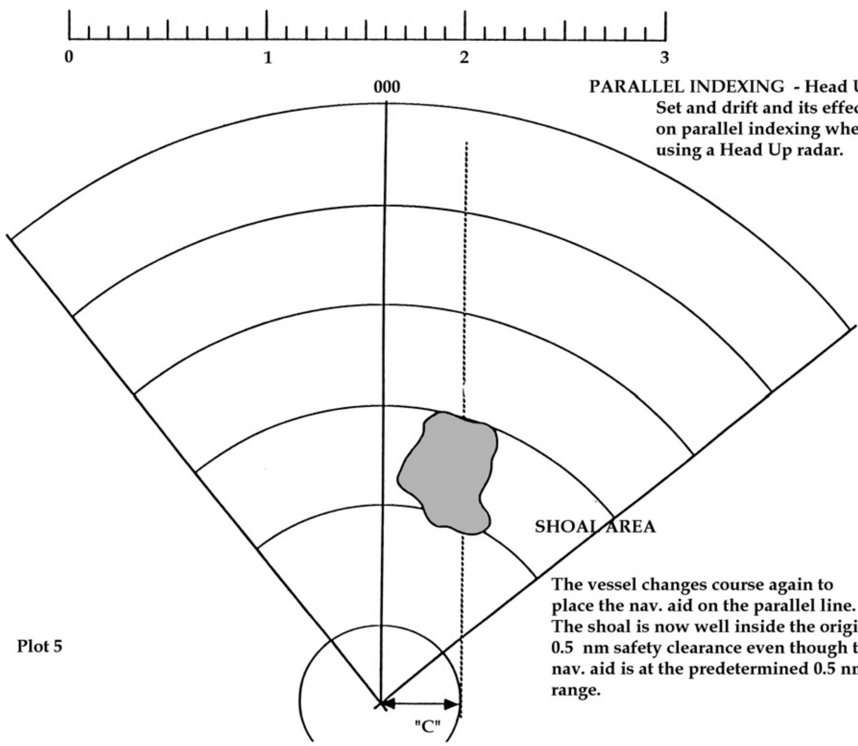
Changing course to move the nav. aid back back to the parallel line can place the vessel in danger if the current is not properly taken into account. In this example, the current will continue to set the vessel towards the shoal, yet it will appear to be the correct distance off (0.5nm)



PARALLEL INDEXING - Head Up
Set and drift and its effect on parallel indexing when using a Head Up radar.

Plot 4

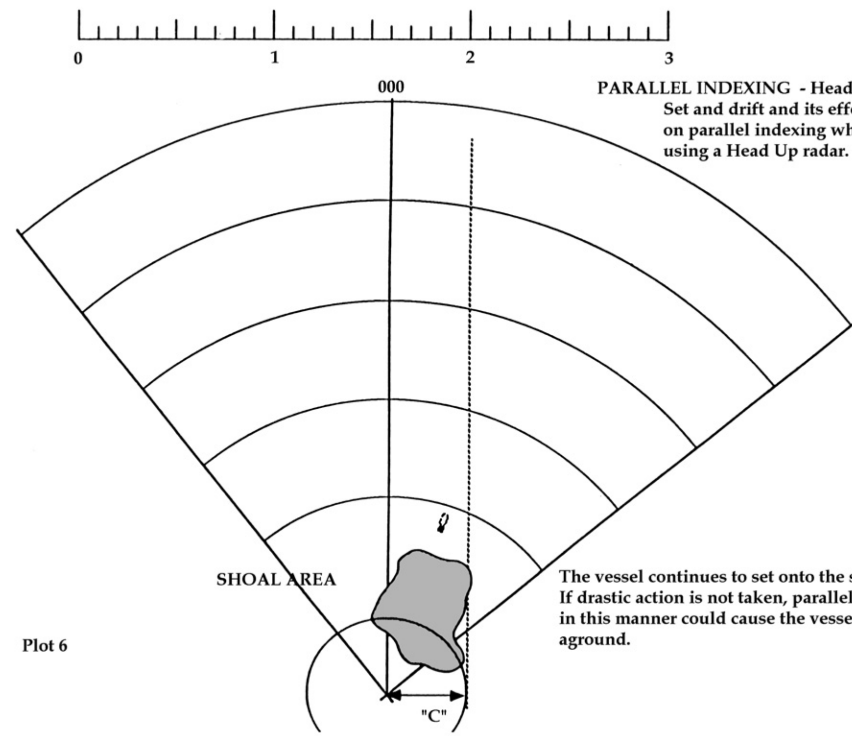
The vessel continues to drift toward the fixed nav. aid. The vessel must steer a proper course allowing for the current or it will run aground while keeping the shoal 0.5nm off.



PARALLEL INDEXING - Head Up
Set and drift and its effect on parallel indexing when using a Head Up radar.

The vessel changes course again to place the nav. aid on the parallel line. The shoal is now well inside the original 0.5 nm safety clearance even though the nav. aid is at the predetermined 0.5 nm range.

Plot 5

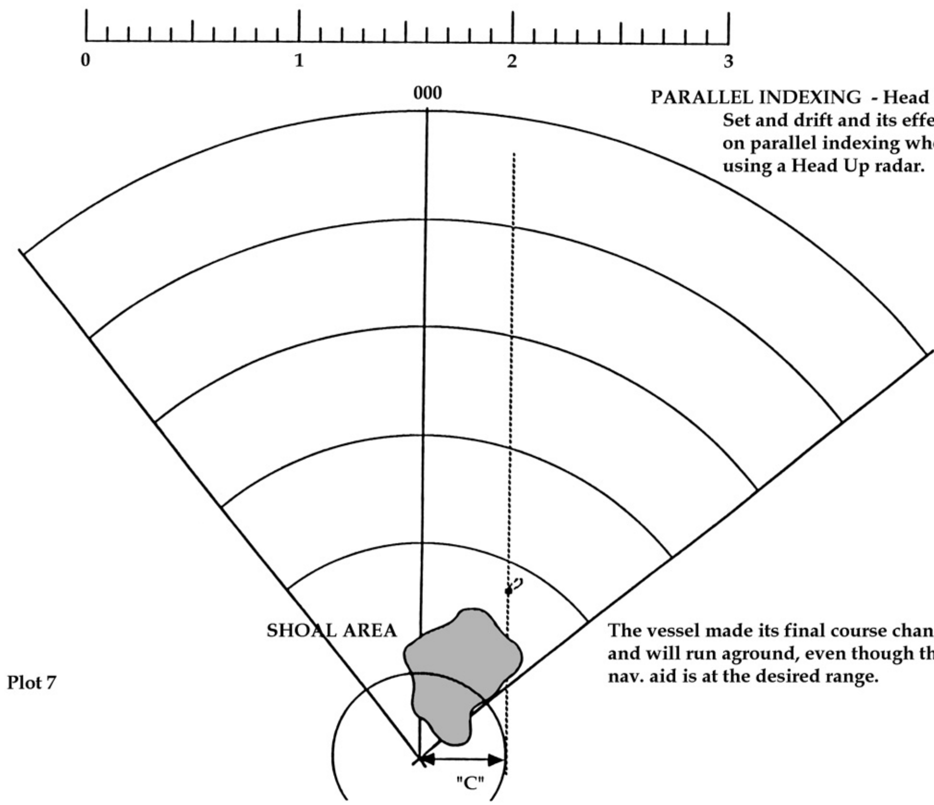


PARALLEL INDEXING - Head Up
Set and drift and its effect on parallel indexing when using a Head Up radar.

The vessel continues to set onto the shoal. If drastic action is not taken, parallel indexing in this manner could cause the vessel to run aground.

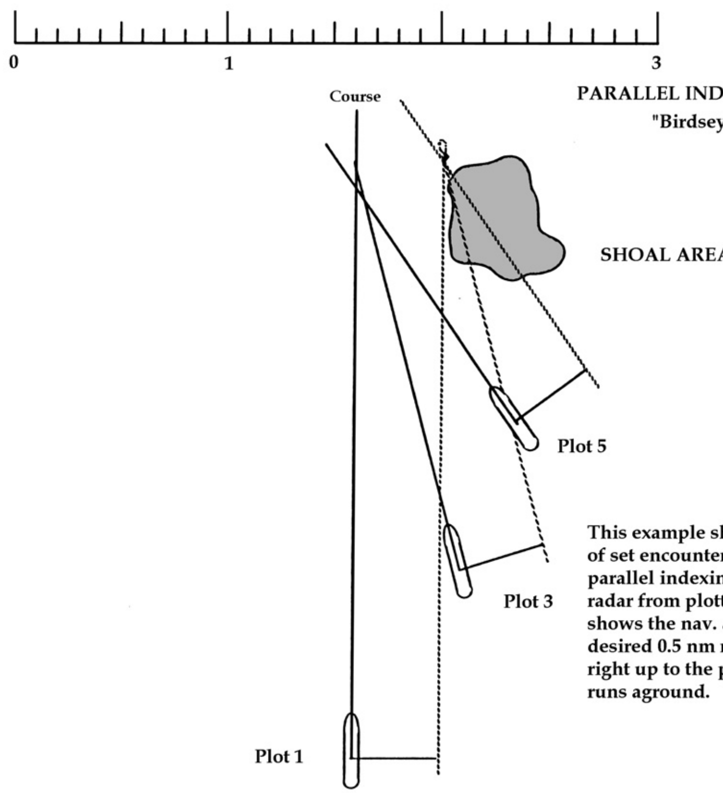
Plot 6

PARALLEL INDEXING - Head Up
Set and drift and its effect on parallel indexing when using a Head Up radar.

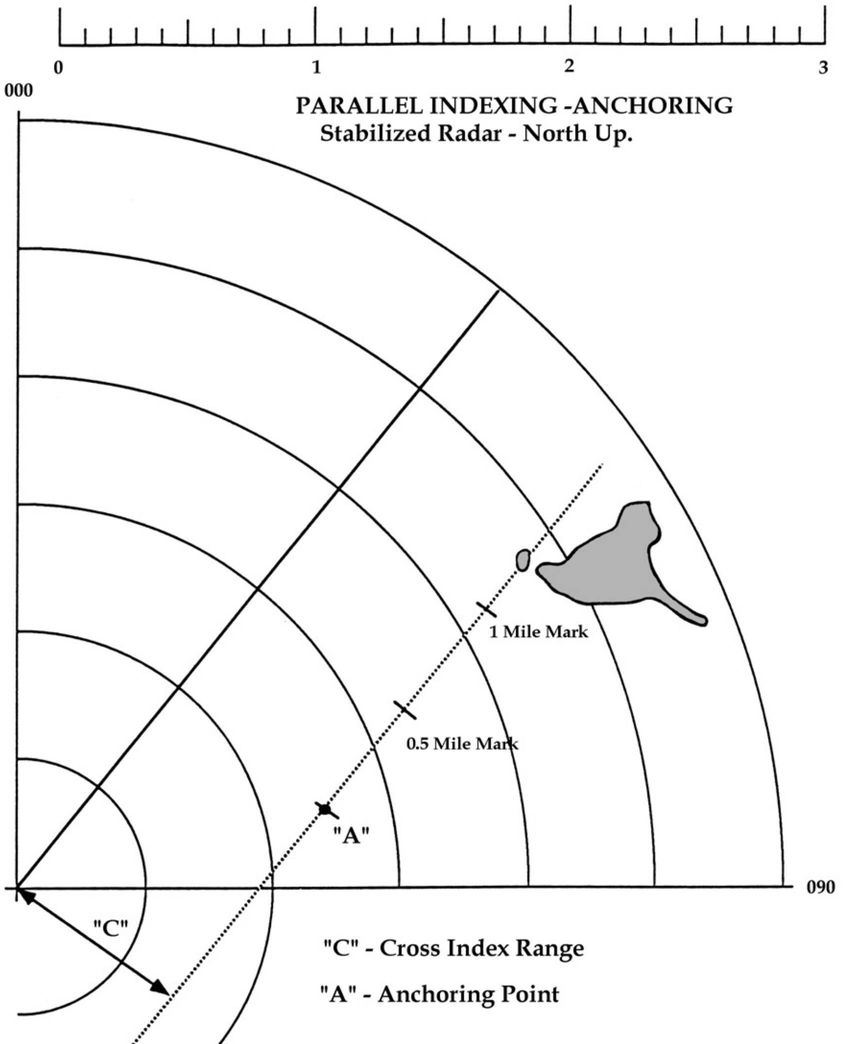


The vessel made its final course change and will run aground, even though the nav. aid is at the desired range.

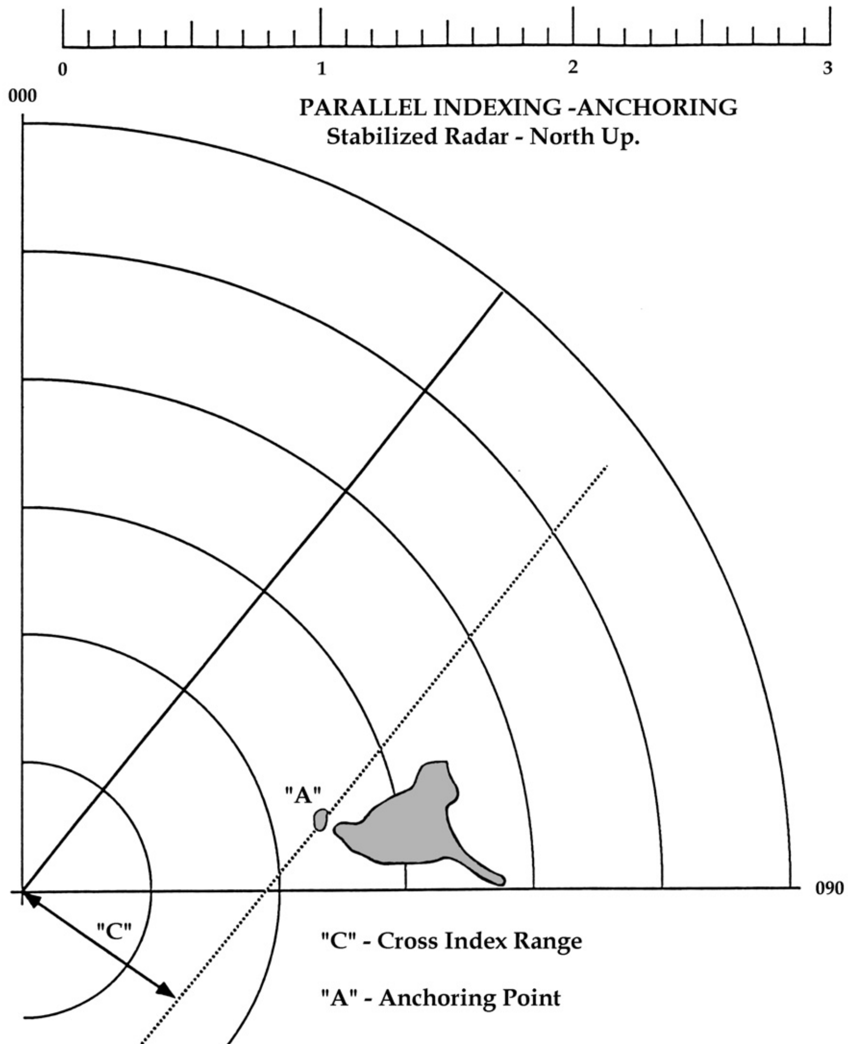
PARALLEL INDEXING - Head Up
"Birdseye plot".



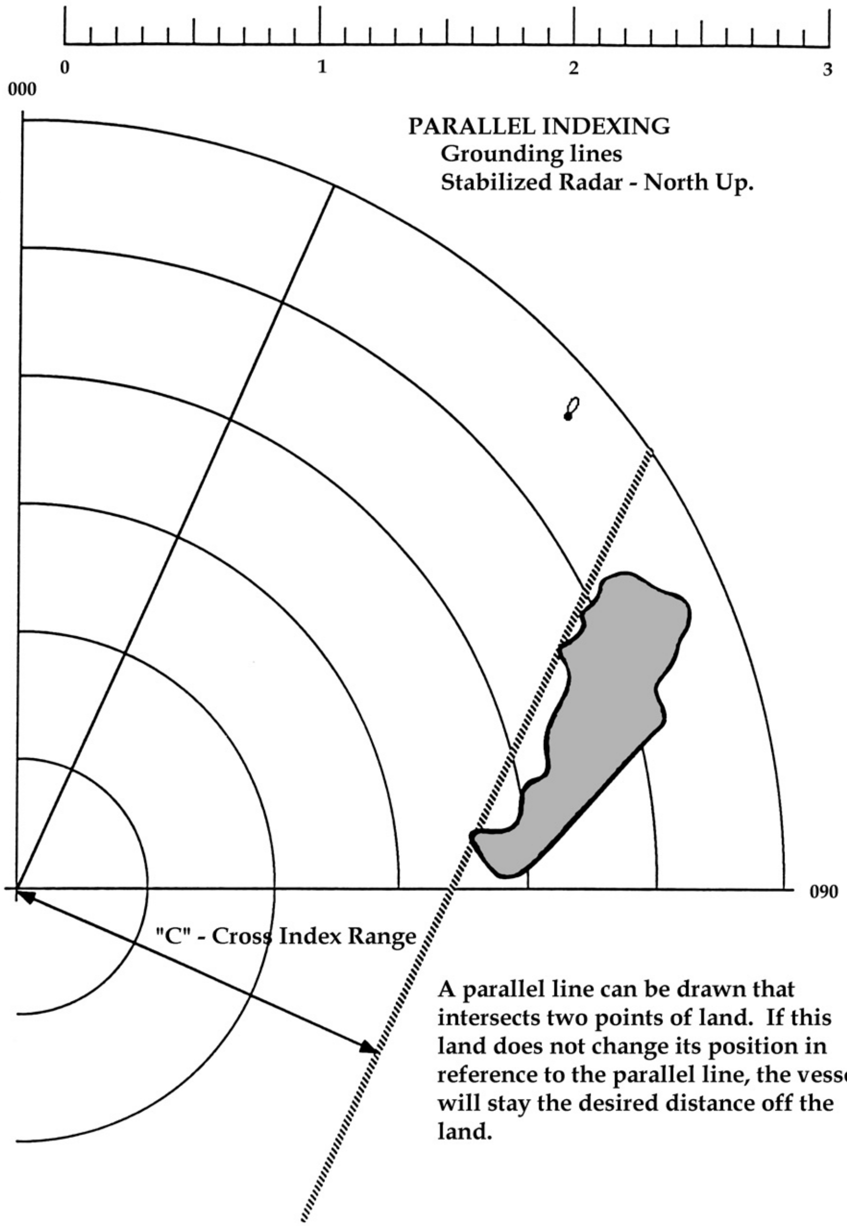
This example shows the amount of set encountered and its effect on parallel indexing with a Head Up radar from plotted positions. This shows the nav. aid being kept at the desired 0.5 nm range at all times right up to the point when the vessel runs aground.



To anchor using parallel indexing techniques, determine the approach course and the distance a specific point would be when abeam (Cross Index Range "C") and draw a line on the screen that parallels the approach course at the desired perpendicular distance.

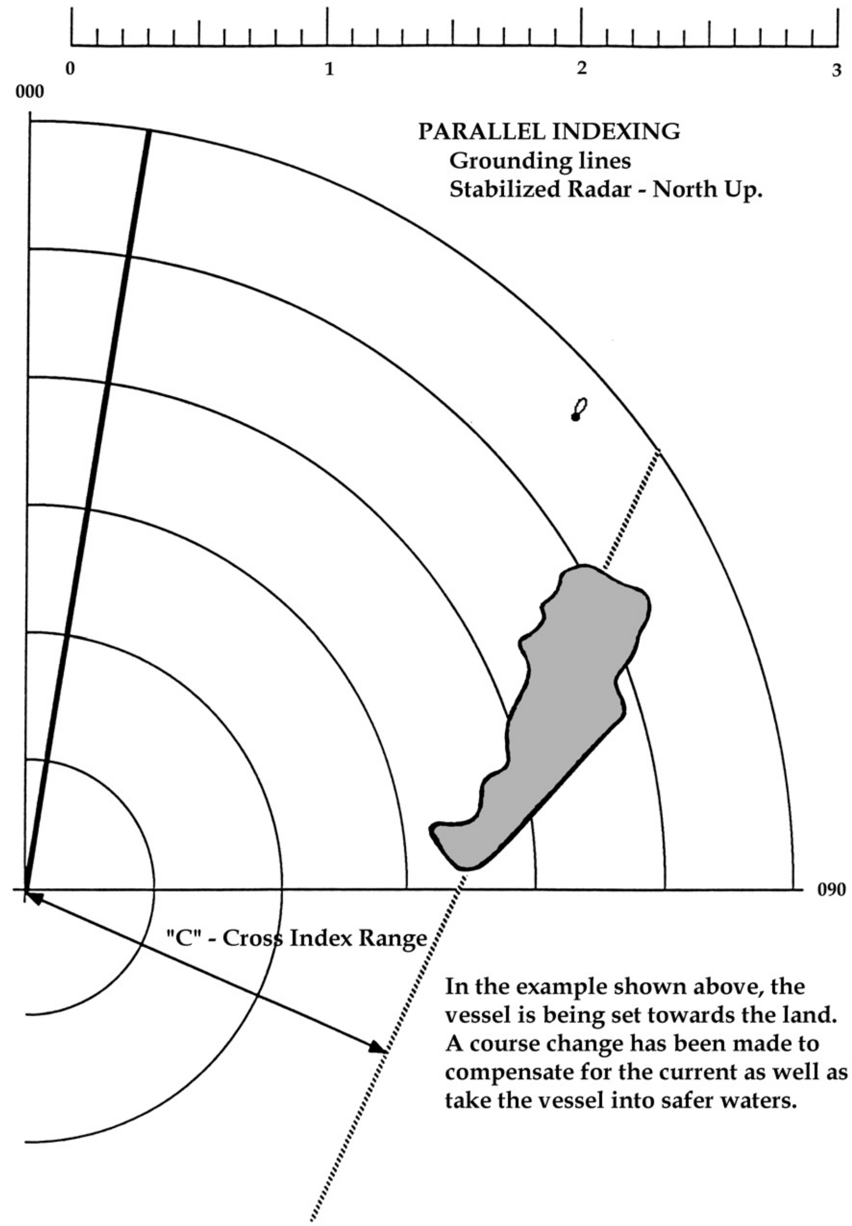


When the Fixed object is directly over point "A" the vessel should be dead in the water (or nearly so) and the anchor can be dropped.



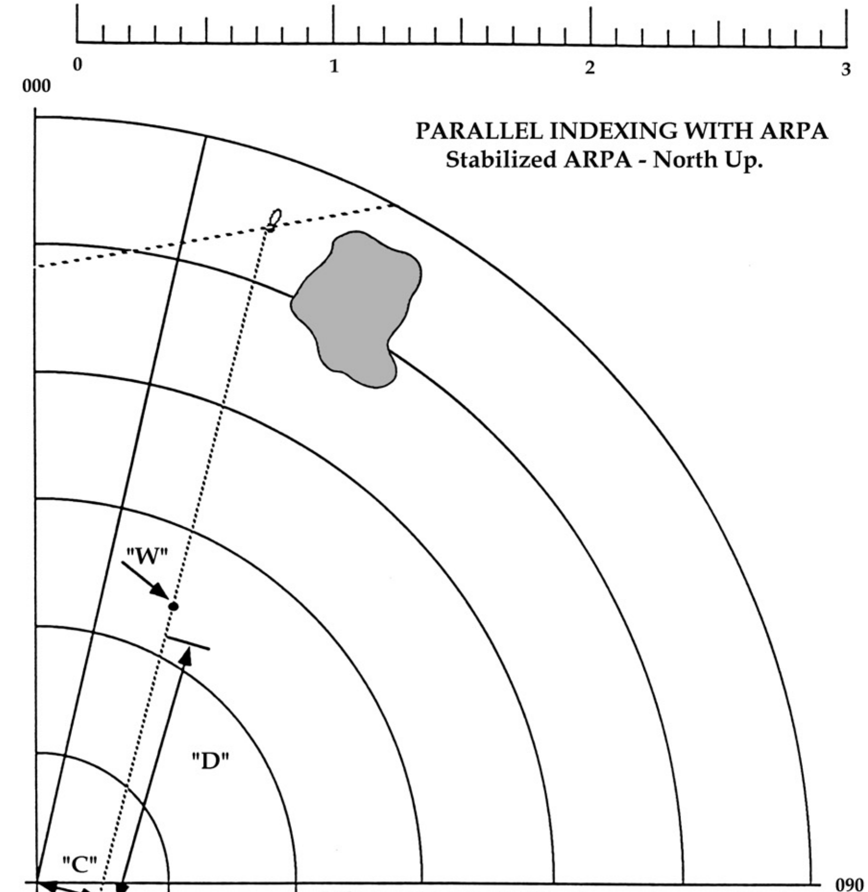
PARALLEL INDEXING
Grounding lines
Stabilized Radar - North Up.

A parallel line can be drawn that intersects two points of land. If this land does not change its position in reference to the parallel line, the vessel will stay the desired distance off the land.



PARALLEL INDEXING
Grounding lines
Stabilized Radar - North Up.

In the example shown above, the vessel is being set towards the land. A course change has been made to compensate for the current as well as take the vessel into safer waters.



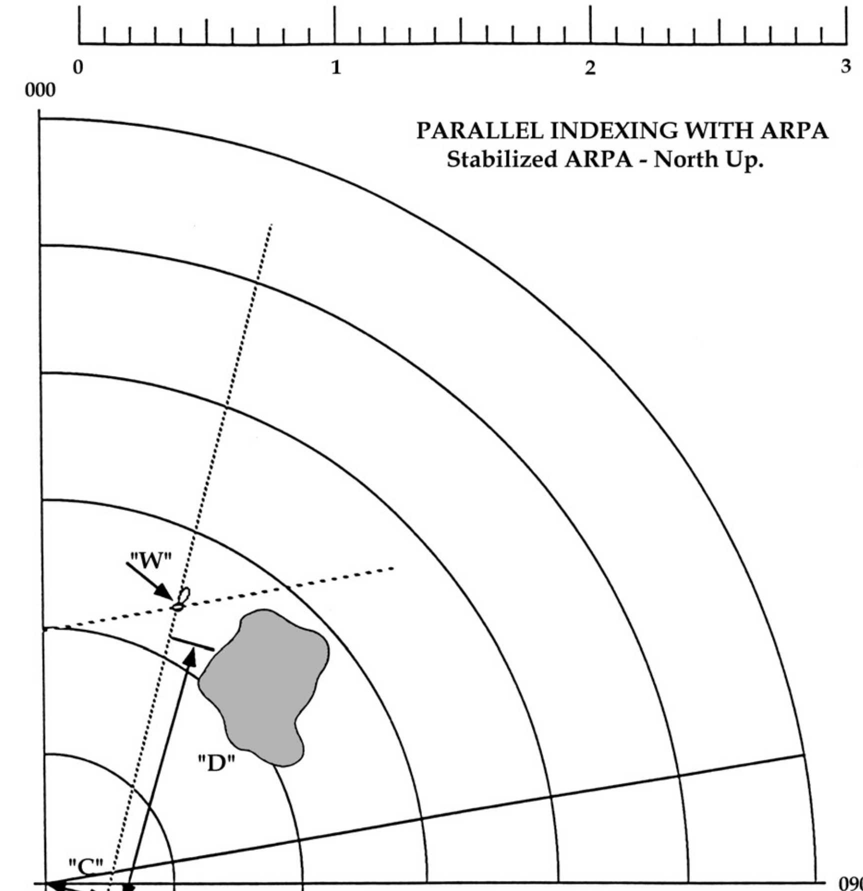
"C" - Cross Index Range

"D" - Dead Range

"W" - Wheel Over Point

When using an ARPA, it may be possible to use an EBL (Electronic Bearing Line) that can be moved or offset from the origin of the display. This line can be set at a specific range and bearing from the origin of the display and rotated to the desired bearing. The course can then be adjusted to bring the desired fixed navigation aid on a parallel course. If navigation lines are available and an accurate speed is in use, navigation lines can be used as well. Set the nav line on the fixed aid in the direction of the new course. When the nav. line tracks to the Wheel Over Point, the course change should be made.

Plot 1



When the course change is made, the fixed nav aid should track down the nav line on the screen. If the nav line moves off the fixed nav. aid, there is probably an error in the course or speed that is being used by the ARPA to move the nav line.

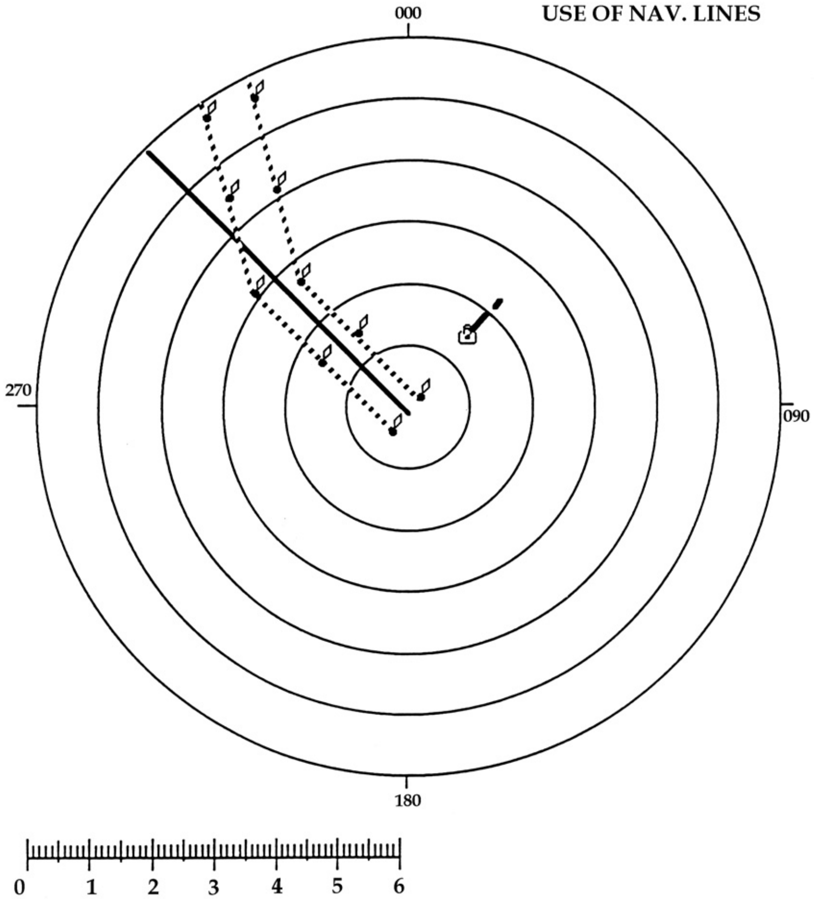
"C" - Cross Index Range

"D" - Dead Range

"W" - Wheel Over Point

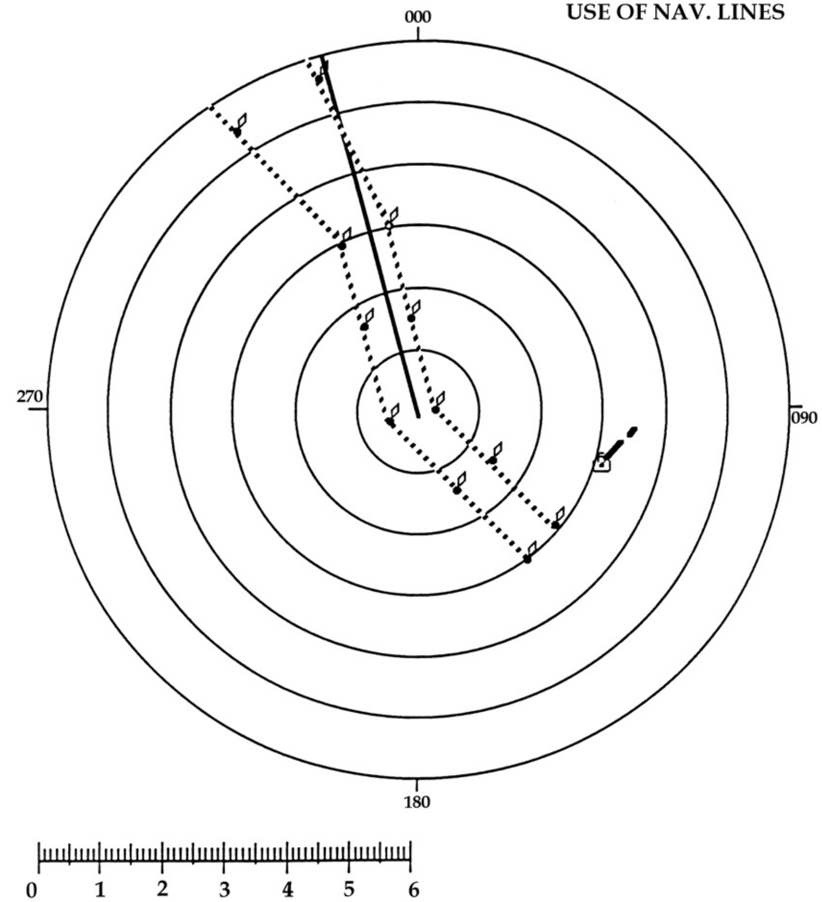
Plot 2

PARALLEL INDEXING
USE OF NAV. LINES



An indexing technique that can be used with an ARPA is the use of nav. lines in channel keeping. In the example above, the operator has selected a fixed nav. aid to ground reference the ARPA. The nav lines were then drawn in. The operator can then determine what part of the channel the vessel is in and prepare for the course change. There is a possibility that the ARPA might try to track the Racon on the reference target. If that happens the nav. lines could move off the channel markers. If this occurs, remove the nav. lines, choose another nav aid to reference on and reconstruct the nav. lines.

PARALLEL INDEXING
USE OF NAV. LINES



Additional nav lines can be placed at a later time on some units and the channel keeping value of the nav lines can continue. The nav lines track based on the vessel's course and speed. On some units, it is possible to fix the position of these lines with respect to the vessel and use these lines in a more traditional parallel indexing manner.

THE FRANKLIN CONTINUOUS RADAR PLOT TECHNIQUE

The Franklin Continuous Radar Plot technique provides means for continuous correlation of a small fixed, radar-conspicuous object with own ship's position and movement relative to a planned track. The technique, as developed by Master Chief Quartermaster Byron E. Franklin, U.S. Navy, while serving aboard USS INTREPID (CVS-11), is a refinement of the parallel-cursor (parallel-index) techniques used as a means for keeping own ship on a planned track or for avoiding navigational hazards.

Ranges and bearings of the conspicuous object from various points, including turning points, on the planned track are transferred from the chart to the reflection plotter mounted on a stabilized relative motion indicator. On plotting the ranges and bearings and connecting them with line segments, the navigator has a visual display of the position of the conspicuous object relative to the path it should follow on the PPI (see figure 4.26).

If the pip of the conspicuous object is painted successively on the constructed path (planned relative movement line or series of such lines), the navigator knows that, within the limits of accuracy of the plot and the radar display, his ship is on the planned track. With the plot labeled with respect to time, he knows whether he is ahead or behind his planned schedule. If the pips are painted to the left or right of the RML, action required to return to the planned track is readily apparent. However, either of the following rules of thumb may be used: (1) Using the DRM as the reference direction for any offsets of the pips, the ship is to the left of the planned track if the pips are painted to the left of the planned RML; the ship is to the right of the planned track if the pips are painted to the right of the planned RML. (2) While facing in the direction of travel of the conspicuous object on the PPI, the ship is to the left or right of the planned track if the pips are painted left or right of the planned RML, respectively.

Through taking such corrective action as is necessary to keep the conspicuous object pip on the RML in accordance with the planned time schedule, continuous radar fixing is, in effect, accomplished. This fixing has the limitation of being based upon the range and bearing method, more subject to identification mistakes than the method using three or more intersecting range arcs.

Except for the limitations of being restricted with respect to the range scale setting and some PPI clutter produced by the construction of the planned RML, the technique does not interfere with the use of the PPI for fixing by other means. Preferably, the technique should be used in conjunction with either visual fixing or fixing by means of three or more intersecting range arcs. Fixing by either means should establish whether the radar-conspicuous object has been identified correctly. With verification that the radar-conspicuous object has been identified correctly, requirements for frequent visual fixes or fixes by range measurements are less critical.

Because of the normal time lag in the latest radar fix plotted on the chart, inspection of the position of the pip of the radar-conspicuous object relative to the planned RML should provide a more timely indication as to whether the ship is to the left or right of the planned track or whether the ship has turned too early or too late according to plan.

Once the radar-conspicuous object has been identified correctly, the planned RML enables rapid re-identification in those situations where the radarscope cannot be observed continuously. Also, this identification of the conspicuous object with respect to its movement along the planned RML provides means for more certain identification of other radar targets.

While the planned RML can be constructed through use of the bearing cursor and the variable range marker (range strobe), the use of plastic templates provides greater flexibility in the use of the technique, particularly when there are requirements for use of more than one range scale setting or a need for shifting to a different radar-conspicuous object during a passage through restricted waters. With a planned RML for a specific radar-conspicuous object cut in a plastic template for a specific range scale setting available, the planned RML can be traced rapidly on the PPI. With availability of other templates prepared for different range scale settings or different objects and associated range scale settings, the planned RML as needed can be traced rapidly on the PPI. Other templates can be prepared for alternative planned tracks.

If the range scale setting is continuously adjustable or "rubberized it may be possible to construct the template by tracing the planned track on a chart having a scale which can be duplicated on the PPI. Because the planned RML is opposite to the planned track, the track cut in the template must be rotated 180˚ prior to tracing the planned RML on the PPI.

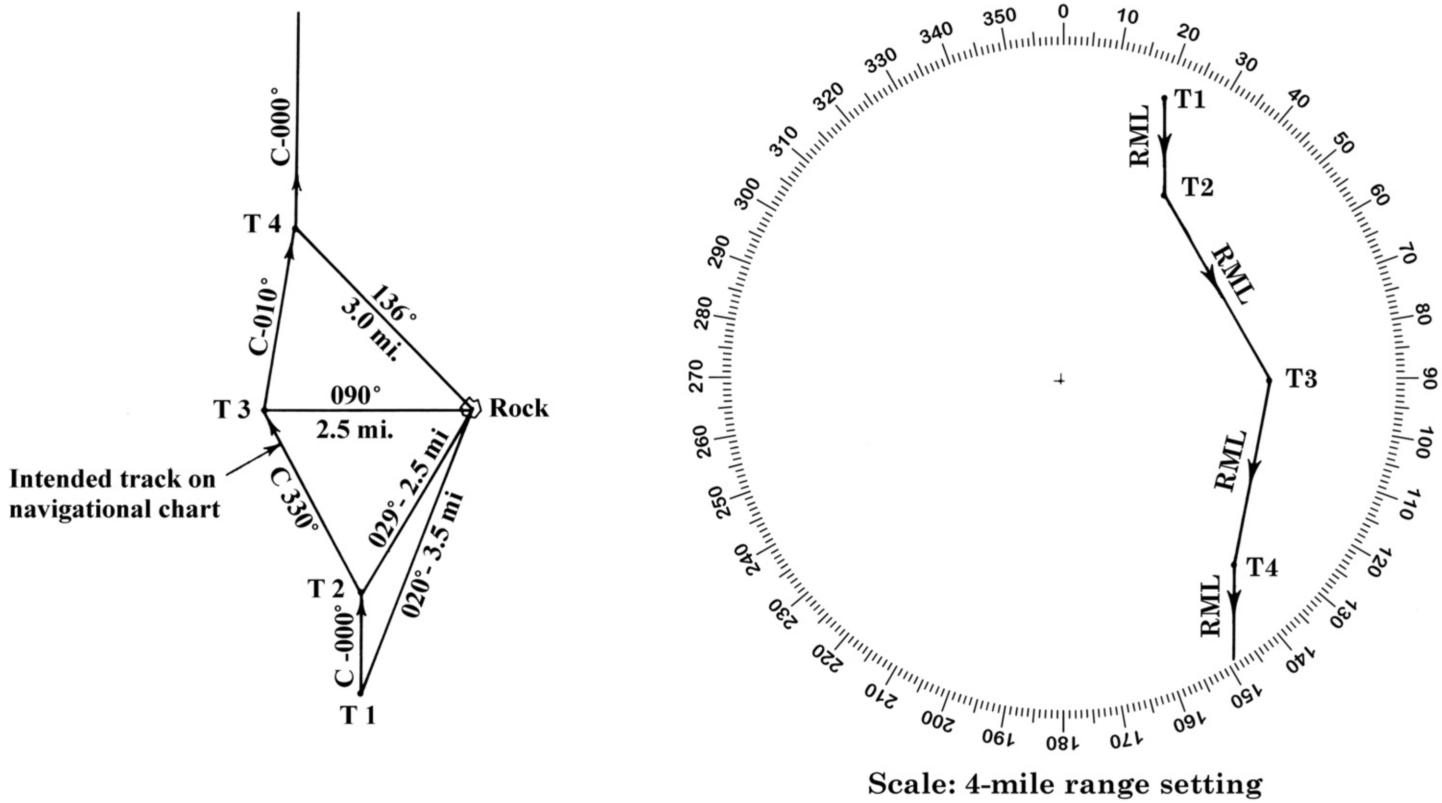


Figure 4.26 - The Franklin continuous radar plot technique.

TRUE MOTION RADAR RESET IN RESTRICTED WATERS

When using true motion displays, the navigator should exercise care in deciding when and where to reset own ship's position on the PPI. While navigating in restricted waters, he must insure that he has adequate warning ahead; through sound planning, he must avoid any need for resetting the display at critical times.

The following is an example of resetting a true motion display for a ship entering the River Tyne. The speed made good is 6 knots. The navigator desires to maintain a warning ahead of at least 1 mile (see figure 4.27).

At 1000
Own ship is reset to the south on the 3-mile range scale to display area A so that Tynemouth is just showing and sufficient warning to the north is obtained for the turn at about 1030.

At 1024
Own ship is reset to the southeast on the 1.5-mile range scale to display area B before the turn at 1030.

At 1040
Own ship is reset to the east to display area C. The reset has been carried out early to avoid a reset in the entrance and to show all traffic up to South Shields.

At 1055
Own ship is reset to the northeast to display area D. The reset has been carried out early before the bend of the river at South Shields and to place the bend at Tyne Dock near the center of the display.

At 1117
Own ship is reset to the east to display area E.

At 1133
Own ship is reset to the northeast to display area F. The reset has been carried out before the bend at Hebburn and up to the northeast because the ship is making good a southwest direction.

At 1200
Own ship is reset to the southeast to display area G.

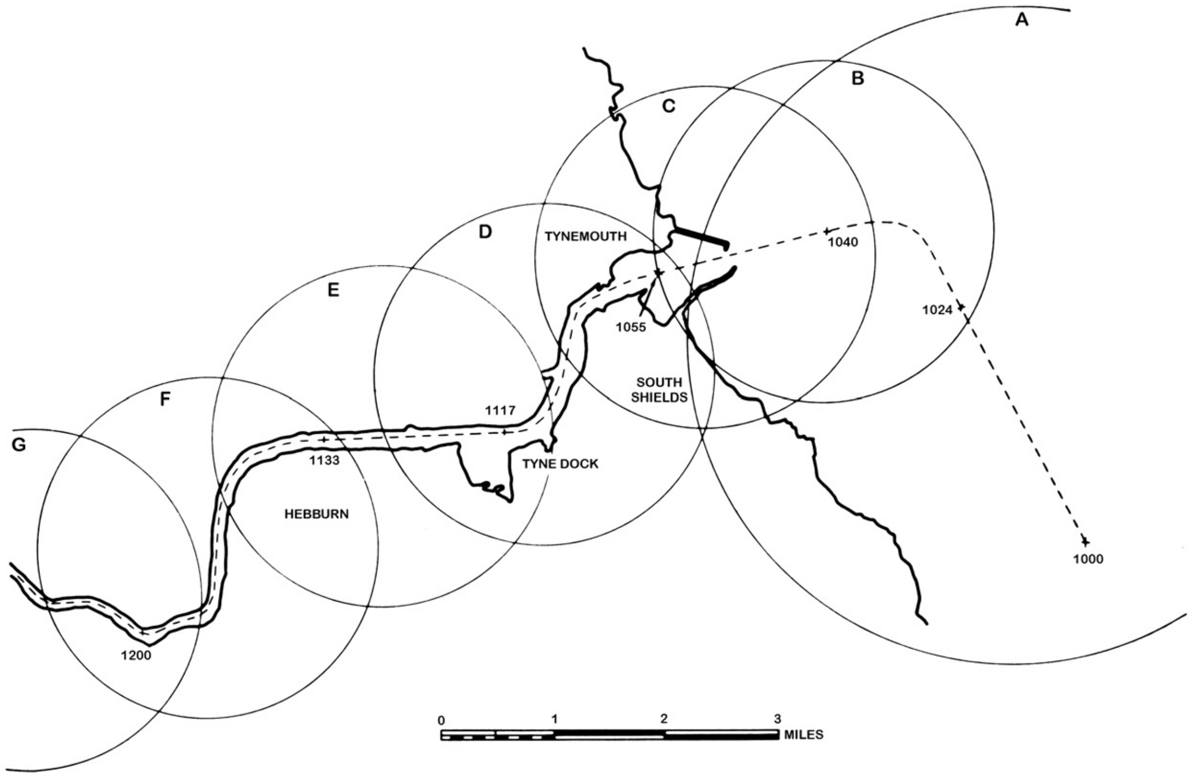


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Figure 4.27 - Resetting a true motion display.

RADAR DETECTION OF ICE

Radar can be an invaluable aid in the detection of ice if used wisely by the radar observer having knowledge of the characteristics of radar propagation and the capabilities of his radar set. The radar observer must have good appreciation of the fact that ice capable of causing damage to a ship may not be detected even when the observer is maintaining a continuous watch of the radarscope and is using operating controls expertly.

When navigating in the vicinity of ice during low visibility, a continuous watch of the radarscope is a necessity. For reasonably early warning of the presence of ice, range scale settings of about 6 or 12 miles are probably those most suitable. Such settings should provide ample time for evasive action after detection. Because any ice detected by radar may be lost subsequently in sea clutter, it may be advisable to maintain a geographical plot. The latter plot can aid in differentiating between ice aground or drifting and ship targets. If an ice contact is evaluated as an iceberg, it should be given a wide berth because of the probability of growlers in its vicinity. If ice contacts are evaluated as bergy bits or growlers, the radar observer should be alert for the presence of an iceberg. Because the smaller ice may have calved recently from an iceberg, the radar observer should maintain a particularly close watch to windward of the smaller ice.

ICEBERGS

While large icebergs may be detected initially at ranges of 15 to 20 miles in a calm sea, the strengths of echoes returned from icebergs are only about $^1/_{60}$ of the strengths of echoes which would be returned from a steel ship of equivalent size.

Because of the shape of the iceberg, the strengths of echoes returned may have wide variation with change in aspect. Also, because of shape and aspect, the iceberg may appear on the radarscope as separate echoes. Tabular icebergs, having flat tops and nearly vertical sides which may rise as much as 100 feet above the sea surface, are comparatively good radar targets.

Generally, icebergs will be detected at ranges not less than 3 miles because of irregularities in the sloping faces.

BERGY BITS

Bergy bits, extending at most about 15 feet above the sea surface, usually cannot be detected by radar at ranges greater than 3 miles. However, they may be detected at ranges as great as 6 miles. Because their echoes are generally weak and may be lost in sea clutter, bergy bits weighing several hundred or a few thousand tons can impose considerable hazard to a ship.

GROWLERS

Growlers, extending at most about 6 feet above the sea surface, are extremely poor radar targets. Being smooth and round because of wave action, as well as small, growlers are recognized as the most dangerous type of ice that can be encountered.

In a rough sea and with sea clutter extending beyond 1 mile, growlers large enough to cause damage to a ship may not be detected by radar. Even with expert use of receiver gain, pulse length, and anti-clutter controls, dangerous growlers in waves over 4 feet in height may not be detected.

In a calm sea growlers are not likely to be detected at a range exceeding 2 miles.

RADAR SETTINGS FOR RADARSCOPE PHOTOGRAPHY

Radar settings are an important factor in preparing good quality radarscope photography. A natural tendency is to adjust the radar image so that it presents a suitable visual display, but this, almost invariably, produces poor photographic results. Usually the resulting photograph is badly overexposed and lacking in detail. Another tendency is to try to record too much information on one photograph such that the clutter of background returns actually obscures the target images. In both cases, the basic problem is a combination of gain and intensity control. A basic rule of thumb is if imagery looks right to visual inspection, it will probably overexpose the recording film. As a rule of thumb, if the image intensity is adjusted so that weak returns are just visible, then a one sweep exposure should produce a reasonably good photograph.

The following list of effects associated with various radar settings can be used as an aid in avoiding improper settings for radarscope photography:

(1) Excessive brightness produces an overall milky or intensely bright appearance of the images. Individual returns will bloom excessively and appear unfocused. It becomes difficult to distinguish the division between land and water, and ground and cultural returns.

(2) Improper contrast results in a lack of balance in the grey tonal gradations on the scope, greatly degrading the interpretive quality.

(3) High gain results in "blooming" of all bright returns adversely affecting the image resolution. High gain also causes the formation of a "hot spot" at the sweep origin.

(4) Low gain results in a loss of weak to medium returns. The result will be poor interpretive quality where there are few bright targets illuminated due to absence of definitive target patterns on the scope.

(5) Excessively bright bearing cursors, heading flashes, and range markers result in wide cursors, flashes, and markers which may obscure significant images.

(6) Improper radarscope or camera focus will result in extremely fuzzy or blurred imagery.

NAVIGATIONAL PLANNING

Before transiting hazardous waters, the prudent navigator should develop a feasible plan for deriving maximum benefit from available navigational means. In developing his plan, the navigator should study the capabilities and limitations of each means according to the navigational situation. He should determine how one means, such as cross-bearing fixing, can best be supported by another means, such as fixing by radar-range measurements.

The navigator must be prepared for the unexpected, including the possibility that at some point during the transit it may be necessary to direct the movements of the vessel primarily by means of radar observations because of a sudden obscurity of charted features. Without adequate planning for the use of radar as the primary means for insuring the safety of the vessel, considerable difficulty and delay may be incurred before the navigator is able to obtain reliable fixes by means of radar following a sudden loss of visibility.

An intended track which may be ideal for visual observations may impose severe limitations on radar observations. In some cases a modification of this intended track can afford increased capability for reliable radar observations without unduly degrading the reliability of the visual observations or increasing the length of the transit by a significant amount. In that the navigator of a radar-equipped vessel always must be prepared to use radar as the primary means of navigating his vessel while in pilot waters, the navigator should effect a reasonable compromise between the requirements for visual and radar fixing while determining the intended track for the transit.

The value of radar for navigation in pilot waters is largely lost when it is not manned continuously by a competent observer. Without continuous manning the problems associated with reliable radarscope interpretation are too great, usually, for prompt and effective use of the radar as the primary means of insuring the safety of the vessel. The continuous manning of the radar is also required for obtaining the best radarscope presentation through proper adjustments of the operating controls as the navigational situation changes or as there is a need to make adjustments to identify specific features.

With radar being used to support visual fixing during a transit of hazardous waters, visual observations can be used as an aid in the identification of radar observations. Through comparing the radar plot with the visual plot, the navigator can evaluate the accuracies of the radar observations. With radar actually being used to support visual fixing, the transition to the use of radar as the primary means can be effected with lesser difficulty and with greater safety than would be the case if the radar were not continuously manned and used to support visual fixing.

While the navigational plan must be prepared in accordance with the manning level and individual skills as well as the navigational situation, characteristics of navigational aids or equipment, characteristics of radar propagation, etc., the navigator should recognize the navigational limitations imposed by lack of provision for continuous manning of the radar. A transit, which may be effected with a reasonable margin of safety if the radar is manned continuously by a competent observer, may impose too much risk if provision is not made for the continuous manning of the radar.

The provision for continuous manning of the radar by a designated and competent observer does not necessarily mean that other responsible navigational personnel should not observe the radarscope from time to time. In fact the observations by other navigational personnel are highly desirable. According to the navigational plan, the designated observer may be relieved by a more experienced and proficient observer in the event that radar must be used as the primary means of insuring the safety of the vessel at some point during the transit. In such event the observer who has been manning the radar should be able to brief his relief rapidly and reliably with respect to the radar situation. Assuming that the previous observer has made optimum range settings according to plan at various points on the track, the new observer should be able to make effective use of the radar almost immediately. If this more proficient observer has been making frequent observations of the radarscope, aided by comment of the observer continuously manning the radar, any briefing requirements on actually relieving the other observer should be minimal.

If radar is to be used effectively in hazardous waters, it is essential that provisions be made for the radar observer and other responsible navigational personnel to be able to inspect the chart in the immediate vicinity of the radar indicator. The practice of leaving a radar indicator installed in the wheelhouse to inspect the chart in the chartroom is highly unsatisfactory in situations requiring prompt and reliable radarscope interpretation. The radar observer must be able to make frequent inspections of the chart without undue delays between such inspections and subsequent radar observations. A continuous correlation of the chart and the PPI display is required for reliable radarscope interpretation.

If the navigational plot is maintained on a chart other than that used by the radar observer for radarscope interpretation, the observer's chart should include the basic planning data, such as the intended track, turning bearings, danger bearings, turning ranges, etc.

In planning for the effective use of radar, it is advisable to have a definite procedure and standardized terminology for making verbal reports of radar and visual observations. At points on the track where simultaneous visual and radar observations are to be made, the lack of an adequate reporting procedure will make the required coordination unduly difficult. Reports of radar observations can be simplified through the use of appropriate annotations on the chart and PPI. For example, a charted rock which is identified on the PPI can be designated as "A"; another radar-conspicuous object can be designated as "B," etc. With the chart similarly annotated, the various objects can be reported in accordance with their letter designations.

SPECIAL TECHNIQUES

In that the navigator of a radar-equipped vessel always must be prepared to use radar as his primary means of navigation in pilot waters, during the planning for a transit of these waters it behooves him to study the navigational situation with respect to any special techniques which can be employed to enhance the use of radar. The effectiveness of such techniques usually is dependent upon adequate preparation for their use, including special constructions on the chart or the preparation of transparent chart overlays.

The correlation of the chart and the PPI display during a transit of confined waters frequently can be aided through the use of a transparent chart overlay on which properly scaled concentric circles are inscribed as a means of simulating the fixed range rings on the PPI. By placing the center of the concentric circles at appropriate positions on the chart, the navigator is able to determine by rapid inspection, and with close approximation, just where the pips of certain charted features should appear with respect to the fixed range rings on the PPI when the vessel is at those positions. This technique compensates for the difficulty imposed by viewing the PPI at one scale and the chart at another scale. Through study of the positions of various charted features with respect to the simulated fixed range rings on the transparency as the center of the simulated rings is moved along the intended track, certain possibilities for unique observations may be revealed.

Identifying Echoes

By placing the center of the properly scaled simulated range ring transparency over the observer's most probable position on the chart, the identification of echoes is aided. The positions of the range rings relative to the more conspicuous objects aid in establishing the most probable position. With better positioning of the center of the simulated rings, more reliable identification is obtained.

Fixing

By placing the simulated range ring transparency over the chart so that the simulated rings have the same relationship to charted objects as the actual range rings have to the corresponding echoes, the observer's position is found at the center of the simulated range rings.

Under some conditions, there may be not be enough suitable objects and corresponding echoes to correlate with the range rings to obtain the desired accuracy.

This method of fixing should be particularly useful aboard small craft with limited navigational personnel, equipment, and plotting facilities. This method should serve to overcome difficulties associated with unstabilized displays and lack of a variable range marker.

CHAPTER 5 — AUTOMATIC RADAR PLOTTING AIDS (ARPA)

INTRODUCTION

The availability of low cost microprocessors and the development of advanced computer technology during the 1970s and 1980s have made it possible to apply computer techniques to improve commercial marine radar systems. Radar manufactures used this technology to create the Automatic Radar Plotting Aids (ARPA). ARPAs are computer assisted radar data processing systems which generate predictive vectors and other ship movement information.

The International Maritime Organization (IMO) has set out certain standards amending the International Convention of Safety of Life at Sea requirements regarding the carrying of suitable automated radar plotting aids (ARPA). The primary function of ARPAs can be summarized in the statement found under the IMO Performance Standards. It states a requirement of ARPAs....“*in order to improve the standard of collision avoidance at sea: Reduce the workload of observers by enabling them to automatically obtain information so that they can perform as well with multiple targets as they can by manually plotting a single target*”. As we can see from this statement the principal advantages of ARPA are a reduction in the workload of bridge personnel and fuller and quicker information on selected targets.

A typical ARPA gives a presentation of the current situation and uses computer technology to predict future situations. An ARPA assesses the risk of collision, and enables operator to see proposed maneuvers by own ship. While many different models of ARPAs are available on the market, the following functions are usually provided:

1. True or relative motion radar presentation.

2. Automatic acquisition of targets plus manual acquisition.

3. Digital read-out of acquired targets which provides course, speed, range, bearing, closest point of approach (CPA, and time to CPA (TCPA).

4. The ability to display collision assessment information directly on the PPI, using vectors (true or relative) or a graphical Predicted Area of Danger (PAD) display.

5. The ability to perform trial maneuvers, including course changes, speed changes, and combined course/speed changes.

6. Automatic ground stabilization for navigation purposes.

ARPA processes radar information much more rapidly than conventional radar but is still subject to the same limitations. ARPA data is only as accurate as the data that comes from inputs such as the gyro and speed log.

STAND-ALONE AND INTEGRAL ARPA’s

Over the past 10 years, the most significant changes to the ARPA systems has been in their design. The majority of ARPAs manufactured today integrate the ARPA features with the radar display.

The initial development and design of ARPAs were Stand-alone units. That is they were designed to be an addition to the conventional radar unit. All of the ARPA functions were installed on board as a separate unit but needed to interfaced with existing equipment to get the basic radar data. The primary benefits were cost and time savings. This of course was not the most ideal situation and eventually it was the integral ARPA that gradually replaced the stand-alone unit.

The modern integral ARPA combines the conventional radar data with the computer data processing systems into one unit. The main operational advantage is that both the radar and ARPA data are readily comparable.

ARPA DISPLAY

From the time radar was first introduced to the present day the radar picture has been presented on the screen of a cathode ray tube. Although the cathode ray tube has retained its function over the years, the way in which the picture is presented has changed considerably. From about the mid-1980s the first raster-scan displays appeared. The radial-scan PPI was replaced by a raster-scan PPI generated on a television type of display. The integral ARPA and conventional radar units with a raster-scan display will gradually replace the radial-scan radar sets.

The development of commercial marine radar entered a new phase in the 1980s when raster-scan displays that were compliant with the IMO Performance Standards were introduced.

The radar picture of a raster-scan synthetic display is produced on a television screen and is made up of a large number of horizontal lines which form a pattern known as a raster. This type of display is much more complex than the radial-scan synthetic display and requires a large amount of memory. there are a number of advantages for the operator of a raster-scan display and concurrently there are some deficiencies too. The most obvious advantage of a raster-scan display is the brightness of the picture. This allows the observer to view the screen in almost all conditions of ambient light. Out of all the benefits offered by a raster-scan radar it is this ability which has assured its success. Another difference between the radial-scan and raster-scan displays is that the latter has a rectangular screen. The screen size is specified by the length of the diagonal and the width and height of the screen with an approximate ratio of 4:3. The raster-scan television tubes have a much longer life than a traditional radar CRT. Although the tubes are cheaper over their counterpart, the complexity of the signal processing makes it more expensive overall.

Raster-scan PPI

The IMO Performance Standards for radar to provide a plan display with an effective display diameter of 180mm, 250mm, or 340mm depending upon the gross tonage of the vessel. With the diameter parameters already chosen, the manufacturer has then to decide how to arrange the placement of the digital numerical data and control status indicators. The raster-scan display makes it easier for design engineers in the way auxiliary data can be written.

Monochrome and Color CRT

A monochrome display is one which displays one color and black. The general monochrome television uses white as the color. This however is not an appropriate color for the conditions under which a commercial marine radar is viewed. Unlike a television screen, marine radar displays tend to be viewed from the shorter distance and the observer has a greater concentration on the details of the screen and therefore is subject to eyestrain. For this reason the color most common to monochrome raster-scan applications was green. The green phosphor provides comfortable viewing by reducing eye strain and stress.

The color tube CRT differs from its monochrome counterpart in that it has three electron guns, which are designated as red, green, and blue.

FEATURES AND OPERATING INSTRUCTIONS FOR A MODERN RASTER SCAN RADAR AND ARPA

INTRODUCTION

The following paragraphs describe the features and operating instructions of the Furuno Heavy-Duty High Performance Raster Scan Radar and ARPA Model FR/FAR-28x5 series. Only selected portions of the Furuno operating instructions are presented in this manual. For the complete operating instructions you should contact a Furuno dealer or representative.

The purpose of this section is to provide a sample of the technical instructions that should be available to the officer. As a radar observer you should thoroughly read and understand the operating instructions for the radar units that you will be using. Operating instructing will of course differ not only between different radar manufactures' but also with different models for the same manufacturer.

As with all equipment, the operator should be completely familiar with the safety instructions prior to turning on the radar. There are a number of dangers, warnings and cautions that should be followed by those operating these radars. Failure to follow the appropriate safety instructions could result in serious injury or death.

FEATURES

The FR-2805 and FAR-2805 series of Radar and ARPAs are designed to fully meet the exacting rules of the International Maritime Organization (IMO) for installations on all classes of vessels.

The display unit employs a 28 inch diagonal multicolored CRT. It provides an effective radar picture of 360 mm diameter leaving sufficient space for on screen alpha-numeric data.

Target detection is enhanced by the sophisticated signal processing technique such as multi-level quantization (MLQ), echo stretch, echo average, and a built-in radar interference rejector. Audible and visual guard zone alarms are provided as standard. Other ship's movement is assessed by trails of target echoes or by electronic plotting. The FAR-2805 series ARPA further provides target assessment by historical plots, vectors and target data table.

On screen data readouts include CPA, TCPA, range, bearing, speed/course on up to 3 targets at a time. The ARPA functions include automatic acquisition of up to 20 targets, or manual acquisition of 40 targets. In addition, the ARPA features display of a traffic lane, buoys, dangerous points, and other important reference points.

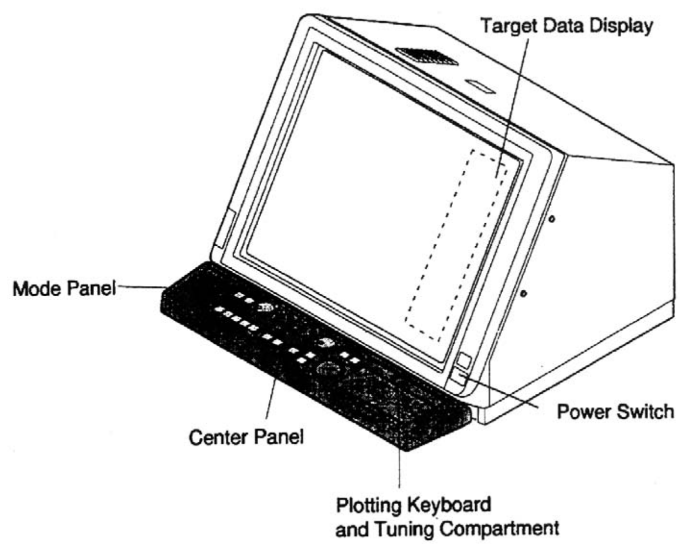


Figure 5.1 - FR-2805 Series Radar Display Unit Overview

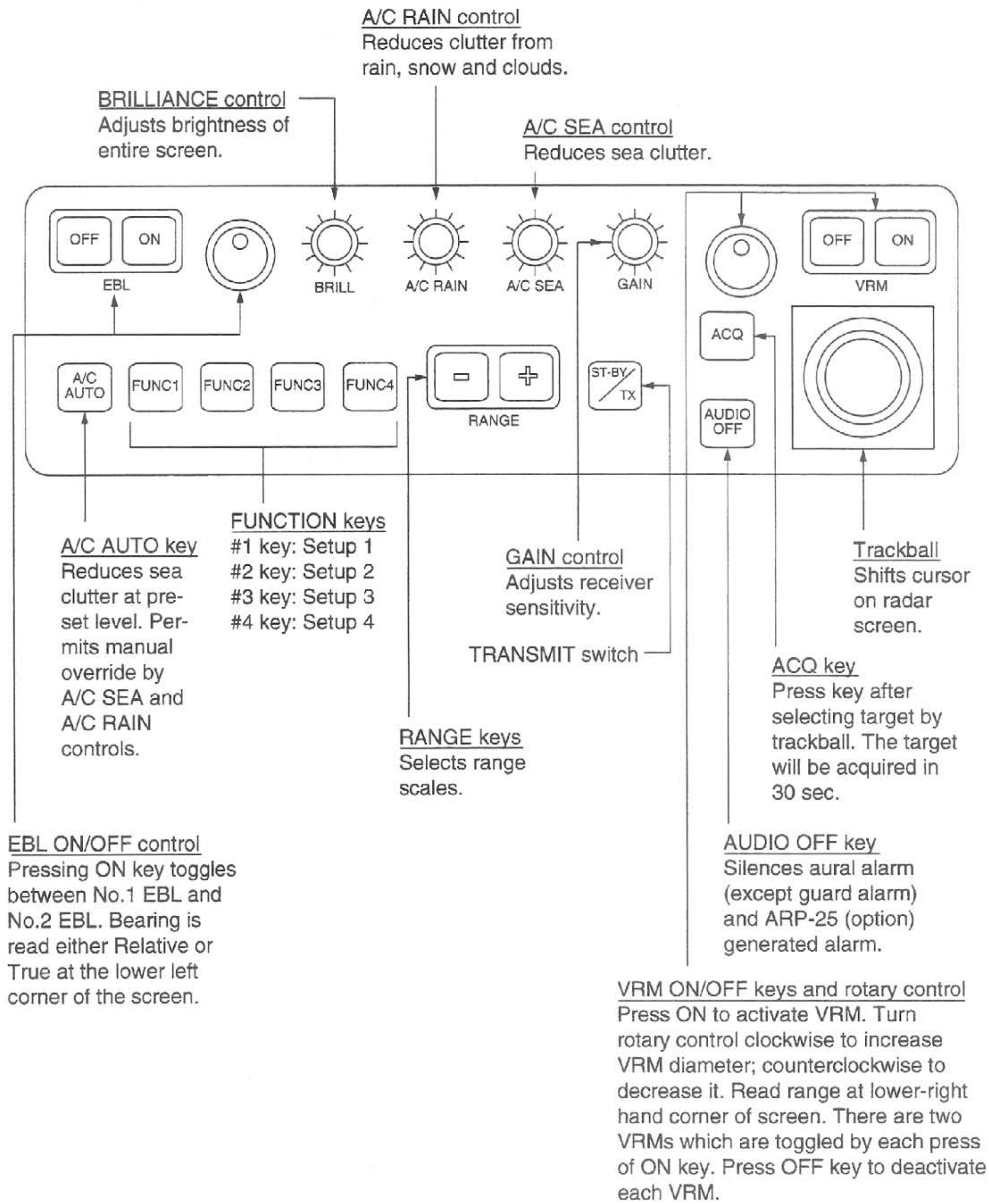
GENERAL FEATURES

- Daylight-bright high-resolution display
- 28 inch diagonal CRT presents radar picture of 360 mm effective diameter with alphanumeric data area around it
- User friendly operation by combination of tactile backlit touchpads, a trackball and rotary controls
- Audio-visual alert for targets in guard zone
- Echo trail to assess targets' speed and course by simulated afterglow
- Electronic plotting of up to 10 targets in different symbols (This function is disabled when ARPA is activated)
- Electronic parallel index lines
- Interswitch (optional) built in radar or ARPA display unit
- Enhanced visual target detection by Echo Average, Echo Stretch, Interference Rejector, and multi-level quantization
- Stylish display
- Choice of 10, 25 or 50 KW output for X-band; 30 KW output for S-band, either in the transceiver aloft (gearbox) or RF down (transceiver in bridge)
- Exclusive FURUNO MIC low noise receiver

ARPA FEATURES

- Acquires up to 20 targets automatically
- Movement of tracked targets shown by true or relative vectors (Vector length 1 to 99 min. selected in 1 min steps)
- Setting of nav lines, buoy marks and other symbols to enhance navigation safety
- On-screen digital readouts of range, bearing, course, speed, CPA, TCPA, BCR (Bow Crossing Range) and BCT (Bow Crossing Time) of two targets out of all tracked targets.
- Audible and visual alarms against threatening targets coming into operator-selected CPA/TCPA limits, lost targets, two guard rings, visual alarm against system failure and target full situation
- Electronic plotting of up to 10 targets in different symbols (This function is disabled when ARPA is activated)
- Electronic parallel index lines
- Interswitching (optional) built in radar or ARPA display unit
- Enhanced visual target detection by Echo Average, Echo Stretch, Interference Rejector, and multi-level quantization
- Stylish display
- Choice of 10,25 or 50 kW output for X-band; 30kw output for S-band, either in the transceiver aloft (gearbox) or RF down (transceiver in bridge)
- Exclusive FURUNO MIC low noise receiver

Main control panel



GAIN, A/C RAIN, A/C SEA and BRILL controls are of push-and-rotate type. Push in wanted switch lightly, and it will pop up. Rotate it to the wanted setting and push it in. The retracted position of the controls provides a better protection for water splash.

Figure 5.2 - Main Control Panel

DISPLAY CONTROLS - MODE PANEL

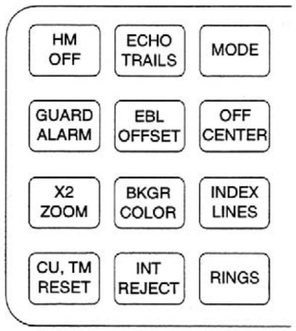


Figure 5.3 - Mode Panel

HM OFF
Temporarily erases the heading marker.

ECHO TRAILS
Shows trails of target echoes in the form of simulated afterglow.

MODE
Selects presentation modes: Head-up, Head-up/TB, North-up, Course-up, and True Motion.

GUARD ALARM
Used for setting the guard alarm.

EBL OFFSET
Activates and deactivates off-centering of the sweep origin.

BKGR COLOR
Selects the background color.

INDEX LINES
Alternately shows and erases parallel index lines.

X2 ZOOM
enlarges a user selected portion of picture twice as large as normal. (R-type only)

CU, TM RESET
Resets the heading line to 000 in course-up mode; moves own ship position 50% radius in stern direction in the true motion mode.

INT REJECT
Reduces mutual radar interference

RANGE RINGS
Adjusts the brightness of range rings.

DISPLAY CONTROLS - PLOTTING KEYPAD

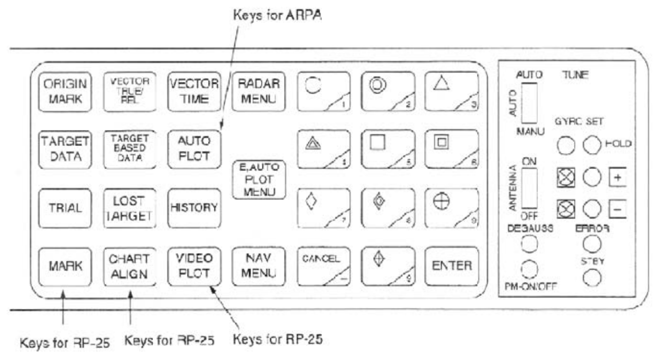


Figure 5.4 - Plotting keypad and tuning compartment

ORIGIN MARK
Show and erases the origin mark (a reference point).

VECTOR TRUE/REL
Selects true or relative vector.

VECTOR TIME
Sets vector length in time.

RADAR MENU
Opens and closes RADAR menus.

E-PLOT, AUTO PLOT MENU
Opens and closes E-plot and AUTO PLT menus.

NAV MENU
Opens and closes NAV menu.

KEYS 0-9
Select plot symbols. Also used for entering numeric data.

CANCEL
Terminates plotting of a specified target or all tracked targets.

ENTER
Used to save settings on menu screen.

TARGET DATA
Displays the acquired target data.

TARGET BASED DATA
Own ship’s speed is measured relative to a fixed target.

AUTO PLOT
Activates and deactivates the Auto Plotter.

TRIAL
Initiates a trial maneuver.

LOST TARGET
Silences the lost target audible alarm and erases the lost target symbol.

HISTORY
Shows and erases past positions of tracked targets.

MARK
Enter/erase mark.

CHART ALIGN
Used to align chart data.

VIDEO PLOT
Turns the video plotter on/off.

OPERATION

TURNING ON POWER

The POWER switch is located at the lower right corner of the display. Push it to switch on the radar set. To turn off the radar, push it again; the switch will extend. The screen shows the bearing scale and digital timer approximately 15 seconds after power-on. The timer counts down three minutes of warm-up time. During this period the magnetron, or the transmitter tube, is warmed for transmission. When the timer has reached 0:00, the legend STBY appears indicating that the radar is now ready to transmit pulses.

In warm-up and standby condition, you will see the message BRG SIG MISSING. This is normal because a bearing signal is not yet generated when the antenna is not rotating. ON TIME and TX TIME values shown at the bottom of the screen are the time counts in hours and tenths of hour when the radar has been powered on and transmitted.

TRANSMITTER ON

When the STANDBY status is displayed on the screen, press the Transmit switch labeled ST-BY/TX on the control panel of the display unit.

The radar is initially set to previously used range and pulse width. Other settings such as brilliance levels, VRMs, ELBs and menu option selections are also set to previous settings.

The Transmit switch toggles the radar between STANDBY and TRANSMIT status. The antenna stops in STANDBY status and rotates in TRANSMIT status.

Notes:
1. If the antenna does not rotate in TRANSMIT status, check whether the antenna switch in the tuning compartment is in the OFF position.
2. The magnetron ages with time resulting in a reduction of output power. It is highly recommended that the radar be set to STANDBY status when not used for an extended period of time.

CRT BRILLIANCE

Operate the BRILL control on the control panel of the display unit to adjust the entire screen brightness. Note that the optimum point of adjustment varies with ambient light conditions, especially between daytime and nighttime.

Note: The CRT brilliance should be adjusted before adjusting relative brilliance levels on the BRILLIANCE menu to be explained later.

TUNING THE RECEIVER

Auto Tune

The radar receiver is tuned automatically each time the power is turned on, thus there is no front panel control for tuning purpose. The tuning indicator and the label AUTO TUNE at the top right corner of the display unit show the tuning circuit is working. If the label AUTO TUNE is not displayed, check that the TUNE selector in tuning compartment is the AUTO position.

Manual Tune

If you are not satisfied with the current auto tune setting, follow these steps to fine-tune the receiver:

1. Push the tune control so that it pops up.

2. Set the TUNE selector in the tuning compartment to MAN for manual tuning.

3. While observing the picture on the 48 mile scale, slowly adjust TUNE control and find the best tuning point.

4. So the TUNE selector to AUTO and wait for about 10 seconds or four scanner rotations.

5. Make sure that the radar has been set to the best tuning point. This condition is where the tuning indicator lights to about 80% of its total length.

6. Push the TUNE control into the retracted position.

Video Lockup Recovery

Video lockup, or picture freeze, can occur unexpectedly on digital rasterscan radars. This is mainly caused by heavy spike noise in the power line and can be noticed by carefully watching the nearly invisible sweep line. If you suspect that the picture is not updated every scan of the antenna or no key entry is accepted notwithstanding the apparently normal picture, do Quick Start to restore normal operation:

1. Turn off the power switch and turn it on again within five seconds.

2. Push the ST-BY switch in the tuning compartment.

3. Push the Transmit switch labeled ST-BY/TX for Transmit status.

ON-SCREEN LEGENDS AND MARKERS

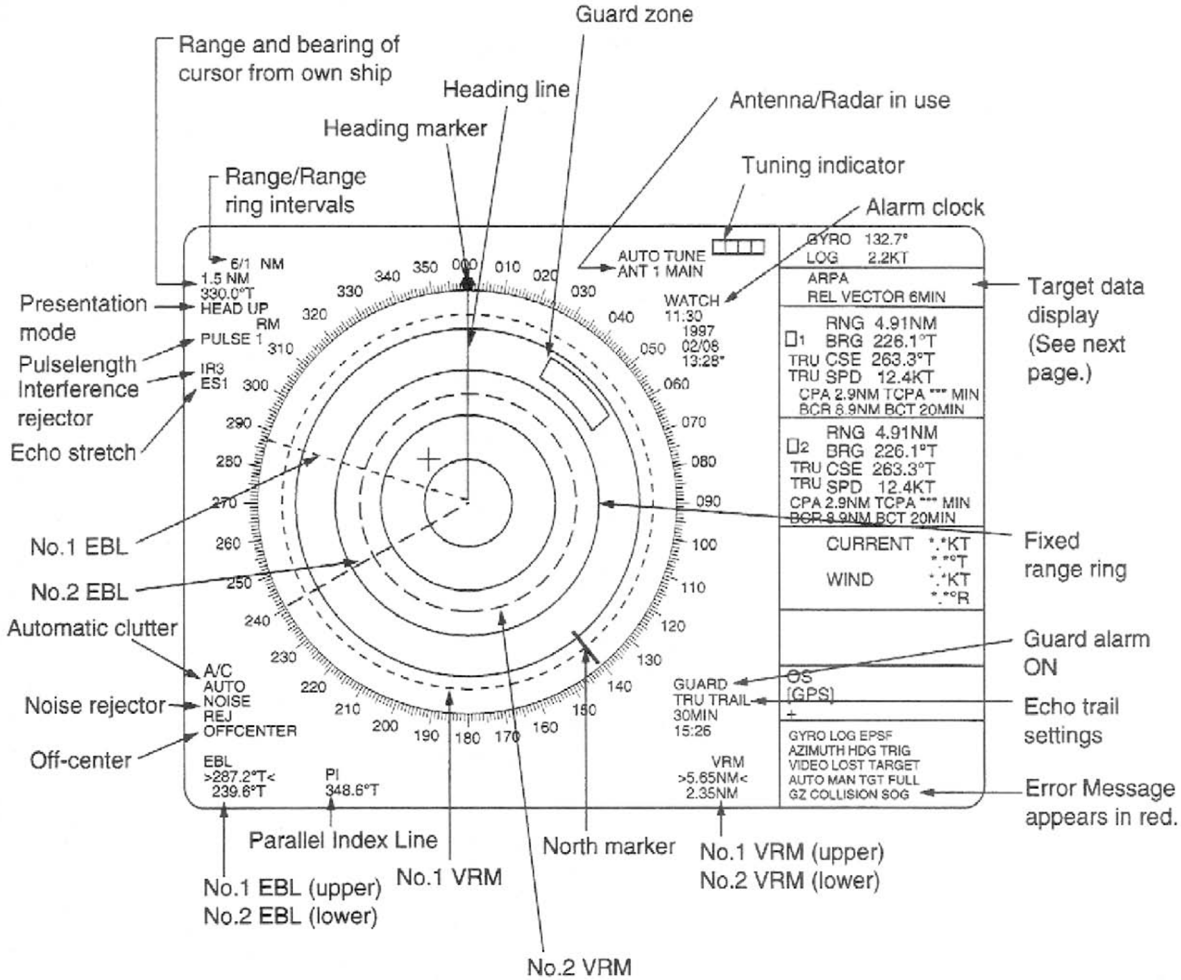


Figure 5.5

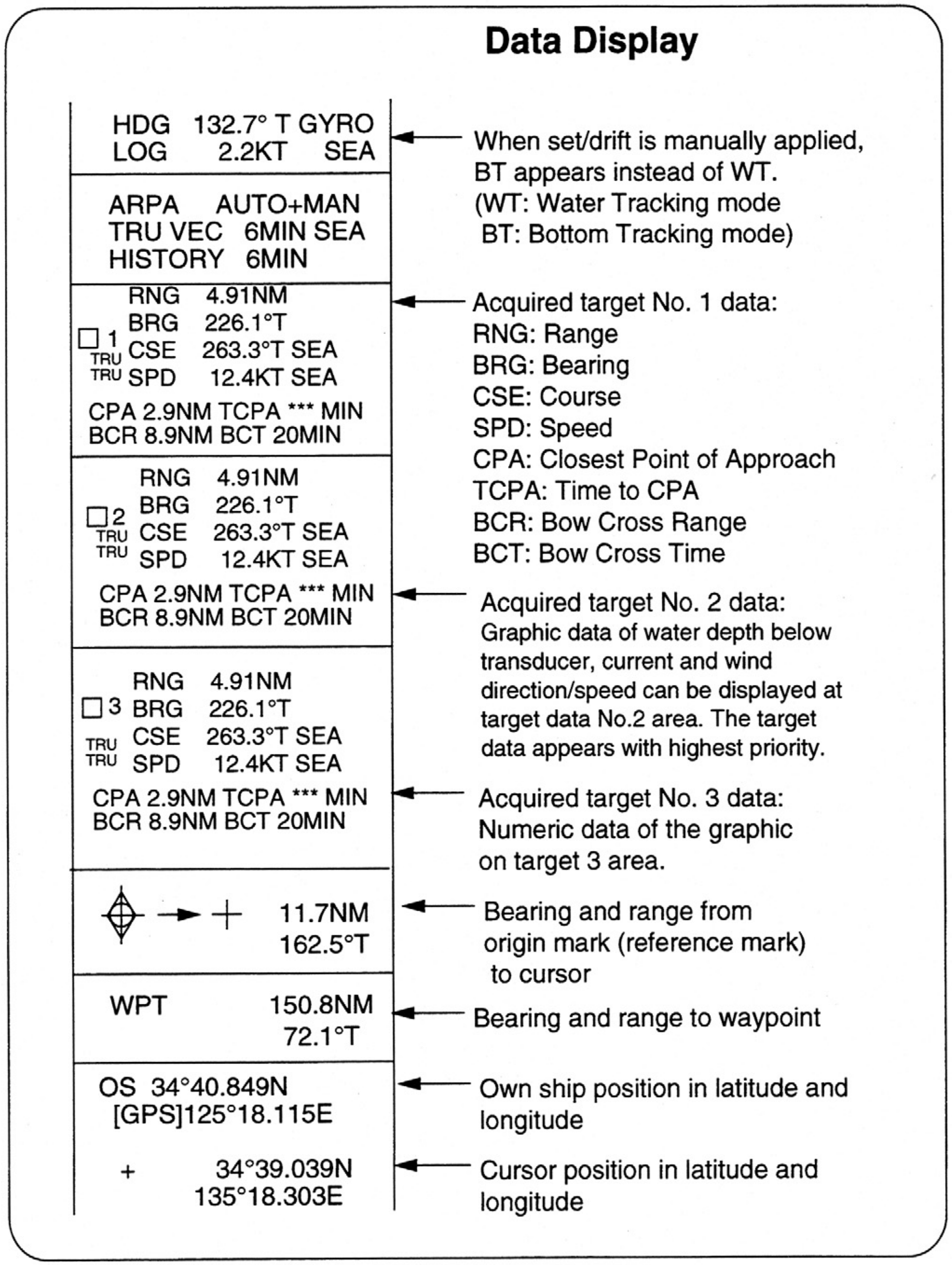


Figure 5.6 - Data display

DEGAUSSING THE CRT SCREEN

Each time the radar is turned on, the degaussing circuit automatically demagnetizes the CRT screen to eliminate color contamination caused by earth's magnetism or magnetized ship structure.

The screen is also degaussed automatically when own ship has made a significant course change. While being degaussed, the screen may be disturbed momentarily with vertical lines. If you wish to degauss by manual operation at an arbitrary time, open and press the Degauss switch in the tuning compartment.

INITIALIZING THE GYRO READOUT

Provided that your radar is interfaced with a gyrocompass, ship's heading is displayed at the top of the screen. Upon turning on the radar, align the on-screen GYRO readout with the gyrocompass reading by the procedure shown below. Once you have set the initial heading correctly, resetting is not usually required. However, if the GYRO readout goes wrong for some reason, repeat the procedure to correct it.

1. Open the tuning compartment and press the HOLD button. The Gyro LED lights.

2. Press the UP or DOWN button to duplicate the gyrocompass reading at the on screen GYRO readout. Each press of these buttons changes the readout by 0.1-degree steps. To change the readout quickly, hold the UP or DOWN button for over two seconds.

3. Press the HOLD switch when the on screen GYRO readout has matched the gyrocompass reading. The Gyro LED goes out.

Note: The HOLD button is used to disengage the built-in gyro interface from the gyrocompass input in the event that you have difficulty in fine-adjusting the GYRO readout due to ship's yawing, for example. When initializing the GYRO readout at a berth (where the gyrocompass reading is usually stable), you may omit steps 1 and 3 above.

PRESENTATION MODES

This radar has the following presentation modes:

Relative Motion (RM)

Head-up:	Unstabilized
Head-up TB:	Head-up with compass-stabilized bearing scale (True Bearing)
Course-up:	Compass-stabilized relative to ship's intended course
North-up:	Compass-stabilized with reference to north)

True Motion (TM)

North-up:	Ground or sea stabilized with compass and speed inputs

SELECTING PRESENTATION MODE

Press the MODE key on the mode panel. Each time the MODE key is pressed, the presentation mode and mode indication at the upper-left corner of the screen change cyclically.

Loss of Gyro Signal: When the gyro signal is lost, the presentation mode automatically becomes head-up and the GYRO readout at the screen top shows asterisks(*****.***). The message SET HDG appears at the upper of the screen. This warning stays on when the gyro signal is restored, to warn the operator that the readout may be unreadable. Press the MODE key to select another presentation mode (the asterisks are erased at this point). Then, align the GYRO readout with the gyrocompass reading and press the CANCEL key to erase the message SET HDG.

Head-up Mode (Figure 5.7)

A display without azimuth stabilization in which the line connecting the center with the top of the display indicates own ship's heading.

The target pips are painted at their measured distances and in their directions relative to own ship's heading.

A short line on the bearing scale is the north marker indicating compass north. A failure of the gyro input will cause the north marker to disappear and the GYRO readout to show asterisks (***.*) and the message SET HDG appears on the screen.

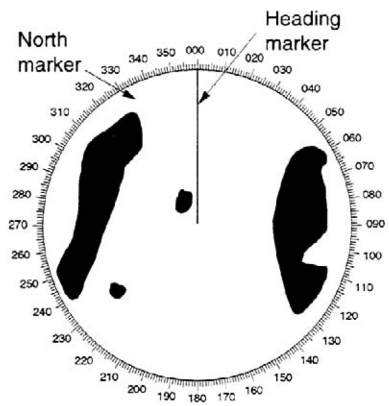


Figure 5.7 - Head-up Mode

Course-up Mode (Figure 5.8)

An azimuth stabilized display in which a line connecting the center with the top of the display indicates own ship's intended course (namely, own ship's previous heading just before this mode has been selected). Target pips are painted at their measured distances and in their directions relative to the intended course which is maintained at the 0° position while the heading marker moves in accordance with ship's yawing and course changes. This mode is useful to avoid smearing of picture during course change. After a course change, press the (CU, TM RESET) key to reset the picture orientation if you wish to continue using the course up mode.

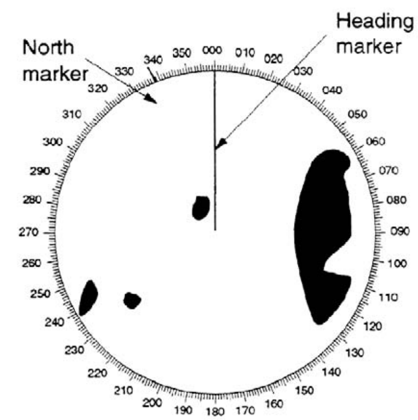


Figure 5.8 - Course-up Mode

Head-up TB (True Bearing) Mode (Figure 5.9)

Radar echoes are shown in the same way as in the head-up mode. The difference from normal head-up presentation lies in the orientation of the bearing scale. The bearing scale is compass stabilized, that is, it rotates in accordance with the compass signal, enabling you to know own ship's heading at a glance.

This mode is available only when the radar in interfaced with a gyrocompass.

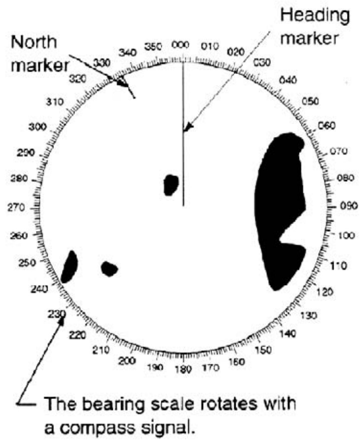


Figure 5.9 - Head-up TB (True Bearing) Mode

North-up Mode (Figure 5.10)

In the north-up mode, target pips are painted at their measured distances and in their true (compass) directions from own ship, north being maintained UP of the screen. The heading marker changes its direction according to the ship's heading.

If the gyrocompass fails, the presentation mode changes to head-up and the north marker disappears. Also, the GYRO readout shows asterisks (***.*) and the message SET HDG appears on the screen.

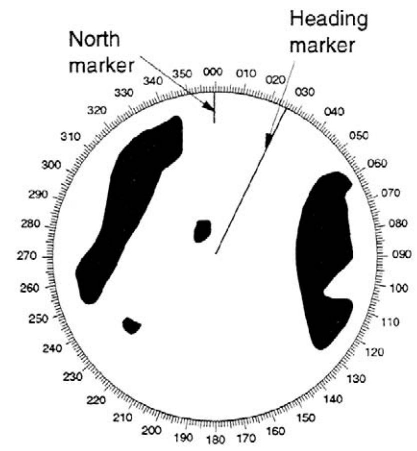


Figure 5.10 - North-up Mode

True Motion Mode (Figure 5.11)

Own ship and other moving objects move in accordance with their true courses and speeds. All fixed targets, such as landmasses, appear as stationary echoes.

When own ship reaches a point corresponding to 75% of the radius of the display, the own ship is automatically reset to a point of 50% radius opposite to the extension of the heading marker passing through the display center. Resetting can be made at any moment before the ship reaches the limit by pressing the (CU, TM RESET) key. Automatic resetting is preceded by a beep sound.

If the gyrocompass fails, the presentation mode is changed to the head-up mode and the north marker disappears. The GYRO readout at the top of the screen shows asterisks (***.*) and the message SET HDG appears on the screen.

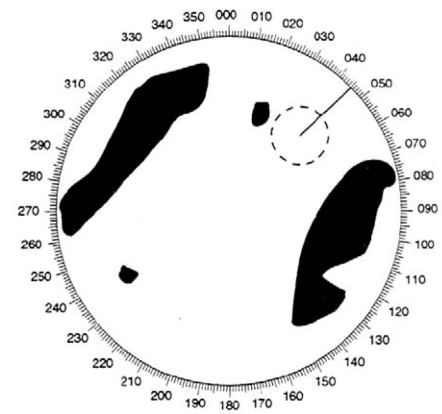


Figure 5.11 - True Motion Mode

SELECTING THE RANGE SCALE

The display range scale is changed in 13 steps on the R-type (11 steps on the IMO-type) by pressing the (+) and (-) keys. The selected range scale and range ring interval are shown at the upper left corner on the screen.

The display range can be expanded by 75% (100% in R-type) in any direction by using the off-centering control.

SELECTING THE PULSEWIDTH

The pulse width in use is displayed at the upper-left position of the screen using the abbreviations shown in the table above.

Appropriate pulse widths are present to individual range scales and function keys. Therefore, you are not usually required to select them. If you are not satisfied with the current pulsewidth settings, however, it is possible to change them by the radar menu operation shown below.

You can choose the pulsewidth 1 or 2 on the scales 0.5 to 24 nm ranges on X-band models and 0.75 to 24 nm ranges on S-band models.

The display range can be expanded by 75% (100% in R-type) in any direction by using the off-centering control.

Selecting Pulsewidth 1 or 2

1. Press the RADAR MENU key on the plotting keypad to show the FUNCTION menu.

2. Press the (1) key to select (or highlight) PLUSEWIDTH 1 or 2 as appropriate.

3. Press the (1) key to select menu item 1 PULSEWIDTH.

4. Press the ENTER key to conclude your selection followed by the RADAR MENU key to close the FUNCTION menu.

Presetting Pulsewidths 1 and 2

Pulsewidth 1 and 2 can be preset on the Pulsewidth 1 and 2 menus. Shown below are examples of the pulsewidth setup procedure:

1. To enable selection of S1 (0.07 microseconds) and S2 (0.15 microseconds) pulsewidth on the 0.5 nm range on an X-band model, select S1 at 0.5 nm on the PULSEWIDTH 1 menu and M1 at 3 nm on the PULSEWIDTH 2 menu.

2. To enable selection of S2 (0.15 microseconds) and M1 (0.3 microseconds) pulsewidth on the 3 nm range on an X-band model, select S2 at 3 nm in the PULSEWIDTH 1 menu and M1 at 3 nm in the PULSEWIDTH 2 menu.

A longer pulse provides an increased detection range, but with reduced discrimination. If you need discrimination in preference to detection, choose a shorter pulse.

Example: To select S1 (0.07us) as Pulsewidth 1 for the 0.5 nm range, display the PULSEWIDTH 1 menu following the steps shown above and hit the (2) key to choose "2 0.5 NM>" Further hit the (2) key until the menu option "S1" is highlighted to the right of "2 0.5" NM."

ADJUSTING THE SENSITIVITY

The GAIN control (see Figure 5.14) is used to adjust the sensitivity of the receiver, and thus the intensity of echoes as they appear on the screen. It should be adjusted so that speckled background noise is just visible on the screen.

To become acquainted with the way the GAIN control works, try rotating it between fully counterclockwise and clockwise positions while observing the radar picture. You will notice that clockwise rotation increases the echo intensity level. A low gain setting results in the loss of weak echoes and a reduced detection range. If you turn the GAIN control too far clockwise for an excessive gain setting, desired echoes will be masked in the strong background noise.

SUPPRESSING SEA CLUTTER

In rough weather conditions returns from the sea service are received over several miles around own ship and mask close targets. This situation can be improved by properly adjusting the A/C SEA (Anti-clutter sea) control (see Figure 5.15).

Automatic Anti-clutter Control

The easiest way to suppress the service clutter is to use the automatic control. Press the A/C AUTO key (see Figure 5.15) next to the EBL rotary control at the left corner on the control panel. Use of a function key is also a good method for reducing sea clutter. For this purpose, presetting is required. Consult a Furuno representative.

Manual Anti-clutter Control

From the fully counterclockwise position, slowly turn the A/C SEA control clockwise. For optimum target detection, you should leave speckles of the surface return slightly visible.

The ant-clutter sea control is often referred to as STC (Sensitivity Time Control) which decreases the amplification of the receiver immediately after a radar pulse id transmitted, and progressively increases the sensitivity as the range increases.

A common mistake is to over adjust the A/C SEA control so that the surface clutter is completely removed. By rotating the control fully clockwise, you see how dangerous this can be; a dark zone is created near the center of the screen and close-in targets can be lost. This dark zone is even more dangerous if the gain has not been properly adjusted. Always leave a little surface clutter visible on the screen. If no surface clutter is observed (on very calm water), set the control at the fully counterclockwise position.

SUPPRESSING PRECIPITATION CLUTTER

In adverse weather conditions, clouds, rain, or snow produce a lot of spray-like spurious echoes and impairs target detection over a long distance. This situation can be improved by using a function key provided that it is programmed. If the function key fails to offer a favorable suppression of the rain clutter, adjust the A/C RAIN control (see Figure 5.16) on the front control panel.

The A/C RAIN control adjusts the receiver sensitivity as the A/C SEA control does but rather in a longer time period (longer range). Clockwise rotation of this control increases the anti-clutter effect.

INTERFERENCE REJECTOR

Mutual radar interference may occur in the vicinity of another shipborne radar operating in the same frequency band (9GHz for X-band, 3 GHz for S-band). It is seen on the screen as a number of bright spikes either in irregular patterns or in the form of usually curved spoke-like dotted lines extending from the center to the edge of the picture. The type of interference can be reduced by activating the interference rejector circuit.

The interference rejector is a kind of signal correlation circuit. It compares the received signals over successive transmissions and suppresses randomly occurring signals. There are three levels of interference rejection depending on the number of transmissions that are correlated. These are indicated by the legends lR1, lR2 and lR3 at the upper left position of the screen.

Press the INT REJECT key to activate the interference rejector circuit. Successive presses of the key increase the effect of interference rejection, up to level 3. A fourth press deactivates the interference rejector. Switch off the interference rejector when no interference exists; otherwise weak targets may be lost.

Note: For stable reception of certain types of radar beacons (racons) or SART (Search and Rescue Radar Transponder) as required by SOLAS 1974 as amended 1988 (GMDSS), it is recommended to turn the interference rejector off.

MEASURING THE RANGE (Figure 5.12)

Use the fixed range rings to obtain a rough estimate of the range to the target. They are concentric solid circles about own ship, or the sweep origin. The number of rings is automatically determined by the selected range scale and their interval is displayed at the upper left position of the screen. Press the RINGS key on the mode panel to show the fixed range rings if they are not displayed. Successive presses of the RINGS key gradually increase their brightness in 4 steps and fifth press erases the range rings.

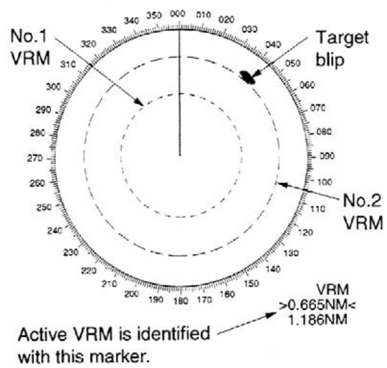


Figure 5.12 - Measuring the range

Use the Variable Range Markers (VRM) for more accurate measurement of the range of the target. There are two VRMs, No.1 and No.2, which appear as dashed rings so that you can discriminate them from the fixed range rings. The two VRMs can be distinguished from each other by different lengths of dashes.

Press the VRM ON key to display either of the VRMs. Successive presses of the VRM ON key toggle the active VRM between No.1 and No.2 and the currently active VRM readout is circumscribed by **>.....<**.

Align the active VRM with the inner edge of the target of interest and read its distance at the lower right corner of the screen. Each VRM remains at the same geographical distance when you operate the RANGE+ or RANGE- key. This means that the apparent radius of the VRM ring changes in proportion to the selected range scale. Press the VRM OFF key to erase each VRM.

MEASURING THE BEARING (Figure 5.13)

Use the Electronic Bearing Lines (EBL) to take bearings of a target. There are two EBLs, No.1 and No.2 which are toggled by successive presses of the EBL ON key. Each EBL is a straight dashed line extending out from the own ship position up to the circumference of the radar picture. The fine dashed line is the No.1 EBL and the course dashed one is the No.2 EBL.

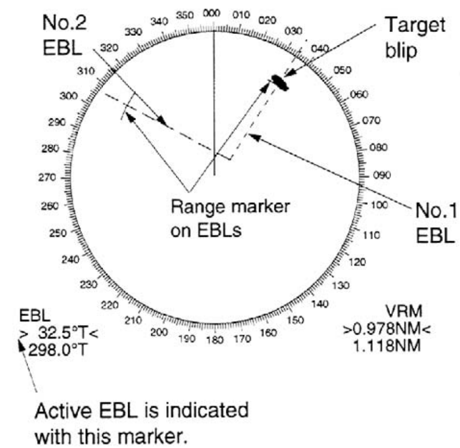


Figure 5.13 - Measuring the bearing

Press the ELB ON key to display either of the EBLs. Successive presses of the EBL ON key toggle the active ELB between No.1 and No.2 and the currently active EBL readout is circumscribed by >... <.

Rotate the EBL rotary control clockwise or counterclockwise until the active EBL bisects the target of interest, and read its bearing at the lower left corner of the screen. The EBL readout is affixed by “R” (relative) if it is relative to own ship’s heading, T (true) if it is referenced to the north, as determined by RADAR 2 menu settings.

Each EBL carries a range marker, or a short line crossing the EBL at right angles and its distance from the EBL origin is indicated at the VRM readout whether or not the corresponding VRM is displayed. The range marker changes its position along the EBL with the rotation of the VRM control.

Press the EBL OFF key to erase each EBL.

COLLISION ASSESSMENT BY OFFSET EBL

The origin of the EBL can be placed anywhere with the trackball to enable measurement of range and bearing between any targets. This function is also useful for assessment of the potential risk of collision. To assess possibility of collision:

1. Press the EBL ON key to display or activate an EBL (No.1 or 2).
2. Place the cursor (+) on a target of interest (A in the illustrated example) by operating the trackball.
3. Press the EBL OFFSET key on the mode panel, and the origin of the active EBL shifts to the cursor position. Press the EBL OFFSET key again to anchor the EBL origin.
4. After waiting for a few minutes (at least 3 minutes), operate the EBL control until the EBL bisects the target at the new position (A'). The EBL readout shows the target ship's course, which may be true or relative depending on the settings on the RADAR 2 menu.

   If relative motion is selected, it is also possible to read CPA by using a VRM as shown in figure 5.14. If the EBL passes through the sweep origin (own ship) as illustrated in figure 5.15, the target ship is on a collision course.

5. To return the EBL origin to the own ship's position, press the EBL OFFSET key again.

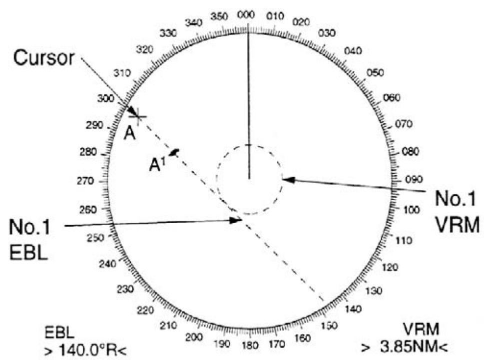


Figure 5.14 - Evaluating target ship's course and CPA in relative motion mode

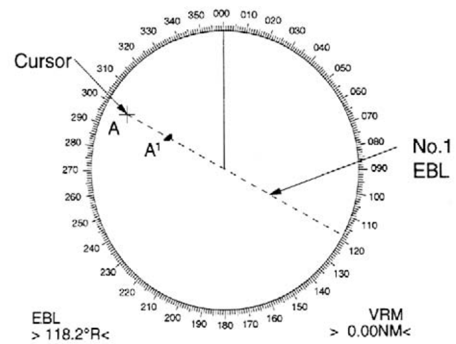


Figure 5.15 - Target ship on collision course

MEASURING RANGE AND BEARING BETWEEN TWO TARGETS

Press the EBL OFFSET key, and place the origin of No.1 EBL, for example, on a target of interest (target 1 in figure 5.16) by operating the trackball.

Turn the EBL control until the EBL passes through another target of interest (target 2).

Turn the VRM control until the range marker aligns with target 2. The active VRM readout at the lower right corner of the screen indicates the distance between the two targets.

You can repeat the same procedure on third and fourth targets (targets 3 and 4) by using No.2 EBL and No. 2 VRM.

Bearing is shown relative to own ship with suffix "R" or as a true bearing with suffix "T" depending on EBL relative/true settings on the RADAR 2 menu. To return the EBL origin to the own ship position, press the EBL OFFSET key again.

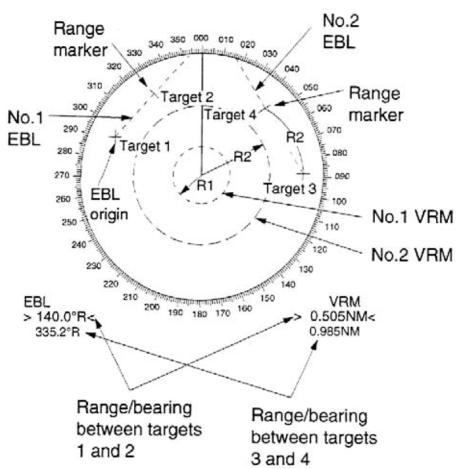


Figure 5.16 - Measuring range and bearing between two targets

SETTING A GUARD ZONE (GUARD ALARM)

The guard zone (guard alarm) feature should never be relied upon as the sole means for detecting the risk of potential collision. The operator of a ship is not relieved of the responsibility to keep visual lookout for avoiding collisions, whether or not the radar is in use.

A guard zone (guard alarm) may be set to alert the navigator to targets (ships, landmasses, etc.) entering a certain area with visual and audible alarms.

The guard zone (guard alarm) has a fixed width of 0.5 nm in the radial direction and is adjustable only within 3.0 to 6.0 nm from own ship. The guard zone (guard alarm) can be set to any sector angle between 0° and 360° in any direction.

To set the guard zone (guard alarm):

1. Place the cursor (+) at point "A" using the trackball and press the GUARD ALARM key on the mode panel (left key group). The message SET GUARD appears at the bottom right corner of the screen.

2. Move the cursor (+) to point "B" and press the GUARD ALARM key. Then, a guard zone (guard alarm) as illustrated is created and the label GUARD appears instead of SET GUARD at the lower right corner of the screen.

Note: If you wish to create a guard zone (guard alarm) having a 360° coverage around own ship, set point "B" in almost the same direction (approx. +/-3°) as point "A" and press the GUARD ALARM key.

SILENCING AUDIBLE ALARM, REACTIVATING GUARD ALARM

A target entering the guard zone produces both visual (flashing) and audible (beeping) alarms. To silence the audible alarm, press the GUARD ALARM key, and the label GUARD ACK replaces GUARD on the display.

This will deactivate the audible alarm but will not stop the flashing of the target in the guard zone. To reactivate the audible alarm, press the GUARD ALARM key again.

DISABLING GUARD ZONE (GUARD ALARM)

Hold the GUARD ALARM key depressed for at least 3 seconds.

Note: The guard alarm is given to targets having a certain level of echo strength. This level does not always imply a landmass, reef, ships or other surface objects but can mean returns from the sea surface or precipitation. Properly adjust the GAIN, A/C SEA, and A/C RAIN controls to reduce noise to avoid generation of guard alarm against false target detection.

INWARD AND OUTWARD GUARD ALARMS

On the R-type, an inward or outward guard alarm can be selected on the RADAR 2 menu. On the IMO type, only the inward guard alarm is available. The inward guard alarm generates visual and audible warnings when a target enters the guard zone from any direction. The outward guard alarm is produced when a target leaves the guard zone.

OFF-CENTERING

Own ship position, or sweep origin, can be displaced to expand the view field without switching to a larger range scale. On the R-type, the sweep origin can be off centered to a point specified by the cursor, up to 100% of the range in use in any direction. On the IMO type, the sweep origin can be off centered to the cursor position, but not more than 75% of the range in use; if the cursor is set beyond 75% of the range scale, the sweep origin will be off centered to the point of 75% of the limit. This feature is not available on the longest range scale.

To off center the radar picture:

1. Place the cursor at a position where you wish to move the sweep origin by operating the trackball.

2. Press the OFF CENTER key. Then, the sweep origin is off centered to the cursor position.

3. To cancel off centering, press the OFF CENTER key again.

The picture cannot be off centered in the true motion mode.

ECHO STRETCH

On long ranges target echoes tend to shrink in the bearing direction, making them difficult to see. On short and medium ranges such as 1.5, 3 and 6 nautical mile scales, the same size targets get smaller on the screen as they approach the own ship. These are due to inherent property of the radiation pattern produced by the antenna. To enhance target video, use the echo stretch function. There are two types: echo stretch 1 for long range detection and echo stretch 2 on 1.5-6 nautical mile scales.

To activate the echo stretch:

1. Press the RADAR MENU key on the plotting keypad to show the FUNCTIONS menu.

2. Press the (2) key to select 2 ECHO STRETCH.

3. Press (2) until Echo Stretch option 1, 2 or OFF as desired is highlighted.

4. Press the ENTER key to conclude your selection followed by the RADAR MENU key to close the FUNCTIONS menu.

Notes:
1. If the 1.5 nm range is preset for pulsewidth of S1 (0.08 microseconds) or S2 (0.2 microseconds), and the 3nm scale for S2 (0.2), the echo stretch function is not available on these range scales.
2. The echo stretch function magnifies not only small target pips but also returns from sea surface, rain and radar interference. For this reason make sure these types of interference have been sufficiently suppressed before activating this function.

ECHO AVERAGING

The echo average feature effectively suppresses sea clutter. Echoes received from stable targets such as ships appear on the screen at almost the same position every rotation of the antenna. On the other hand, unstable echoes such as sea clutter appear at random positions.

To distinguish real target echoes from sea clutter, this radar performs scan-to-scan correlation. Correlation is made by storing and averaging echo signals over successive picture frames.If an echo is solid and stable, it is presented in its normal intensity. Sea clutter is averaged over successive scans resulting in the reduced brilliance, making it easier to discriminate real targets from sea clutter.

To properly use the echo average function, it is recommended to first suppress sea clutter with the A/C SEA control and then to do the following:

1. Press the RADAR MENU key on the plotting keypad to show the functions menu.

2. Press the (3) key to select 3 ECHO STRETCH.

3. Press (3) until echo average option 1, 2 or OFF as desired is highlighted.

OFF: No averaging effect

- Helps distinguish targets from sea clutter and suppresses brilliance of unstable echoes
- Distinguishes small stationary targets such as navigation buoys
- Stably displays distant targets

4. Press the ENTER key to conclude your selection followed by the RADAR MENU key to close the FUNCTIONS menu.

Echo averaging uses scan to scan signal correlation technique based on the true motion over the ground of each target. Thus, small stationary targets such as buoys will be shown while suppressing random echoes such as sea clutter. True echo average is not however effective for picking up small targets running at high speeds over the ground.

Echo average is inoperable when a gyrocompass signal is not available. If you wish to use this feature without a gyrocompass signal, consult a Furuno representative.

Manual speed entry is done at menu item 6 SHIP'S SPEED on the FUNCTIONS menu which is accessed by pressing the RADAR MENU key.

CAUTION: Do not use the Echo Average feature under heavy pitching and rolling; loss of true targets can result.

ELECTRONIC PLOTTING AID (E-PLOT)

A maximum of 10 operator selected targets can be plotted electronically (manually) to assess their motion trend. Five past positions can be displayed for each of the plotted targets. If you enter a 6th plot on a certain target, the oldest plot (past position) will be erased.

A vector appears when you enter a second plot for the target and is updated each time a new plot is entered. The vector shows the target motion trend based on its latest two plots.

Alphanumeric readouts at the upper right hand corner of the screen show range, bearing, course, speed, CPA, and TCPA of the last plotted target.

It should be noted that the vector and alphanumeric data are not updated in real time, but only when you enter a new plot.

Note: EPA requires own speed input (automatic or manual) and a compass signal. The vector and data are updated on real time between plot entries, but do not neglect to plot a new position over a long period of time. Otherwise, the accuracy will be reduced. Note that the plots will be lost when the compass fails; start the plotting exercise again.

Plotting a Target

To perform electronic plotting:

1. Place the cursor (+) on a target of interest by operating the trackball.

2. Select a desired plot symbol by pressing one of the plot symbol keys on the plotting keypad.

3. Press the ACQ key on the operator control panel, and the selected plot symbol is marked at the cursor position.

4. Watching the EPA time (TIM xx:xx) shown at the upper right margin of the screen, wait for at least 30 seconds. Place the cursor (+) on the target at its new location, select the same plot symbol for the target and press the ACQ key. The plot symbol moves to the new target position and previous position is marked by a small dot.

5. To acquire other targets, repeat the above steps selecting different plot symbols.

Note: If a target once plotted is not plotted again within 10 minutes, the warming "UPDATE PLOT NO" will appear on the upper right margin of the screen and the plot symbol of the target flashes. If you want to continue plotting this target, reacquire it within five minutes. Otherwise, the target will be regarded as a "lost target" and its plot symbol and target data will be erased. The larger the plotting interval, the less accurate the plotted target data. Plotting of each target should normally be made every 3 or 6 minutes as far as possible.

When a target has been plotted more than once, the radar calculates its motion rend and automatically displays a vector on the target.

True or Relative Vector

True vectors can be displayed relative to own ship's heading (Relative) or with reference to the north (True). Press the VECTOR TRUE/REL key to select the proper indication. This feature is available in all presentation modes (gyrocompass must be working correctly). The current vector mode is indicated at the upper right corner of the screen.

Vector Time

Vector time (or the length of vectors) can be set to 30 sec, 1, 2, 3, 6, 12, 15 or 30 minutes and the selected vector time is indicated at the upper right corner of the screen. Press the VECTOR TIME key until the desired vector time is reached. The vector tip shows an estimated position of the target after the selected vector time elapses. It can be valuable to extend the vector length to evaluate the risk of collision with any target.

Target Data

The radar calculates motion trends (range, bearing, course, speed, CPA, and TCPA) of all plotted targets.

In head up and head up true bearing modes, target bearing, course and speed shown in the upper right target data field become true (suffix "T") or relative (suffix "R") to own ship in accordance with true/relative vector setting. In north up, course up, and true motion modes, the target data field always displays true bearing, true course and speed over the ground or through the water.

Reading the Target Data

Press the corresponding plot symbol key, and the following target data is displayed.

RNG/BRG: (Range/Bearing): Range and bearing from own ship to last plotted target with suffix "T" or "R" plot symbol.

CSE/SPD: (Course/Speed): Course and speed are displayed for the last plotted target with suffix "T" or "R" plot symbol.

CPA/TCPA: CPA is a closest range the target will approach to own ship. TCPA is the time to CPA. Both are automatically calculated. TCPA is counted up to 99.9 minutes and beyond this., it is indicated as TCPA >*99.9 MIN.

BCR/BCT: BCR (Bow Cross Range) is the range at which target will cross own ship's bow. BCT (Bow Cross Time) is the estimated time at which target will cross own

Terminating Target Plotting

With E-plot you can plot up to 10 targets. You may wish to terminate plotting of less important targets to newly plot other threatening targets.

By Symbol: To terminate plotting of a certain target, press the corresponding plot symbol key. Then press the CANCEL key.

With Trackball: Place the cursor (+) on a target which you do not want to be tracked any longer by operating the trackball and press the CANCEL key.

All Targets: To terminate plotting of all targets at once, press and hold the CANCEL key until all plot symbols and marks disappear in about 3 seconds.

Entering Own Ship's Speed

EPA requires an own ship speed input and compass signal. The speed can be entered from a speed log (automatic) or through the plotting keypad (manual).

Automatic Speed Input

1. Press the RADAR MENU key on the plotting keypad to show the functions menu,

2. Press the (6) key to select menu item 6 SHIP'S SPEED.

3. Press the (6) key to select (or Highlight) LOG option.

4. Press the ENTER key to confirm your selection followed by the RADAR MENU key to close the FUNCTIONS menu. The ship's speed readout at the screen top shows own ship's speed fed from the speed log preceded by the label "LOG".

Notes:
1. IMO Resolution A.823(19) for ARPA recommends that a speed log to be interfaced with an ARPA should be capable of providing through-the-water speed data.
2. Be sur not to select LOG when a speed log is not connected. If the log signal is not provided, the ship's speed readout at the screen top will be blank.

Manual Speed Input

If the radar is not interfaced with a speed log, or the speed log does not feed correct speed enter the ship's speed as follows:

1. Press the RADAR MENU key on plotting keypad to show the FUNCTIONS menu.

2. Press the (6) key to select menu 6 SHIP'S SPEED.

3. Press the (6) key to select menu 6 SHIP's SPEED.

4. Press the ENTER key to confirm selection. At this point, "MAN+XX.KT" appears at the bottom of the FUNCTIONS menu.

5. Enter the ship speed by hitting corresponding numeric keys followed by the ENTER without omitting leading zeros, if any. As an example, if the ship speed is 8 knots, punch (0) (8) (ENTER).

6. Press the RADAR MENU key to close FUNCTIONS menu. The ship speed displayed at the screen top shows own ship speed entered by the label "MAN".

TARGET TRAILS (ECHO TRAILS)

Echo trails are simulated afterglow of target echoes that represent their movements relative to own ship or true movements with respect to true north in a single tone or gradual shading depending on the settings on the RADAR 1 menu.

True or Relative Trails

You may display echo trails in true or relative motion. Relative trails show relative movements between targets and own ship. True motion trails require a gyrocompass signal and own ship speed input to cancel out own ship's movement and present true target movements in accordance with their over the ground speeds and courses.

Refer to the automatic and manual speed input procedures for entering own ship's speed information.

Note: When true trail is selected on the RM mode, the legend TRUE TRAIL appears in red. No true relative selection on TM, it is only TRUE TRAIL on TM mode.

To select true or relative echo trail presentation:

1. Press the RADAR MENU key on the plotting keypad to show the FUNCTIONS menu.
2. Press the (0) key to show the SYSTEM SETTING 1 menu.
3. Press the (2) key to show the RADAR 1 menu.
4. Press the (6) key to select menu item 6 TRAIL REF.
5. Press the (6) key to select (or highlight) REL (Relative) or TRUE option.
6. Press the ENTER key to confirm your selection followed by the RADAR MENU key to close the menu.

Trail Gradation

Echo trails may be shown in monotone or gradual shading. Gradual shading paints the trails getting thinner with time just like the afterglow on an analog PPI radar.

Selection of monochrome or gradual shading requires almost the same operation as for true or relative trails setup procedure described above except that you should:

- Press the (7) key to select menu item 7 TRAIL GRAD (graduation) in step 4, and
- Press the (7) key to select (or highlight) GGL (single tone) or MULT (multiple shading) option in step 5.

Displaying and Erasing Echo Trails

Press the ECHO TRAILS key to activate or deactivate the echo trails feature.

Each press of the ECHO TRAILS key within 5 seconds cyclically changes echo trail length (time) to 30 seconds, 1, 3, 6, 15, and 30 minutes, continuous echo trailing and OFF. The current echo trail setting is displayed at the lower right corner of the screen.

Suppose that "3 MIN" has just been selected. If the ECHO TRAILS key is hit more than 5 seconds later, echo trails are removed from the display (memory) still alive with echo trail timer count going on). Next hitting of the key calls out the echo trails on the screen. To proceed to longer plot intervals, successively push the ECHO TRAILS key with a hit and release action. The larger the echo trail length, the larger the larger the echo trail plot interval.

Note: Holding the ECHO TRAILS key depressed for about 3 seconds will cause a loss of echo trail data so far stored in an in memory.

Resetting Echo Trails

To reset (or clear) the echo trail memory, hold the ECHO TRAILS key depressed for about 3 seconds. Echo trails are cleared and the trailing process restarts from time count zero at current echo trail plot interval. When memory assigned to echo trailing becomes the echo trail timer at the lower right corner of the screen freezes and the oldest trails are erased to show the latest trails.

PARALLEL INDEX LINES

Parallel index lines are useful for keeping a constant distance between own ship and coastline or a partner ship when navigating. Index lines are drawn in parallel with the No. 2 EBL (no. 2 EBL must be active). The orientation of the index lines is controlled with the EBL control and the intervals between the lines adjusted with the VRM rotary control (provided that No. 2 VRM is active).

Maximum number of the index line can be set the initial Setting menu: 2, 3, or 6.

Displaying and Erasing the Index Lines

1. Press the INDEX LINES key if the index lines are not already shown.

2. Make sure that the No. 2 EBL is active and orient the index lines in a desired direction with the EBL rotary control.

3. To erase the index lines, press the INDEX LINES key again.

Adjusting Index Line Intervals

1. Press the RADAR MENU key on the plotting keypad to show the FUNCTIONS menu.

2. Press the (7) key to select menu item 7 INDEX LINES.

3. Press the (7) key to select or (highlight) No. 2 VRM or MAN (manual) option.

4. Press the ENTER key to conclude your selection.

5. If you have selected MAN in step 3 above, “MAN=XX.XX NM” appears at the bottom of the functions menu. Enter a desired line interval by hitting numeric keys followed by the ENTER key without omitting leading zeroes, if any. There are six index lines but the number of lines visible on the screen may be less than six depending on the line setting interval.

6. If you have selected NO. 2 VRM in step 3 above, make sure that the No. 2 VRM is active and adjust the spacing between the index lines by operating the VRM control.

7. Press the RADAR MENU key to close the functions menu.

ANCHOR WATCH

The anchor watch feature helps you monitor whether own ship is dragged by wind and/or tide while at anchor. This feature requires ship position data from a suitable radio navigational aid. Provided that own ship’s physical data has been entered, an own ship mark can be displayed when the anchor watch feature is activated. The message “ANCHOR WATCH ERR” appears in red when position data is not inputted.

Notes:
1. The own ship mark is available on the R-type radar only; unavailable on the IMO type.
2. The own ship mark is created with data on own ship’s length, width, radar antenna location, etc. To display an own ship mark, ask your nearest Furuno representative.

Activating Anchor Watch

To set up the anchor watch feature:

1. On the ANCHOR WATCH menu, press the (2) key to select menu item 2 ANCHOR WATCH OFF/ON.

2. Further press the (2) key to select (or highlight) ON, followed by the ENTER key to conclude your selection. The label WATCH appears at the lower left corner of the screen.

3. Press the (3) key to select menu item 3 ALARM OFF/ON. Further press the (3) key to select (or highlight) ON or OFF, followed by the ENTER key to conclude your selection. (This operation determines whether to activate the anchor watch audible alarm).

Alarm range setting

Press the (4) key to select menu item 4 ALARM RANGE on the ANCHOR WATCH menu. Enter a desired alarm range between 0.1 and 9.999 nautical miles with numeric keys and press the ENTER key to conclude your key input.

An anchor watch alarm circle thus established shows up as a red circle on the screen. When own ship is dragged out of this alarm circle, an audible alarm is generated and the on screen label ANCHOR WATCH turns red.

To silence the audible alarm, press the AUDIO OFF key on the control panel.

Showing Drag Line

Press the (5) key to select menu item 5 HISTORY on the ANCHOR WATCH menu. Further press the (5) key to select ON, followed by the ENTER key to conclude your selection.

A drag line, or a series of dots along which own ship was carried by wind and water current, appears as illustrated below. During the first 50 minute period, dots or own ship's past positions are plotted every minute. When 50 dots have been plotted in 50 minutes, the plot interval becomes 2 minutes and up to 25 dots are plotted during the succeeding 50 minute period. Next, the dot interval becomes 4 minutes and the maximum number of dots will be 12.

Anchor Watch in Standby or Transmit Status

On the R-type the anchor watch feature is available in either STANDBY or TRANSMIT status.

On the IMO type the anchor watch feature is available only in STANDBY status.

Origin Mark

You can mark any dangerous point, prominent target or a particular reference point using the origin mark feature. This mark is geographically fixed.

To use the origin mark:

1. Place the cursor (+) at a point where you want to place a reference mark by operating the trackball.

2. Press the ORIGIN MARK key on the plotting keypad. The origin mark appears at the cursor position of which range and bearing are indicated at the lower left section of the screen.

3. To measure the range and bearing to a target of interest from the origin mark, move the cursor to the target of interest. Then, the range and bearing from the origin mark to the target are shown at the target data display.

4. To erase the origin mark, press the ORIGIN MARK key once again.

Zoom

The zoom function is available on the R-type radar only to enlarge an area of interest.

1. Place the cursor (+) close to the point of interest by operating the trackball.

2. Press the X2 ZOOM key. The area around the cursor and own ship is enlarged twice as large as the original size and the label ZOOM appears at the lower left corner of the screen.

3. To cancel zoom, press the X2 ZOOM key again.

Note: The zoom feature is inoperative when the display is off centered.

MARKERS

Heading Marker

The heading marker indicates the ship's heading in all presentation modes. It appears at zero degrees on the bearing scale in head up mode, in any direction depending on the ship orientation in north up and true motion modes.

Temporarily Erasing Heading Marker

To temporarily extinguish the heading marker to look at targets existing dead ahead of own ship, press the HM OFF key on the mode panel. This heading marker reappears when the key is released.

North Marker

The north marker appears as a short dashed line. In the head up mode, the north marker moves around the bearing scale in accordance with the compass signal.

Stern Marker

The stern marker (a dot-and-dash line) appears opposite to the heading marker. This marker can be displayed on the R type only provided that the STERN MARK ON is selected on the RADAR 2 menu.

Menu Keys

Three menu keys are provided on the plotting keypad: RADAR MENU, E-AUTO PLOT MENU and NAV MENU keys.

RADAR MENU: Permits setting of basic radar parameters.

E, AUTO PLOT MENU: Provides a choice of standard or large size of plotting symbols for plot.

NAV MENU: Provides a choice of navigation data for on screen display. Also select display for the Video Plotter.

FUNCTION KEYS

The four function keys (#1-4) on the control panel (figure 5.17) work like the auto dialing feature of a telephone, instantly calling out desired settings to perform specially assigned functions. The function keys provide optimum radar settings for a specific purpose with a single key operation.

Each function key can be assigned a combination of particular radar settings that will be most suited to your specific navigating purpose, and an adhesive label (such as BUOY, HARBOR, COAST or the like) is usually attached to the key top for easy identification of the assigned purpose.

The individual function keys are preset, or programed, for the following purposes by qualified service personnel at the time of installation using the procedures described in the succeeding paragraphs;

Function key #1: Picture setup
Function keys #2 and #3: Picture setup and specific operation
Function key #4: Specific operation or watch alarm

Suppose that you have been navigating along a coast for hours and now you are approaching a harbor, your final destination. You will have to adjust your radar to change from the settings for coastal navigation to those for harbor approach. Every time your navigating environment or task changes, you must adjust the radar, which can be a nuisance in a busy situation. Instead of changing radar settings case by case, it is possible to assign the function keys to provide optimum settings for often encountered situations.

The radar's internal computer offers several picture setup options to be assigned to each function key for your specific navigating requirements. For instance, one of the functions keys may be assigned the buoy detecting function and labeled BUOY on the key top. If you press this key, the radar will be instantly set for optimum detection of navigation buoys and similar objects and the label BUOY is shown at the left margin of the screen. If you re-press the same key, the radar returns to the previous settings.

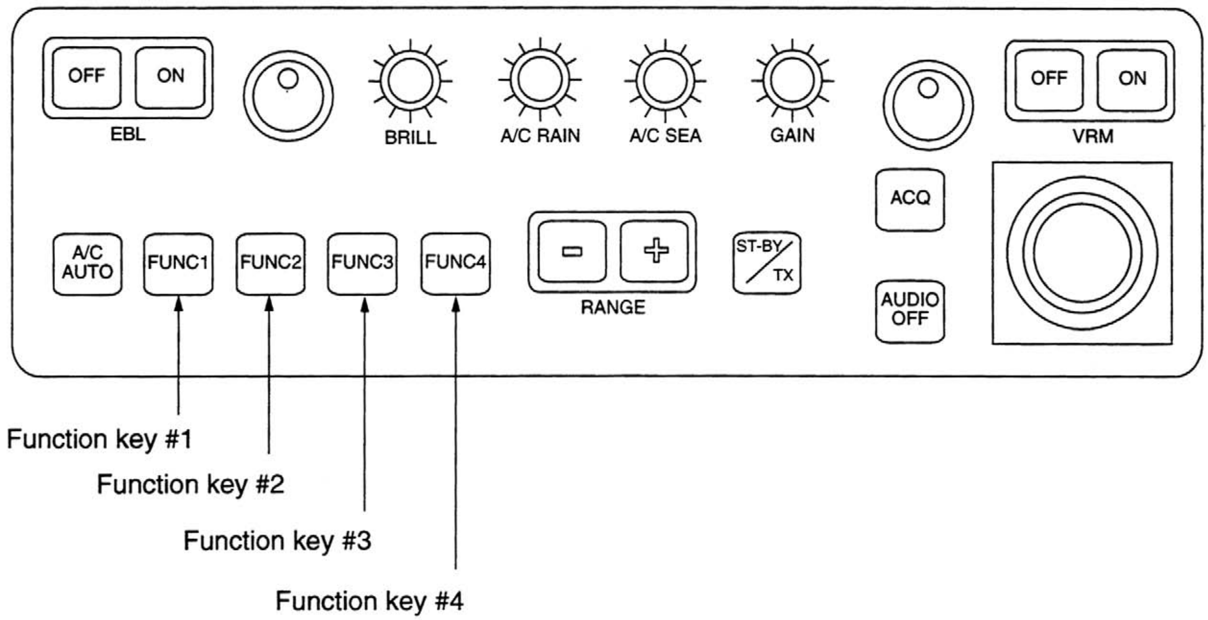


Figure 5.17 - Function keys

The radar's internal computer offers several picture setup options to be assigned to each function key for your specific navigating requirements. For instance, one of the functions keys may be assigned the buoy detecting function and labeled BUOY on the key top. If you press this key, the radar will be instantly set for optimum detection of navigation buoys and similar objects and the label BUOY is shown at the left margin of the screen. If you re-press the same key, the radar returns to the previous settings.

The picture setup options assignable to any of the function keys are shown in the table below.

LABEL	*DESCRIPTION*
RIVER	Optimum setting for navigation on river.
BUOY	Optimum setting for detecting navigation buoys, small vessels and other small surface objects.
SHIP	Optimum setting for detecting vessels.
SHORT	Optimum setting for short range detection using a range scale of 6 nm or larger.
CRUISING	For cruising using a range scale of 1.5 nm or larger.
HARBOR	Optimum setting for short range navigation in a harbor area using a range scale of 1.5 nm or less.
COAST	For coastal navigation using a range of 12 nm or less.
OCEAN	Transoceanic voyage using a range scale of 12nm or larger.
ROUGH SEA	Optimum setting for rough weather or heavy rain.

Each picture setup option defines a combination of several radar settings for achieving optimum setup for a particular navigating situation. Those involved are interference rejector, echo stretch, echo average, automatic ant clutter, pulsewidth and noise rejector settings.

Adjusting these features on a function key menu changes the original function key settings. To restore the original settings for a particular function key, it is necessary to display the relevant function key menu and select appropriate menu options.

Note: Function key presetting requires a good knowledge of optimum radar settings. If you want to change the original function key settings, consult your Furuno representative or dealer.

Watch Alarm

The watch alarm sounds an external buzzer selected time intervals to help you keep regular watch of the radar picture for safety or other purposes. This feature can be assigned to function key #4 with a choice of alarm intervals of 3, 6, 10, 12, 15 and 20 minutes.

Provided that function key #4 is assigned the watch alarm feature, just press function key #4 to activate the feature. The label WATCH appears at the lower left corner of the screen associated with a watch alarm timer counts down from the initial value (namely, "12:00").

When an audible watch alarm is released the preset time interval has elapsed, the screen label WATCH turns red and the watch alarm timer freezes at "0:00".

To silence the alarm, press the AUDIO key. The label WATCH turns to normal color and the watch alarm timer is reset to the initial value and starts the count down sequence again.

If you press the AUDIO OFF key before the selected time interval is reached, the watch alarm timer is reset to the initial value and starts the countdown sequence again.

EPA Menu

EPA menu appears by pressing the E, AUTO PLOT MENU key. You can set the following items.

1. COLLISION ALARM: You can set CPA and TCPA for the tracked target. Refer to 2.12 setting CPA/TCPA alarm range. Note that TCPA setting is available over one minute.

2. MARK SIZE: Change the size of the plotting.

3. PLOT NO.: Displays or hides plot number inside of the plot symbol (circle and square).

4. TARGET DATA: Selects target vector mode between TRUE or REL. Selection of REL provides the target mode in REL on HU and HU TB.

Menu and Navigation Data Display

Various navigation data can be displayed on the radar screen. The data includes, depending on whether appropriate information is fed into the radar, own ship position, cursor position, waypoint data, wind data, water current data, depth data, water temperature, rudder angle, rate of turn and navigation lane.

Note that data not directly related with the radar presentation is not available. Shown below id a typical navigational data display.

1. Press the NAV MENU key on the plotting keypad to show the NAV INFORMATION menu.

2. Select navigation data input device and press the ENTER key to confirm your selection.

3. Also, set other nav data parameters as appropriate referring to the operation flow diagram (not shown).

4. Press the NAV MENU key to close the NAV INFORMATION menu.

Notes:
1. Own ship position display requires an input from an EPFS (elest rouis position fixing system) such as a GPS receiver or a Loran-C receiver. Such an EPFS should be of the type which provides output data in accordance with IEC 1162.
2. When the sensor in use changes (ex. from GPS or DGPS), the name of sensor in the own ship call turns red, and EPFS label appears. To erase, press the CANCEL key.

Suppressing Second-trace Echoes

In certain situations, echoes from very distant targets may appear as false echoes (second trace echoes) on the screen. This occurs when the return echo is received one transmission cycle later, that is, after a next radar pulse has been transmitted.

To activate or deactivate the second trace echo rejector:

1. Press the RADAR MENU key on the plotting keypad to show the FUNCTIONS menu.

2. Press the (8) key to select menu item 8: 2ND ECHO REJ.

3. Further press the (8) key to activate (ON) or deactivate (OFF) the second trace echo rejector.

4. Press the ENTER key to conclude selection followed by the RADAR MENU key to close the FUNCTIONS menu.

Adjusting Relative Brilliance Levels of Screen Data

You can adjust relative brilliance levels of various marks and alphanumeric readouts displayed on the screen by following the steps shown below:

1. Press the RADAR MENU key on the plotting keypad to show the FUNCTIONS menu.

2. Press the (9) key to show the BRILLIANCE menu.

3. Select a desired menu item by pressing the corresponding numeric key. As an example, press (4) if you want to change the brilliance of echo trails.

4. Further press the same numeric key as you pressed in step 3 above to select or highlight a desired brilliance level.

5. Press the ENTER key to conclude your selection followed by the RADAR MENU key to close the FUNCTIONS menu.

Set and Drift (Set and Rate)

Set the direction in which a water current flows, can be manually entered on 0.1 - degree steps. Drift (rate), the speed of the tide, can also be entered manually in 0.1 knot steps.

Set and drift corrections are beneficial for increasing the accuracy of the vectors and target data. The correction is best made in the head up mode with true vector, watching landmasses, or other stationary targets. If they have vectors, set and drift values should be adjusted until they lose vectors.
Note: Set and drift correction is available on selecting the water tracking mode only.

Proceed as follows to enter set and drift (rate):

1. Press the RADAR MENU key on the plotting keyboard to show the FUNCTIONS 1 menu.

2. Press the (8) key to select menu item 8; SET, DRIFT.

3. Further press the (8) key to select OFF or MAN option.

OFF: No correction against set and drift.
MAN: Manual entry of set and drift data.

4. If OFF is selected, press the ENTER key.

5. If you have selected MAN in step 3 above, the highlight cursor will advance one line down requesting you to enter SET xxx.x .Enter the value of set in degrees by hitting numeric keys without omitting leading zeroes, if any, and press the ENTER key.

6. The highlight cursor will then advance to the next line DRIFT xx.x KT. Enter the value of drift in knots by hitting numeric keys without omitting leading zeroes, if any, and press the ENTER key. Set and drift have the same effect on own ship and all targets.

7. Press the RADAR MENU key to close the menu.

OPERATION OF ARPA

GENERAL

The FAR-2805 series with ARP-25 board provide the full ARPA functions complying with IMO A. 823 and IEC-60872-1 as well as complying with the radar performance MSC.64(67) Annex 4.

PRINCIPAL SPECIFICATIONS

Acquisition and Tracking

Automatic acquisition of up to 20 targets plus manual acquisition of 20 targets, or fully manual acquisition of 40 targets between 0.1 and 32 nm (0.1 and 24 nm depending on initial setting)

Automatic tracking of all acquired targets between 0.1 and 32 nm (0.1 and 24 nm depending on initial setting)

Vectors

Vector length:	30 sec, 1, 2, 3, 6, 12, 15, 30 min.
Orientation:	True velocity or relative velocity
Motion trend:	Displayed within 20 scans, full accuracy within 60 scans after acquisition.
Past positions:	Choice of 5 or 10 past positions at intervals of 30 sec, 1,2,3 or 6 min.
Alarms:	Visual and audible alarms against targets violating CPA/ TCPA limits, lost targets, targets crossing guard zone (guard ring), system failure and target full status.
Trial maneuver:	Predicted situation appears in 1 min after selected delay (1-60 minutes).

KEYS USED FOR ARPA

The Auto Plotter uses the keys on the plotting keypad on the right side of the radar screen and two keys on the control panel. Below is a brief description of these keys.

CANCEL: Terminates tracking of a single target specified by the trackball if the key is pressed with a hit-and-release action. If the key is held depressed for about 3 seconds, tracking of all targets is terminated.

ENTER: Registers menu options selected.

VECTOR TRUE/REL: Selects a vector length of 30s 1, 2, 3, 6, 12, 15 or 30min.

TARGET DATA: Displays data on one of tracked targets selected by the trackball.

TARGET BASED SPEED: Own ship's speed is measured relative to a fixed target.

AUTO PLOT: Activates and deactivates the ARPA functions.

TRIAL: Shows consequences of own ship's speed and course against all tracked targets.

LOST TARGET: Silences the lost target aural alarm and erases the lost target symbol.

HISTORY: shows and erases pat positions of tracked targets.

ACQ: (on control panel): Manually acquires a target.

AUDIO OFF: (on control panel): Silences aural alarm.

ARPA MENU OPERATION

Various parameters or the Auto Plotter are set on the ARPA 1 and ARPA 2 menus. To do this, follow the steps shown below:

1. Press the AUTO PLOT key if the Auto Plotter is not yet activated. Note that the label ARPPA appears in the upper right box on the screen.

2. Press the E, AUTO PLOT MENU key to show the ARPA 1 menu.

3. Press the (0) key once if you wish to go to the ARPA 2 menu.

4. Select a desired menu item by pressing the corresponding numeric key.

5. Select a menu option by pressing the same numeric key as pressed in step 3 above. If there is more than one option on the current menu item, you may need to press the numeric key several times. Press it until the desired option is highlighted. (Note that certain menu items will prompt you to enter numeric data or to define points on the radar screen with the trackball).

6. Press the ENTER key to register settings.

7. Press the E, AUTO PLOT MENU key to close the menu.

START UP PROCEDURE

Activating the ARPA

To activate the ARPA:

1. Adjust the A/C RAIN, A/C SEA and GAIN controls for proper radar picture.

2. Press the AUTO PLOT key. The label ARPA appears in the box at the upper right on the screen.

Entering Own Ship's Speed

The ARPA requires own ship's speed and heading data. Of these, the speed data can be entered automatically from a speed log, navaid, or manually through the numeric keys or based on a selected reference target (such as a buoy or other prominent stationary target).

Automatic Speed Input

1. Press the RADAR MENU key on the plotting keypad to show the FUNCTIONS menu.

2. Press the (6) key to select menu item 6 SHIP'S SPEED.

3. Press the (6) key to select (or highlight) LOG option.

4. Press the ENTER key to conclude your selection followed by the RADAR MENU key to close the FUNCTIONS menu. The ship's speed readout at the top of the screen shows own ship's speed fed from the speed log preceded by the label "LOG".

5. When the speed log is used, select speed reference to either of SEA or GND (ground) on the ARPA 2 menu.

Notes:
1. IMO Resolution A.823:1995 for ARPA recommends that a speed log to be interfaced with an ARPA should be capable of providing through the water speed data rather than over the ground speed.
2. Be sure not to select LOG when a speed log is not connected. If the log signal is not provided, the ship speed readout at the top of the screen will be blank. In the event of a log error, you can continue plotting by entering a manual speed.
3. If a log signal interval becomes more than 30 seconds with the ship's speed 5 knots or more, the radar regards the speed log is in trouble and LOG FAIL appears, reading xx.xKT. For R-type, if no speed input is present for 3 minutes at below 0.1 knots, the radar regards the log is in failure.

Manual Speed Input

To manually enter the ship's speed with the numeric keys:

1. Press the RADAR MENU key on the plotting keypad to show the FUNCTIONS menu.

2. Press the key (6) to select menu item 6 SHIP'S SPEED.

3. Press the key (6) to select (or highlight) MAN option.

4. Press the ENTER key to conclude your selection. At this point, "MAN=xx.xKT" appears at the bottom of the FUNCTIONS menu.

5. Enter the ship speed by hitting corresponding numeric keys followed by the ENTER key without omitting leading zeroes, if any. As an example, if the ship speed is 8 knots, press (0)(8) ENTER. For 4.5 knots, (0)(4)(5) ENTER.

6. Press the RADAR MENU key to close the FUNCTIONS menu. The ship speed readout at the screen top shows own ship's speed you entered preceded by the label "MANU".

Target Based Speed

The use of target based speed is recommended when:

1. The speed log is not operating properly. or not connected to the radar.

2. The vessel has no device which can measure ship's leeward movement (doppler sonar, speed log, etc.) though leeward movement cannot be disregarded.

If you select target based speed, the Auto Plotter calculates own ship's speed relative to a fixed reference target.

Note: When the target based speed is adopted, automatically or manually entered ship's speed is disregarded.

To establish target based speed:

1. Select a small fixed island or any radar prominent point located at 0.2 to 24 nm from own ship.

2. Place the cursor (+) on the target by operating the trackball.

3. Press the TARGET BASED SPEED key. the reference target mark appears at the cursor position and the own ship data label changes from "LOG", "NAV" or "MENU" to "REF". Note that it takes one minute before a new speed is displayed.

Notes:
1. When the reference target is lost or goes out of the acquisition range, the reference target mark blinks and the speed reads "xx.x."
2. When all targets are deleted, the reference target mark is also deleted and the target based speed becomes invalid. the speed is indicated in KTBT where BT means Bottom Track (speed over ground).
3. The vector of the reference target can be displayed by menu operation (Auto Plot 1 menu).

Cancelling Target Based Speed

To cancel the target based speed, just press the TARGET BASED SPEED key. The speed is shown by LOG, NAV* or MANUAL as selected previously. (NAV only on R-type).

Deactivating the ARPA

To deactivate the ARPA, just press the AUTO PLOT key. Target plotting symbols and the on-screen label ARPA will disappear.

Note: Even when the ARPA is turned off, target tracking still goes on until the radar id turned off.

AUTOMATIC ACQUISITION

The ARPA can acquire up to 40 targets (20 automatically and 20 manually or all 40 manually). If AUTO ACQ is selected after more than 20 targets have been manually acquired, only the remaining capacity of targets can be automatically acquired. For example, when 30 targets have been acquired manually, then the ARPA is switched to AUTO ACQ. Only 10 targets can be acquired automatically. A target just acquired automatically is marked with a broken square and a vector appears about one minute after acquisition indicating the target's motion trend. Three minutes after acquisition, the initial tracking stage is finished and the target becomes ready for stable tracking. At this point, the broken square mark changes to a solid circle. (Targets automatically acquired are distinguished from those acquired manually, displayed by bold symbol).

Enabling and Disabling Auto Acquisition

1. Press the E, AUTO PLOT key if the ARPA is not yet activated. Note that the label ARPA appears in the box at the upper right on the screen.

2. Press the E, AUTO PLOT MENU key to show the ARPA 1 menu.

3. Press the (1) key to select menu item 1 AUTO ACQ.

4. Further press the (1) key to select (or highlight) ON (enable auto acquisition) or OFF (disable auto acquisition) as appropriate.

5. Press the ENTER key to conclude your selection followed by the E, AUTO PLOT MENU key to close the AUTO PLOT 1 menu. Note that the label AUTO+MAN is displayed in the box at the upper right on the screen when auto acquisition is enabled; MAN when auto acquisition is disabled.

Note: When the ARPA has acquired 20 targets automatically, the message AUTO TARGET FULL is displayed in the box at the right hand side of the screen.

Setting Auto Acquisition Areas

Instead of limits lines, auto acquisition areas are provided in the system. There are two setting methods:

3, 6 Nautical Miles: Two predefined auto acquisition areas; one between 3.0 and 3.5 nautical miles and the other between 5.5 and 6.0 nautical miles.

SET: Two sector shaped or full circle auto acquisition areas set by using the trackball.

To activate two predefined auto acquisition areas (3 & 6 NM):

1. Press the E, AUTO PLOT MENU key to show the ARPA 1 menu.

2. Press the (2) key to select menu item 2 AUTO ACQ AREA.

3. Further press the (2) key to select (or highlight) menu option 3, 6 nautical miles.

4. Press the ENTER key to confirm your selection followed by the E, AUTO PLOT MENU key to close the ARPA 1 menu.

To set auto acquisition areas with trackball:

1. Press the E, AUTO PLOT MENU key to show the ARPA 1 menu.

2. Press the (2) key to select menu item 2 AUTO ACQ AREA.

3. Further press the (2) key to select (or highlight) SET option.

4. Press the ENTER key to conclude your selection. At this point the AUTO ACQ SETTING menu is displayed at the screen bottom.

5. Press the (2) key to select menu item 2 1/2 and press the ENTER key.

6. Place the cursor at the outer counterclockwise corner of the area and press the ENTER key.

7. Place the cursor at the clockwise edge of the area and press the ENTER key.

Note: If you wish to create an auto acquisition area having a 360 degree coverage around own ship, set point B in almost the same direction (approx. +/-3) as point A and press the ENTER key.

8. Repeat steps 5 and 7 above if you want to set another auto acquisition area with the trackball.

9. Press the (1) key followed by the E, AUTO PLOT MENU key to close the ARPA 1 menu.

An auto acquisition area like the example shown above appears on the display. Note that each auto acquisition area has a fixed radial extension width of 0.5 nautical miles.

Note that the auto acquisition areas are preserved in an internal memory of the ARPA even when auto acquisition is disabled or the ARPA is turned off.

Terminating Tracking of Targets

When the ARPA has acquired 20 targets automatically, the message AUTO TARGET FULL is displayed in the box at right hand side of the screen and no more auto acquisition occurs unless targets are lost. You may find this message before you set an auto acquisition area. Should this happen, cancel tracking of less important targets or perform manual acquisition.

Individual Targets

Place the cursor (+) on a target to cancel tracking by operating the trackball. Press the CANCEL key.

All Targets

Press and hold the CANCEL key down more than 3 seconds. In the automatic acquisition mode, acquisition begins again.

Discrimination Between Landmass and True Targets

A target is recognized as a landmass and thus not acquired if it is 800 meters or more in range or bearing direction.

MANUAL ACQUISITION

In auto acquisition mode (AUTO ACQ ON), up to 20 targets can be manually acquired in addition to 20 auto acquired targets. When auto acquisition is disabled (AUTO ACQ OFF), up to 40 targets can be manually acquired and automatically tracked.

To manually acquire a target:

1. Place the cursor (+) on a target of interest by operating the trackball.

2. Press the ACQ key on the control panel. The selected plot symbol is marked at the cursor position.

Note that the plot symbol is drawn by broken lines during the initial tracking stage. A vector appears in about one minute after acquisition indicating the target's motion trend. If the target is consistently detected for three minutes, the plot symbol changes to a solid mark. If acquisition fails, the target plot symbol blinks and disappears shortly.

Notes:
1. For successful acquisition, the target to be acquired should be within 0.1 to 32 nautical miles from own ship and not obscured by sea or rain clutter.
2. When you have acquired 40 targets manually, the message MAN TARGET FULL is displayed at the screen bottom. Cancel tracking of non threatening targets if you wish to acquire additional targets manually.

CHANGING PLOT SYMBOL SIZE

You may also choose plot symbol size. To choose a large or standard size for all plot symbols:

1. Press the E, AUTO PLOT MENU key on the plotting keypad followed by the keys (0) to show the ARPA 2 menu.

2. Press the (3) key to select 3 MARK SIZE.

3. Further press the (3) key to select (or highlight) STANDARD or LARGE as appropriate.

4. Press the ENTER key to conclude your selection followed by the E, AUTO PLOT MENU key to close the ARPA 2 menu.

ADJUSTING BRILLIANCE OF PLOT MARKS

1. Press the RADAR MENU key on the plotting keypad to show the FUNCTIONS menu.

2. Press the (9) key to show the BRILLIANCE menu.

3. Press the (7) key to select 7 PLOT BRILL.

4. Further press the (7) key to select (or highlight) a desired brilliance level.

5. Press the ENTER key to confirm your selection followed by the RADAR MENU key to close the FUNCTION menu.

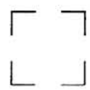
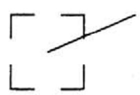
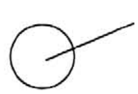
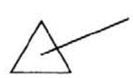
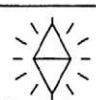
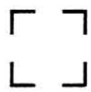
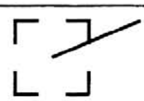
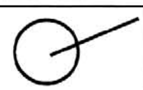
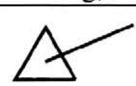
Item	Symbol	Status	Remarks
Automatically acquired targets		Initial stage EPVS symbol NO. 3	Broken square around an echo to indicate the target under acquisition and initial stage of tracking, before steady-state tracking.
		EPVS symbol NO. 3	Between 20 and 60 scans of antenna after acquisition (vector still unreliable)
		Steady tracking EPVS symbol NO. 4a	Solid circle with vector indicating steady state tracking (60 scans after acquisition)
	 (flashing)	CPA alarm EPVS symbol NO. 8	Plot symbol changes to an equilateral triangle flashing to indicate the target is predicted to come into CPA or TCPA.
		CPA alarm acknowledge EPVS symbol NO. 8	Flashing stops after CPA/TCPA alarm is acknowledged.
	 (flashing)	Lost target EPVS symbol NO. 9	Lost target is indicated by flashing diamond symbol. The diamond is formed from two equal triangles.
Manually acquired targets		Initial stage EPVS symbol NO. 3	Plot symbol selected for a target acquired manually is shown in bold broken lines.
		EPVS symbol NO. 3	Bold broken square for 20 - 60 scans of antenna after acquisition.
		Steady tracking EPVS symbol NO. 4a	Manual plot symbol in a bold solid circle (60 scans after acquisition)
	 (flashing)	CPA alarm (collision course) EPVS symbol NO. 8	Plot symbol changes to an equilateral triangle flashing if a target is predicted to come into the preset CPA or TCPA.
		EPVS symbol NO. 8	Flashing stops after CPA/TCPA alarm is acknowledged.
	 (flashing)	Lost target EPVS symbol NO. 9	Lost target is indicated by flashing diamond symbol. The diamond is formed from two equal triangles (one apex up and the other apex down).

Figure 5.18 - ARPA Symbols

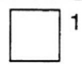
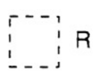
Item	Symbol	Status	Remarks
Guard zone	 (flashing)	On target passing through operator-set guard zone EPVS symbol NO. 7	Plot symbol changes to an equilateral triangle apex down, flashing together with vector if target entering guard zone (guard ring).
Automatic acquisition area		5.5-6.0 nm, 3-3.5 nm or anywhere EPVS symbol NO. 2	Sector or full circle as selected by the operator.
Target selected for data readout		On selected target EPVS symbol NO. 12	Target data (range, bearing, course, speed, CPA and TCPA).
Reference target	 (In 60 scans, change to )	On reference target	Used to calculate own ship's over-the-ground speed (target-based speed) for ground stabilization. Note: Only one point is useable.
Trial maneuver	**T** (flashing)	Bottom center EPVS symbol NO. 10	Appears during execution of a trial maneuver.
Auto Plotter performance test	**XX** (flashing)	Bottom center EPVS symbol NO. 11A	Appears during execution of a performance test (Track Test).

Figure 5.19 - ARPA Symbols (continued)

DISPLAYING TARGET DATA

The Auto Plotter calculates motion trends (range, bearing, course, speed, CPA and TCPA) of all plotted targets

In head up and head up true bearing modes, target bearing, course and speed shown in the upper right target data field become true (suffix "T") or relative (suffix "R") to own ship in accordance with the true/relative vector setting. In north up, course up and true motion modes, the target data field always displays true bearing, true course and speed over the ground.

Place the cursor on the desired target and press the TARGET DATA key on the plotting keypad. Data on the selected target is displayed at the upper right corner of the screen. A typical target data display is shown in figure 5.20.

RNG/BRG: Range and bearing from own ship to the selected target with suffix "T" (True) or "R" (Relative).

CSE/SPD: Course and speed are displayed for the selected target with suffix "T" or "R".

CSE/SPD: CPA (Closest Point of Approach) is the closest range a target will approach to own ship. TCPA is the time to CPA. Both CPA and TCPA are automatically calculated. When a target ship has passed clear of own ship, CPA is prefixed with an asterisk such as, CPA * 1.5NM. TCPA is counted to 99.9 min and beyond this, it reads TCPA.*99.9MIN.

BCR/BCT: Bow crossing range is a range of a target which will pass dead ahead of own ship at a calculated distance. BCT is the time when BCR occurs.

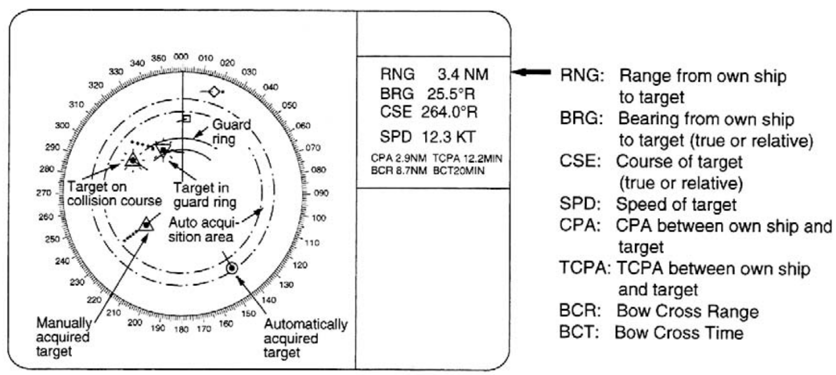


Figure 5.20 - Target Data

MODE AND LENGTH OF VECTORS

True or Relative Vector

Target vectors can be displayed relative to own ship's heading (relative) or with reference to the north (true).

Press the VECTOR TRUE/REL key to select true or relative vectors. This feature is available in all presentation modes (gyrocompass must be working correctly). The current vector mode is indicated at the upper right corner of the screen.

True Vector

In the true motion mode, all fixed targets such as land, navigational marks and ships at anchor remain stationary on the radar screen with vector length zero. But in the presence of wind and/or current, true vectors appear on fixed targets representing the reciprocal of set and drift affecting own ship unless set and drift values are properly entered (see figure 5.21).

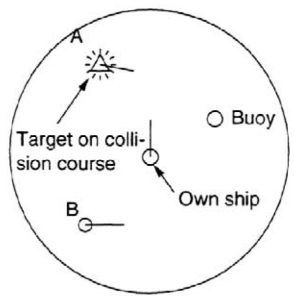


Figure 5.21 - True vectors in head-up mode

Relative Vector

Relative vectors on targets which are not moving over the ground such as land, navigational marks and ships at anchor will represent the reciprocal of own ship's ground track. A target of which vector extension passes through own ship is on the collision course. (See figure 5.22 - dotted lines are for explanation only).

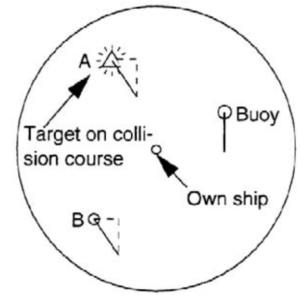


Figure 5.22 - Relative vectors in head-up mode

Vector Time

Vector time (or length of vectors) can be set to 30 seconds, 1, 2, 3, 6, 12, 15 or 30 minutes and the selected vector time is indicated at the upper right corner of the screen.

Press the VECTOR TIME key to select desired vector time. The vector tip shows an estimated position of the target after the selected vector time elapses. It can be valuable to extend the vector length to evaluate the risk of collision with any target.

PAST POSITIONS

The ARPA displays equally time spaced dots marking the past positions of any targets being tracked.

A new dot is added every minute (or at preset time intervals) until the present number is reached. If a target changes it speed, the spacing will be uneven. If it changes the course, its plotted course will not be a straight line.

Displaying and Erasing Past Positions

To display past positions, press the HISTORY key to display past positions of targets being tracked. The label HISTORY appears at the upper right corner of the screen.

To erase past positions, press the HISTORY key again.

Selecting the Number of Dots and Past Position Intervals

1. Press the E, AUTO PLOT MENU key on the plotting keyboard to show the ARPA 1 menu.

2. Press the (7) key to select menu item 7 HISTORY POINTS.

3. Further press the (7) key to select a desired number of past positions (5, 10, 20, 30, 100, 150 or 200). The IMO-type has the selection of only 5 or 10.

4. Press the ENTER key to confirm your selection.

5. Press the (8) key to select menu item 8 HISTORY INTERVAL.

6. Further press the (8) key to select a desired past position plot interval (30 seconds, 1, 2, 3 or 6 minutes).

7. Press the ENTER key to conclude your selection.

8. Press the E, AUTO PLOT MENU key to close the menu.

SETTING CPA/TCPA ALARMS RANGES

The ARPA continuously monitors the predicted range at the CPA and predicted time to CPA (TCPA) of each tracked target to own ship.

When the predicted CPA of any target becomes smaller than a preset CPA alarm range and its predicted TCPA less than a preset TCPA alarm limit, the ARPA releases an aural alarm and displays the warning label COLLISION on the screen. In addition, the ARPA symbol changes to a triangle and flashes together with its vector.

Provided that this feature is used correctly, it will help prevent the risk of collision by alerting you to threatening targets. It is important that GAIN, A/C SEA, A/C RAIN and other radar controls are properly adjusted.

CPA/TCPA alarm ranges must be set up properly taking into consideration the size, tonnage, speed, turning performance and other characteristics of own ship.

CAUTION: The CPA/TCPA alarm feature should never be relied upon as the sole means for detecting the risk of collision. The navigator is not relieved of the responsibility to keep visual lookout for avoiding collisions, whether or not the radar or other plotting aid is in use.

To set the CPA/TCPA alarm ranges:

1. Press the E, AUTO PLOT MENU key on the plotting keypad to show the ARPA 1 menu.

2. Press the (6) key to select menu item 6 CPA, TCPA SET. At this point, a highlight cursor appears at the “CPAx.xNM” field.

3. Enter the CPA alarm range in nautical miles (max 9.9 min) without omitting leading zeroes, if any, and press the ENTER key. The highlight cursor now moves to the:TCPAxx.xMIN” field.

4. Enter the TCPA alarm limit in minutes (max.99.0 min) without omitting leading zeroes, if any, and press the ENTER key.

5. Press the E, AUTO PLOT MENU key to close the menu.

Silencing CPA/TCPA Aural Alarm

Press the AUDIO OFF key to acknowledge and silence the CPA/TCPA aural alarm.

The warning label COLLISION and the flashing of the triangle plot symbol and vector remain on the screen until the dangerous situation is gone or you intentionally terminate tracking of the target by using the CANCEL key.

Setting a Guard Zone

When a target transits the operator-set guard zone, the buzzer sounds and the indication GUARD RING appears at the screen bottom. The target causing the warning is clearly indicated with an inverted flashing triangle.

CAUTION: The Guard Zone (Guard Ring) should never be relied upon as a sole means for detecting the risk of collision. The navigator is not relieved of the responsibility to keep a visual lookout for avoiding collisions, whether or not the radar or other plotting aid is in use.

Activating the Guard Zone

No. 1 Guard Zone is available between 3 and 6 nm with a fixed range depth of 0.5 nm. No. 2 GZ may be set anywhere when No. 1 GZ is valid.

To set and activate the guard zone:

1. Press the E, AUTO PLOT MENU key on the plotting keyboard to show the ARPA 1 menu.
2. Press the (3) key to select menu item 3 GUARD RING.
3. Further press the (3) key to select (or highlight) ON to activate the guard zone.
4. Press the ENTER key to conclude your selection.
5. Press the (4) key to select menu item 4 GUARD RING SET. At this point the GUARD SETTING menu is displayed at the screen bottom.
6. Press the (2) key and enter key. (2) (2) (ENTER) when setting the no. 2 ring.
7. Place the cursor at the outer left corner of the area (point 1) and press the ENTER key.
8. Place the cursor at the right edge of the area (point 2) and press the ENTER key.

Note: If you wish to create a guard zone having a 360-degree coverage around own ship, set point 2 in almost the same direction (approx. +/- 3°) as point 1 and press the ENTER key.

9. Press the (1) key followed by the E, AUTO PLOT MENU key to close the ARPA 1 menu.

Deactivating the Guard Zone

1. Press the E, AUTO PLOT MENU key on the plotting keyboard to show the ARPA 1 menu.
2. Press the (3) key to select menu item 3 GUARD RING.
3. Further press the (3) key to select (or highlight) OFF to deactivate the guard zone.
4. Press the ENTER key to conclude your selection followed by the E, AUTO PLOT MENU key to close the ARPA 1 menu.

Silencing the Guard Zone Audible Alarm

Press the AUDIO OFF key to acknowledge and silence the guard zone audible alarm.

Operational Warnings

There are six main situations which cause the Auto Plotter to trigger visual and aural alarms:

- CPA/TCPA alarm
- Guard zone alarm
- Lost target alarm
- Target full alarm for manual acquisition
- Target full alarm for automatic acquisition
- System failures

The audible alarm can be set to OFF through the AUTO PLOT 2 menu.

CPA/TCPA Alarm

Visual and aural alarms are generated when the predicted CPA and TCPA of any target become less than their preset limits. Press the AUDIO OFF key to acknowledge and silence the CPA/TCPA aural alarm.

Guard Zone Alarm

Visual and audible alarms are generated when a target transmits the operator-set guard zone. Press the AUDIO OFF key to acknowledge and silence the guard zone audible alarm.

Lost Target Alarm

When the system detects a loss of a tracked target, the target symbol becomes a flashing diamond. and the label “LOST” appears at the screen bottom. At the same time, an aural alarm is produced for one second.

Press the LOST TARGET key to acknowledge the lost target alarm. Then, the lost target mark disappears.

Target Full Alarm

When the memory becomes full, the memory full status is indicated and the relevant indication appears on the screen and a short beep sounds.

Manually Acquired Targets

The indication “MAN TARGET FULL” appears at the screen bottom and a short beep tone sounds when the number of manually acquired targets reaches 20 or 40 depending on whether auto acquisition is activated or not.

Automatically Acquired Targets

The indication “AUTO TARGET FULL” appears at the screen bottom and a short beep tone sounds when the number of automatically acquired targets reaches 20.

System Failure Alarm

When the ARP board receives no signal input from the radar or external equipment, the screen shows both “SYSTEM FAIL” associated with an indication denoting offending equipment, also releasing an aural alarm. The missing signals are denoted as shown below:

TRIAL MANEUVER

Trial simulates the effect on all tracked targets against own ship's maneuver without interrupting the updating of target information.

There are two types of trial maneuvers: STATIC and DYNAMIC.

Dynamic Trial Maneuver

A dynamic trial maneuver displays predicted positions of the tracked targets and own ship. You enter own ship's intended speed and course with a certain "delay time". Assuming that all tracked targets maintain their present speeds and courses, the targets' and own ship's future movements are simulated in one second increments indicating their predicted positions in one minute intervals.

The delay time represents the time lag from the present time to the time when own ship will actually start to change her speed and/or course. You should therefore take into consideration own ship's maneuvering characteristics such as rudder delay, turning delay and acceleration delay. This is particularly important on large vessels. How much the delay is set the situation starts immediately and ends in a minute.

Note that once a dynamic trial maneuver is initiated, you cannot alter own ship's trial speed, course or delay time until the trial maneuver is terminated.

Static Trial Maneuver

A static trial maneuver displays only the final situation of the simulation. If you enter the same trial speed, course and delay time under the same situation as in the aforementioned example of dynamic trial maneuver, the screen will instantly show position OS7 for own ship, position A7 for target A and position B7 for target B, omitting the intermediate positions. Thus, the static trial maneuver will be convenient when you wish to know the maneuver result immediately.

Note: For accurate simulation of ship movements in a trial maneuver, own ship's characteristics such as acceleration and turning performance should be properly set in initial settings at the time of installation.

To perform a trial maneuver:

1. Press the E, AUTO PLOT MENU key on the plotting keypad followed by the (0) key to show the ARPA 2 menu.

2. Press the (2) key to select 2 TRIAL MANEUVER.

3. Further press the (2) key to select (or highlight) STATIC or DYNAMIC trial maneuver option as appropriate.

4. Press the ENTER key to conclude your selection followed by the E, AUTO PLOT MENU key to close the ARPA 2 menu.

5. Press the VECTOR TRUE/REL key to select true or relative vector.

6. Press the TRIAL key. The TRIAL DATA SETTING menu appears at the screen bottom associated with the current own ship's speed and course readouts.

Note: The second line reads (STATIC MODE) in the event of a static trial maneuver.

7. Enter own ship's intended speed, course and delay time in the following manner:

Speed:	Set with the VRM control.
Course:	Set with the EBL control.
Delay time:	Enter in minutes by hitting numeral keys. This is the time after which own ship takes a new situation, not the time the simulation begins. Change the delay time according to own ship loading condition, etc.

8. Press the TRIAL key again to start a trial maneuver.

Trial maneuver takes place in three minutes with the letter "T" displayed at the bottom of the screen. If any tracked target is predicted to be on a collision course with own ship (that is, the target ship comes within preset CPA/TCPA limits), the target plot symbol changes to a triangle and flashes. If this happens, change own ship's trial speed, course or delay time to obtain a safe maneuver. The trial maneuver is automatically terminated and the normal radar picture is restored three minutes later.

Terminating Trial Maneuver

Press the TRIAL key again at any time.

CRITERIA FOR SELECTING TARGETS FOR TRACKING

The FURUNO ARPA video processor detects targets in midst of noise and discriminates radar echoes on the basis of their size. Target whose echo measurements are greater than those of the largest ship in range or tangential extent are usually land and are displayed only as normal radar video. All smaller ship sized echoes which are less than this dimension are further analyzed and regarded as ships and displayed as small circles superimposed over the video echo.

When a target is first displayed, it is shown as having zero true speed but develops a course vector as more information is collected. In accordance with the International Maritime Organization Automatic Radar Plotting Aid requirements, an indication of the motion trend should be available in 1 minute and full vector accuracy in 3 minutes of plotting. The FURUNO ARPAs comply with these requirements.

Acquisition and Tracking

A target which is hit by 5 consecutive radar pulses is detected as a radar echo. Manual acquisition is done by designing a detected echo with the trackball. Automatic acquisition is done in the acquisition areas when a target is detected 5-7 times continuously depending upon the congestion. Tracking is achieved when the target is clearly distinguishable on the display for 5 out of 10 consecutive scans whether acquired automatically or manually. Targets not detected in 5 consecutive scans become “lost targets”.

Quantization

The entire picture is converted to a digital from called “Quantized Video”. A sweep range is divided into small segments and each range elements is “1” if there is radar echo return above a threshold level, or “0” if there is no return.

The digital radar signal is then analyzed by a ship sized echo discriminator. As the antenna scans, if there are 5 consecutive radar pulses with l’s indicating an echo presence at the exact same range, a target “start” is initiated. Since receiver noise is random, it is not three bang correlated, and it is filtered out and not classified as an echo.

RADAR OBSERVATION

GENERAL

Minimum Range

The minimum range is defined by the shortest distance at which, using a scale of 1.5 or 0.75 nm, a target having an echoing area of 10 square meters is still shown separate from the point representing the antenna position.

It is mainly dependent on the pulse length, antenna height, and signal processing such as main bang suppression and digital quantization. It is good practice to use a shorter range scale as far as it gives favorable definition or clarity of picture. The IMO Resolution A. 477 (XII) and IEC 936 require the minimum range to be less than 50m. All FURUNO radars satisfy this requirement.

Maximum Range

The maximum detecting range of the radar, Rmax, varies considerably depending on several factors such as the height of the antenna above the waterline, the height of the target above the sea, the size, shape and material of the target, and the atmospheric conditions.

Under normal atmospheric conditions, the maximum range is equal to the radar horizon or a little shorter. The radar horizon is longer than the optical one about 6% because of the diffraction property of the radar signal. It should be noted that the detection range is reduced by precipitation (which absorbs the radar signal).

X-Band and S-Band

In fair weather, the above equation does not give a significant difference between X and S band radars. However, in heavy precipitation condition, an S band radar would have better detection than X band.

Radar Resolution

There are two important factors in radar resolution: bearing resolution and range resolution.

Bearing Resolution

Bearing resolution is the ability of the radar to display as separate pips the echoes received from two targets which are at the same range and close together. It is proportional to the antenna length and reciprocally proportional to the wavelength. The length of the antenna radiator should be chosen for a bearing resolution better than 2.5° (IMO Resolution). This condition is normally satisfied with a radiator of 1.2 meters (4 feet) or longer in the X band. The S band radar requires a radiator of about 12 feet (3.6 meters) or longer.

Range Resolution

Range resolution is the ability to display as separate pips the echoes received from two targets which are on the same bearing and close to each other. This is determined by pulselength only. Practically, a 0.08 microsecond pulse offers the discrimination better than 25 meters as do so with all Furuno radars.

Test targets for determining the range and bearing resolution are radar reflectors having an echo area of 10 square meters.

Bearing Accuracy

One of the most important features of the radar is how accurately the bearing of a target can be measured. The accuracy of bearing measurement basically depends on the narrowness of the radar beam. However, the bearing is usually taken relative to the ship’s heading, and thus, proper adjustment of the heading marker at installation is an important factor in ensuring bearing accuracy. To minimize error when measuring the bearing of a target, put the target echo at the extreme position on the screen by selecting a suitable range.

Range Measurement

Measurement of the range to a target is also a very important function of the radar. Generally, there are two means of measuring range: the fixed range rings and the variable range marker (VRM). The fixed range rings appear on the screen with a predetermined interval and provide a rough estimate of the range to a target. The variable range marker’s diameter is increased or decreased so that the marker touches the inner edge of the target, allowing the operator to obtain more accurate range measurements.

FALSE ECHOES

Occasionally echo signals appear on the screen at positions where there is no target or disappear even if there are targets. They are, however, recognized if you understand the reason why they are displayed. Typical false echoes are shown below.

Multiple Echoes

Multiple echoes occur when a transmitted pulse returns from a solid object like a large ship, bridge, or breakwater. A second, a third or more echoes may be observed on the display at double, triple or other multiples of the actual range of the target. Multiple reflection echoes can be reduced and often removed by decreasing the gain (sensitivity) or properly adjusting the A/C SEA control.

Sidelobe Echoes

Every time the radar pulse is transmitted, some radiation escapes on each side of the beam, called “sidelobes”. If a target exists where it can be detected by the side lobe as well as the main lobe, the side echoes may be represented on both sides of the true echo at the same range. Side lobes show usually only on short ranges and from strong targets. They can be reduced through careful reduction of the gain or proper adjustment of the A/C SEA control.

Virtual Image

A relatively large target close to your ship may be represented at two positions on the screen. One of them is the true echo directly reflected by the target and the other is a false echo which is caused by the mirror effect of a large object on or close to your ship. If your ship comes close to a large metal bridge, for example, such a false echo may temporarily be seen on the screen.

Shadow Sectors

Funnels, stacks, masts, or derricks in the path of the antenna block the radar beam. If the angle subtended at the scanner is more than a few degrees, a non-detecting sector may be produced. Within this sector targets cannot be detected.

SEARCH AND RESCUE TRANSPONDER (SART)

A Search and Rescue Transponder (SART) may be triggered by any X-Band (3 cm) radar within a range of approximately 8 nautical miles. Each radar pulse received causes it to transmit a response which is swept repetitively across the complete radar frequency band. When interrogated, it first sweeps rapidly (0.4 microseconds) through the band before beginning a relatively slow sweep (7.5 microseconds) through the back band to the starting frequency. This process is repeated for a total of twelve complete cycles. At some point in each sweep, the SART frequency will match that of the interrogating radar and be within the pass band of the radar receiver. If the STRT is within range, the frequency match during each of the 12 slow

POST-IT NOTE METHOD OF RADAR CONTACT THREAT AND ASPECT ASSESSMENT

Contributed by Mr. Eric K. Larsson

Rapid radar plotting has been useful for the ocean mariner, but has always been viewed as a burden by the coastal or inland mariner. Some common complaints are listed below:

- I don't have a reflection plotter!
- I don't stay on course long enough to plot a target!
- I don't have time to plot - I'm the only one in the wheelhouse and I have to steer!

Many of these statements are valid, but if one does not use radar plotting or some other form of systematic observation, as required by the Rules of the Road, that person is missing out on vital information and they are putting themselves and their vessel in an unfavorable position. When the U.S. Coast Guard N-VIC on radar training for tugboat captains, mates and pilots was issued, it was felt that some sort of useful, practical training should be added to the plotting requirements that have always been part of radar courses. Because most of the individuals affected by the N-VIC were on tugs or towboats, that practical method of plotting or observation had been geared to the equipment found on board those vessels.

Radar on tugs have small screens and are usually a raster scan head up unstabilized type display. there is no reflection plotter. Because of limited space and time constraints, transfer plotting is not practical. Experience shows that without use, plotting skills deteriorate. To keep these skills sharp, post-it notes and the use of echo trails or the plot feature on certain radar units can be used to substitute for plotting with pencils and rulers. Other variations have been utilized in the past such as tongue depressor or a plastic overlay but the post-it note method seems to be quicker and easier to use. It also deals with the four complaints stated above.

"*I don't have a reflection plotter.*" In exchange for a reflection plotter, the plot feature on certain small screen radars allows the operator to view the relative track of the target at selected intervals of 15, 30 or 60 seconds or more A continuous track of the target with a timer that counts up in seconds can also be selected. In figure 5.23, a continuous echo trail has been selected and allowed to run for 3 minutes. This is the equivalent of a three minute

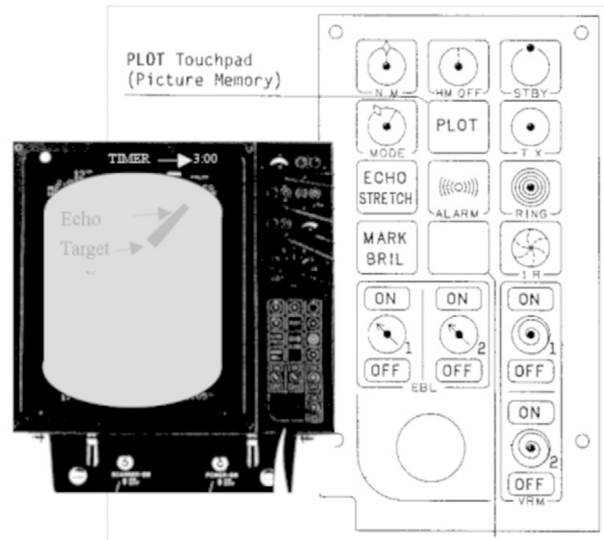


Figure 5.23

"*I don't stay on course long enough to plot a targets* this statement the question is asked, "Do you stay on course for 3 minutes?" The answer is usually "Yes." The plot feature allows the operator to note the time the target began tracking and choose a time interval that is appropriate for the vessel, the range scale used on the radar and the speed of the vessel.

In figure 5.24, our vessel is moving at a speed of 8 knots. A time interval of 3 minutes is selected. Using the 6 minute rule, a vessel moving 8 miles in 60 minutes will move 0.8 miles in 6 minutes (1/10 the time and 1/10 the distance). In order to find the distance traveled in 3 minutes, the distance for 6 minutes is cut in half and a vessel moving 0.8 miles in 6 minutes will move 0.4 miles in 3 minutes (1/2 the time and 1/2 the distance).

The radar range scale in use is 3 miles. A distance of 0.4 miles is measured on the radar using the Variable Range Marker (VRM). Place the post-it note parallel to the heading flasher and the upper left or right corner touching the 0.4nm VRM. Mark the post-it note at the corner and at the start point of the heading flasher. This measured distance on the pot-it note is the equivalent of a 3-minute segment of our vessel's movement. It is the equivalent of the "er" vector in rapid radar plotting.

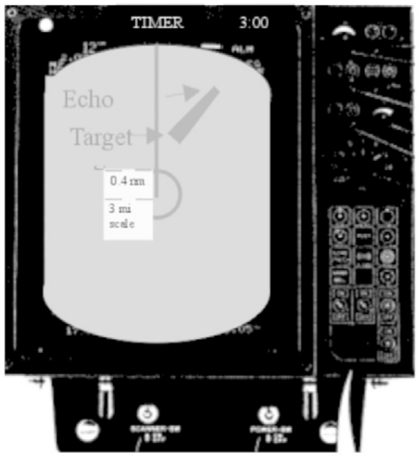


Figure 5.24

Repeat the process for the other corner/side of the post-it note. Once made, the post-it note will work for that range scale and speed, and can be stuck to the side of the radar ready for use at any time. Other scales can be mode for different speeds or ranges as needed. This process only takes a few seconds and can be done "on the spot."

"*I don't have time to plot - I'm the only one in the wheelhouse and I have to steer*!" The echo trail allows the single officer in the wheelhouse to "systematically observe" the movement of vessels. The echo trails alone, however will not give the officer much more information than which targets are collision threats. The post-it note will allow the officer to obtain more information. This includes the aspect of the target as well as the ability to obtain the approximate course and speed of the target.

Assume in this example (figure 5.25) that our course is 270 degrees at a speed of 8 knots. To obtain the course and speed of the target place the corner with the first mark on the post-it note at the beginning of the target trail or plot echo parallel to the heading flasher. Observe the direction of a line that would connect the second mark on the post-it note with the target. This line indicates the course of the target (indicated by a red line). The speed of the target over the 3-minute time period can be compared with the distance we would travel over 3 minutes as indicated by the two marks on the post-it note.

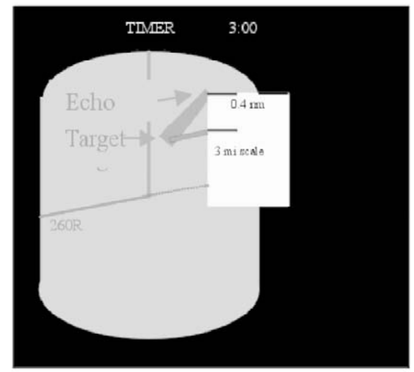


Figure 5.25

If you drew a line drawn from the second mark to the target at the end of a 3 minute interval you can determine the targets course relative to our heading of 270 degrees. The dashed EBL line shown above is parallel to the line drawn from the post-it note to the target position at minute 3.00. It has to be read in the direction from the post-it note to the target (hence the solid line in the direction of 260). With our heading of 270 degrees the relative bearing will read 260 degrees. If you add 260 and 270 (530) and then subtract 360 the target's true course is found to be 170 degrees.

This is shown on the compass rose in figure 5.26.

The length of the line is a little shorter than the distance between marks on the post-it note. This length could be measured at about 0.35nm in three

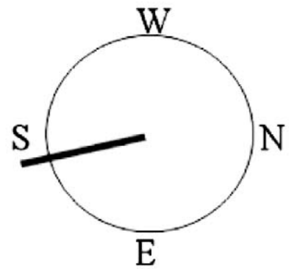


Figure 5.26

minutes which translates to about 7 knots. This line is the equivalent of the target course and speed vector “em” in rapid radar plotting.

A second example is shown in figure 5.27 for a target on a reciprocal course at a speed approximately equal to our own.

Because of the valid statements listed above about the ability to reflection plot, and rules of the road requirement to plot, a practical method of plotting needs to be used. It is hoped the pot-it method will assist the mariner in his efforts to “systematically observe” all targets.

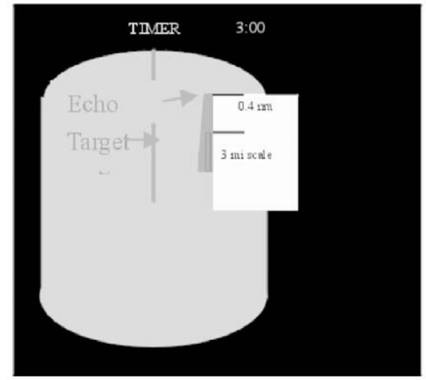


Figure 5.27

CHAPTER 6 - MANEUVERING BOARD MANUAL

PART ONE

OWN SHIP AT CENTER

EXAMPLE 1

CLOSEST POINT OF APPROACH

Situation:

Other ship M is observed as follows:

Time	*Bearing*	*Range (yards)*	*Rel. position*
0908	275˚	12,000	M_1
0913	270˚	10,700	M_2
0916	266˚.5	10,000	M_3
0920	260˚	9,000	M_4

Required:

(1) Direction of Relative Movement (DRM).
(2) Speed of Relative Movement (SRM).
(3) Bearing and range at Closest Point of Approach (CPA).
(4) Estimated time of Arrival at CPA.

Solution:

(1) Plot and label the relative positions M_1, M_2, etc. The direction of the line M_1 M_4 through them is the direction of relative movement (DRM): 130˚.

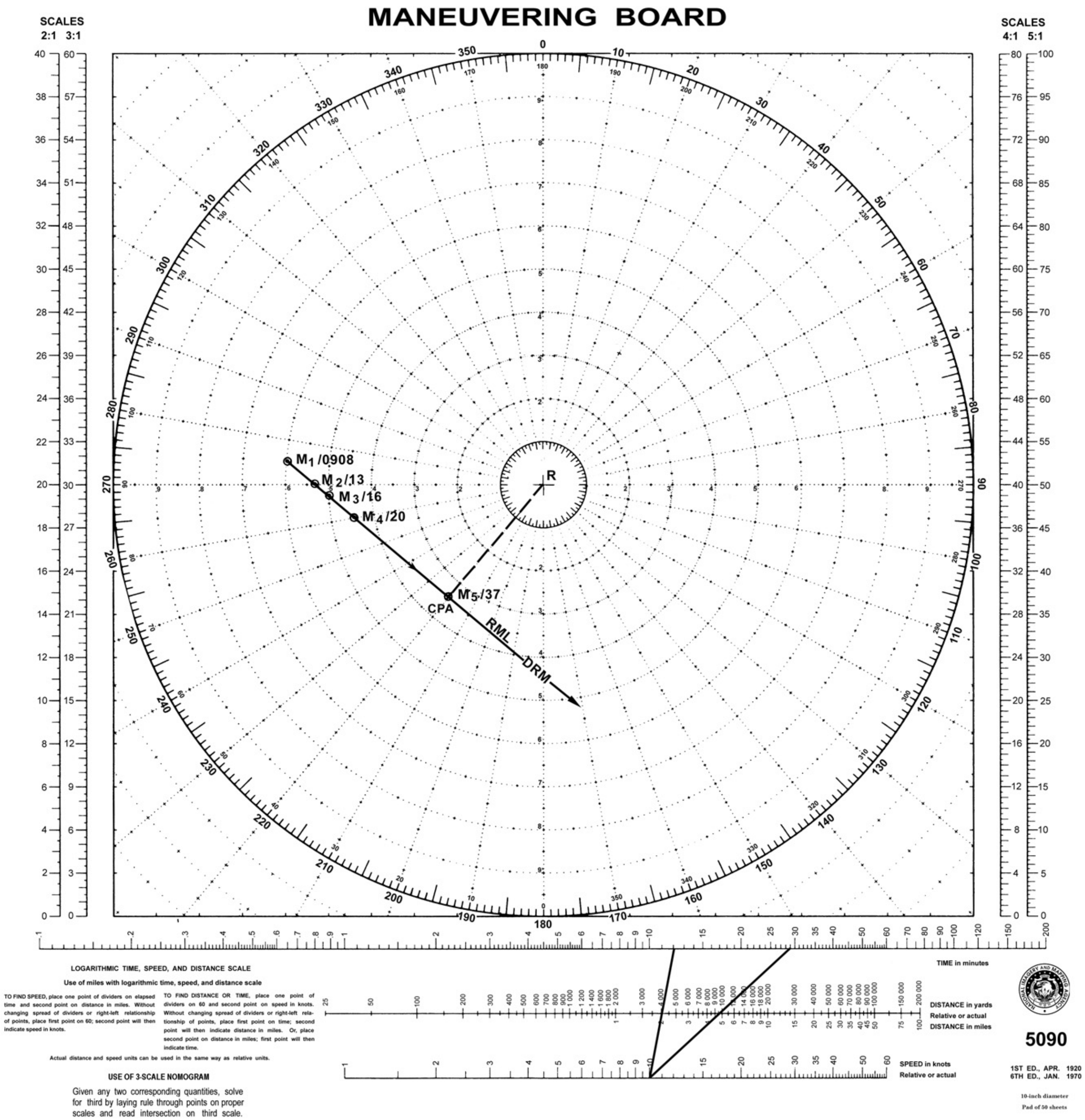
(2) Measure the relative distance (MRM) between any two points on M_1M_4. M_1 to M_4 = 4,035 yards. Using the corresponding time interval (0920 - 0908 = 12^m), obtain the speed of relative movement (SRM) from the Time, Distance, and Speed (TDS) scales: 10 knots.

(3) Extend M_1M_4. Provided *neither* ship alters course or speed, the successive positions of M will plot along the relative movement line. Drop a perpendicular from R to the relative movement line at M_5. This is the CPA: 220˚, 6,900 yards.

(4) Measure M_1M_5: 9,800 yards. With this MRM and SRM obtain time interval to CPA from TDS scale: 29 minutes. ETA at CPA= 0908 + 29 = 0937.

Answer:

(1) DRM 130˚.
(2) SRM 10 knots.
(3) CPA 220˚, 6,900 yards.
(4) ETA at CPA 0937.



OWN SHIP AT CENTER

EXAMPLE 1

Scale: Distance 2:1 yd.

EXAMPLE 2

COURSE AND SPEED OF OTHER SHIP

Situation:

Own ship *R* is on course 150˚, speed 18 knots. Ship *M* is observed as follows:

Time	*Bearing*	*Range (yards)*	*Rel. position*
1100........................	255˚	20,000	M_1
1107........................	260˚	15,700	M_2
1114........................	270˚	11,200	M_3

Required:

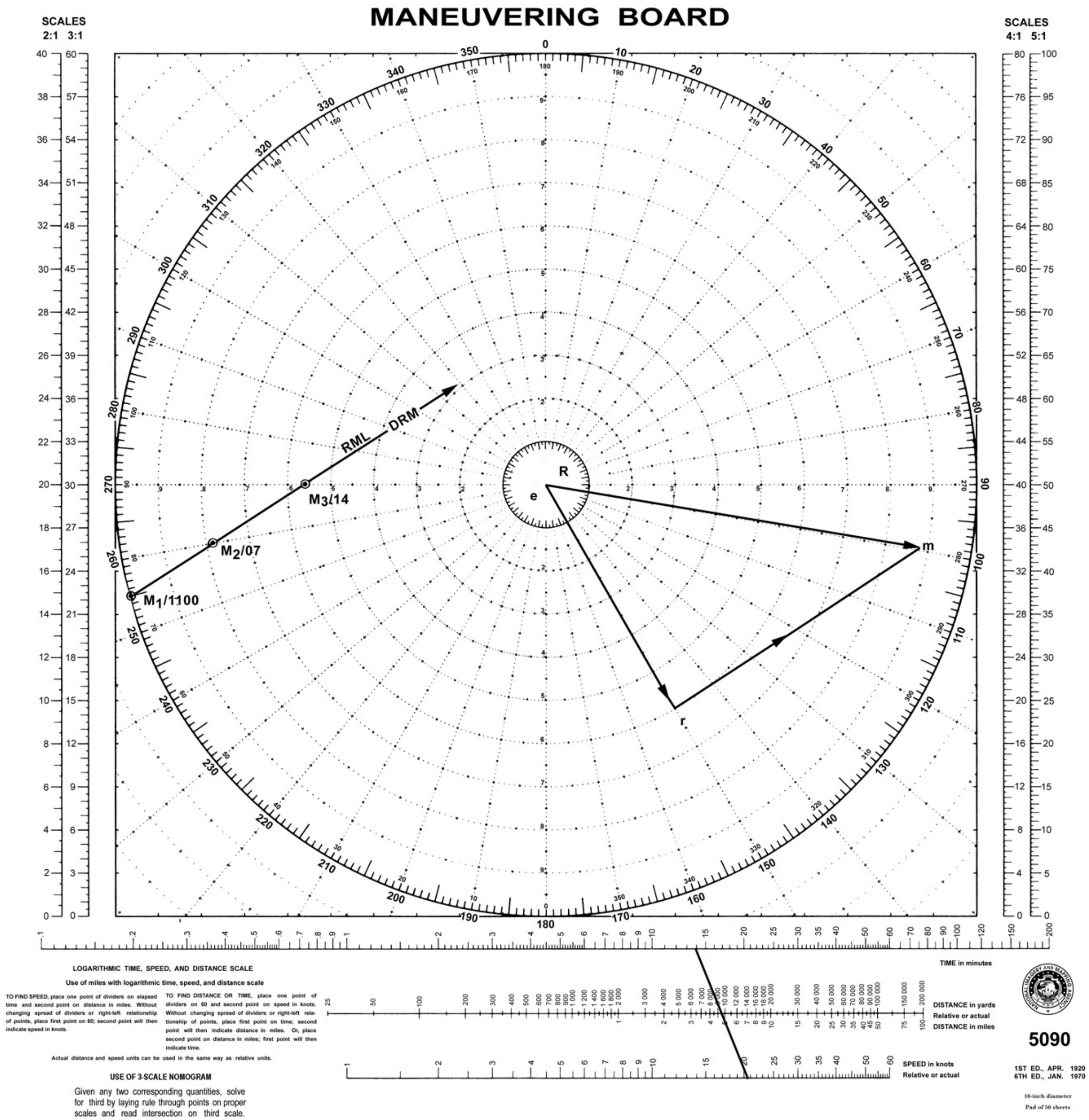
(1) Course and speed of *M*.

Solution:

(1) Plot M_1, M_2, M_3, and *R*. Draw the direction of relative movement line (RML) from M_1 through M_3. With the distance $M_1 M_3$ and the interval of time between M_1 and M_3, find the relative speed (SRM) by using the TDS scale: 21 knots. Draw the reference ship vector *er* corresponding to the course and speed of *R*. Through *r* draw vector *rm* parallel to and in the direction of $M_1 M_3$ with a length equivalent to the SRM of 21 knots. The third side of the triangle, *em*, is the velocity vector of the ship *M*: 099˚, 27 knots.

Answer:

(1) Course 099˚, speed 27 knots.



OWN SHIP AT CENTER

EXAMPLE 2

Scale: Speed 3:1;
Distance 2:1 yd.

EXAMPLE 3

COURSE AND SPEED OF OTHER SHIP USING RELATIVE PLOT AS RELATIVE VECTOR

Situation:

Own ship *R* is on course 340˚, speed 15 knots. The radar is set on the 12-mile range scale. Ship *M* is observed as follows:

Time	*Bearing*	*Range (mi.)*	*Rel. position*
1000........................	030˚	9.0	M_1
1006........................	025˚	6.3	M_2

Required:

(1) Course and speed of *M*.

Solution:

(1) Plot *M* and M_2. Draw the relative movement line (RML) from M_1 through M_2.

(2) For the interval of time between M_1 and M_2, find the distance own ship *R* travels through the water. Since the time interval is 6 minutes, the distance in nautical miles is one-tenth of the speed of *R* in knots, or 1.5 nautical miles.

(3) Using M_1M_2 directly as the relative vector *rm*, construct the reference ship true vector *er* to the same scale as *rm* (M_1 - M_2), or 1.5 nautical miles in length.

(4) Complete the vector diagram (speed triangle) to obtain the true vector *em* of ship *M*. The length of *em* represents the distance (2.5 nautical miles) traveled by ship *M* in 6 minutes, indicating a true speed of 25 knots.

Note:

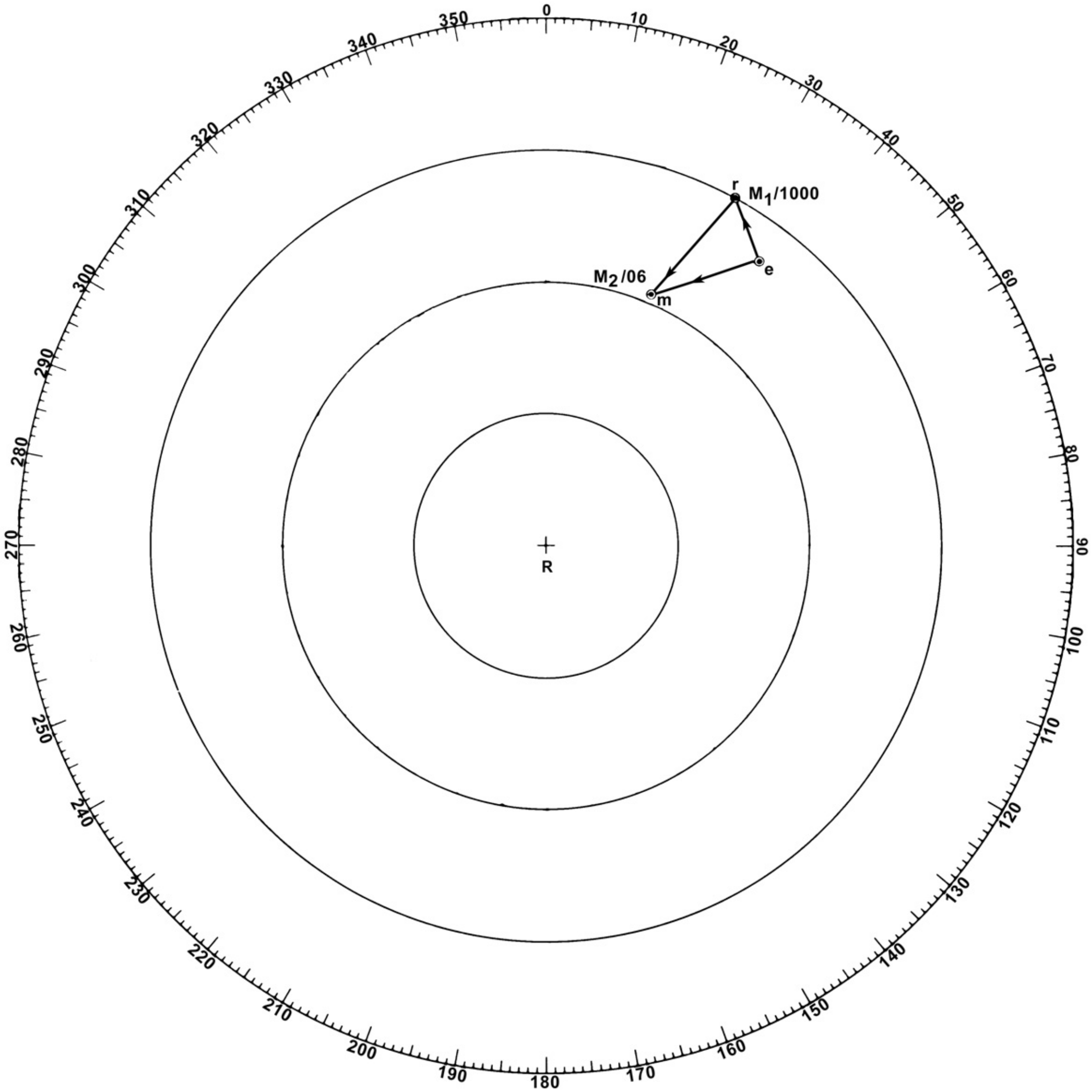
In some cases it may be necessary to construct own ship's true vector originating at the end of the segment of the relative plot used directly as the relative vector. The same results are obtained, but the advantages of the conventional vector notation are lost.

Answer:

(1) Course 252˚, speed 25 knots.

Note:

Although at least three relative positions are needed to determine whether the relative plot forms a straight line, for solution and graphical clarity only two relative positions are given in examples 3, 6, and 7.



OWN SHIP AT CENTER

EXAMPLE 3

Scale: 12-mile range setting

EXAMPLE 4

CHANGING STATION WITH TIME, COURSE, OR SPEED SPECIFIED

Situation:

Formation course is 010˚, speed 18 knots. At 0946 when orders are received to change station, the guide *M* bears 140˚, range 7,000 yards. When on new station, the guide will bear 240˚, range 6,000 yards.

Required:

(1) Course and speed to arrive on station at 1000.

(2) Speed and time to station on course 045˚. Upon arrival on station orders are received to close to 3,700 yards.

(3) Course and minimum speed to new station.

(4) Time to station at minimum speed.

Solution:

(1) Plot M_1 140˚, 7,000 yards and M_2 240˚, 6,000 yards from *R*. Draw *em* corresponding to course 010˚ and speed 18 knots. The distance of 5.0 miles from M_1 to M_2 must be covered in 14 minutes. The SRM is therefore 21.4 knots. Draw r_1m parallel to M_1 M_2 and 21.4 knots in length. The vector er_1 denotes the required course and speed: 062˚, 27 knots.

(2) Draw er_2, course 045˚, intersecting r_1m the relative speed vector at the 21-knot circle. By inspection r_2m is 12.1 knots. Thus the distance M_1M_2 of 5.0 miles will be covered in 24.6 minutes.

(3) To *m* draw a line parallel to and in the direction of M_2M_3. Drop a perpendicular from *e* to this line at r_3. Vector er_3 is the course and minimum speed required to complete the final change of station: 330˚, 13.8 knots.

(4) By measurement, the length of r_3 *m* is an SRM of 11.5 knots and the MRM from M_2 to M_3 is 2,300 yards. The required maneuver time MRM/r_3 *m* = 6 minutes.

Answer:

(1) Course 062˚, speed 27 knots.

(2) Speed 21 knots, time 25 minutes.

(3) Course 330˚, speed 13.8 knots.

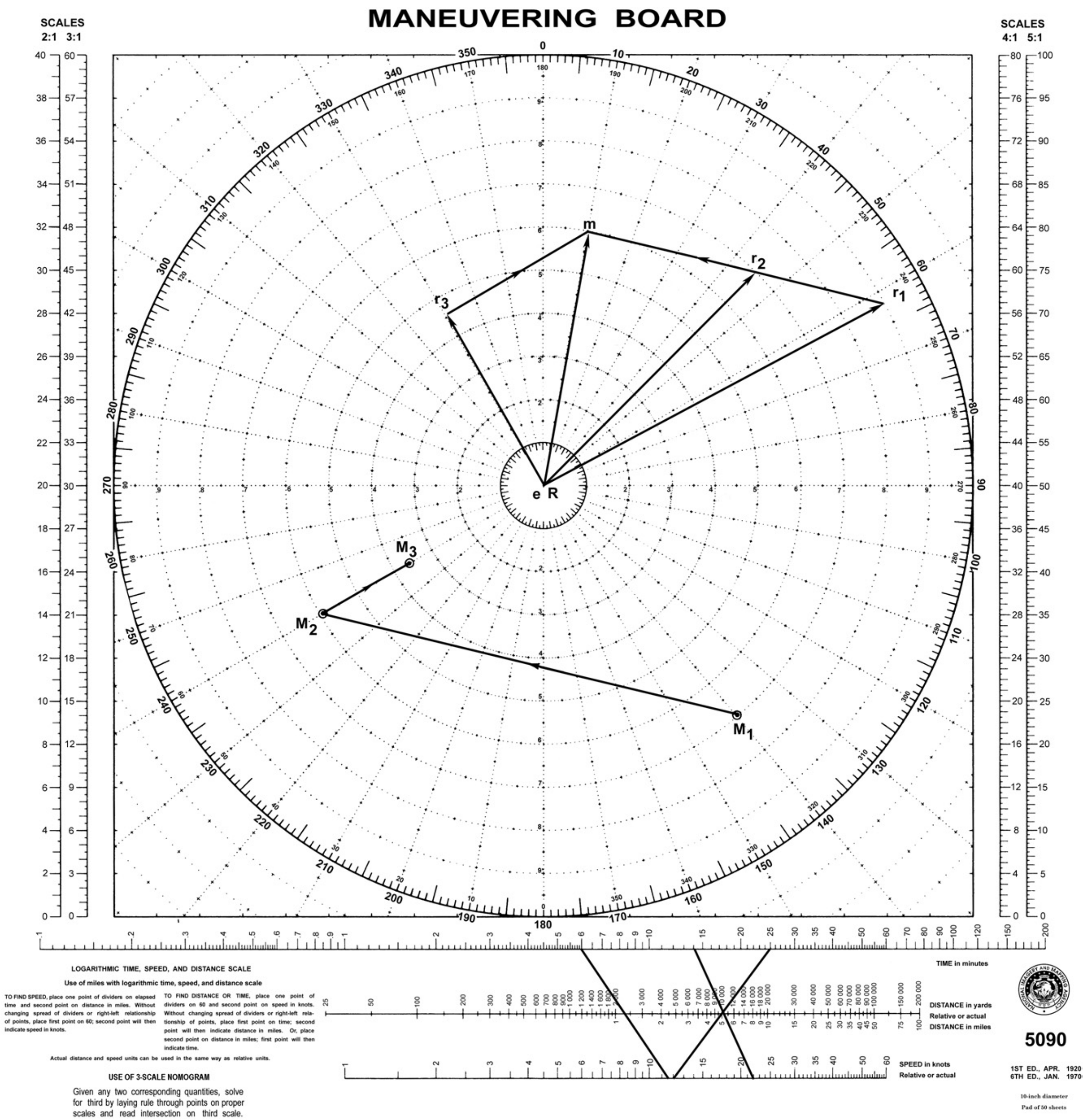
(4) Time 6 minutes.

Explanation:

In solution step (1) the magnitude (SRM) of the *required* relative speed vector *(r_1m)* is established by the relative distance *(M_1M_2)* and the time specified to complete the maneuver (14^m). In solution step (2), however, the magnitude (12.1 knots) of the *resulting* relative speed vector *(r_2m)* is determined by the distance from the head of vector *em* along the reciprocal of the DRM to the point where the required course (045˚) is intersected. Such intersection also establishes the magnitude (21 knots) of vector er_2. The time (25^m) to complete the maneuver is established by the SRM (12.1 knots) and the relative distance (5 miles).

In solution step (3) the course, and minimum speed to make the guide plot along M_2M_3 are established by the shortest true vector for own ship's motion that can be constructed to complete the speed triangle. This vector is perpendicular to the relative vector *(r_3 m)*.

In solution step (4) the time to complete the maneuver is established by the relative distance (2,300 yards) and the relative speed (11.5 knots).



OWN SHIP AT CENTER

EXAMPLE 4

Scale: Speed 3:1;
Distance 1:1 yd.

EXAMPLE 5

THREE-SHIP MANEUVERS

Situation:

Own ship *R* is in formation proceeding on course 000˚, speed 20 knots. The guide *M* bears 090˚, distance 4,000 yards. Ship *N* is 4,000 yards ahead of the guide.

Required:

R and *N* are to take new stations starting at the same time. *N* is to take station 4,000 yards on the guide's starboard beam, using formation speed. *R* is to take *N*'s old station and elects to use 30 knots.

(1) *N*'s course and time to station.
(2) *R*'s course and time to station.
(3) CPA of *N* and *R* to guide.
(4) CPA of *R* to *N*.
(5) Maximum range of *R* from *N*.

Solution:

(1) Plot *R*, M_1, M_2, and N_1. Draw *em*. From M_1 plot *N*'s new station *NM*, bearing 090˚, distance 4,000 yards. From M_2 plot N_3 bearing 090˚, distance 4,000 yards (*N*'s final range and bearing from *M*). Draw N_1NM, the DRM of *N* relative to *M*. From *m*, draw *mn* parallel to and in the direction of N_1NM intersecting the 20-knot speed circle at *n*. *N*'s course to station is vector *en*: 090˚. Time to station N_1NM/mn is 6 minutes.

(2) To *m*, draw a line parallel to and in the direction of M_1M_2 intersecting the 30-knot speed circle at *r*. *R*'s course to station is vector *er*: 017˚. Time to station M_1M_2/rm is 14 minutes.

(3) From M_1 drop a perpendicular to N_1NM. At CPA, *N* bears 045˚, 2,850 yards from *M*. From *R* drop a perpendicular to M_1M_2. At CPA, *R* bears 315˚, 2,850 yards from *M*.

(4) From *r* draw *rn*. This vector is the direction and speed of *N* relative to *R*. From N_1 draw a DRM line of indefinite length parallel to and in the direction of *rn*. From *R* drop a perpendicular to this line. At CPA, *N* bears 069˚, 5,200 yards from *R*.

(5) The intersection of the DRM line from N_1 and the line NMN_3 is N_2, the point at which *N* resumes formation course and speed. Maximum range of *N* from *R* is the distance RN_2, 6,500 yards.

Answer:

(1) *N*'s course 090˚, time 6 minutes.
(2) *R*'s course 017˚, time 14 minutes.
(3) CPA of *N* to *M* 2,850 yards at 045˚. *R* to *M* 2,850 yards at 315˚.
(4) CPA of *N* to *R* 5,200 yards at 069˚.
(5) Range 6,500 yards.

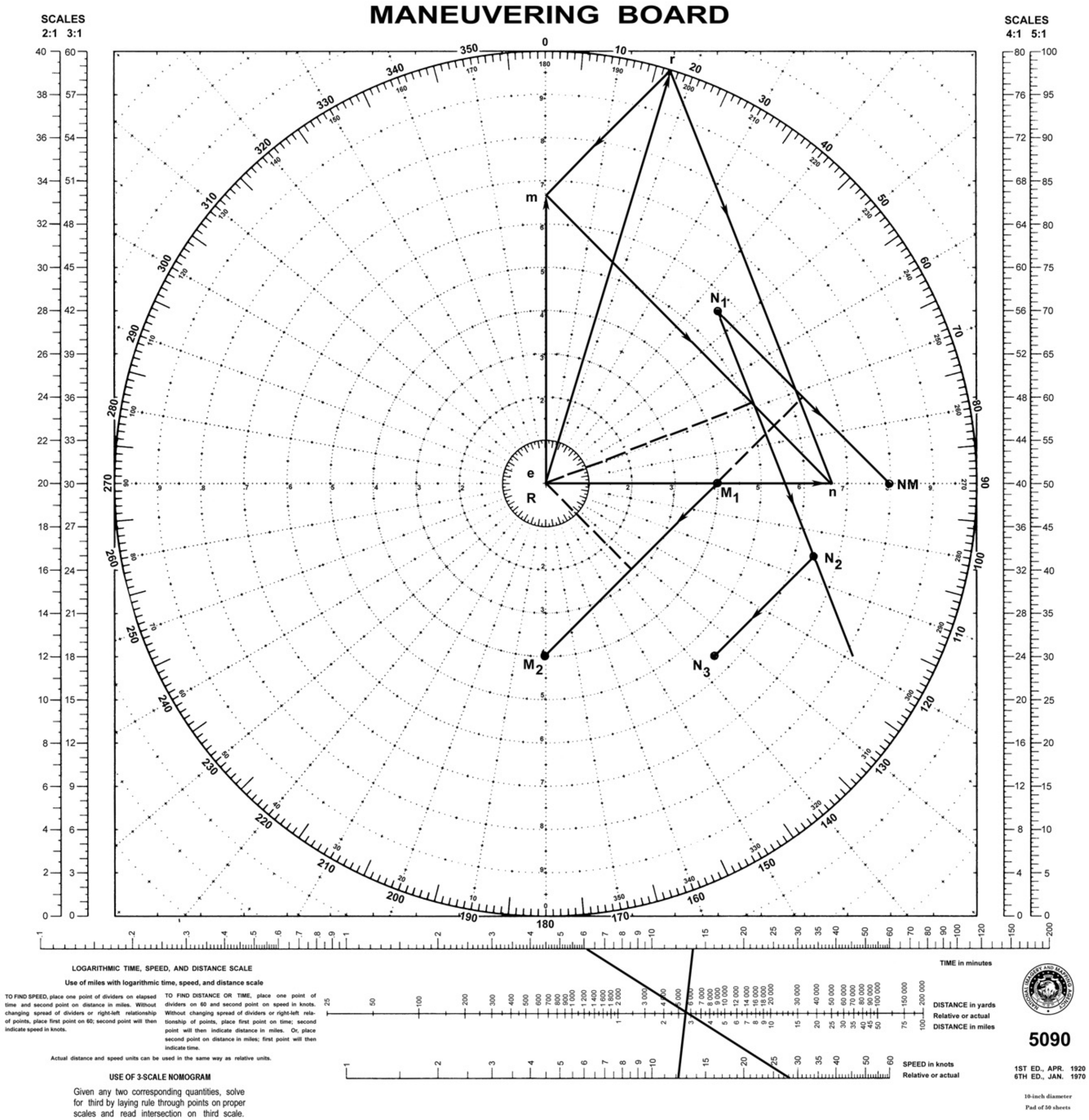
Solution Key:

(1) Solutions for changing station by own ship *R* and ship *N* are effected separately in accordance with the situation and requirements. The CPAs of *N* and *R* to guide are then obtained.

(2) Two solutions for the motion of ship *N* relative to own ship *R* are then obtained: relative motion while *N* is proceeding to new station and relative motion after *N* has taken new station and resumed base course and speed.

Explanation:

In solution step (4) the movement of *N* in relation to *R* is parallel to the direction of vector *rn* and from N_1 until such time that *N* returns to base course and speed. Afterwards, the movement of *N* in relation to *R* is parallel to vector *rm* and from N_2 toward that point, N_3, that *N* will occupy relative to *R* when the maneuver is completed.



OWN SHIP AT CENTER

EXAMPLE 5

Scale: Speed 3:1;
Distance 1:1 yd.

EXAMPLE 6

COURSE AND SPEED TO PASS ANOTHER SHIP AT A SPECIFIED DISTANCE

Situation 1:

Own ship *R* is on course 190˚, speed 12 knots. Other ship *M* is observed as follows:

Time	*Bearing*	*Range (yards)*	*Rel. position*
1730..................	153˚	20,000	M_1
1736..................	153˚	16,700	M_2

Required:

(1) CPA.

(2) Course and speed of *M*.

Situation 2:

It is desired to pass ahead of *M* with a CPA of 3,000 yards.

Required:

(3) Course of *R* at 12 knots if course is changed when range is 13,000 yards.

(4) Bearing and time of CPA.

Solution:

(1) Plot M_1 and M_2 at 153˚, 20,000 yards and 153˚, 16,700 yards, respectively, from *R*. Draw the relative movement line, M_1M_2, extended. Since the bearing is steady and the line passes through *R*, the two ships are on collision courses.

(2) Draw own ship's velocity vector er_1 190˚, 12 knots. Measure M_1M_2, the relative distance traveled by *M* from 1730 to 1736: 3,300 yards. From the TDS scale determine the relative speed, SRM, using 6 minutes and 3,300 yards: 16.5 knots. Draw the relative speed vector r_1m parallel to M_1M_2 and 16.5 knots in length. The velocity vector of *M* is *em*: 287˚, 10 knots.

(3) Plot M_3 bearing 153˚, 13,000 yards from *R*. With *R* as the center describe a circle of 3,000 yards radius, the desired distance at CPA. From M_3 draw a line tangent to the circle at M_4. This places the relative movement line of $M(M_3M_4)$ the required minimum distance of 3,000 yards from *R*. Through *m*, draw r_2m parallel to and in the direction of M_3M_4 intersecting the 12-knot circle (speed of *R*) at r_2. Own ship velocity vector is er_2: course 212˚, speed 12 knots.

(4) Measure the relative distance (MRM), M_2M_3: 3,700 yards. From the TDS scale determine the time interval between 1736 and the time to change to new course using M_2M_3, 3,700 yards, and an SRM of 16.5 knots: 6.7 minutes. Measure the relative distance M_3M_4: 12,600 yards. Measure the relative speed vector r_2m: 13.4 knots. Using this MRM and SRM, the elapsed time to CPA after changing course is obtained from the TDS scale: 28 minutes. The time of CPA is 1736 + 6.7 + 28 = 1811.

Note:

If *M*'s speed was greater than *R*'s, two courses would be available at 12 knots to produce the desired distance.

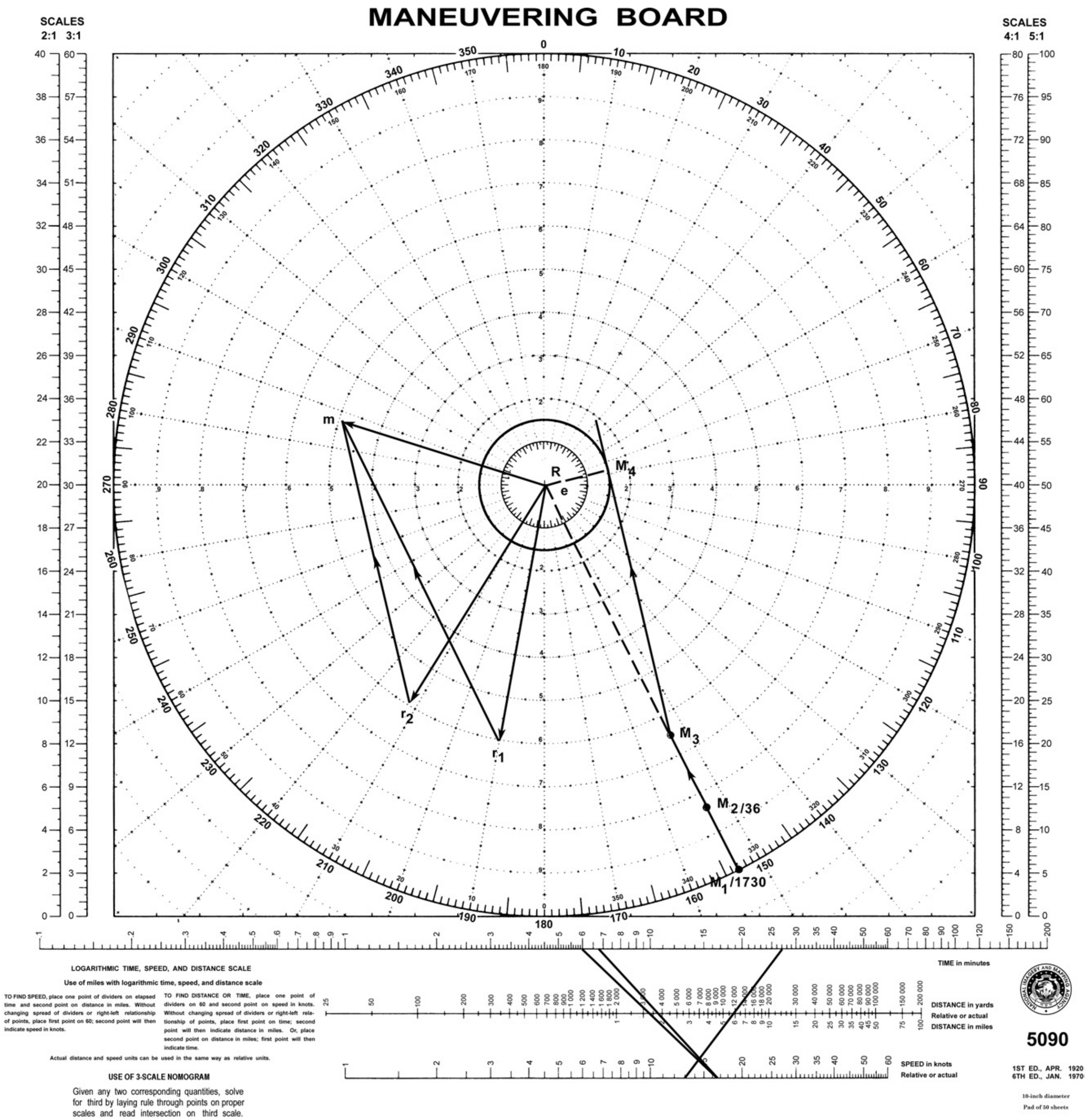
Answer:

(1) *M* and *R* are on collision courses and speeds.

(2) Course 287˚, speed 10 knots.

(3) Course 212˚.

(4) Bearing 076˚, time of CPA 1811.



OWN SHIP AT CENTER

EXAMPLE 6

Scale: Speed 2:1;
Distance 2:1 yd.

EXAMPLE 7

COURSE AND SPEED TO PASS ANOTHER SHIP AT A SPECIFIED DISTANCE USING RELATIVE PLOT AS RELATIVE VECTOR

Situation 1:

Own ship R is on course 190˚, speed 12 knots. Other ship M is observed as follows:

Time	*Bearing*	*Range (mi.)*	*Rel. position*
1730..................	153˚	10.0	M_1
1736..................	153˚	8.3	M_2

Required:

(1) CPA.

(2) Course and speed of M.

Situation 2:

It is desired to pass ahead of M with a CPA of 1.5 nautical miles.

Required:

(3) Course of R at 12 knots if course is changed when range is 6.5 nautical miles.

(4) Bearing and time of CPA.

Solution:

(1) Plot M_1 and M_2 at 153˚, 10.0 nautical miles and 153˚, 8.3 nautical miles, respectively from R. Draw the relative movement line, M_1M_2, extended. Since the bearing is steady and the line passes through R, the two ships are on collision courses.

(2) For the interval of time between M_1 and M_2, find the distance own ship R travels through the water. Since the time interval is 6 minutes, the distance in nautical miles is one-tenth of the speed of R in knots, or 1.2 nautical miles.

(3) Using M_1M_2 directly as the relative vector $r_1\,m$, construct the reference ship true vector er_1 to the same scale as $r_1\,m$ (M_1M_2), or 1.2 nautical miles in length.

(4) Complete the vector diagram (speed triangle) to obtain the true vector em of ship M. The length of em represents the distance (1.0 nautical miles) traveled by ship M in 6 minutes, indicating a true speed of 10 knots.

(5) Plot M_3 bearing 153˚, 6.5 nautical miles from R. With R as the center describe a circle of 1.5 nautical miles radius, the desired distance at CPA. From M_3 draw a line tangent to the circle at M_4. This places the relative movement line of M (M_3M_4) the required minimum distance of 1.5 nautical miles from R.

(6) Construct the true vector of ship M as vector $e'm'$, terminating at M_3. From e' describe a circle of 1.2 miles radius corresponding to the speed of R of 12 knots intersecting the new relative movement line (M_3M_4) extended at point r_2. Own ship R true vector required to pass ship M at the specified distance is vector $e'r_2$: course 212˚, speed 12 knots.

(7) For practical solutions, the time at CPA may be determined by inspection or through stepping off the relative vectors by dividers or spacing dividers. Thus the time of CPA is 1736 + 6.5 + 28 = 1811.

Note:

If the speed of ship M is greater than own ship R, there are two courses available at 12 knots to produce the desired distance.

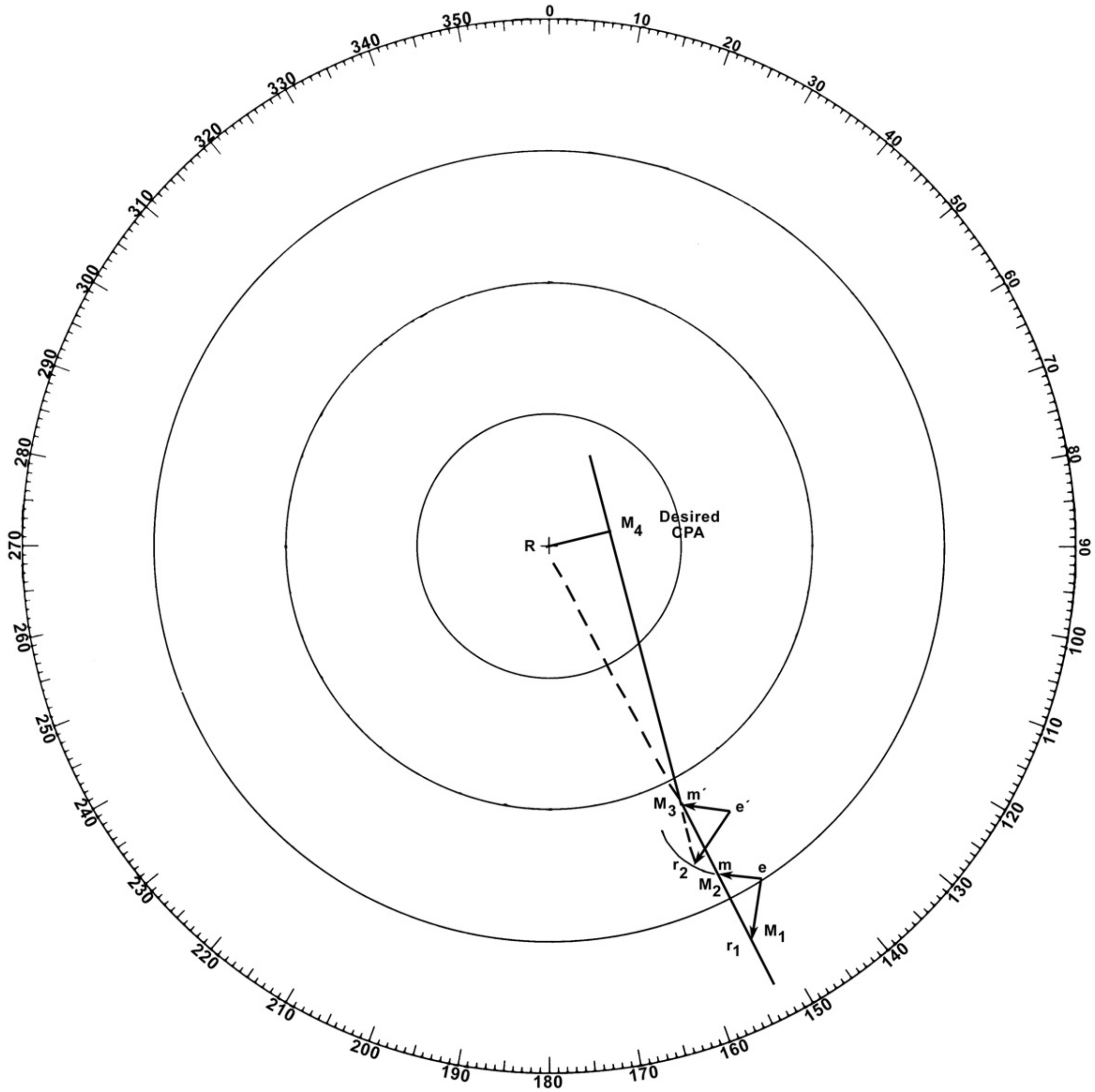
Answer:

(1) M and R are on collision courses and speeds.

(2) Course 287˚, speed 10 knots.

(3) Course 212˚.

(4) Bearing 076˚, time of CPA 1811.



OWN SHIP AT CENTER

EXAMPLE 7

Scale: 12-mile range setting

EXAMPLE 8

COURSE AT SPECIFIED SPEED TO PASS ANOTHER SHIP AT MAXIMUM AND MINIMUM DISTANCES

Situation:

Ship *M* on course 300˚, speed 30 knots, bears 155˚, range 16 miles from own ship *R* whose maximum speed is 15 knots.

Required:

(1) *R*'s course at 15 knots to pass *M* at (a) maximum distance (b) minimum distance.

(2) CPA for each course found in (1).

(3) Time interval to each CPA.

(4) Relative bearing of *M* from *R* when at CPA on each course.

Solution:

(1) Plot M_1 155˚, 16 miles from *R*. Draw the vector *em* 300˚, 30 knots. With *e* as the center, describe a circle with radius of 15 knots, the speed of *R*. From *m* draw the tangents $r_1\,m$ and $r_2\,m$ which produce the two limiting courses for *R*. Parallel to the tangents plot the relative movement lines through M_1. Course of own ship to pass at maximum distance is er_1: 000˚. Course to pass at minimum distance is er_2: 240˚.

(2) Through *R* draw RM_2 and RM'_2 perpendicular to the two possible relative movement lines. Point M_2 bearing 180˚, 14.5 miles is the CPA for course of 000˚. Point M'_2 bearing 240˚, 1.4 miles is the CPA for course 240˚.

(3) Measure M_1M_2: 6.8 miles, and $M_1M'_2$: 15.9 miles. *M* must travel these relative distances before reaching the CPA on each limiting course. The relative speed of *M* is indicated by the length of the vectors $r_1\,m$ and $r_2\,m$: 26 knots. From the TDS scale the times required to reach M_2 and M'_2 are found: 15.6 minutes and 36.6 minutes, respectively.

(4) Bearings are determined by inspection. M_2 bears 180˚ relative because own ship's course is along vector er_1 for maximum CPA. M'_2 bears 000˚ relative when own ship's course is er_2 for minimum passing distance.

Note:

This situation occurs only when own ship *R* is (1) ahead of the other ship and (2) has a maximum speed less than the speed of the other ship. Under these conditions, own ship can intercept (collision course) only if *R* lies between the slopes of M_1M_2 and $M_1M'_2$. Note that for limiting courses, and only for these, CPA occurs when other ship is dead ahead or dead astern. The solution to this problem is applicable to avoiding a tropical storm by taking that course which results in maximum passing distance.

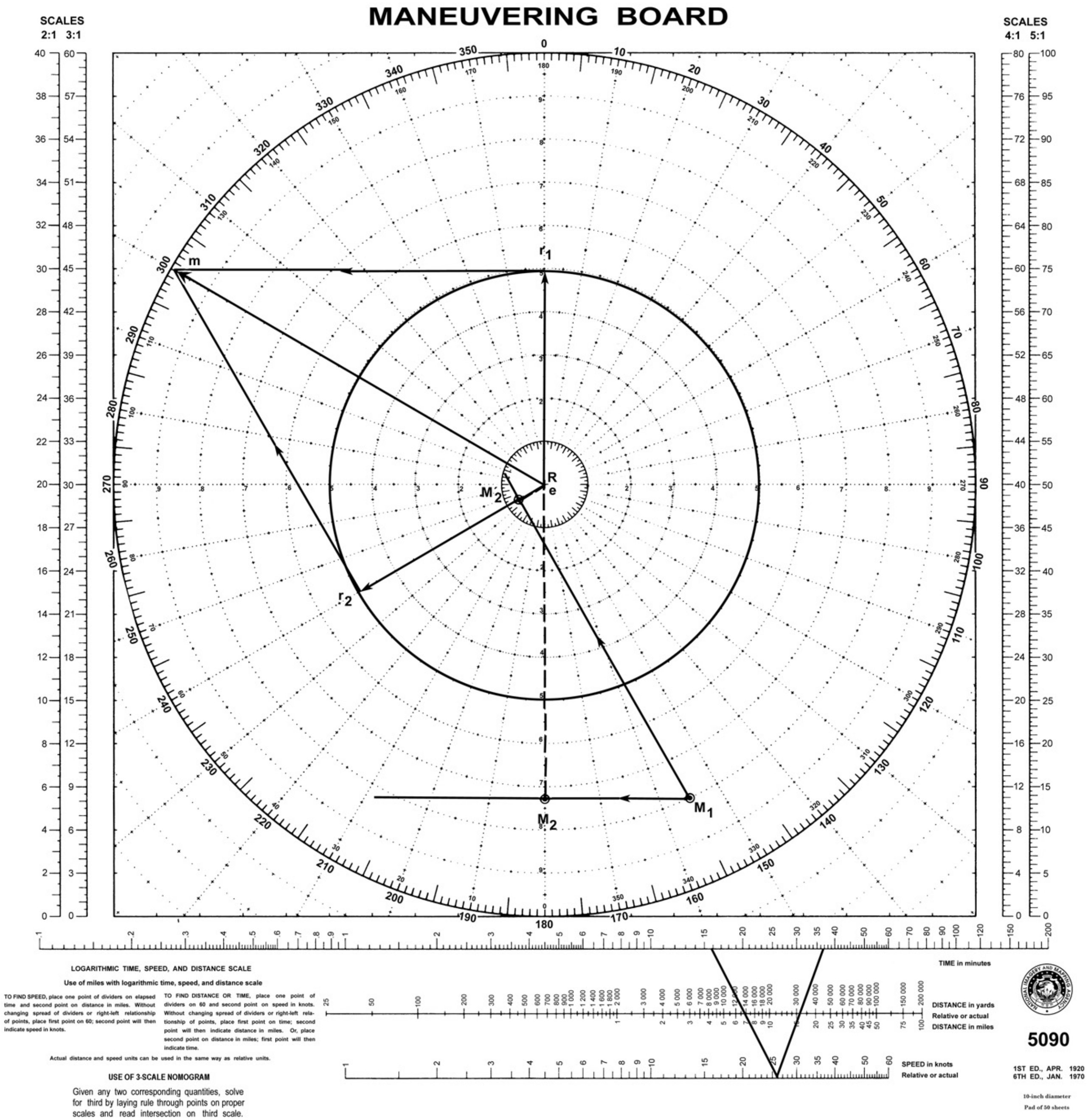
Answer:

(1) Course (a) 000˚; (b) 240˚.

(2) CPA (a) 180˚, 14.5 miles; (b) 240˚, 1.4 miles.

(3) Time (a) 16 minutes; (b) 37 minutes.

(4) Relative bearing (a) 180˚; (b) 000˚.



OWN SHIP AT CENTER

EXAMPLE 8

Scale: Speed 3:1;
Distance 2:1 mi.

EXAMPLE 9

COURSE CHANGE IN COLUMN FORMATION ASSURING LAST SHIP IN COLUMN CLEARS

Situation:

Own ship *D*1 is the guide in the van of a destroyer unit consisting of four destroyers (*D*1, *D*2, *D*3, and *D*4) in column astern, distance 1,000 yards. *D*1 is on station bearing 090˚, 8 miles from the formation guide *M*. Formation course is 135˚, speed 15 knots. The formation guide is at the center of a concentric circular ASW screen stationed on the 4-mile circle.

The destroyer unit is ordered to take new station bearing 235˚, 8 miles from the formation guide. The unit commander in *D*1 decides to use a wheeling maneuver at 27 knots, passing ahead of the screen using two course changes so that the CPA of his unit on each leg is 1,000 yards from the screen.

Required:

(1) New course to clear screen commencing at 1000.
(2) Second course to station.
(3) Bearing and range of *M* from *D*1 at time of coming to second course.
(4) Time of turn to second course.
(5) Time *D*1 will reach new station.

Solution:

(1) Plot own ship *D*1 at the center on course 135˚ with the remaining three destroyers in column as *D*2, *D*3, *D*4. (*D*2 and *D*3 not shown for graphical clarity.) Distance between ships 1,000 yards. Plot the formation guide *M* at M_1 bearing 270˚, 8 miles from *D*1. Draw *em*, the speed vector of *M*. It is required that the last ship in column, *D*4, clear *M* by 9,000 yards (screen radius of 4 miles plus 1,000 yards). At the instant the signal is executed to change station, only *D*1 changes both course and speed. The other destroyers increase speed to 27 knots but remain on formation course of 135˚ until each reaches the turning point. *D*4's movement of 3,000 yards at 27 knots to the turning point requires 3 minutes, 20 seconds. During this interval there is a 12 knot true speed differential between *D*4 and the formation guide *M*. Thus to establish the *relative position of D4 to M at the instant D4 turns*, advance *D*4 to *D*4' ($3^m\ 20^s$ x 12 knots = 1,350 yards). With *D*4' as a center, describe a CPA circle of radius 9,000 yards. Draw a line from M_1 tangent to this circle. This is the relative movement line required for *D*4 to clear the screen by 1,000 yards. Draw a line to *m* parallel to M_1M_2 intersecting the 27-knot circle at r_1. This point determines the initial course, er_1: 194˚.2.

(2) Plot the final relative position of *M* at M_3 bearing 055˚, 8 miles from *D*1. Draw a line from M_3 tangent to the CPA circle and intersecting the first relative movement line at M_2. Draw a line to *m* parallel to and in the direction of M_2M_3. The intersection of this line and the 27-knot circle at r_2 is the second course required, er_2: 252˚.8.

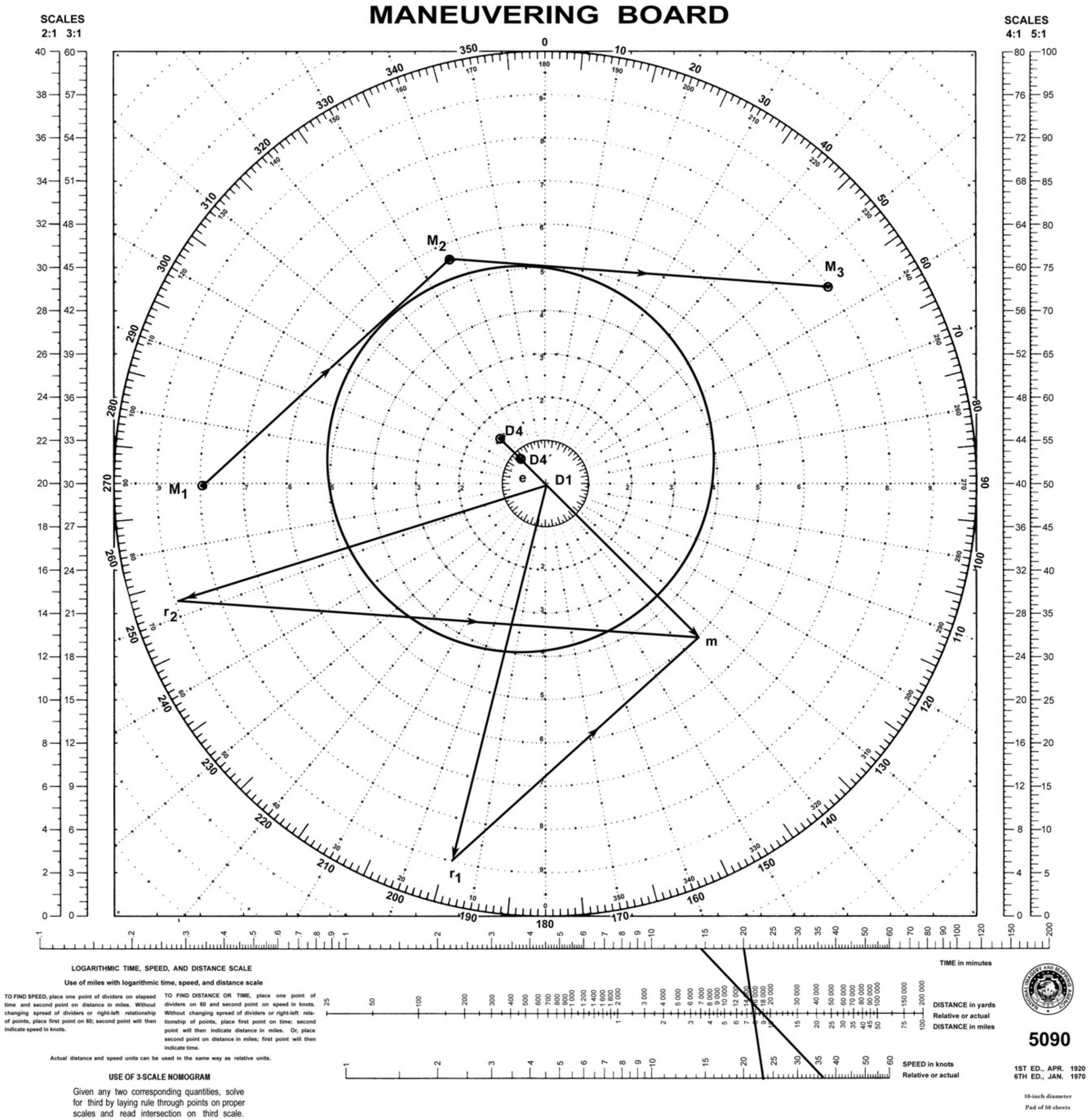
(3) Bearing and range of M_2 from *D*1 is obtained by inspection: 337˚ at 11,250 yards.

(4) Time interval for *M* to travel to M_2 is M_1M_2/r_1m = 7.8 miles/23.2 knots = 20.2 minutes. Time of turn 1000 + 20 = 1020.

(5) Time interval for the second leg is M_2M_3/r_2m = 8.8 miles/36.5 knots =14.2 minutes. *D*1 will arrive at new station at 1034.

Answer:

(1) Course 194˚.
(2) Course 253˚.
(3) Bearing 337˚, range 11,250 yards.
(4) Time 1020.
(5) Time 1034.



OWN SHIP AT CENTER

EXAMPLE 9

Scale: Speed 3:1;
Distance 1:1 mi.

EXAMPLE 10

DETERMINATION OF TRUE WIND

Situation:

A ship is on course 240˚, speed 18 knots. The relative wind across the deck is 30 knots from 040˚ relative.

Required:

Direction and speed of true wind.

Solution:

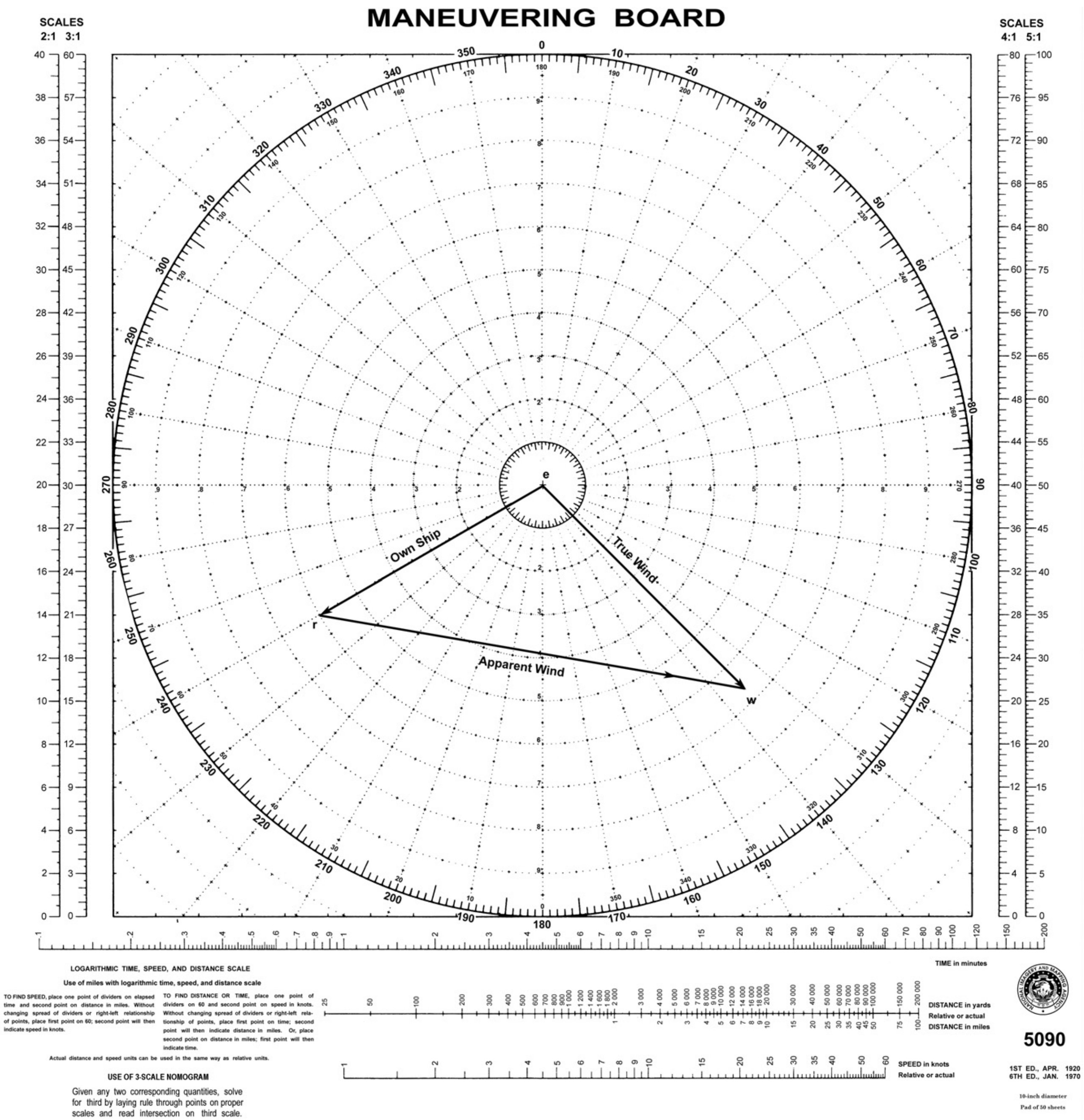
Plot *er*, the ship's vector of 240˚, 18 knots. Convert the relative wind to apparent wind by plotting *rw* 040˚ relative to ship's head which results in a true direction of 280˚T. Plot the apparent wind vector (reciprocal of 280˚T, 30 knots) from the end of the vector *er*. Label the end of the vector *w*. The resultant vector *ew* is the true wind vector of 135˚, 20 knots (wind's course and speed). The true wind, therefore, is *from* 315˚.

Answer:

True wind from 315˚, speed 20 knots.

Note:

As experienced on a moving ship, the direction of true wind is always on the same side and aft of the direction of the apparent wind. The difference in directions increases as ship's speed increases. That is, the faster a ship moves, the more the apparent wind draws ahead of true wind.



OWN SHIP AT CENTER

EXAMPLE 10

Scale: Speed 3:1

EXAMPLE 11a

DESIRED RELATIVE WIND
(First Method)

Situation:

An aircraft carrier is proceeding on course 240˚, speed 18 knots. True wind has been determined to be from 315˚, speed 10 knots.

Required:

Determine a launch course and speed that will produce a relative wind across the flight deck of 30 knots from 350˚ relative (10˚ port).

Solution:

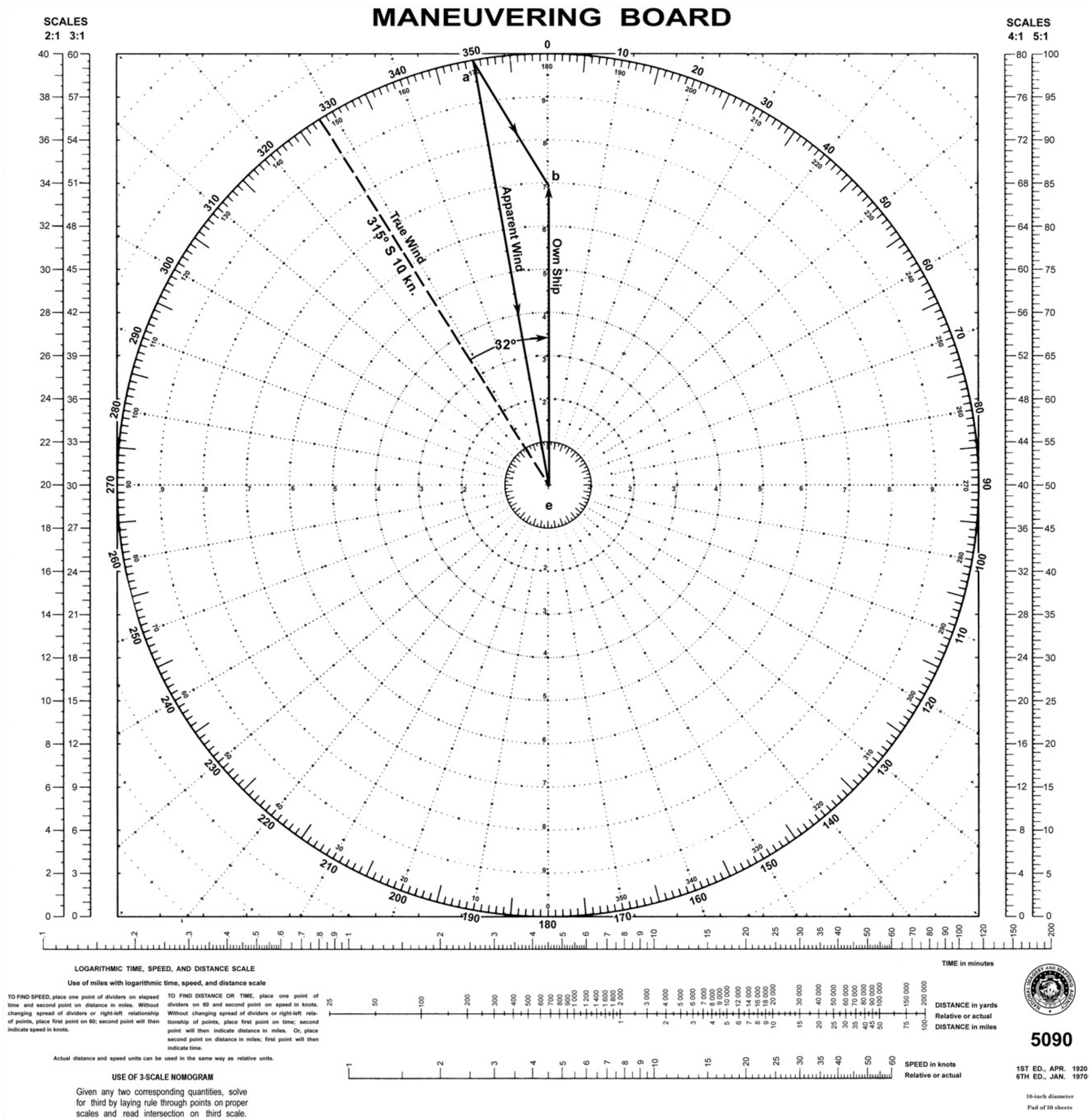
Set a pair of dividers for 30 knots using any convenient scale. Place one end of the dividers at the origin *e* of the maneuvering board and the other on the 350˚ line, marking this point *a*. Set the dividers for the true wind speed of 10 knots and place one end on point *a*, the other on the 000˚ line (centerline of the ship). Mark this point on the centerline *b*. Draw a dashed line from origin *e* parallel to *ab*. This produces the angular relationship between the direction from which the true wind is blowing and the launch course. In this problem the *true* wind should be from 32˚ off the port bow (328˚ relative) when the ship is on launch course and speed. The required course and speed is thus 315˚ + 32˚ = 347˚, 21 knots.

Answer:

Course 347˚, speed 21 knots.

Note:

As experienced on a moving ship, the direction of true wind is always on the same side and aft of the direction of the apparent wind. The difference in directions increases as ship’s speed increases. That is, the faster a ship moves, the more the apparent wind draws ahead of true wind.



OWN SHIP AT CENTER

EXAMPLE 11a

Scale: Speed 3:1

EXAMPLE 11b

DESIRED RELATIVE WIND
(Second Method)

Situation:

A ship is on course 240˚, speed 18 knots. True wind has been determined to be from 315˚, speed 10 knots.

Required:

Determine a course and speed that will produce a wind across the deck of 30 knots from 350˚ relative (10˚ port).

Solution:

(1) A preliminary step in the desired relative wind solution is to indicate on the polar plotting sheet the direction from which the true wind is blowing. The direction of the true wind is along the radial from 315˚.

(2) The solution is to be effected by first finding the magnitude of the required ship's true (course-speed) vector; knowing the true wind (direction-speed) vector and the magnitude (30 knots) of the relative wind vector, and that the ship's course should be to the right of the direction from which the true wind is blowing, the vector triangle can then be constructed.

(3) Construct the true wind vector *ew*.

(4) With a pencil compass adjusted to the true wind (10 knots), set the point of the compass on the 30-knot circle at a point 10˚ clockwise from the intersection of the 30-knot circle with the radial extending in the direction from which the wind is blowing. Strike an arc intersecting this radial. That part of the radial from the center of the plotting sheet to the intersection* represents the magnitude of the required ship's true vector (21 knots). The direction of a line extending from this intersection to the center of the arc is the direction of the ship's true vector.

(5) From *e* at the center of the plotting sheet, strike an arc of radius equal to 21 knots. From *w* at the head of the true wind vector, strike an arc of radius equal to 30 knots. Label intersection *r*. This intersection is to the right of the direction from which the true wind is blowing.

(6) Alternatively, the ship's true (course-speed) vector can be constructed by drawing vector *er* parallel to the direction established in (4) and to the magnitude also established in (4). On completing the vector triangle, the direction of the relative wind is 10˚ off the port bow.

Answer:

Course 346˚, speed 21 knots.

Note:

If the point of the compass had been set at a point on the 30-knot circle 10˚ counterclockwise from the radial extending in the direction from which the true wind is blowing in (4), the same magnitude of the ship's true vector would have been obtained. However, the direction established for this vector would have been for a 30-knot wind across the deck from 10˚ off the starboard bow.

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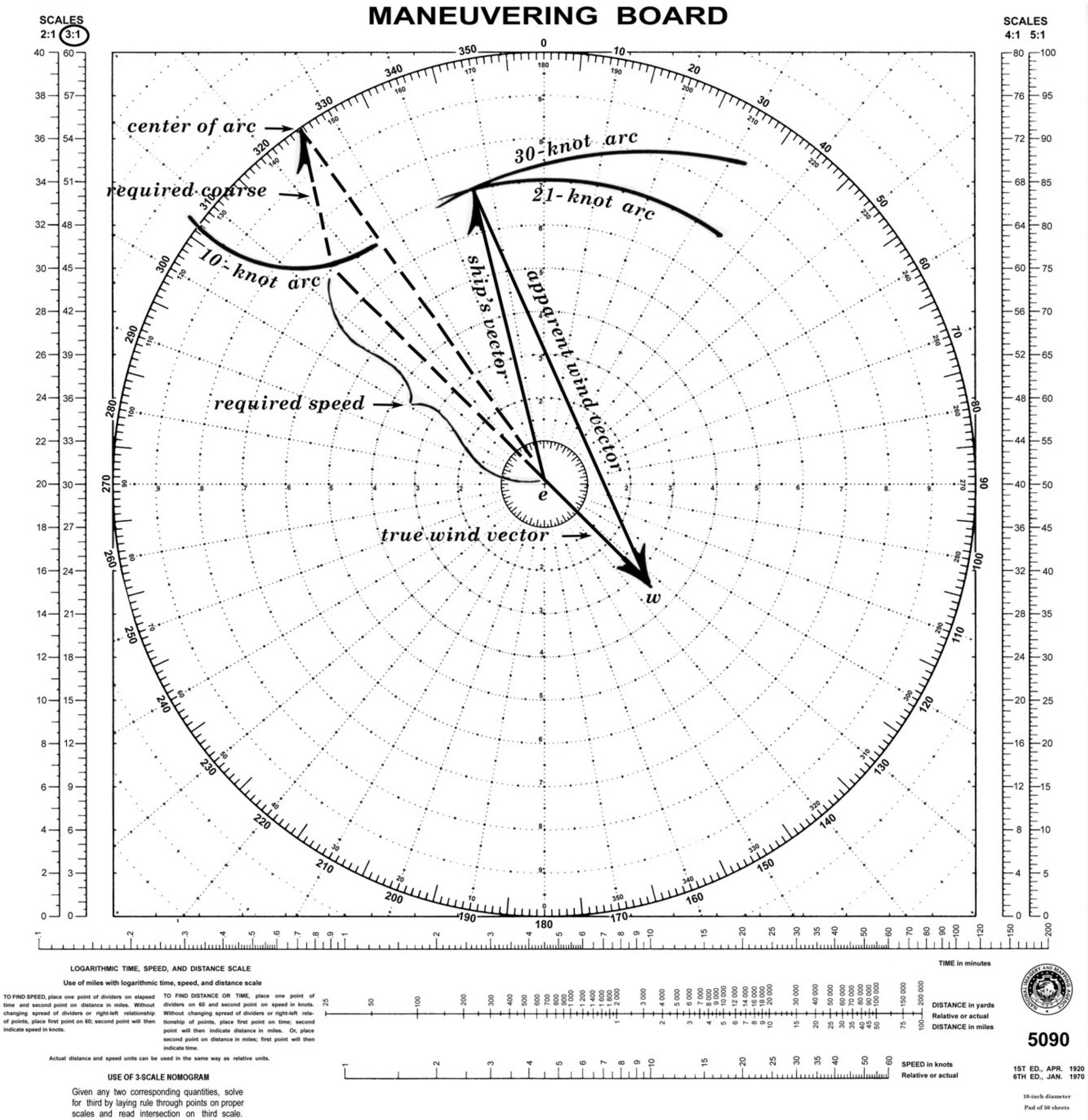
* *Use that intersection closest to the center of the polar diagram.*



OWN SHIP AT CENTER

EXAMPLE 11b

Scale: Speed 3:1

EXAMPLE 11c

DESIRED RELATIVE WIND
(Third Method)

Situation:

A ship is on course 240˚ speed 18 knots. True wind has been determined to be from 315˚ speed 10 knots.

Required:

Determine a course and speed that will produce a wind across the deck of 30 knots from 350˚ relative (10˚ port).

Solution:

(1) A preliminary step in the desired relative wind solution is to indicate on the polar plotting sheet the direction toward which the true wind is blowing. The direction of the true wind is along the radial from 315˚.

(2) The solution is to be effected by first finding the magnitude of the required ship's true (course-speed) vector; knowing the true wind (direction-speed) vector and the magnitude (30 knots) of the relative wind vector, and that the ship's course should be to the right of the direction from which the true wind is blowing, the vector triangle can then be constructed.

(3) Construct the true wind vector *ew*.

(4) With a pencil compass adjusted to the true wind (10 knots), set the point of the compass on the 30-knot circle at a point 10˚ clockwise from the intersection of the 30-knot circle with the radial extending in the direction toward which the wind is blowing. Strike an arc intersecting this radial. That part of the radial from the center of the plotting sheet to the intersection* represents the magnitude of the required ship's true vector (21 knots). The direction of a line extending from the center of the arc to the intersection with the radial is the direction of the ship's true vector.

(5) From *e* at the center of the plotting sheet, strike an arc of radius equal to 21 knots. From *w* at the head of the true wind vector, strike an arc of radius equal to 30 knots. Label intersection *r*. This intersection is to the right of the direction from which the true wind is blowing.

(6) Alternatively, the ship's true (course-speed) vector can be constructed by drawing vector *er* parallel to the direction established in (4) and to the magnitude also established in (4). On completing the vector triangle, the direction of the relative wind is 10˚ off the port bow.

Answer:

Course 346˚, speed 21 knots.

Note:

If the point of the compass had been set at a point on the 30-knot circle 10˚ counterclockwise from the radial extending in the direction from which the true wind is blowing in (4), the same magnitude of the ship's true vector would have been obtained. However, the direction established for this vector would have been for a 30-knot wind across the deck from 10˚ off the starboard bow.

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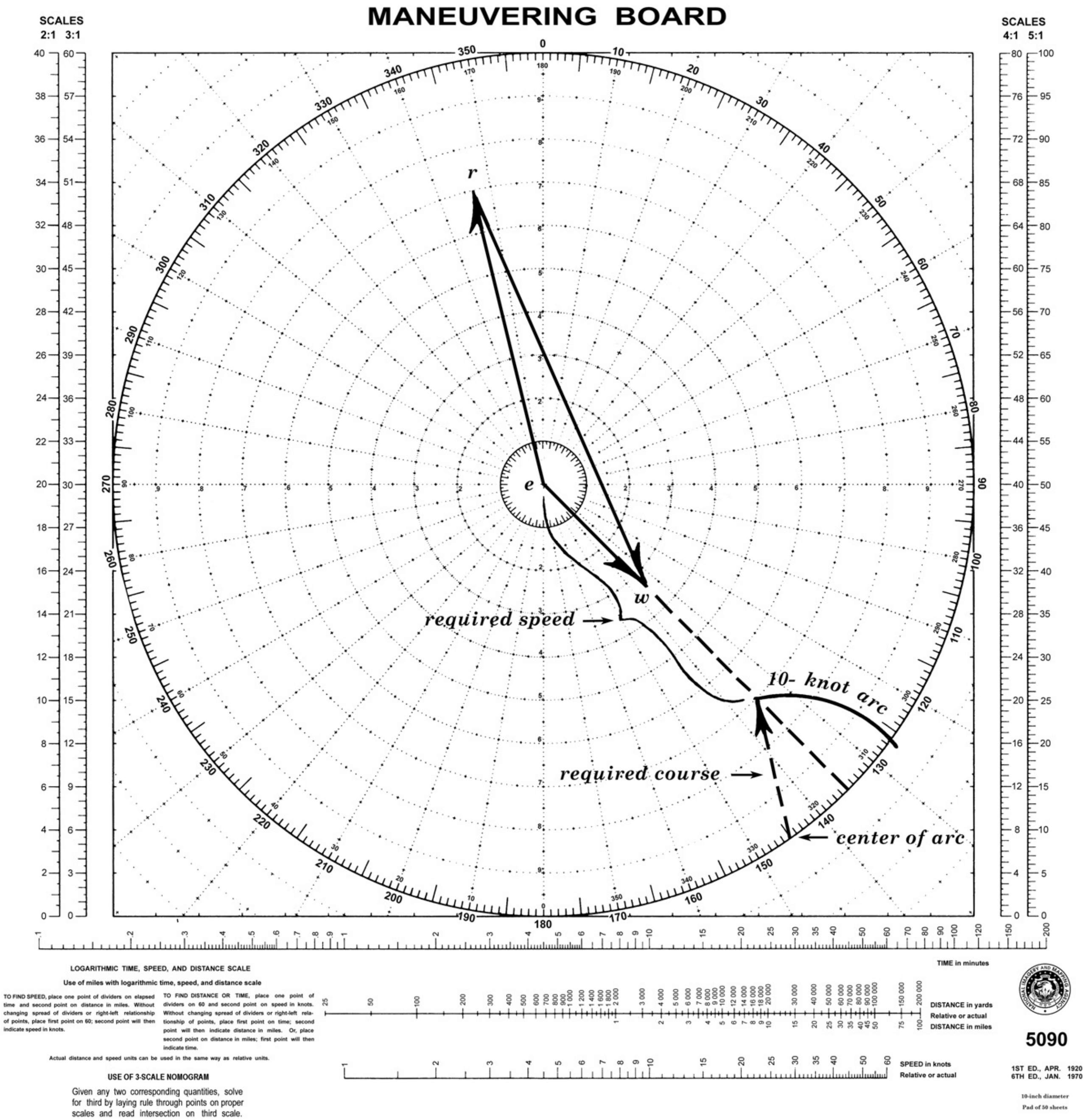
* *Use that intersection closest to the center of the polar diagram.*



OWN SHIP AT CENTER

EXAMPLE 11c

Scale: Speed 3:1

PRACTICAL ASPECTS OF MANEUVERING BOARD SOLUTIONS

The foregoing examples and their accompanying illustrations are based upon the premise that ships are capable of instantaneous changes of course and speed. It is also assumed that an unlimited amount of time is available for determining the solutions.

In actual practice, the interval between the signal for a maneuver and its execution frequently allows insufficient time to reach a complete graphical solution. Nevertheless, under many circumstances, safety and smart seamanship both require prompt and decisive action, even though this action is determined from a quick, mental estimate. The estimate must be based upon the principles of relative motion and therefore should be nearly correct. Course and speed can be modified enroute to new station when a more accurate solution has been obtained from a maneuvering board.

Allowance must be made for those tactical characteristics which vary widely between types of ships and also under varying conditions of sea and loading. Experience has shown that it is impractical to solve for the relative motion that occurs during a turn and that acceptable solutions can be found by eye and mental estimate.

By careful appraisal of the PPI and maneuvering board, the relative movement of own ship and the guide during a turn can be approximated and an estimate made of the relative position upon completion of a turn. Ship's characteristic curves and a few simple thumb rules applicable to own ship type serve as a basis for these estimates. During the final turn the ship can be brought onto station with small compensatory adjustments in engine revolutions and/or course.

EXAMPLE 12

ADVANCE, TRANSFER, ACCELERATION, AND DECELERATION

Situation:

Own ship *R* is a destroyer on station bearing 020˚, 8,000 yards from the guide *M*. Formation course is 000˚, speed 15 knots. *R* is ordered to take station bearing 120˚, 8,000 yards from guide, using 25 knots.

Required:

(1) Course to new station.
(2) Bearing of *M* when order is given to resume formation course and speed.
(3) Time to complete the maneuver.

Solution:

(1) Plot *R* at the center with M_1 bearing 200˚, 8,000 yards and M_2 bearing 300˚, 8,000 yards. Draw the guide's speed vector *em* 000˚, 15 knots.

By eye, it appears *R* will have to make a turn to the right of about 150˚, accelerating from 15 to 25 knots during the turn. Prior to reaching the new station a reverse turn of about the same amount and deceleration to 15 knots will be required. Assume that *R* averages 20 knots during each turn.

Using 30˚ rudder at 20 knots, a DD calibration curve indicates approximately 2˚ turn per second and a 600 yard tactical diameter. Thus, a 150˚ turn will require about 75 seconds and will produce an off-set of about 600 yards. During the turn, *M* will advance 625 yards ($1^1/_4$ minutes at 15 knots). Plotting this approximate off-set distance on the maneuvering board gives a new relative position of M_3 at the time the initial turn is completed. Similarly, a new off-set position at M_4 is determined where *R* should order a left turn to formation course and reduction of speed to 15 knots.

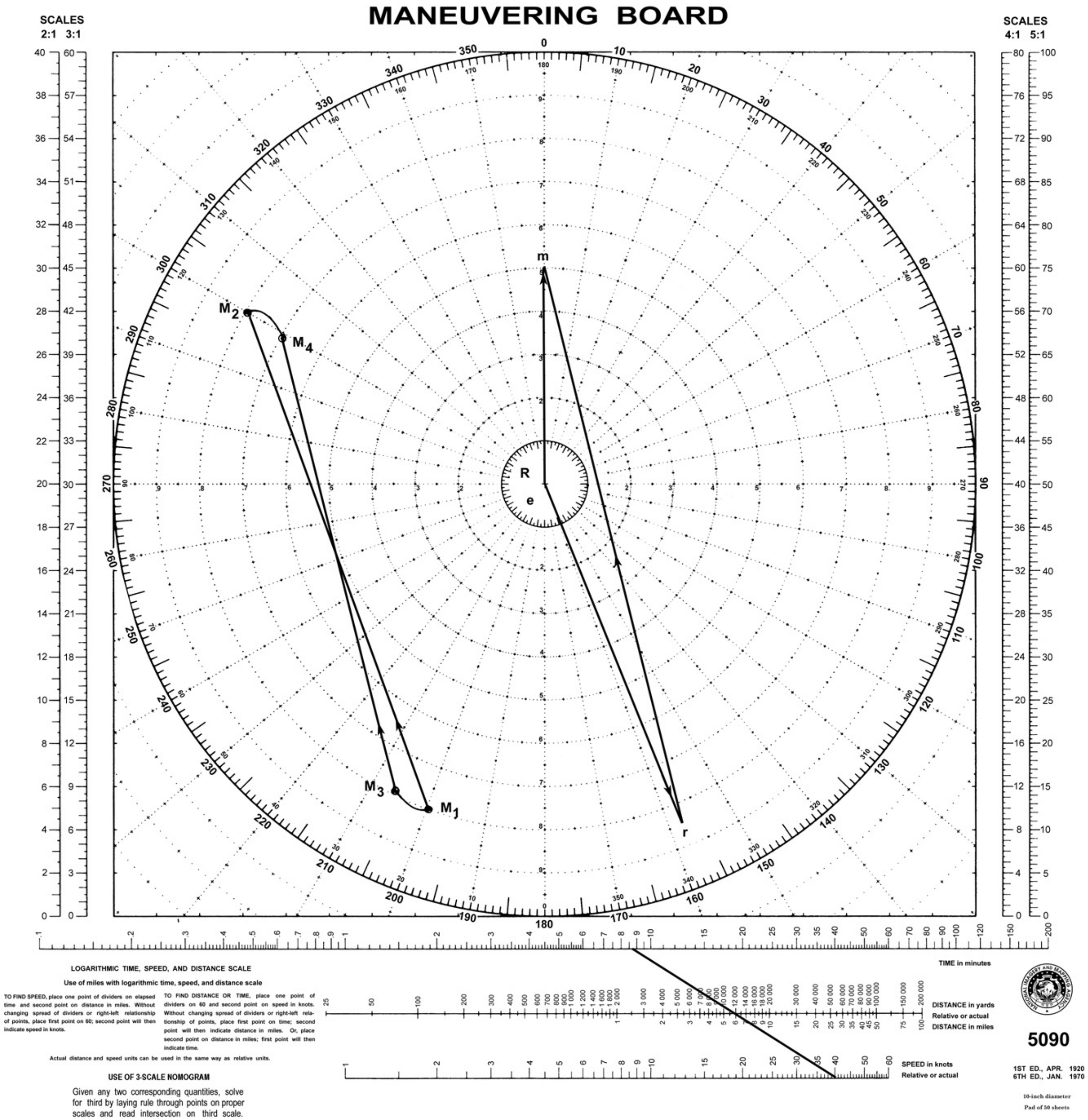
Draw a line to *m* parallel to and in the direction of M_3M_4 and intersecting the 25-knot speed circle at *r*. Vector *er* is the required course of 158˚.

(2) When *M* reaches point M_4 bearing 299˚, turn left to formation course using 30˚ rudder and slow to 15 knots.

(3) Time to complete the maneuver is M_3M_4/SRM + 2.5 minutes = 11,050 yards/39.8 knots + 2.5 minutes = 11 minutes.

Answer:

(1) Course 158˚.
(2) Bearing 299˚.
(3) Time 11 minutes.



OWN SHIP AT CENTER

EXAMPLE 12

Scale: Speed 3:1;
Distance 1:1 yd.

COLLISION AVOIDANCE

Numerous studies and the inventive genius of man have provided the mariner with adequate means for virtually eliminating collisions at sea. One of the most significant of these is radar. However, radar is merely an aid, and is no substitute for good judgment coupled with good seamanship. Its use grants no special license in applying the Rules of the Road in a given situation. Properly interpreted, however, the information it does provide the mariner can be of inestimable value in forewarning him of possible danger.

The following example is a practical problem encountered in the approaches to many of the world's busy ports.

EXAMPLE 13

AVOIDANCE OF MULTIPLE CONTACTS

Situation:

Own ship is proceeding toward a harbor entrance about 30 miles to the southeast. Own ship's course 145˚, speed 15 knots. Visibility is estimated to be 2 miles. Numerous radar contacts are being made. At the present time, 2235, six pips are being plotted on the PPI scope.

Problems:

(1) By visual inspection of the PPI (Fig. 1), which of the contacts appear dangerous and require plotting on a maneuvering board? (Radar is set on 20-mile range scale.)

(2) After plotting the contacts selected in (1), what are their CPA's, true courses and speeds? (Fig. 2 is an example.)

(3) Assume the PPI plots indicate all contacts have maintained a steady course and speed during your solution in (2). What maneuvering action, if any, do you recommend? (Fig. 2 shows one possibility.)

(4) Assume that you maneuver at 2238 and all other ships maintain their courses and speeds. What are the new CPA's of the dangerous contacts in (2) above? (Fig. 2 shows a possible solution.)

(5) Assume that all ships maintain course and speed from 2238 until 2300. What will be the PPI presentation at 2300? (Fig. 3 is an example.)

(6) At what time would you return to original course and speed or make other changes?

Solutions:

(1) Ships *E* and *F* look dangerous. Their bearings are almost steady and range is decreasing rapidly. *F* will reach the center in about one half hour. All other contacts appear safe enough to merely track on the scope. *A* is closing, but too slowly to be of concern for several hours. *B* is overtaking at a very slow rate. *C* should cross well clear astern in about an hour. *D* is harmless and needs only cursory checks.

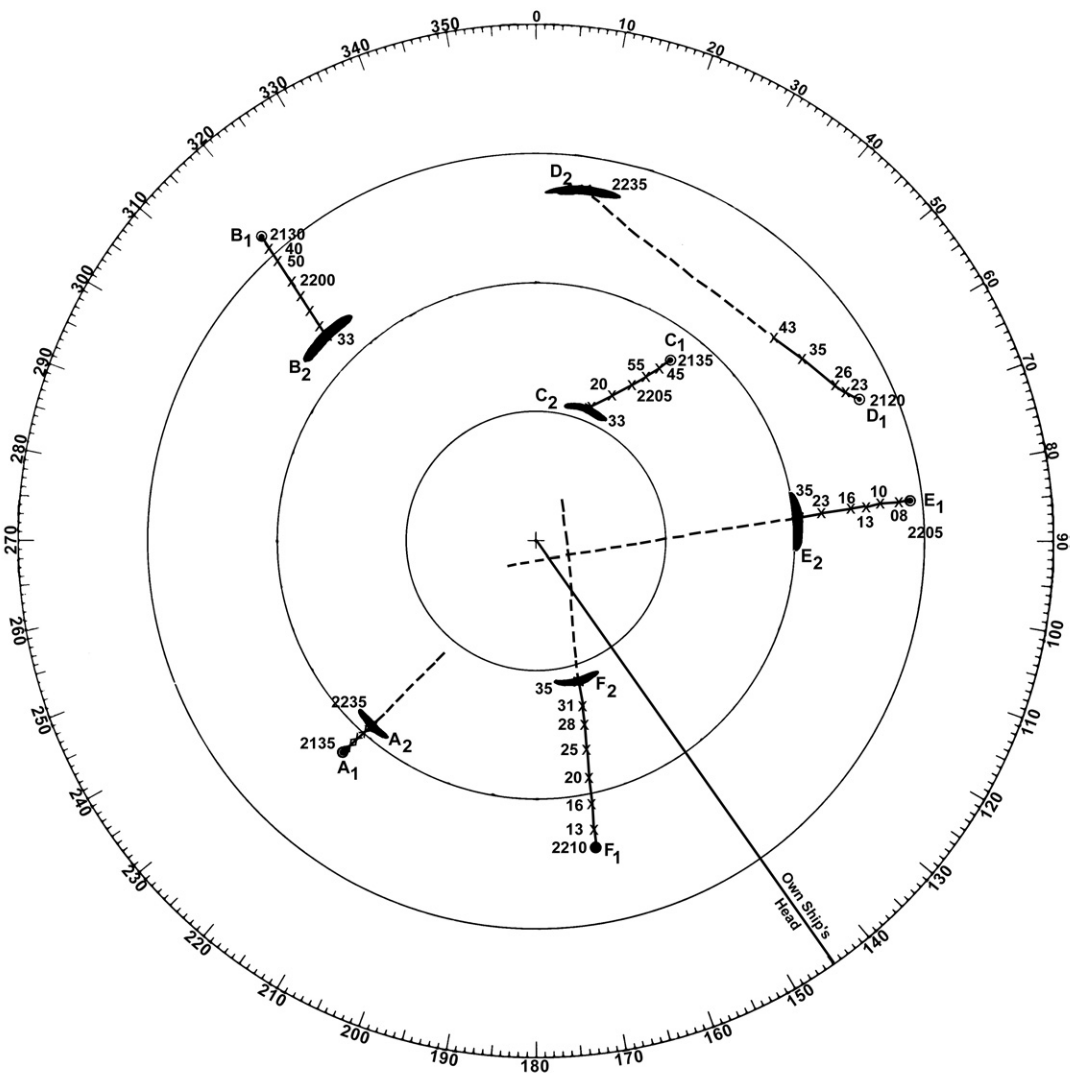
		CPA	Time	Course	Speed
(2)	Ship *F* ...	1,700 yds.	2258	069˚	7.5 knots
	Ship *E* ...	1,900 yds.	2338	182˚	14.0 knots

(3) Change course to 180˚, maintain 15 knots.

		CPA	Time
(4)	Ship *F* ...	6,300 yds.	2250
	Ship *E* ...	17,700 yds.	(Both own ship and *E* are now on about the same course with *E* drawing very slowly astern. CPA thus has little meaning.)

(5) See Fig. 3. *D* has faded from the scope.

(6) With *F* well clear at 2300, a return to original course appears desirable. Apparently *A*, *B*, and *C* also are making the same approach and should cause no trouble. The intentions of *E* are unknown but you have about an hour's time before convergence.



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EXAMPLE 13 Figure 1

PPI SCOPE (20-mile scale)

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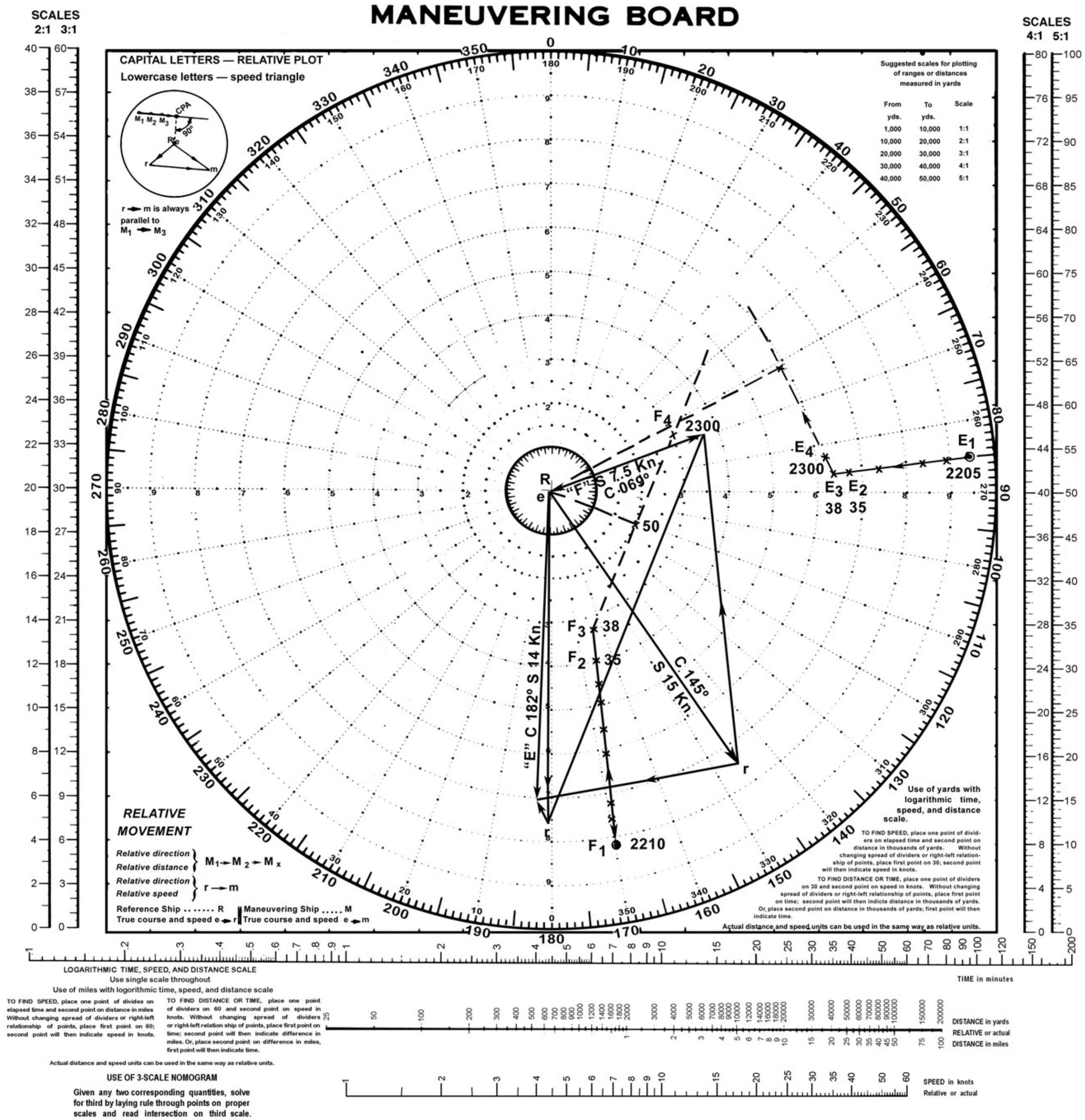
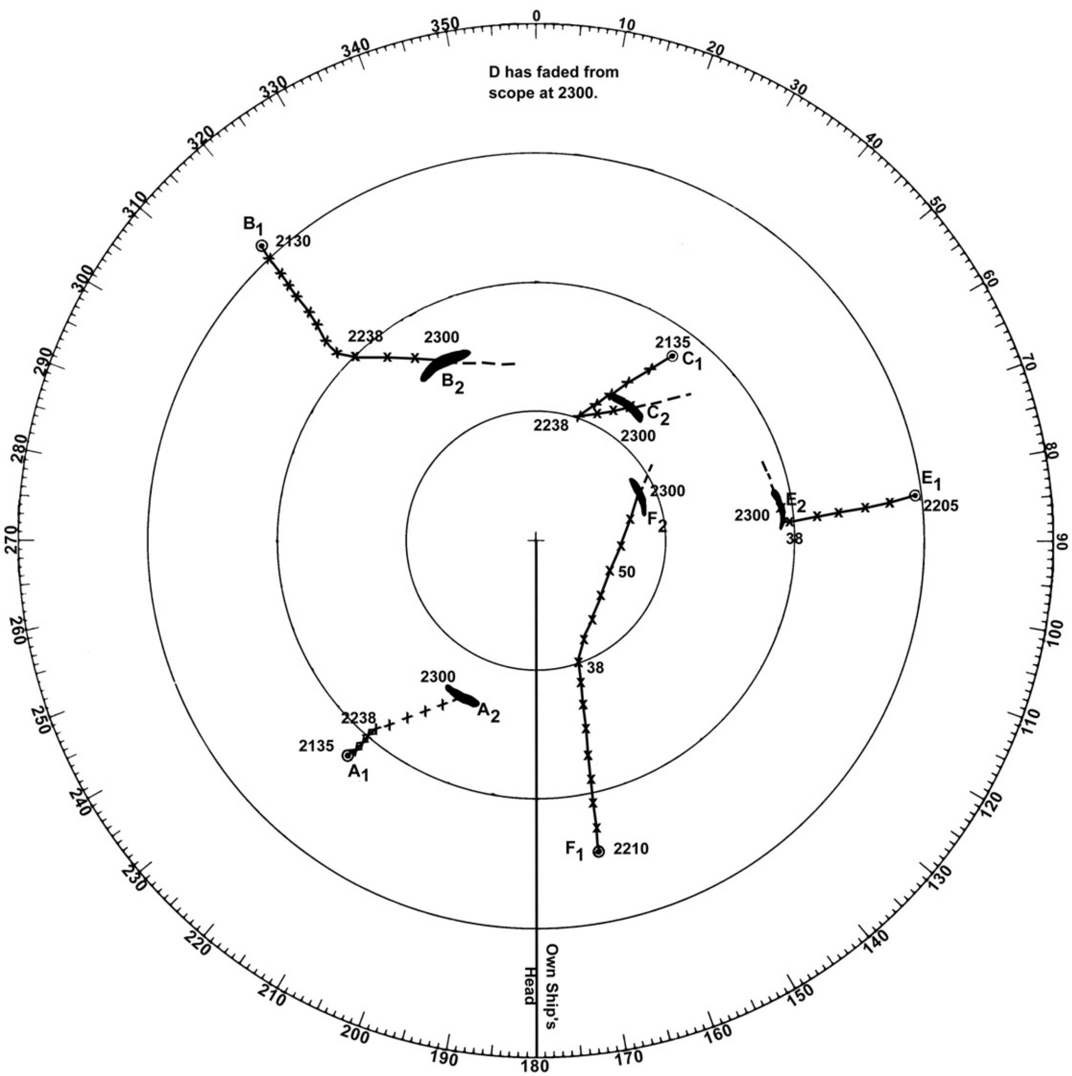


EXAMPLE 13 Figure 2

Scale: Speed 2:1; Distance 3:1 yd.



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EXAMPLE 13 Figure 3

PPI SCOPE (20-mile scale)

EXAMPLE 14

AVOIDANCE OF MULTIPLE CONTACTS WITHOUT FIRST DETERMINING THE TRUE COURSES AND SPEEDS OF THE CONTACTS

Situation:

Own ship *R* is on course 000˚, speed 20 knots. With the relative motion presentation radar set at the 12-mile range setting, radar contacts are observed as follows:

Time 1000

	Bearing	*Range (mi.)*	*Rel. position*
Contact *A*	050˚	9.0	A_1
Contact *B*	320˚	8.0	B_1
Contact *C*	235˚	8.0	C_1

Time 1006

	Bearing	*Range (mi.)*	*Rel. position*
Contact *A*	050˚	7.5	A_2
Contact *B*	333˚	6.0	B_2
Contact *C*	225˚	6.0	C_2

Required:

(1) Determine the new relative movement lines for contacts *A*, *B*, and *C* which would result from own ship changing course to 065˚ and speed to 15 knots at time 1006.

(2) Determine whether such course and speed change will result in desirable or acceptable CPA's for all contacts.

Solution:

(1) With the center of the radarscope as their origin, draw own ship's true vectors *er* and *er'* for the speed in effect or to be put in effect at times 1000 and 1006, respectively. Using the distance scale of the radar presentation, draw each vector of length equal to the distance own ship *R* will travel through the water during the time interval of the relative plot (relative vector), 6 minutes. Vector *er*, having a speed of 20 knots, is drawn 2.0 miles in length in true direction 000˚; vector *er'*, having a speed of 15 knots, is drawn 1.5 miles in length in true direction 065˚.

(2) Draw a dashed line between *r* and *r'*.

(3) For Contacts *A*, *B*, and *C*, offset the initial plots (A_1, B_1, and C_1) in the same direction and distance as the dashed line *r-r'*; label each such offset plot *r'*.

(4) In each relative plot, draw a straight line from the offset initial plot, *r'*, through the final plot (A_2 or B_2 or C_2). The lines $r'A_2$, $r'B_2$, and $r'C_2$ represent the new RML's which would result from a course change to 065˚ and speed change to 15 knots at time 1006.

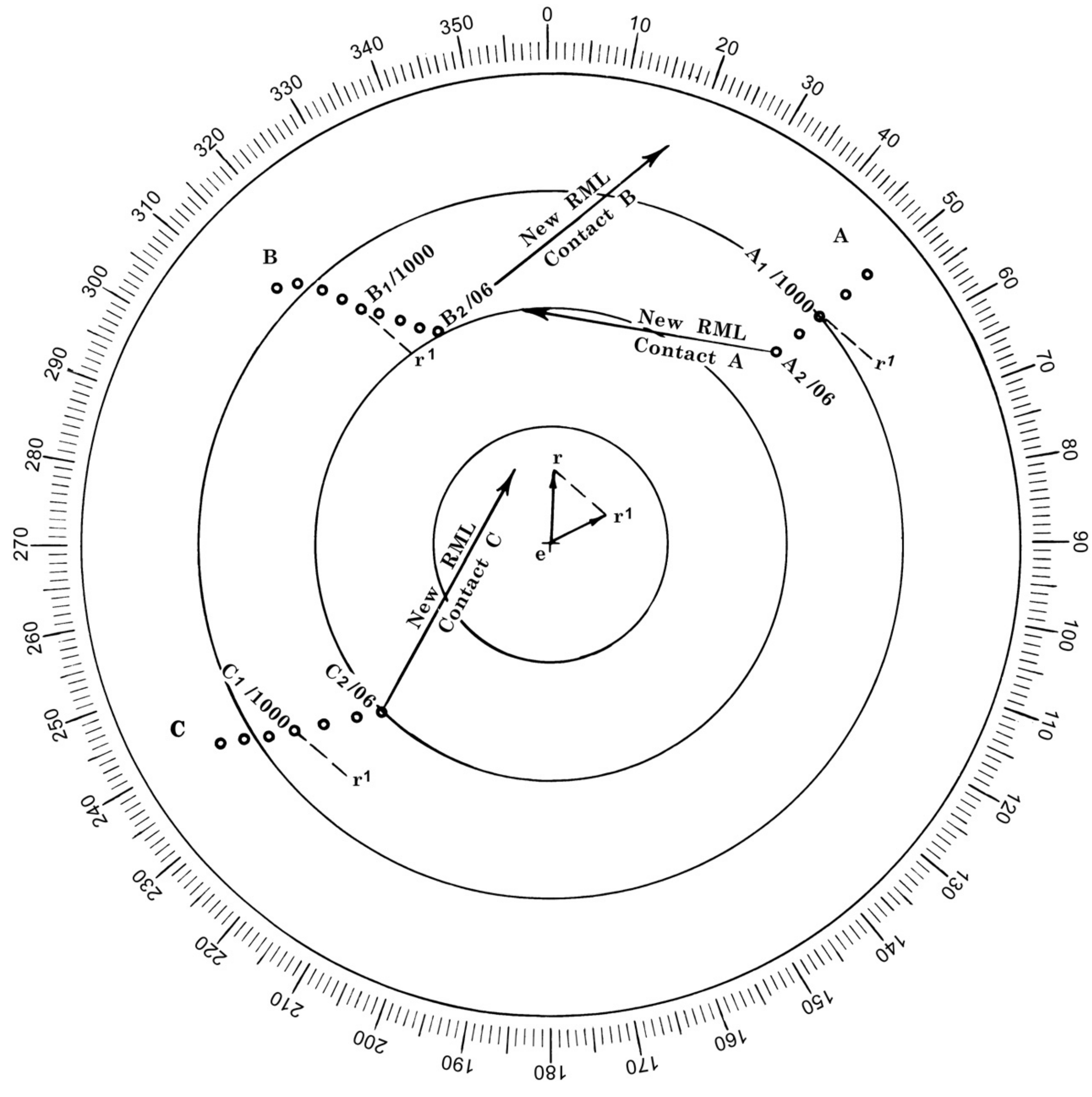
Answer:

(1) New DRM of Contact *A* 280˚.
New DRM of Contact *B* 051˚.
New DRM of Contact *C* 028˚.

(2) Inspection of the new relative movement lines for all contacts indicates that if all contacts maintain course and speed, all contacts will plot along their respective relative movement lines at safe distances from own ship *R* on course 065˚, speed 15 knots.

Explanation:

The solution method is based upon the use of the relative plot as the relative vector as illustrated in Example 4. With each contact maintaining true course and speed, the *em* vector for each contact remains static while own ship's vector is rotated about *e* to the new course and changed in magnitude corresponding to the new speed.



OWN SHIP AT CENTER

EXAMPLE 14

Scale: 12-mile range setting

EXAMPLE 15

DETERMINING THE CLOSEST POINT OF APPROACH FROM THE GEOGRAPHICAL PLOT

Situation:

Own ship is on course 000°, speed 10 knots. The true bearings and ranges of another ship are plotted from own ship's successive positions to form a geographical (navigational) plot:

Time	*Bearing*	*Range (mi.)*	*True position*
0200	074°	7.3	T_1
0206	071°	6.3	T_2
0212	067°	5.3	T_3

Required:

(1) Determine the Closest Point of Approach.

Solution:

(1) Since the successive *timed* positions of each ship of the geographical plot indicate rate of movement and true direction of travel for each ship, each line segment between successive plots represents a true velocity vector. Equal spacing of the plots timed at regular intervals and the successive plotting of the true positions in a straight line indicate that the other ship is maintaining constant course and speed.

(2) The solution is essentially a reversal of the procedure in relative motion solutions in which, from the relative plot and own ship's true vector, the true vector of the other ship is determined. Accordingly, the true vectors from the two true plots for the same time interval, 0206-0212 for example, are subtracted to obtain the relative vector $(\overrightarrow{rm} = \overrightarrow{em} - \overrightarrow{er})$.

(3) The relative (DRM-SRM) vector *rm* is extended beyond own ship's 0212 position to form the relative movement line (RML).

(4) The closest point of approach (CPA) is found by drawing a line from own ship's 0212 plot perpendicular to the relative movement line.

Answer:

(1) CPA 001°, 2.2 miles.

Explanation:

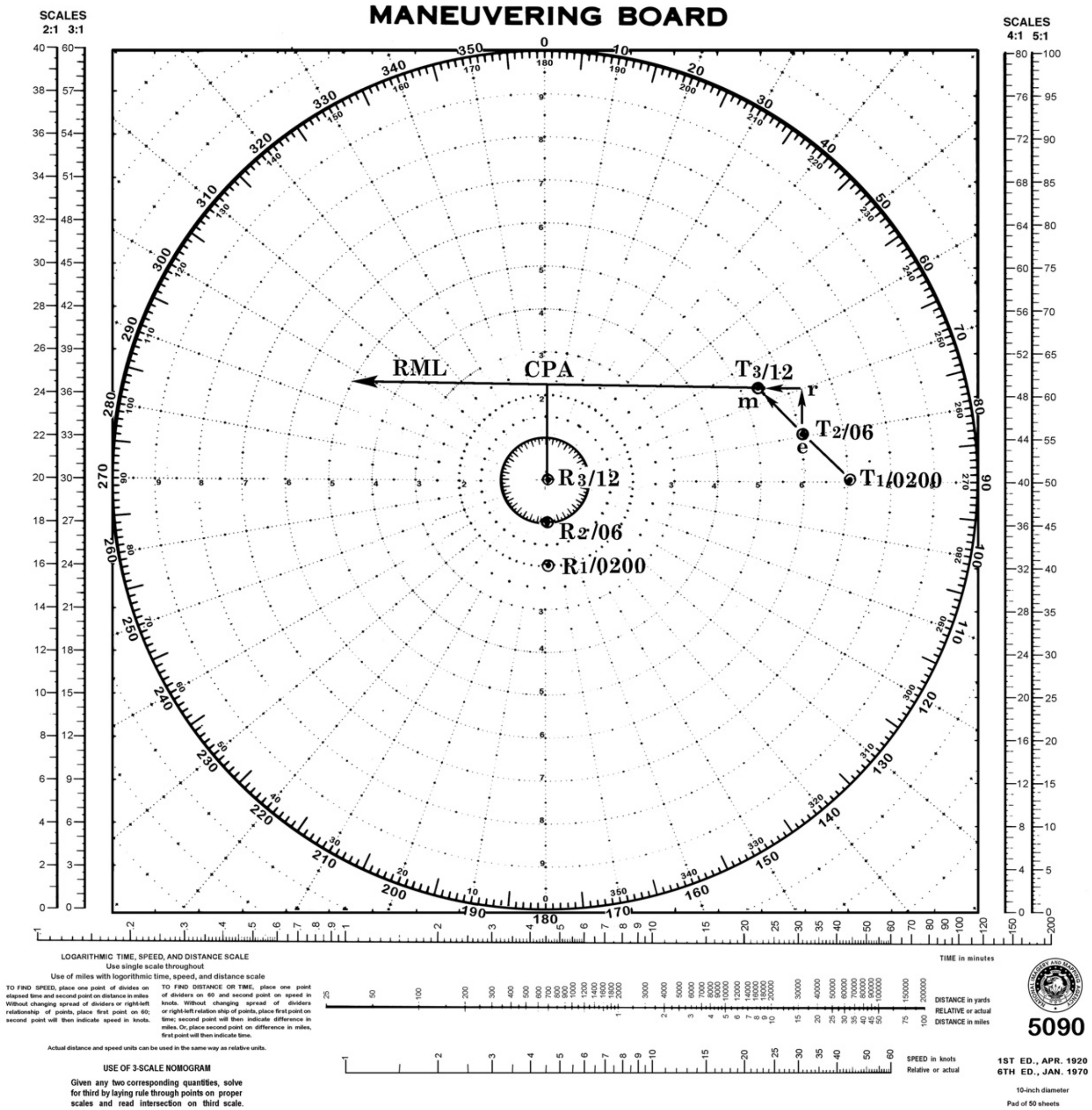
This solution is essentially a reversal of the procedure in relative motion solutions in which, from the relative plot and own ship's true vector, the true vector of the other ship is determined. See Example 3.

Notes:

(1) Either the time 0200, 0206, or 0212 plots of the other ship can be used as the origin of the true vectors of the vector diagram. Using the time 0200 plot as the origin and a time interval of 6 minutes for vector magnitude, the line perpendicular to the extended relative movement line would be drawn from the time 0206 plot of own ship.

(2) A practical solution for CPA in the true motion mode of operation of a radar is based on the fact that the end of the Interscan (electronic bearing cursor) moves from the point, at which initially set, in the direction of own ship's course at a rate equivalent to own ship's speed. With the contact at this point, initially, the contact moves away from the point in the direction of its true course at a rate equivalent to its speed. Thus, as time passes, a vector triangle is being continuously generated. At any instant, the vertices are the initial point, the position of the contact, and the end of the Interscan. The side of the triangle between the end of the Interscan and the contact is the *rm* vector, the origin of which is at the end of the Interscan.

The CPA is found by setting the end of the Interscan at the contact, and, after the vector triangle has been generated, extending the *rm* vector beyond own ship's position of the PPI.



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EXAMPLE 15

Scale: Distance: 1:1 mi.

EXAMPLE 16

COURSE AND SPEED BETWEEN TWO STATIONS, REMAINING WITHIN A SPECIFIED RANGE FOR SPECIFIED TIME INTERVAL ENROUTE

Situation:

Own ship *R* is on station bearing 280˚, 5 miles from the guide *M* which is on course 190˚, speed 20 knots.

Required:

At 1500 proceed to new station bearing 055˚, 20 miles, arriving at 1630. Remain within a 10-mile range for 1 hour. The commanding officer elects to proceed directly to new station adjusting course and speed to comply.

(1) Course and speed to remain within 10 miles for 1 hour.

(2) Course and speed required at 1600.

(3) Bearing of *M* at 1600.

Solution:

(1) Plot the 1500 and 1630 positions of *M* at M_1 and M_3, respectively. Draw the relative motion line, M_1M_3, intersecting the 10-mile circle at M_2. Draw *em*. Measure M_1M_2: 13.6 miles. The time required to transit this distance is 1 hour at an SRM of 13.6 knots. Through *m* draw $r_1\,m$ 13.6 knots in length, parallel to and in the direction M_1M_3. Vector er_1 is 147˚.5, 16.2 knots.

(2) Measure M_2M_3, 10.3 miles, which requires an SRM of 20.6 knots for one half hour. Through *m* draw $r_2\,m$. Vector er_2 is 125˚.5, 18.2 knots.

(3) By inspection, M_2 bears 226˚ from *R* at 1600.

Answer:

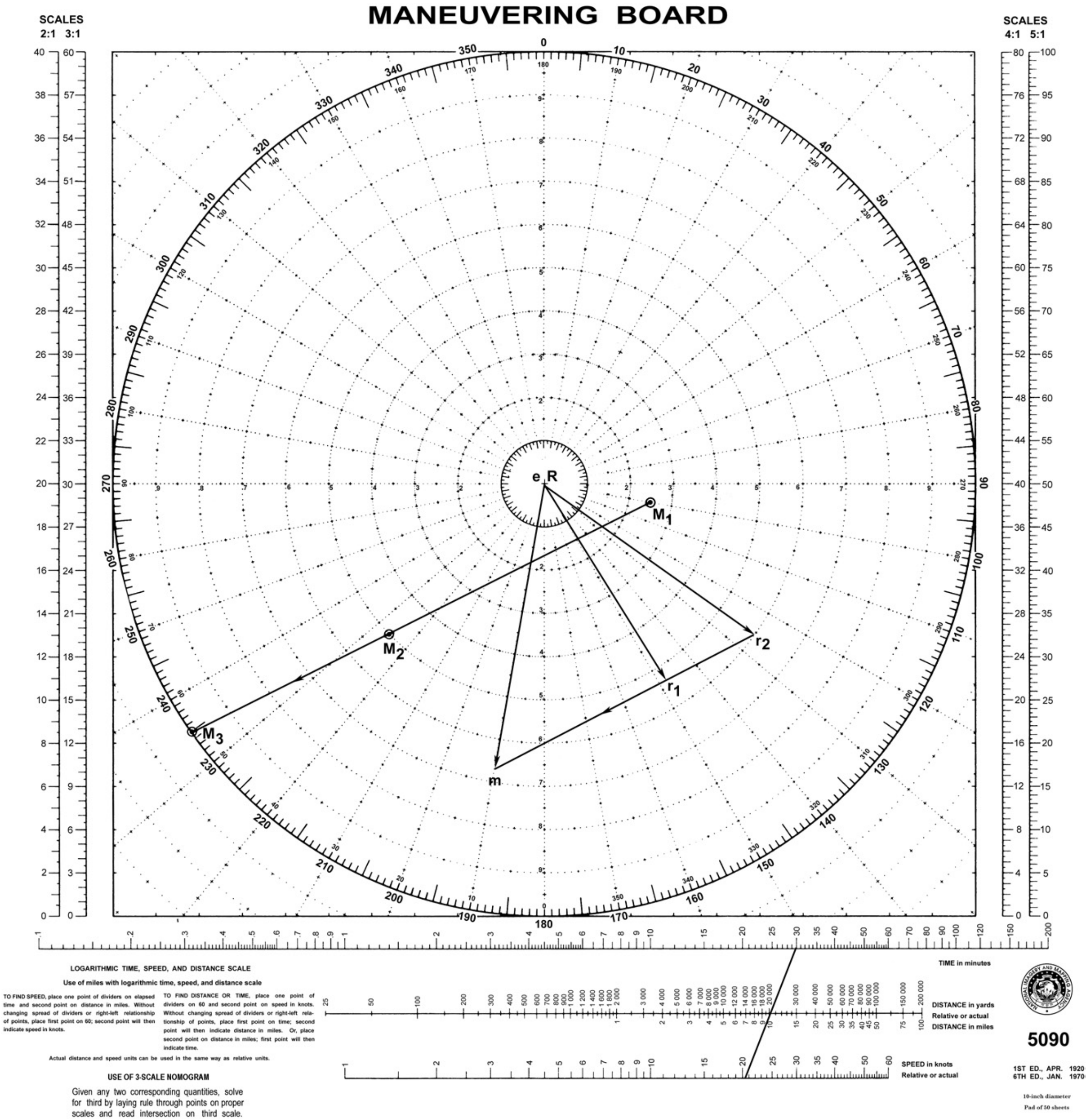
(1) Course 148˚, speed 16.2 knots.

(2) Course 126˚, speed 18.2 knots.

(3) Bearing 226˚.

Explanation:

Since own ship *R* must remain within 10 miles of the guide for 1 hour, *M* must not plot along M_1M_2 farther than M_2 prior to 1600. The required magnitudes of the relative speed vectors for time intervals 1500 to 1600 and 1600 to 1630 together with their common direction are combined with the true vector of the guide to obtain the two true course vectors for own ship.



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EXAMPLE 16

Scale: Speed 3:1; Distance 2:1 mi.

EXAMPLE 17

COURSE AT MAXIMUM SPEED TO OPEN RANGE TO A SPECIFIED DISTANCE IN MINIMUM TIME

Situation:

Own ship *R* has guide *M* bearing 240˚, range 12 miles. The guide is on course 120˚, speed 15 knots. Own ship's maximum speed is 30 knots.

Required:

Open range to 18 miles as quickly as possible.

(1) Course at 30 knots.

(2) Time to complete the maneuver.

(3) Bearing of guide upon arrival at specified range.

Solution:

The key to this solution is to find that relative position (*M′*) of the guide that could exist *before* the problems starts in order to be able to draw the RML through the given relative position (M_1) and *M′* to intersect the specified range circle.

(1) Plot *R* and M_1. About *R* describe a circle of radius 18 miles. Draw *em*. On the reciprocal of *M*'s course plot *M′* 9 miles from *R*.

$$\frac{\text{Speed of } M}{\text{Speed of } R} \times 18 \text{ miles} = 9 \text{ miles}$$

Draw a line through *M′* and M_1 and extend it to intersect the 18-mile range circle at M_2.

Through *m* draw *rm* parallel to and in the direction M_1M_2. The intersection of *rm* and the 30-knot speed circle is the course required to complete the maneuver in minimum time. Vector *er* is 042˚.6, 30 knots.

(2) SRM is 30.5 knots. MRM is 7.5 miles. Time to complete the maneuver: 14.8 minutes.

(3) Upon reaching the 18-mile range circle, *M* is dead astern of *R* bearing 222˚.6.

Answer:

(1) Course 043˚.

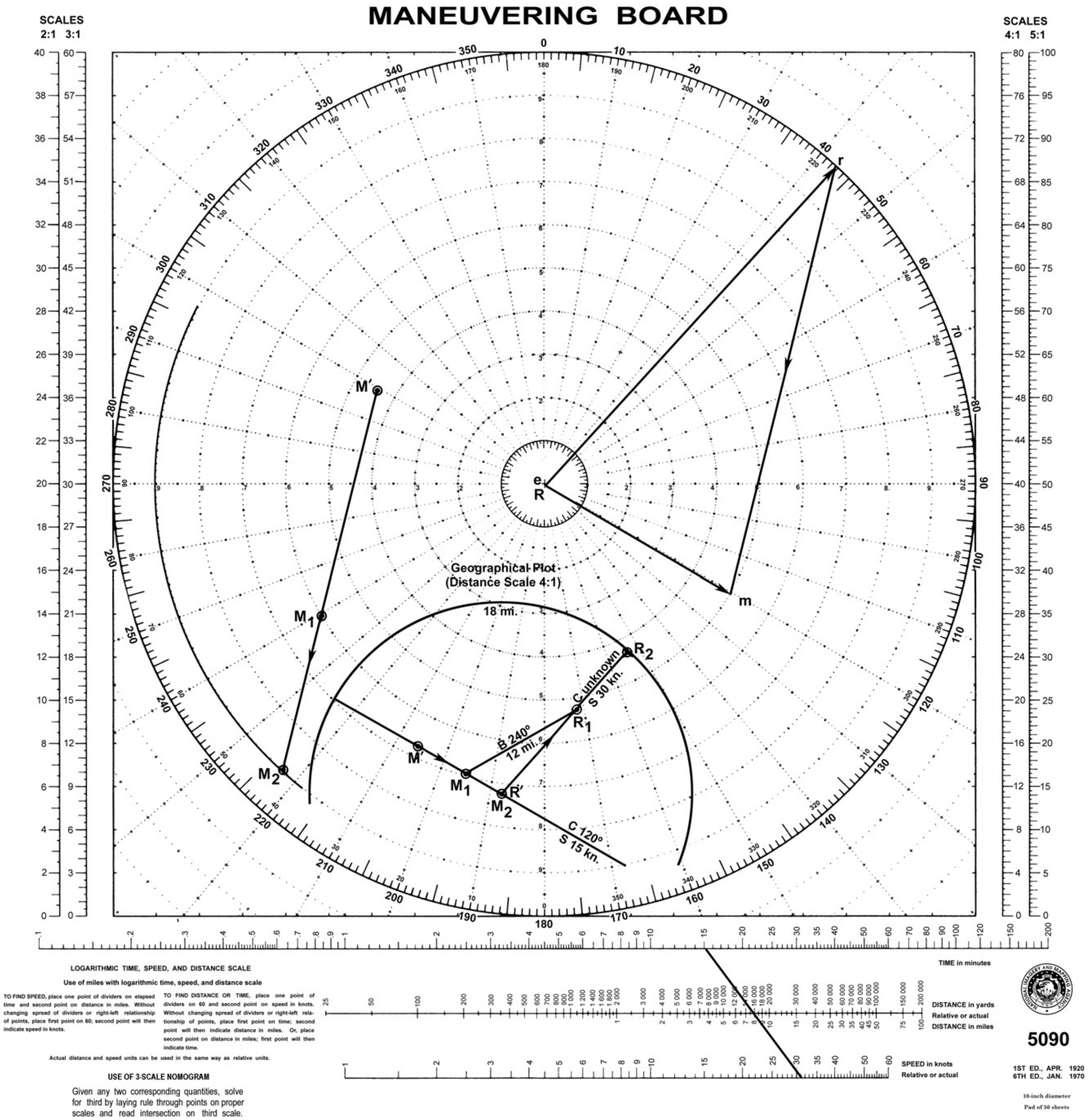
(2) Time 15 minutes.

(3) Bearing 223˚.

Explanation:

For *R* to open or close to a specified range in minimum time, *R* must travel the shortest geographical distance at maximum speed. The shortest distance is along the radius of a circle centered at the position occupied by *M* at the instant *R* reaches the specified range circle.

In the "opening range" problem, determine hypothetical relative positions of *M* and *R* that could exist *before the problem starts*. Referring to the **geographical plot**, assume *R* starts from position *R′* and proceeds outward along some radius 18 miles in length on an unknown course at 30 knots. If *M* moves toward its final position at M_2 along the given course of 120˚, speed 15 knots, it should arrive at M_2 the instant *R* reaches the 18-mile circle. At this instant, the problem conditions are satisfied by *R* being 18 miles distant from *M*. However, own ship's course required to reach this position is not yet known. During the time interval *R* opens 18 miles at 30 knots, *M* moves 9 miles at 15 knots from *M′* on *M*'s track. This provides the needed second relative position of *M′* from *R′*, 9 miles bearing 300˚. This position is then transferred to the **relative plot**.



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EXAMPLE 17

Scale: Speed 3:1;
Distance 2:1 mi.

EXAMPLE 18

COURSE AT MAXIMUM SPEED TO CLOSE RANGE TO A SPECIFIED DISTANCE IN MINIMUM TIME

Situation:

Own ship *R* has the guide *M* bearing 280˚, range 10 miles. The guide is on course 020˚, speed 15 knots. Own ship's maximum speed is 24 knots.

Required:

Close range to 2 miles as quickly as possible.
(1) Course at 24 knots.
(2) Time to complete the maneuver.
(3) Bearing of guide upon arrival at the specified range.

Solution:

The key to this solution is to find that relative position (M') of the guide that could exist *after* the problem starts in order to be able to draw the RML through the given relative position (M_1) and M' to intersect the specified range circle.

(1) Plot *R* and M_1. About *R* describe a circle of radius 2 miles. Draw *em*. On *M*'s course plot M' 1.25 miles from *R*.

$$\frac{\text{Speed of } M}{\text{Speed of } R} \times 2 \text{ miles} \;=\; 1.25 \text{ miles}$$

Draw a line through M' and M_1. The intersection of this line and the 2-mile range circle is M_2.

To *m* draw a line parallel to and in the direction M_1M_2. The intersection of this line and the 24-knot speed circle is the course required to complete the maneuver in minimum time. Vector *er* is 309˚.8, 24 knots.

(2) SRM is 23.6 knots. MRM is 8.3 miles. Time to complete the maneuver: 21.1 minutes.

(3) Upon reaching the 2-mile range circle, *M* is dead ahead of *R* on a bearing 309˚.8.

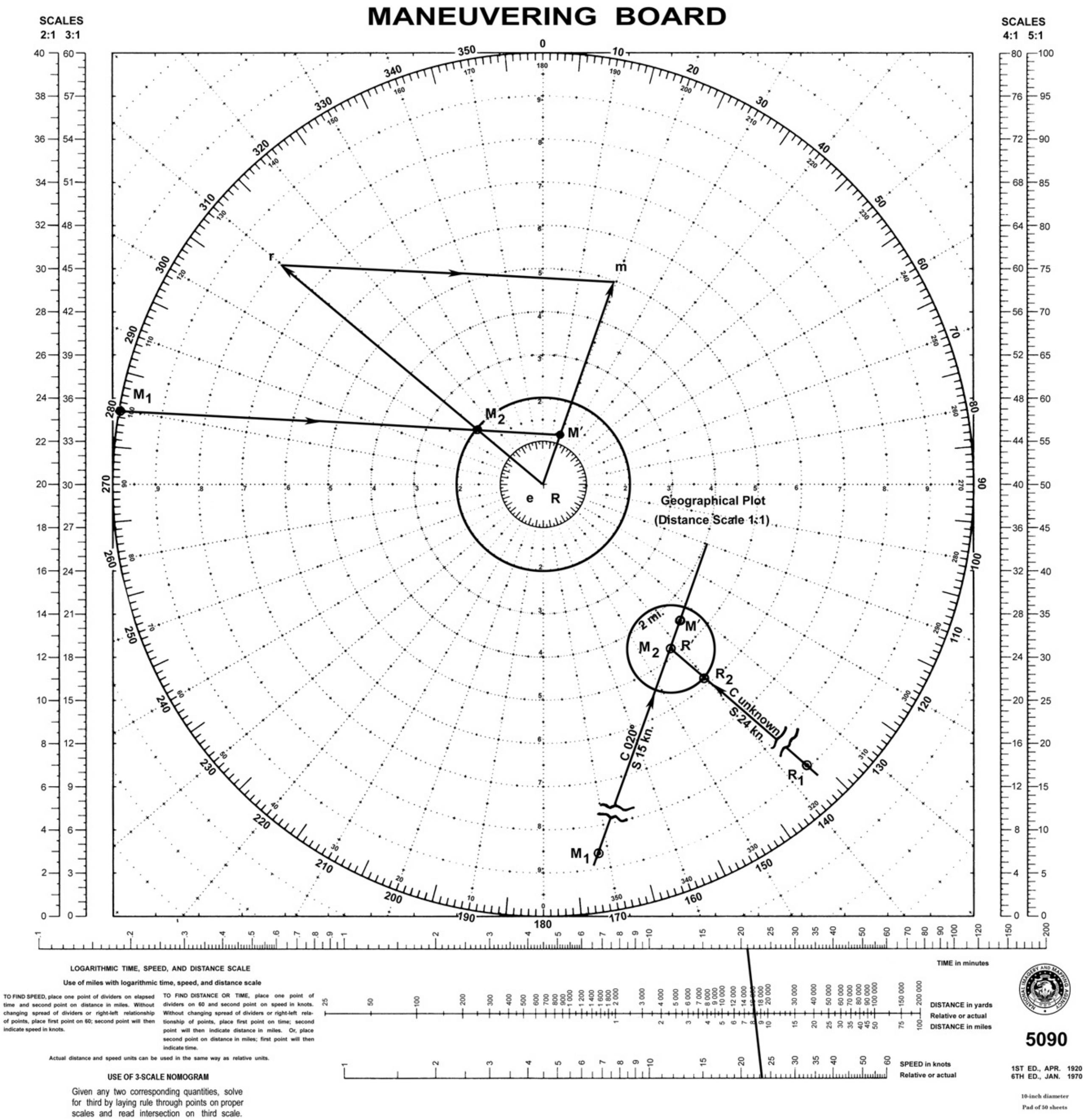
Answer:

(1) Course 310˚.
(2) Time 21 minutes.
(3) Bearings 310˚.

Explanation:

For *R* to open or close to a specified range in minimum time, *R* must travel the shortest geographical distance at maximum speed. The shortest distance is along the radius of a circle centered at the position occupied by *M* at the instant *R* reaches the specified range circle.

In the "closing range" problem, determine hypothetical relative positions of *M* and *R* that could exist *after the problem ends*. Referring to the **geographical plot**, assume *R* starts from position R_1 and proceeds inward along some radius on an unknown course at 24 knots. If *M* moves toward its final position at M_2 along the given course 020˚, speed 15 knots, it should arrive at M_2 the instant *R* reaches the 2-mile circle. At this instant the problem conditions are satisfied although the solution for own ship's course is not yet known. Assume that *R* continues on the same course and speed through the 2 miles to the center of the circle while *M* moves away from the center on course 020˚, speed 15 knots. During the time interval *R* moves these 2 miles at 24 knots, *M* opens 1.25 miles. This provides the needed second relative position of M' from R': 1.25 miles, bearing 020˚. This position is then transferred to the **relative plot**.



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EXAMPLE 18

Scale: Speed 3:1; Distance 1:1 mi.

EXAMPLE 19

COURSE AT MAXIMUM SPEED TO REMAIN WITHIN A SPECIFIED RANGE FOR MAXIMUM TIME

Situation:

Ship *M* bears 110˚, 4 miles from *R*. *M* is on course 230˚, 18 knots. Maximum speed of *R* is 9 knots.

Required:

Remain within a 10-mile range of *M* for as long as possible.
(1) Course at maximum speed.
(2) Bearing of *M* upon arrival at specified range.
(3) Length of time within specified range.
(4) CPA.

Solution:

(1) Plot *R* and *M*. About *R* describe circles of radius 9 knots and range 10 miles. Draw *em*. On *M*'s course, plot *M'* 20 miles from *R*.

$$\frac{\text{Speed of } M}{\text{Speed of } R} \times 10 \text{ miles} = 20 \text{ miles}$$

Draw a line through *M'* and M_1. The intersection of the 10-mile range circle and $M'M_1$ is M_2, the point beyond which the specified or limiting range is exceeded. Through *m* draw *rm* parallel to and in the direction M_1M_2. The intersection of *rm* and the 9-knot speed circle is the course required for *R*, at 9 knots, to remain within 10 miles of *M*. Vector *er* is 220˚.8, 9 knots.

(2) Upon arrival at limiting range at M_2, *M* is dead ahead of *R* bearing 220˚.8.

(3) The time interval within specified range is:

$$\frac{M_1M_2}{rm} = \frac{12 \text{ miles}}{9.1 \text{ knots}} = 78.8 \text{ minutes}$$

(4) Drop a perpendicular from *R* to M_1M_2. CPA is 148˚.9, 3.1 miles.

Note:

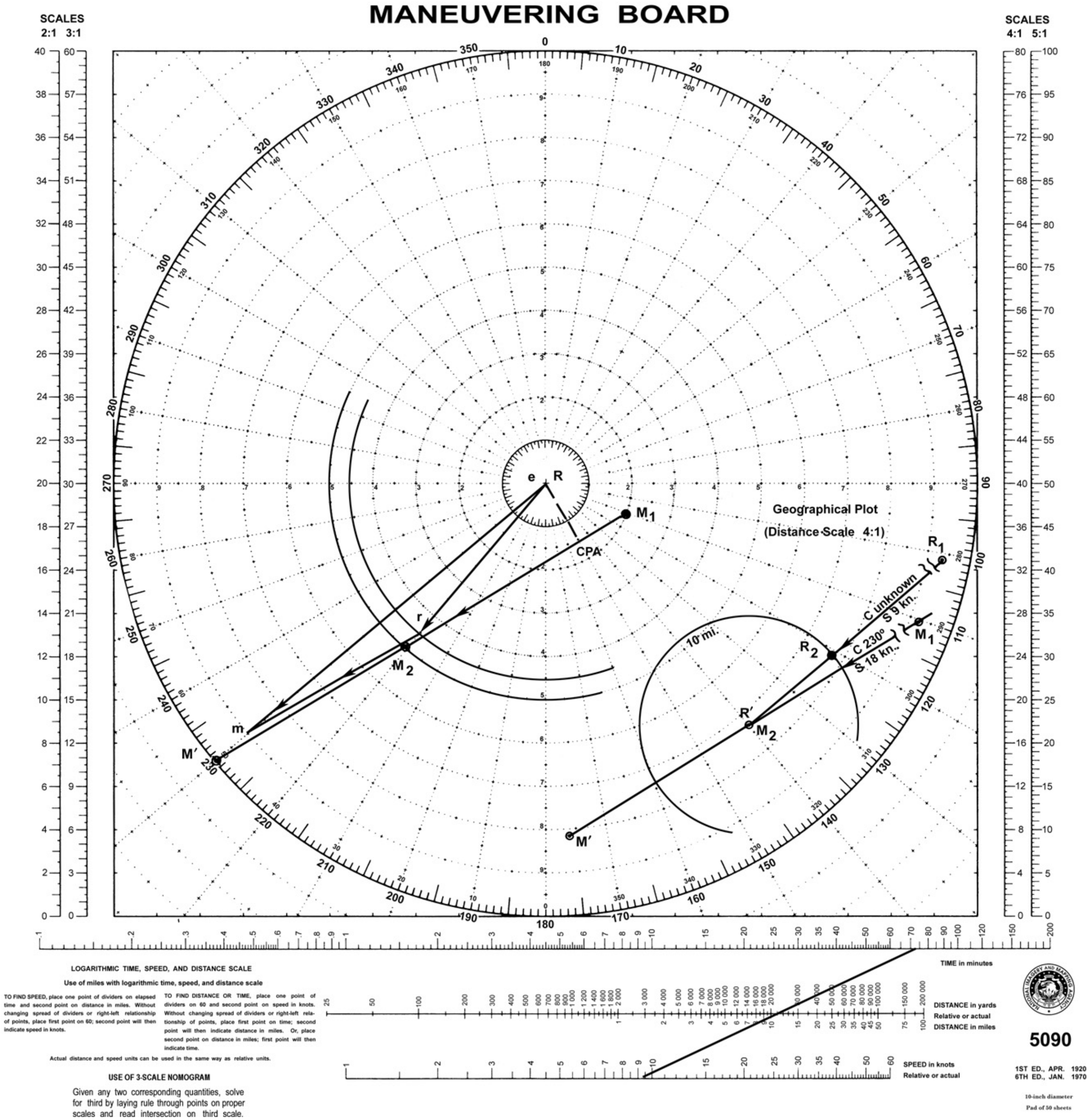
When *R*'s speed is equal to or greater than that of *M*, a special case exists in which there is no problem insofar as remaining within a specified range.

Answer:

(1) Course 221˚.
(2) Bearing 221˚.
(3) Time 79 minutes.
(4) CPA 149˚, 3.1 miles.

Explanation:

As in the "closing range" problem, example 18, determine hypothetical relative positions of *M* and *R* that could exist *after the problem ends*. Referring to the **geographical plot**, assume *R* starts from position R_1 and proceeds inward along some radius on an unknown course at 9 knots. *M* is on course 230˚ at 18 knots. At the instant *M* passes through M_2, *R* reaches the 10-mile limiting range at R_2. At this instant the problem conditions are satisfied although the solution is not yet known. Assume that *R* continues on the same course and speed the 10 miles to the center of the circle while *M* moves away from the center on course 230˚, speed 18 knots. During the time interval *R* closes 10 miles at 9 knots, *M* opens 20 miles at 18 knots. This provides the needed second relative position of *M'* from *R'*, 20 miles bearing 230˚. This position is then transferred to the **relative plot**.



OWN SHIP AT CENTER

EXAMPLE 19

Scale: Speed 2:1; Distance 2:1 mi.

EXAMPLE 20

COURSE AT MAXIMUM SPEED TO REMAIN OUTSIDE OF A SPECIFIED RANGE FOR MAXIMUM TIME

Situation:

Ship *M* bears 020˚, 14 miles from own ship *R*. *M* is on course 210˚, speed 18 knots. Maximum speed of *R* is 10 knots.

Required:

Remain outside a 10-mile range from *M* for as long as possible.
(1) Course at maximum speed.
(2) Bearing of *M* upon arrival at specified range.
(3) Time interval before reaching specified range.

Solution:

(1) Plot *R* and M_1. About *e* and *R*, describe circles of radius 10 knots and 10 miles. Draw *em*. On the reciprocal of *M*'s course, plot *M′* 18 miles from *R*.

$$\frac{\text{Speed of } M}{\text{Speed of } R} \times 10 \text{ miles} = 18 \text{ miles}$$

Draw a line through *M′* and M_1 intersecting the 10-mile range circle at M_2 and M_3.

To *m* draw a line parallel to and in the direction of M_1M_2 intersecting the 10-knot speed circle at r_1 and r_2. M_2 and er_1 are selected for use in completing the solution. M_2 is the first point at which limiting range is reached and r_1m is the minimum relative speed vector which gives the maximum time. Vector er_1 is 175˚.9, 10 knots.

(2) Upon arrival at limiting range at point M_2, *M* is dead astern of *R* bearing 355˚.9.

(3) The time interval outside of specified range is:

$$\frac{M_1M_2}{r_1m} = \frac{6.3 \text{ miles}}{11.1 \text{ knots}} = 34.2 \text{ minutes}$$

Note:

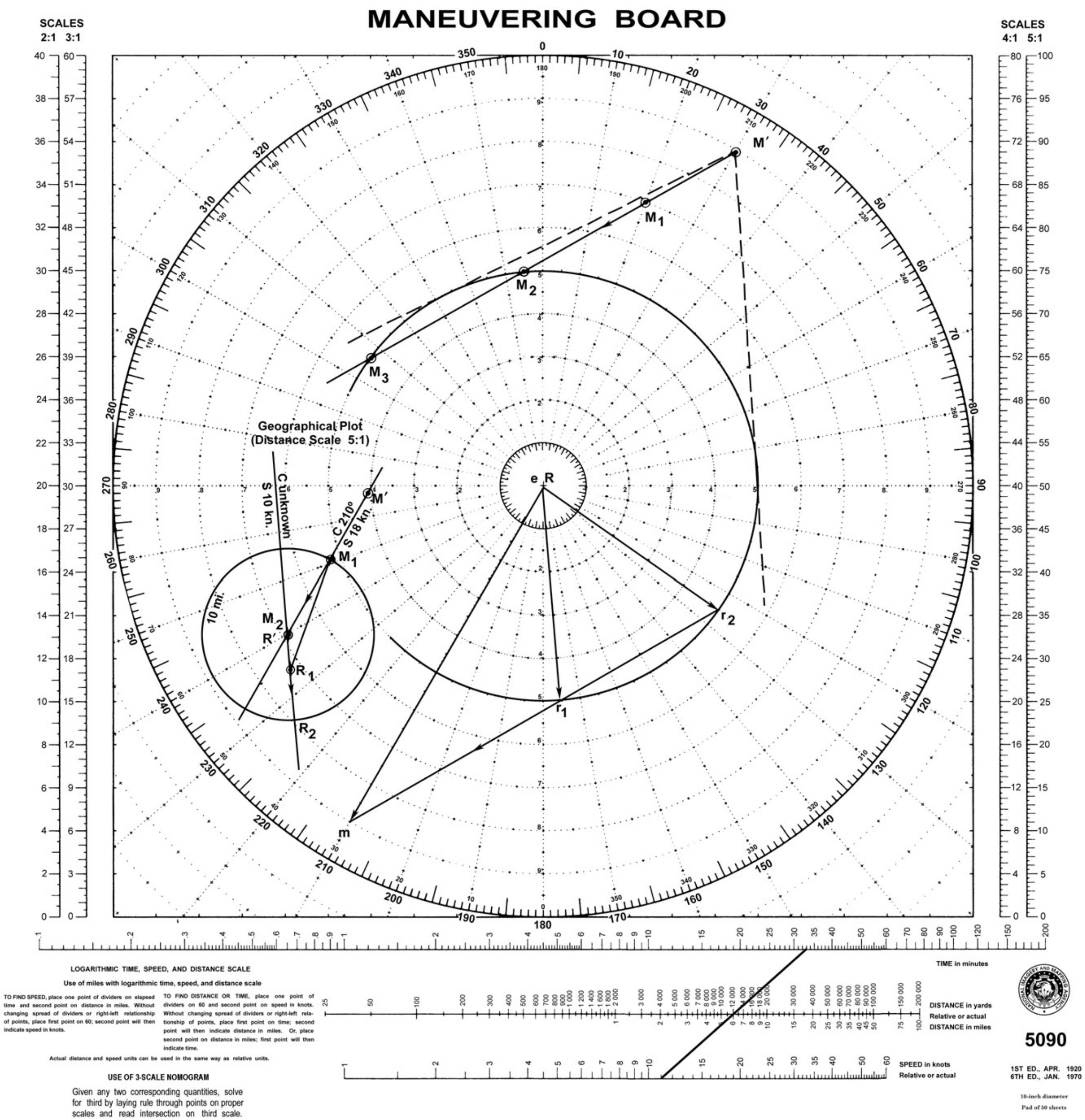
Own ship can remain outside the limiting range indefinitely if M_1 falls outside the area between two tangents drawn to the limiting range circle from *M′*.

Answer:

(1) Course 176˚.
(2) Bearing 356˚.
(3) Time 34 minutes.

Explanation:

To determine a course to remain outside of a given range for maximum time, determine hypothetical relative positions of *M* and *R* that could exist *before the problem starts*. Referring to the **geographical plot**, assume *R* starts from position *R′* and proceeds outward along some radius on an unknown course at 10 knots. If *M* moves toward its final position at M_2 along the given course 210˚, speed 18 knots, it should arrive at M_2 the instant *R* reaches the 10 mile circle at R_2. At this instant the problem conditions are satisfied although the solution for own ship's course is not yet known. During the time interval required for *R* to move from *R′* to R_2, 10 miles at 10 knots, *M* moves from *M′* to M_2, 18 miles at 18 knots along the given course 210˚. This provides the needed second relative positions. *M′* bears 030˚, 18 miles from *R′*. This position is then transferred to the **relative plot**.



OWN SHIP AT CENTER

EXAMPLE 20

Scale: Speed 2:1;
Distance 2:1 mi.

USE OF A FICTITIOUS SHIP

The examples given thus far have been confined to ships that have either maintained constant courses and speeds during a maneuver or else have engaged in a succession of such maneuvers requiring only repeated application of the same principles. When one of the ships alters course and/or speed during a maneuver, a preliminary adjustment is necessary before these principles can be applied.

This adjustment consists, in effect, of substituting a **fictitious ship** for the ship making the alteration. This fictitious ship is presumed to:

(1) maintain a constant course and speed throughout the problem (this is the *final* course and speed of the actual ship).

(2) start and finish its run at times and positions determined by the conditions established in the problem.

For example, the course and speed of advance of a ship zig-zagging are considered to be the constant course and speed of a fictitious ship which departs from a given position at a given time simultaneously with the actual ship, and arrives simultaneously with the actual ship at the same final position. The principles discussed in previous examples are just as valid for a fictitious ship as for an actual ship, both in the relative plot and speed triangle. A **geographical plot** facilitates the solution of problems of this type.

EXAMPLE 21

ONE SHIP ALTERS COURSE AND/OR SPEED DURING MANEUVER

Situation:

At 0630 ship *M* bears 250˚, range 32 miles. *M* is on course 345˚, speed 15 knots but at 0730 will change course to 020˚ and speed to 10 knots.

Required:

Own ship *R* takes station 4 miles on the starboard beam of *M* using 12 knots speed.

(1) Course to comply.

(2) Time to complete maneuver.

Solution:

The key to this solution is to determine the 0630 position of a **fictitious ship** that by steering course 020˚, speed 10 knots, will pass through the actual ship's 0730 position. In this way the fictitious ship travels on a steady course of 020˚ and speed 10 knots throughout the problem.

(1) Plot *R*, M_1, and M_3. Draw em_1 and em_2/emf.

Construct a **geographical plot** with initial position M_1. Plot M_1 and M_2, *M*'s 0630-0730 travel along course 345˚, distance 15 miles. Plot MF_1, the fictitious ship's initial position, on bearing 200˚, 10 miles from M_2. MF_1 to MF_2 is the fictitious ship's 0630-0730 travel.

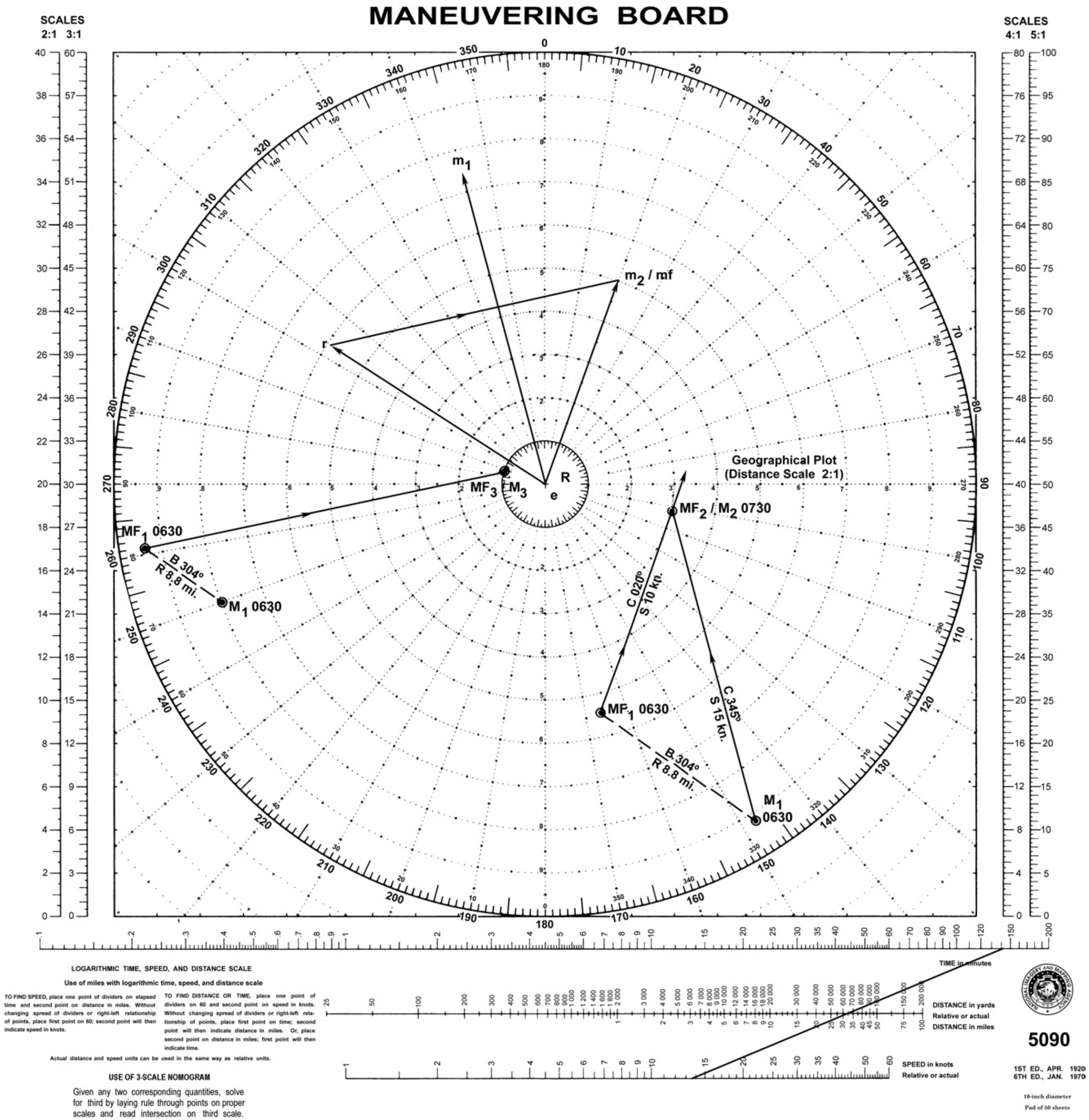
Transfer the relative positions of M_1 and MF_1 to the **relative plot**. MF_1MF_3 is the required DRM and MRM for problem solution. Draw rm_2 parallel to and in the direction of MF_1MF_3. The intersection of rm_2 and the 12-knot speed circle is the course, *er*: 303˚, required by *R* in changing stations while *M* maneuvers.

(2) The time to complete the maneuver is obtained from the TDS scale using fictitious ship's MRM from MF_1 to MF_3 and the SRM of *rmf*.

Answer:

(1) Course 303˚.

(2) Time 2 hours 29 minutes.



OWN SHIP AT CENTER

EXAMPLE 21

Scale: Speed 2:1; Distance 4:1 mi.

EXAMPLE 22

BOTH SHIPS ALTER COURSE AND/OR SPEED DURING MANEUVER

Situation:

At 0800 *M* is on course 105˚, speed 15 knots and will change course to 350˚, speed 18 knots at 0930. Own ship *R* is maintaining station bearing 330˚, 4 miles from *M*. *R* is ordered to take station bearing 100˚, 12 miles from *M*, arriving at 1200.

Required:

(1) Course and speed for *R* to comply if maneuver is begun at 0800.

(2) Course for *R* to comply if *R* delays the course change as long as possible and remains at 15 knots speed throughout the maneuver.

(3) Time to turn to course determined in (2).

Solution:

Since the relative positions of *R* and *M* at the beginning and end of the maneuver and the time interval for the maneuver are given, the solution for (1) can be obtained directly from a **geographical plot**. Solve the remainder of the problem using a **relative plot**.

(1) Using a geographical plot, lay out *M*'s 0800-1200 track through points M_1, M_2, and M_3. Plot R_1 and R_3 relative to M_1 and M_3, respectively. The course of 040˚ from R_1 to R_3 can be measured directly from the plot. *R* will require a speed of 10.8 knots to move 43.4 miles in 4 hours.

(This solution can be verified on the relative plot. First, using a geographical plot, determine the 0800 position of a **fictitious ship**, MF_1, such that by departing this point at 0800 on course 350˚, 18 knots it will arrive at point MF_2 simultaneously with the maneuvering ship *M*. MF_1 bears 141˚, 41.7 miles from M_1. Transfer the positions of M_1 and MF_1 to the relative plot. Plot *R* and M_2. Draw the fictitious ship's vector, emf_1. To mf_1 construct the SRM vector parallel to $MF_1\ MF_2$ and 13.8 knots in length. Vector er_1 is the required course of 040˚.)

(2) To find the two legs of *R*'s 0800-1200 track, use a relative plot. Draw er_2, own ship's speed vector which is given as 105˚, 15 knots. At this stage of the solution, disregard *M* and consider own ship *R* to maneuver relative to a new fictitious ship. Own ship on course 040˚, 10.8 knots from part (1) is the fictitious ship used. Label vector er_1 as emf_2, the fictitious ship's vector. From point r_2 draw a line through mf_2 extended to intersect the 15-knot speed circle at r_3. Draw er_3, the second course of 012˚ required by *R* in changing station.

(3) To find the time on each leg draw a time line from r_2 using any convenient scale. Through r_3 draw r_3X. Through r_1 draw r_1Y parallel to r_3X. Similar triangles exist; thus, the time line is divided into proportional time intervals for the two legs: XY is the time on the first leg: 1 hour 22 minutes. The remainder of the 4 hours is spent on the second leg.

Answer:

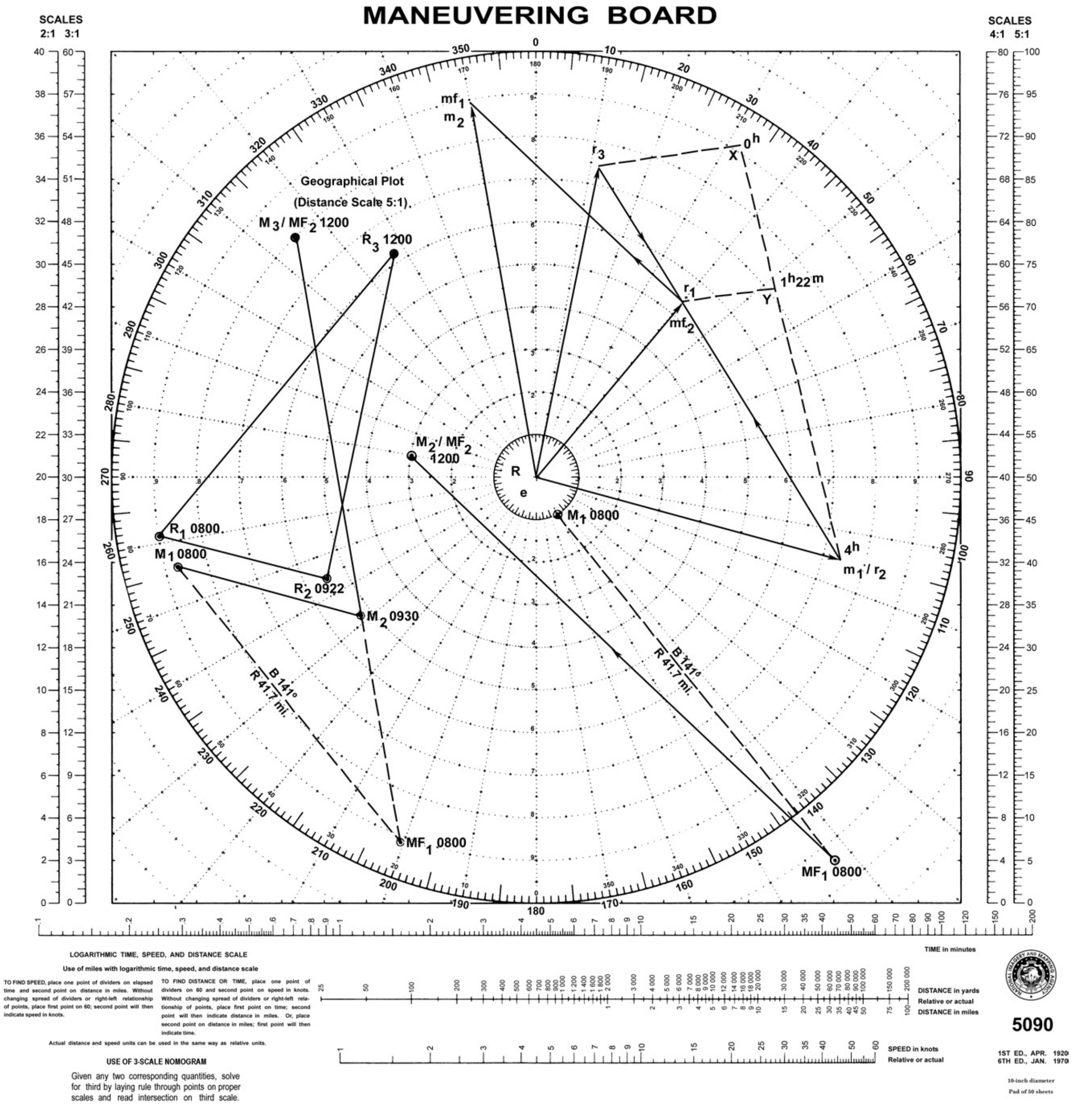
(1) Course 040˚, 10.8 knots.

(2) Course 012˚.

(3) Time 0922.

Note:

In the above example, an alternative construction of the time line as defined in the glossary is used so that the line can be drawn to a convenient scale. The proportionality is maintained by constructing similar triangles. See Note with example 24.



OWN SHIP AT CENTER

EXAMPLE 22

Scale: Speed 2:1; Distance 4:1 mi.

EXAMPLE 23

COURSES AT A SPECIFIED SPEED TO SCOUT OUTWARD ON PRESENT BEARING AND RETURN AT A SPECIFIED TIME

Situation:

Own ship *R* is maintaining station on *M* which bears 110˚, range 5 miles. Formation course is 055˚, speed 15 knots.

Required:

Commencing at 1730, scout outward on present bearing and return to present station at 2030. Use 20 knots speed.

(1) Course for first leg.
(2) Course for second leg.
(3) Time to turn.
(4) Maximum distance from the guide.

Solution:

(1) Plot *R* and M_1. Draw *em*. The DRM "out" is along the bearing of *M* from *R*. The DRM "in" is along the bearing of *R* from *M*. Through *m* draw a line parallel to the DRM's intersecting the 20-knot circle at r_1 and r_2. Vector r_1m is the DRM "out". Vector er_1 is 327˚.8, the course "out".

(2) Vector r_2m is the DRM "in". Vector er_2 is 072˚, the course "in".

(3) To find the time on each leg, draw a time line from r_1 using any convenient scale. Through r_2 draw r_2X. Through *m* draw *m*Y parallel to r_2X. Similar triangles exist; thus, the time line is divided into proportional time intervals for the two legs. XY is the time on the first leg, 41 minutes. The remainder of the time is spent on the second leg returning to station.

(4) Range of *M* when course is changed to "in" leg is 21.7 miles. Initial range + (r_1m x *time* on "out" leg).

Answer:

(1) Course 328˚.
(2) Course 072˚.
(3) Time 1811.
(4) Distance 21.7 miles.

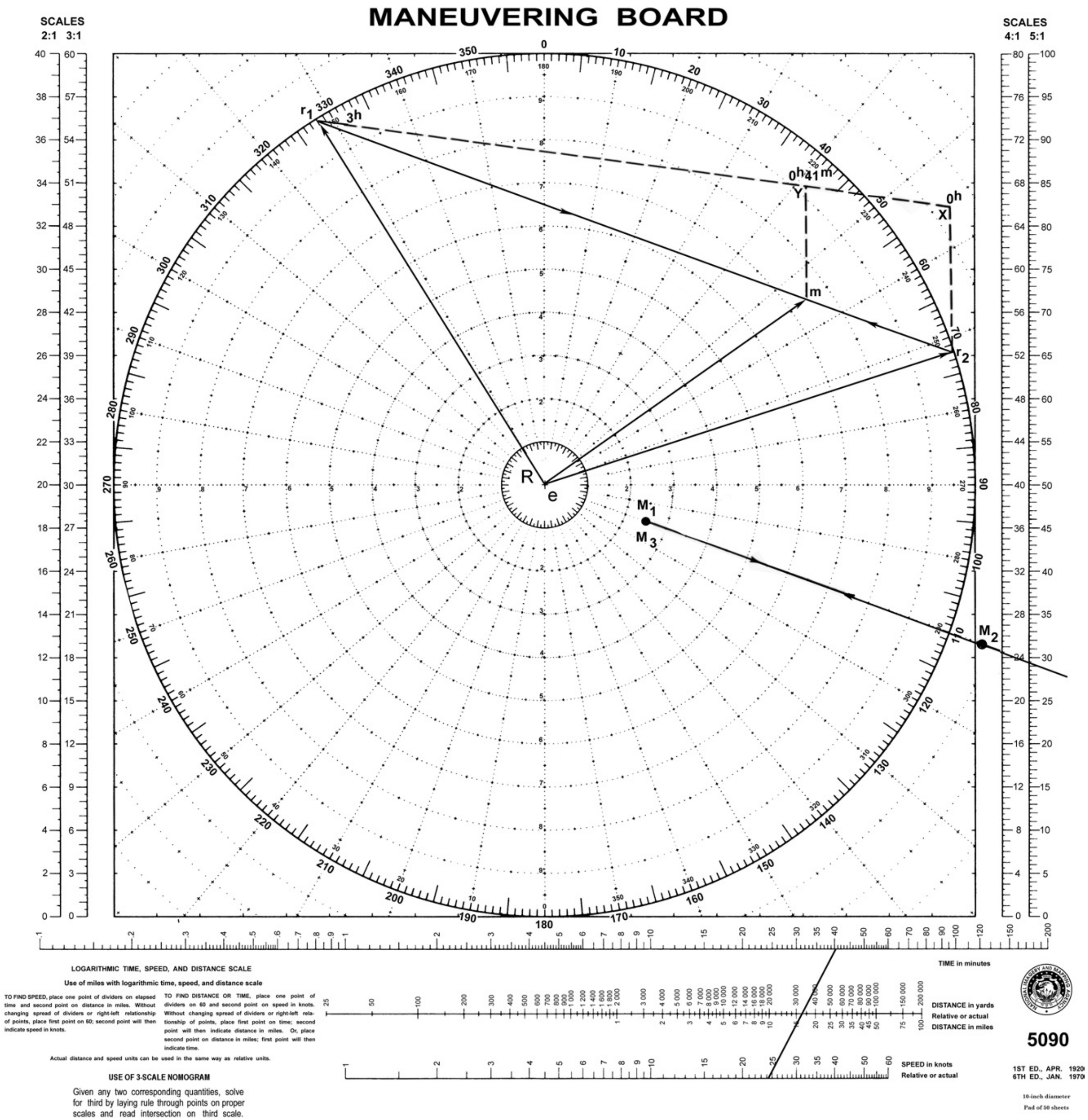
Explanation:

Since own ship *R* returns to present station, relative distances out and in are equal. In going equal distances, time varies inversely as speed:

$$\frac{\text{time (out)}}{\text{time (in)}} = \frac{\text{relative speed (in)}}{\text{relative speed (out)}} = \frac{r_1m\ \text{(in)}}{r_2m\ \text{(out)}}$$

Therefore, the time out part of the specified time (3^h) is obtained by simple proportion or graphically.

As defined in the glossary, the time line is the line joining the heads of vectors er_1 and er_2. This line is divided by the head of vector *em* into segments inversely proportional to the times spent by own ship *R* on the first (out) and second (in) legs. In the above example an alternative construction is used so that the line can be drawn to a convenient scale. The proportionality is maintained by constructing similar triangles.



OWN SHIP AT CENTER

EXAMPLE 23

Scale: Speed 2:1;
Distance 2:1 mi.

EXAMPLE 24

COURSES AND MINIMUM SPEED TO CHANGE STATIONS WITHIN A SPECIFIED TIME, WHILE SCOUTING ENROUTE

Situation:

Own ship *R* bears 130˚, 8 miles from the guide *M* which is on course 040˚, speed 12 knots.

Required:

Proceed to new station bearing 060˚, 10 miles from the guide, passing through a point bearing 085˚, 25 miles from the guide. Complete the maneuver in 4.5 hours using minimum speed.

(1) First and second courses for *R*.

(2) Minimum speed.

(3) Time to turn to second course.

Solution:

(1) Plot M_1, M_2 and M_3. Draw *em*. From *m* draw lines of indefinite length parallel to and in the direction of M_1M_2 and M_2M_3. Assume that a **fictitious ship**, *MF*, departs M_1 simultaneously with *M* and proceeds directly to M_3 arriving at the same time as *M* which traveled through M_2 enroute. The fictitious ship covers a relative distance of 10.5 miles in 4.5 hours. SRM of the fictitious ship is 2.3 knots. To *m* draw *mfm* 2.3 knots in length parallel to and in the direction of M_1M_3. Vector *emf* is the true course and speed vector of the fictitious ship. With *mf* as a pivot, rotate a straight line so that it intersects the two previously drawn lines on the same speed circle. The points of intersection are r_1 and r_2. Vector er_1 is the course out: 049˚. Vector er_2 is the course in: 316˚.9.

(2) Vectors r_1 and r_2 lie on the 17.2 knot circle which is the minimum speed to complete the maneuver.

(3) From r_2 lay off a 4.5 hour time line using any convenient scale. Draw r_1X. Draw *mf*Y parallel to r_1X. The point Y divides the time line into parts that are inversely proportional to the relative speeds r_2mf and r_1mf. XY the time “in” is 51 minutes. Yr_2 the time “out” is 3 hours 39 minutes. Time on each leg may also be determined mathematically by the formula MRM/SRM=time.

Answer:

(1) First course 049˚, second course 317˚.

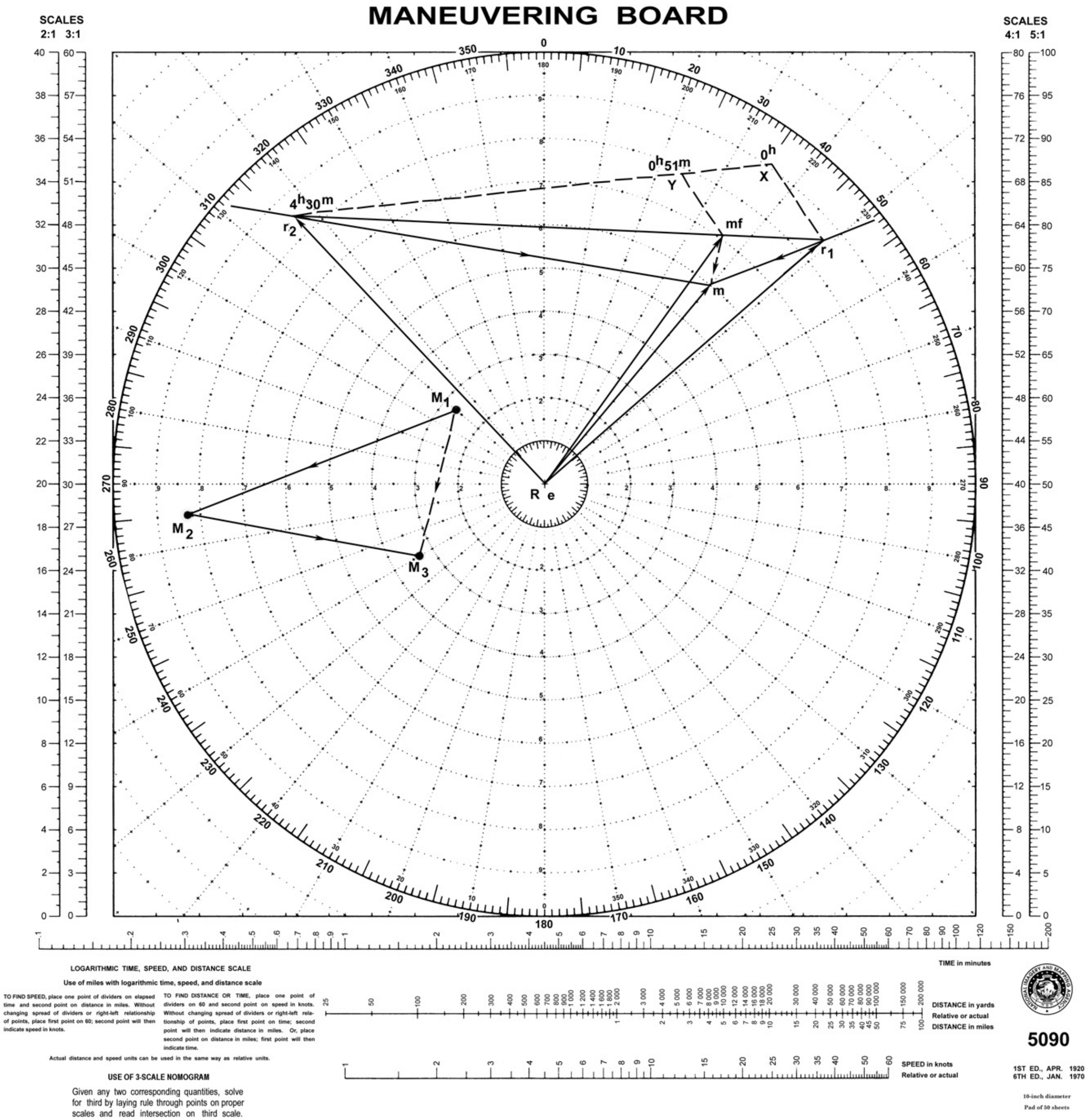
(2) Speed 17.2 knots.

(3) Time 3 hours and 39 minutes.

Note:

The *time line*, as defined in the glossary, is the line joining the heads of vectors er_1 and er_2 and touching the head of the fictitious ship vector *emf*. This time line is divided by the head of the fictitious ship vector into segments inversely proportional to the times spent by the unit on the first and second legs.

In the above example, an alternative construction of the time line is used so that the line can be drawn to a convenient scale. The proportionality is maintained by constructing similar triangles.



OWN SHIP AT CENTER

EXAMPLE 24

Scale: Speed 2:1;
Distance 3:1 mi.

EXAMPLE 25

COURSE, SPEED, AND POSITION DERIVED FROM BEARINGS ONLY

Situation:

Own ship is on course 090°, speed 15 knots. The true bearings of another ship are observed as follows:

Time	*Bearing*
1300	010°
1430	358°
1600	341°

At 1600 own ship changes course to 050° and increases speed to 22 knots. The following bearings of ship *M* are then observed:

Time	*Bearing*
1630	330°
1730	302°
1830	274°.5

Required:

(1) Course and speed of ship *M*.
(2) Distance of *M* at time of last bearing.

Solution:

(1) Draw own ship's vector er_1.
(2) Plot first three bearings and label in order observed, B_1, B_2, and B_3.
(3) At any point on B_1, construct perpendicular which intersects B_2 and B_3. Label these points P_1, P_2, and P_3.
(4) Measure the distance P_1 to P_2 and plot point *X* at the same distance from P_2 towards P_3.
(5) From *X* draw a line parallel to B_1 until it intersects B_3. Label this intersection *Y*.
(6) From *Y* draw a line through P_2 until it intersects B_1 at *Z*.
(7) From head of own ship's vector er_1, draw a line parallel to *YZ*. This establishes the DRM on the original course and speed. The head of the *em* vector of ship *M* lies on the line drawn parallel to *YZ*. It is now necessary to find the DRM following a course and/or speed change by own ship. The intersection of the two lines drawn in the direction of relative movement from the heads of own ship's vector establishes the head of vector *em*.
(8) Following course and speed change made to produce a good bearing drift, three more bearings are plotted; the new direction of relative movement is obtained following the procedure given in steps (3) through (7). The lines drawn in the directions of relative movement from the heads of vector er_1 and er_2 intersect at the head of the vector *em*. Ship *M* is on course 170° at 10 knots.
(9) From relative vector r_2m, the SRM is found as 28.4 knots during the second set of observations.
(10) Compute the relative distance traveled during the second set of observations (MRM 56.8 mi.).
(11) On the line *ZY* for the second set of observations, lay off the relative distance *ZA*. From *A* draw a line parallel to B_4 until it intersects B_6. Label this point *B*. This is the position of *M* at the time of the last bearing.

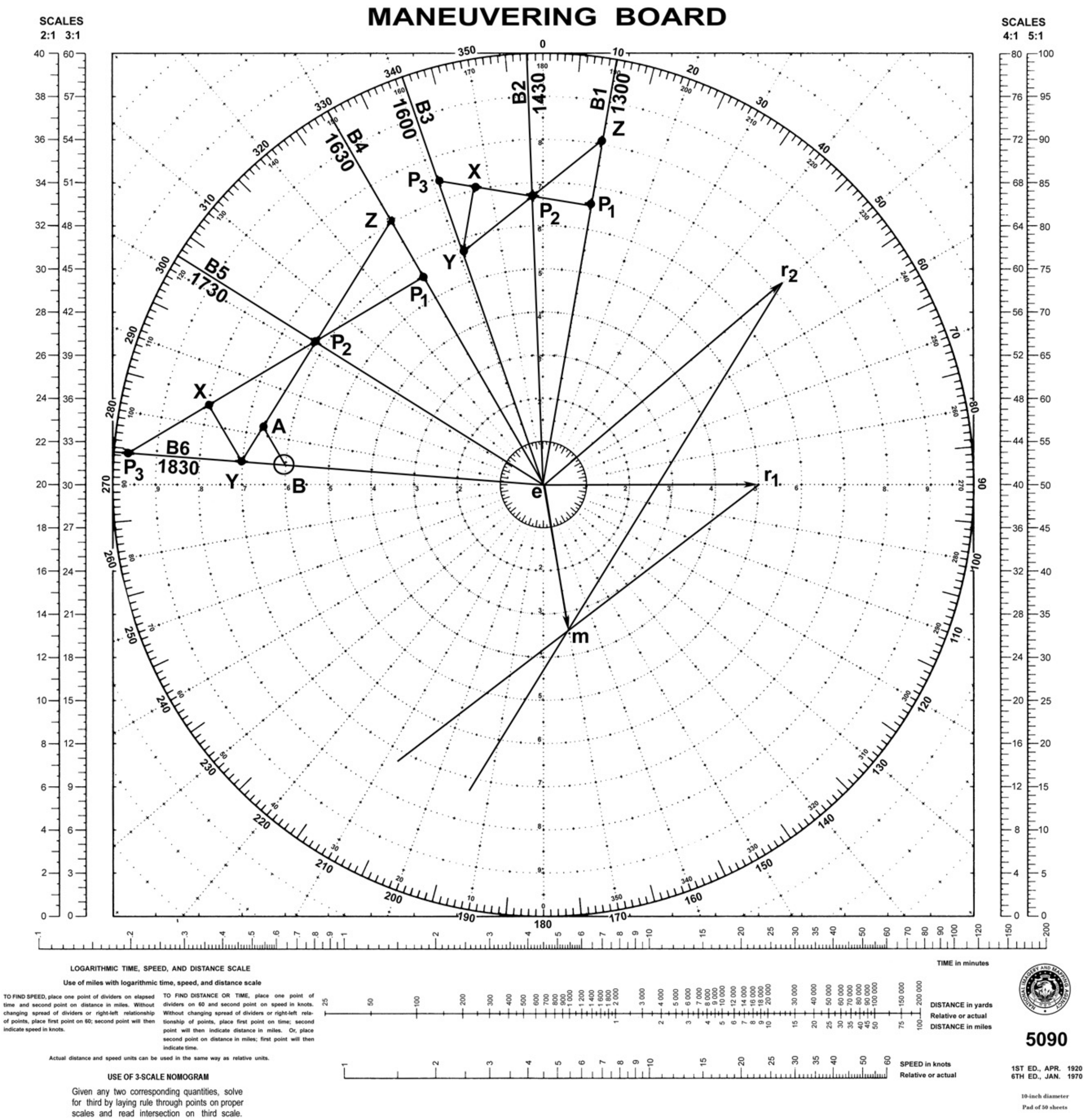
Answer:

(1) Course 170°, speed 10 knots.
(2) Position of *M* at 1830: 274°.5 at 61 miles.

Note:

These procedures are based on bearings observed at equal intervals. For unequal intervals, use the following proportion:

$$\frac{\text{Time difference between } B_1 \text{ and } B_2}{\text{Distance from } P_1 \text{ to } P_2} = \frac{\text{Time difference between } B_2 \text{ and } B_3}{\text{Distance from } P_2 \text{ to } X}.$$



OWN SHIP AT CENTER

EXAMPLE 25

Scale: Speed 3:1;
Distance 10:1 mi.

EXAMPLE 26

LIMITING LINES OF APPROACH
(single ship)

Situation:
Own ship R's course and speed is 000˚, 20 knots. At 0930, both sonar and radar report a contact bearing 085˚, distance 22,500. At 0931, radar loses contact and at 0932 sonar loses contact. Last known position was 085˚, distance 20,000. Datum error is 1,000 yards.

Required:
(1) Advanced position.
(2) Limiting lines of approach for submarine with maximum quiet speed of 15 knots.

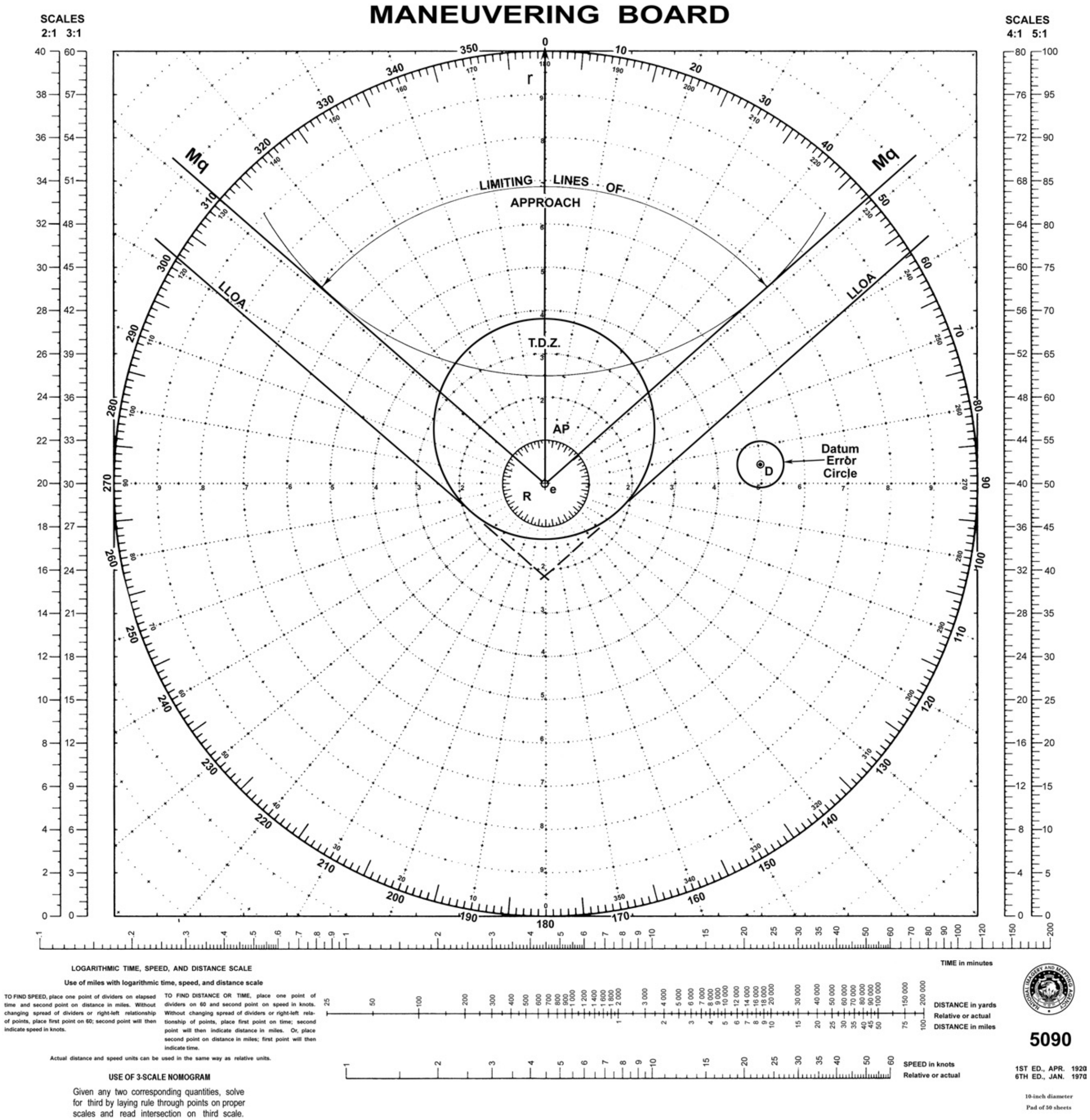
Solution:
(1) Plot R at center of maneuvering board and draw the vector "*er*" 000˚, 20 knots.
(2) Plot datum position from own ship (085˚, 20,000 yards).
(3) Plot datum error (circle of radius 1,000 yards) around datum.
(4) Compute own ship's advanced position using the formula:

$$\frac{\text{Torpedo Firing Range}}{\text{Torpedo Speed}} \times \text{Vessel Speed} = \frac{10{,}000 \text{ yds}}{45 \text{ kts}} \times 20 \text{ kts} = 4{,}444 \text{ yds}$$

(5) Plot advanced position along own ship's course and speed vector.
(6) Plot Torpedo Danger Zone (10,000 yard circle) around advanced position.
(7) From "*r*", describe an arc with a radius of 15 nautical miles (the assumed quiet speed of the submarine).
(8) Draw the tangent vector "*eMq*" until it intersects the edge of the maneuvering board plotting circle. Do this on both sides of the ship's head. The true bearing of the tangent lines are the limiting lines of approach.
(9) Parallel the tangent vectors "*eMq*" until they are tangent to the Torpedo Danger Zone to complete the plotting picture.

Answer:
(1) Advanced position = 4,444 yards.
(2) Left side limiting line = 310˚.
Right side limiting line = 050˚.
Limiting lines of approach = 310˚ - 050˚.

Notes:
(1) Limiting lines of approach are read clockwise.
(2) This example assumes the submarine maintains a constant speed throughout the approach.
(3) The submarine and torpedo data were chosen for example purposes and should NOT be used as real estimates. Consult appropriate intelligence publications for correct data.



OWN SHIP AT CENTER

EXAMPLE 26

Scale: Speed 1:1;
Distance 1:1 mi.

EXAMPLE 27a

CONES OF COURSES
Solution: 1

Situation:

Own ship *R* is on course 000˚, 15 knots. At 1600, submarine *M* is reported bearing 325˚, 40 miles from *R*. Maximum assumed speed for *M* is 10 knots.

Required:

(1) Courses at 10 knots the submarine *M* will steer to intercept *R*.

(2) Time of the first and last intercept opportunities for submarine *M* against *R* at the assumed speed of 10 knots.

Solution:

(1) Plot the 1600 position of the submarine *M* 325˚, 40 miles from *R*. Draw the vector "*er*" 000˚, 15 knots. From *M*, draw a DRM line to *R* and from "*r*" draw the vector "*rm*" parallel and in the same direction as the DRM. With "*e*" as the center, describe an arc with radius of 10 knots, the assumed speed of *M*. The points em_1 and em_2 where the arc intersects the "*rm*" vector, define the courses at 10 knots that the submarine will steer to intercept *R*. Courses between "em_1" and "em_2" are lower assumed speed intercepts and "em_L", the perpendicular line from *R* to "*rm*", is the course for the lowest possible assumed speed at which the submarine can move and still intercept *R*.

(2) Parallel the "em_1" and "em_2" lines as vectors to the 1600 position at *M* and extend "*er*" until it crosses these vectors; the area enclosed by these 3 vectors represents the true geographic area through which the submarine will move at or below 10 knots to intercept *R*. The elapsed times to the first ("t_1") and the last ("t_2") intercept opportunities is obtained by dividing the relative distance at 1600 (*RM*) by the respective relative speed ("rm_1" and "rm_2").

Answer:

(1) Courses 024˚ to 086˚.

(2) $$\text{"}t_1\text{"} = \frac{RM}{\text{"}rm_1\text{"}} = \frac{40 \text{ miles}}{17.5 \text{ knots}} = 2 \text{ hrs } 17 \text{ mins}$$

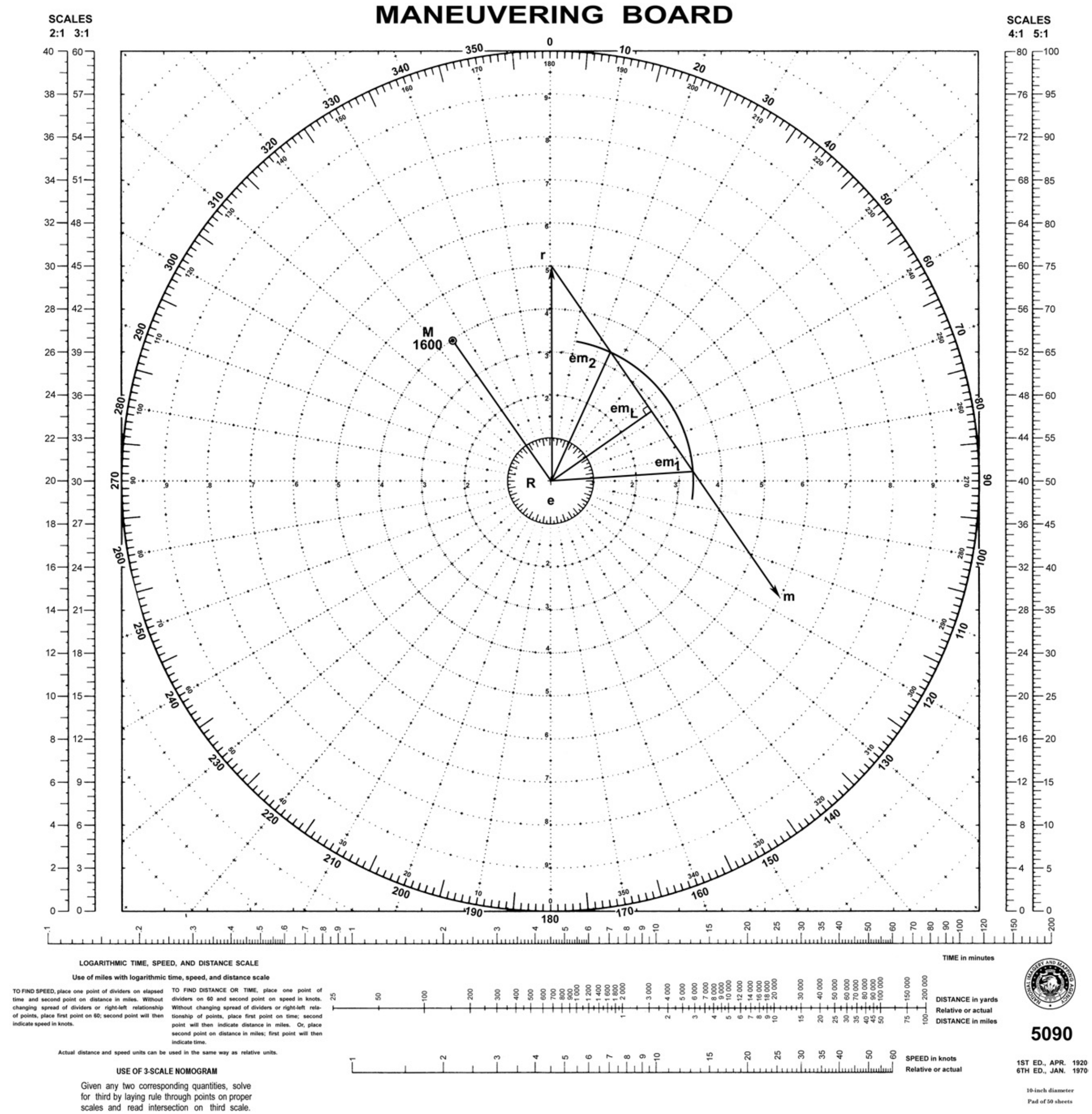
$$T_1 = 1600 + \text{"}t_1\text{"} = 1817$$

$$\text{"}t_2\text{"} = \frac{RM}{\text{"}rm_2\text{"}} = \frac{40 \text{ miles}}{7 \text{ knots}} = 5 \text{ hrs } 43 \text{ mins}$$

$$T_2 = 1600 + \text{"}t_2\text{"} = 2143$$

Note:

If the submarine's position involves an error (i.e., datum error) and a main body or convoy formation is present (with an associated Torpedo Danger Zone (TDZ) around it) the DRM from *M* to *R* becomes tangential lines drawn from "*r*" with a high speed and low speed leg corresponding to a forward or aft DRM on the formation.



OWN SHIP AT CENTER

EXAMPLE 27a

Scale: Speed 3:1;
Distance 10:1 mi.

EXAMPLE 27b

CONES OF COURSES
Solution: 2

Situation:

Own ship *R* is on course 000˚, 15 knots. At 1600, submarine *M* is reported bearing 325˚, 40 miles from *R*. Maximum assumed speed for *M* is 10 knots.

Required:

(1) Courses at 10 knots the submarine *M* will steer to intercept *R*.
(2) Time of the first and last intercept opportunities for submarine *M* against *R* at the assumed speed of 10 knots.

Solution:

(1) Plot the 1600 position of the submarine *M* 325˚, 40 miles from *R*. Draw the vector "*er*" 000˚, 15 knots. From *M*, draw a DRM line to *R* and from "*r*" draw the vector "*rm*" parallel and in the same direction as the DRM. With "*e*" as the center, describe an arc with radius of 10 knots, the assumed speed of *M*. The points EM_1 and EM_2 where the arc intersects the "*rm*" vector, define the courses at 10 knots that the submarine will steer to intercept *R*. Courses between "em_1" and "em_2" are lower assumed speed intercepts and "em_2", the perpendicular line from *R* to "*rm*", is the course for the lowest possible assumed speed at which the submarine can move and still intercept *R*.

(2) Parallel the "em_1" and "em_2" lines as vectors to the 1600 position at *M* and extend "*er*" until it crosses these vectors; the area enclosed by these 3 vectors represents the true geographic area through which the submarine will move at or below 10 knots to intercept *R*. The elapsed times to the first ("t_1") and the last ("t_2") intercept opportunities is obtained by dividing the relative distance at 1600 (*RM*) by the respective relative speed ("rm_1" and "rm_2").

Answer:

(1) Courses 024˚ to 086˚.

(2)

$$"t_1" = \frac{RM}{"rm_1"} = \frac{40 \text{ miles}}{17.5 \text{ knots}} = 2 \text{ hrs } 17 \text{ mins}$$

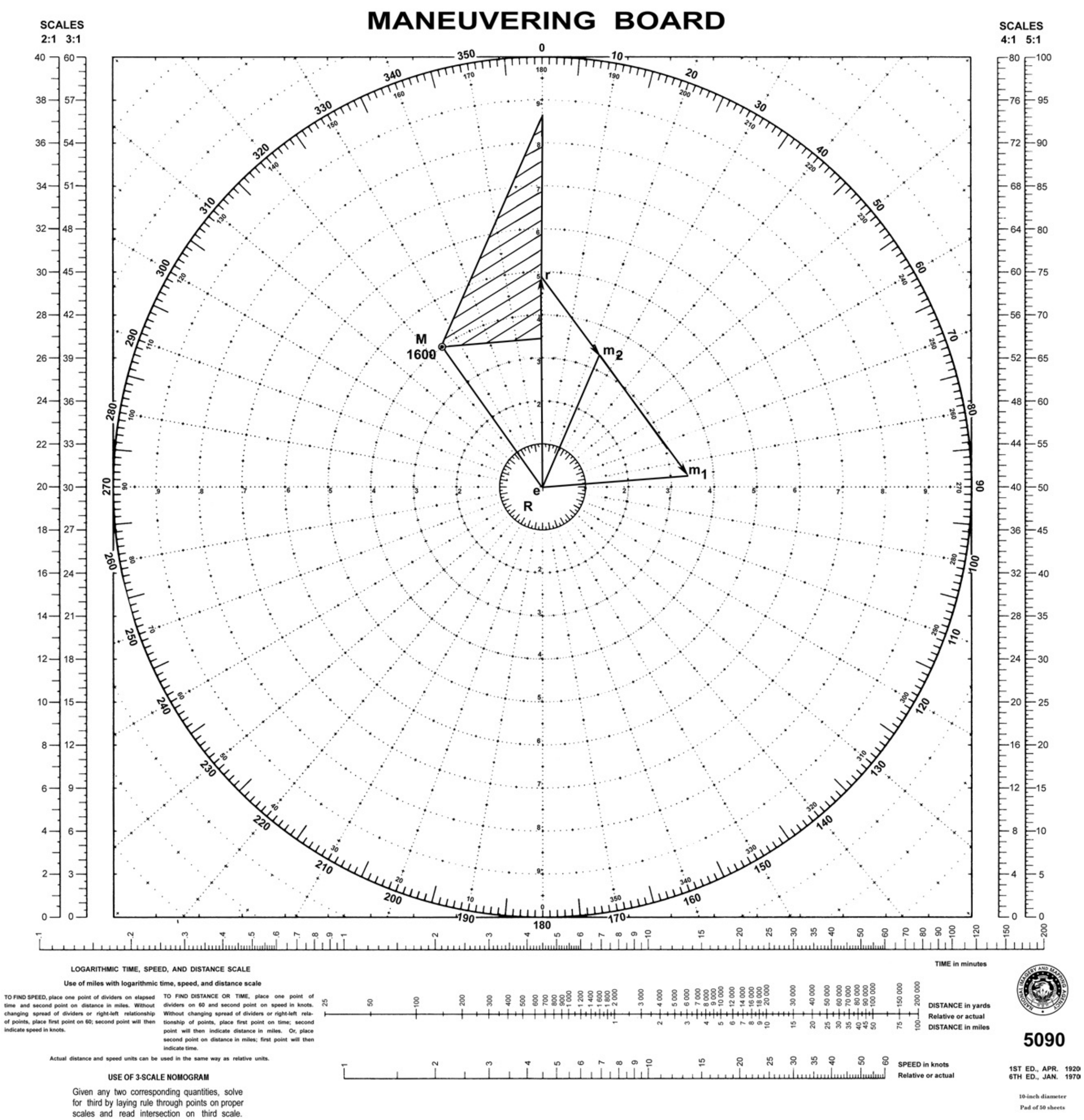
$$T_1 = 1600 + "t_1" = 1817$$

$$"t_2" = \frac{RM}{"rm_2"} = \frac{40 \text{ miles}}{7 \text{ knots}} = 5 \text{ hrs } 43 \text{ mins}$$

$$T_2 = 1600 + "t_2" = 2143$$

Note:

If the submarine's position involves an error (i.e., datum error) and a main body or convoy formation is present (with an associated Torpedo Danger Zone (TDZ) around it) the DRM from *M* to *R* becomes tangential lines drawn from "*r*" with a high speed and low speed leg corresponding to a forward or aft DRM on the formation.



OWN SHIP AT CENTER

EXAMPLE 27b

Scale: Speed 3:1;
Distance 10:1 mi.

EXAMPLE 28

EVASIVE ACTION AGAINST A TARGET MOVING AT SLOW SPEED

Situation:

A vessel possessing a speed advantage is always capable of taking evasive action against a slow-moving enemy. It may be necessary to take evasive action against a slow-moving enemy. For example, when a surface vessel is attempting to evade attack by a submarine.

Required:

The essence of the problem is to find the course for the maneuvering ship at which no matter how the enemy maneuvers he will not be able to come any closer than distance D (Torpedo/Missile Danger Zone) to the maneuvering ship. In order to accomplish this, the maneuvering ship should press the slow-moving enemy at a relative bearing greater than critical.

Solution:

Evasive action is graphically calculated in the following manner. The position of the slow-moving enemy vessel K_0 is plotted on a maneuvering board and the distance it travels from the moment of detection to the beginning of evasive action is calculated:

$$S = V_k(T_1 - T_0)$$

where T_1 = time at which evasive action begins;

T_0 = time of detection of the enemy.

The accuracy of determination of the position of the enemy, assumed to be within the datum error zone, (r) is also verified. Then the minimum divergence from the enemy (d) is determined (e.g., 2 - 3 times the range of fire of torpedoes or 1.5 to 2 times the sonar detection range). Adding up the selected values, with a radius of:

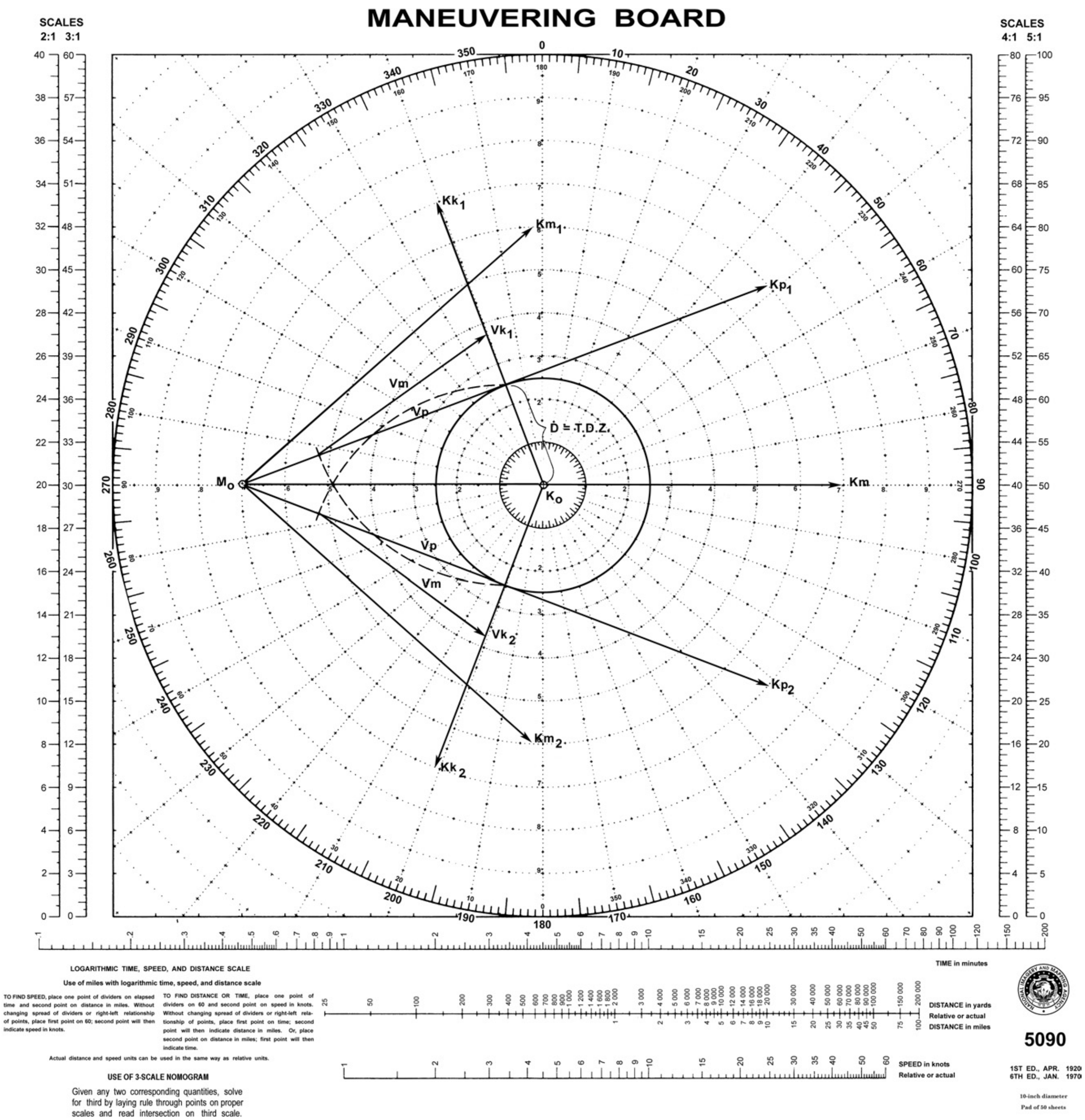
$$D_1 = r + S + d,$$

we have a circle about the initial position of the enemy K_0.

Constructing a tangent to this circle from the position of the maneuvering ship (point M_0) and, constructing a speed triangle at the point of tangency, we obtain the course of the maneuvering vessel Km_1 or Km_2 which the latter must steer in order to avoid meeting the enemy.

Note:

As a rule, the point of turn to the previous course after taking evasive action is not calculated and the turn is usually executed after the bearing on the point of detection of the slow-moving enemy vessel changes more than 90˚.



OWN SHIP AT CENTER

EXAMPLE 28

Scale: Speed 1:1; Distance 1:1 mi.

PART TWO

GUIDE AT CENTER

EXAMPLE 29

CHANGING STATION WITH TIME, COURSE, OR SPEED SPECIFIED

Situation:

Formation course is 010˚, speed 18 knots. At 0946 when orders are received to change station, the guide *R* bears 140˚, range 7,000 yards. When on new station, the guide will bear 240˚, range 6,000 yards.

Required:

(1) Course and speed to arrive on station at 1000.

(2) Speed and time to station on course 045˚. Upon arrival on station orders are received to close to 3,700 yards.

(3) Course and minimum speed to new station.

(4) Time to station at minimum speed.

Solution:

(1) Plot M_1 320˚, 7,000 yards and M_2 060˚, 6,000 yards from *R*. Draw *er* corresponding to course 010˚ and speed 18 knots. The relative distance of 10,000 yards from M_1 to M_2 must be covered in 14 minutes. SRM is therefore 21.4 knots. Draw rm_1 parallel to M_1M_2, and 21.4 knots in length. On completing the vector diagram, the vector em_1 denotes the required course and speed: 062˚, 27 knots.

(2) Draw em_2, course 045˚, intersecting the relative speed vector rm_1 at the 21-knot circle. The length rm_2 is 12.1 knots. Thus the relative distance M_1M_2 of 10,000 yards will be covered in 24.6 minutes.

(3) Plot M_3 060˚, 3,700 yards from *R* after closing. Through *r* draw a line parallel to and in the direction of M_2M_3. Drop a perpendicular from *e* to this line at m_3. Vector em_3 is the course and minimum speed required to complete the final change of station: 330˚, 13.8 knots.

(4) By measurement, the length of rm_3 is an SRM of 11.5 knots; the distance from M_2 to M_3 is 2,300 yards. M_2M_3/rm_3 is the required maneuver time: 6 minutes.

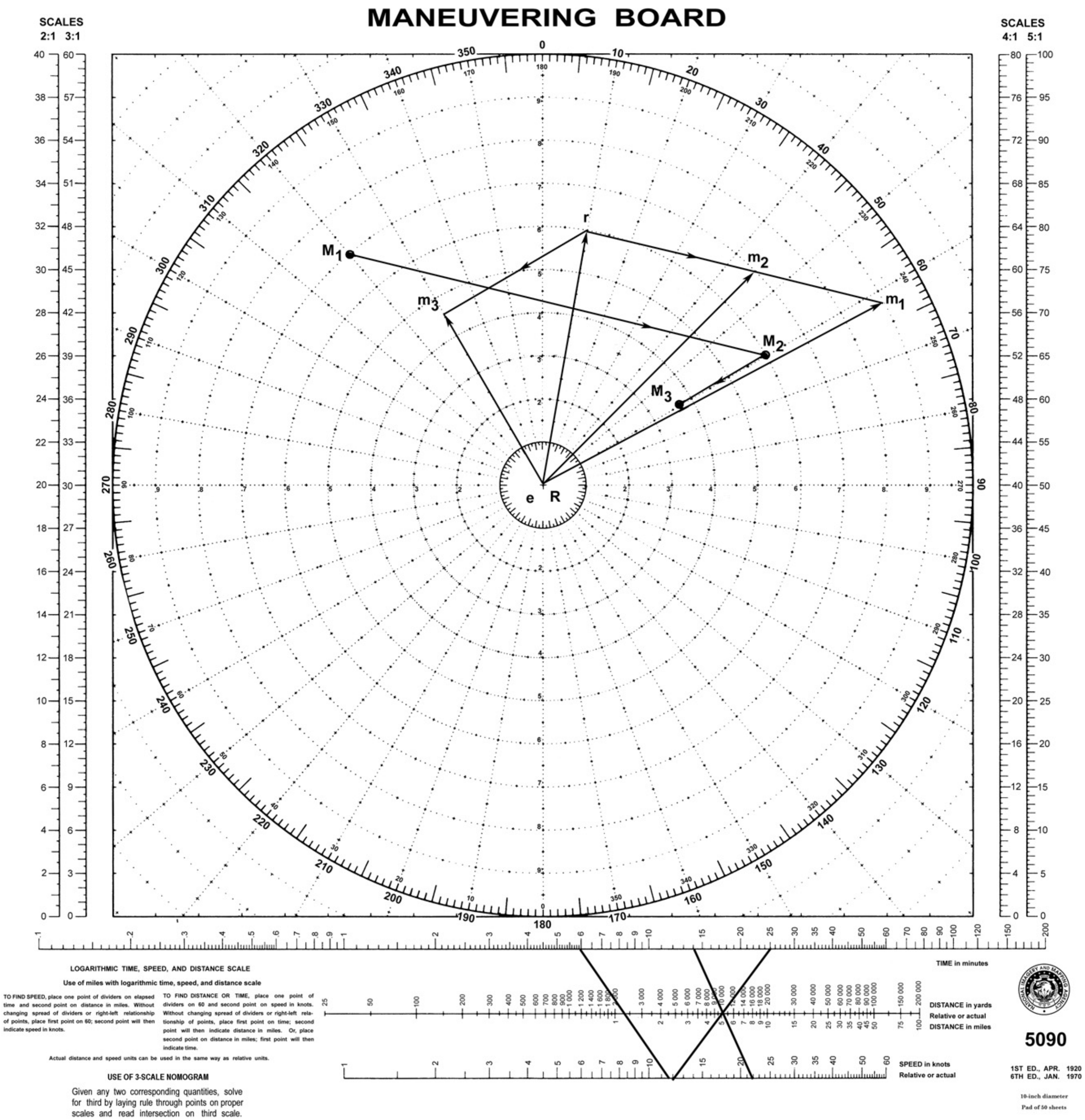
Answer:

(1) Course 062˚, speed 27 knots.

(2) Speed 21 knots, time 25 minutes.

(3) Course 330˚, speed 13.8 knots.

(4) Time 6 minutes.



GUIDE AT CENTER

EXAMPLE 29

Scale: Speed 3:1; Distance 1:1 yd.

EXAMPLE 30

THREE-SHIP MANEUVERS

Situation:

Own ship *M* is in formation proceeding on course 000˚, speed 20 knots. The guide *R* bears 090˚, distance 4,000 yards. Ship *N* is 4,000 yards ahead of the guide.

Required:

M and *N* are to take new stations starting at the same time. *N* is to take station 4,000 yards on the guide's starboard beam using formation speed. *M* is to take *N*'s old station and elects to use 30 knots.

(1) *N*'s course and time to station.
(2) *M*'s course and time to station.
(3) CPA of *M* and *N* to guide.
(4) CPA of *M* to *N*.
(5) Maximum range of *M* from *N*.

Solution:

(1) Plot *R* at the center with M_1 at 270˚, 4,000 yards; M_2 and N_1 at 000˚, 4,000 yards. Draw *er* 000˚, 20 knots. From *R* plot *N*'s new station *NR*, bearing 090˚, distance 4,000 yards. In relation to *R*, *N* moves from N_1 to *NR*. From *r*, draw a line parallel to and in the direction of N_1 *NR* and intersecting the 20-knot speed circle at *n*. *N*'s course to station is vector *en*: 090˚. Time to station N_1 *NR/rn* is 6 minutes.

(2) In relation to *R*, *M* moves from M_1 to M_2. From *r*, draw *rm* parallel to and in the direction of M_1M_2 and intersecting the 30-knot speed circle at *m*. *M*'s course to station is vector *em*: 017˚. Time to station M_1M_2/*rm* is 14 minutes.

(3) From *R* drop a perpendicular to N_1NR. At CPA, *N* bears 045˚, 2,850 yards from *R*. From *R* drop a perpendicular to M_1M_2. At CPA, *M* bears 315˚, 2,850 yards from *R*.

(4) In relation to *M*, *N* travels from N_1 to N_2 to N_3. Plot N_3 bearing 135˚, 5,700 yards from M_1. From point *m* draw the relative speed vector *mn*. Draw a relative movement line from N_1 parallel to and in the same direction as *mn*. When *N* arrives on new station and returns to base course the relative speed between *M* and *N* is the same as *rm*. From N_3 draw a relative movement line parallel to and in the same direction as *rm*. These lines intersect at N_2. From M_1 drop a perpendicular to line N_1N_2. At CPA, *N* bears 069˚, 5,200 yards from *M*.

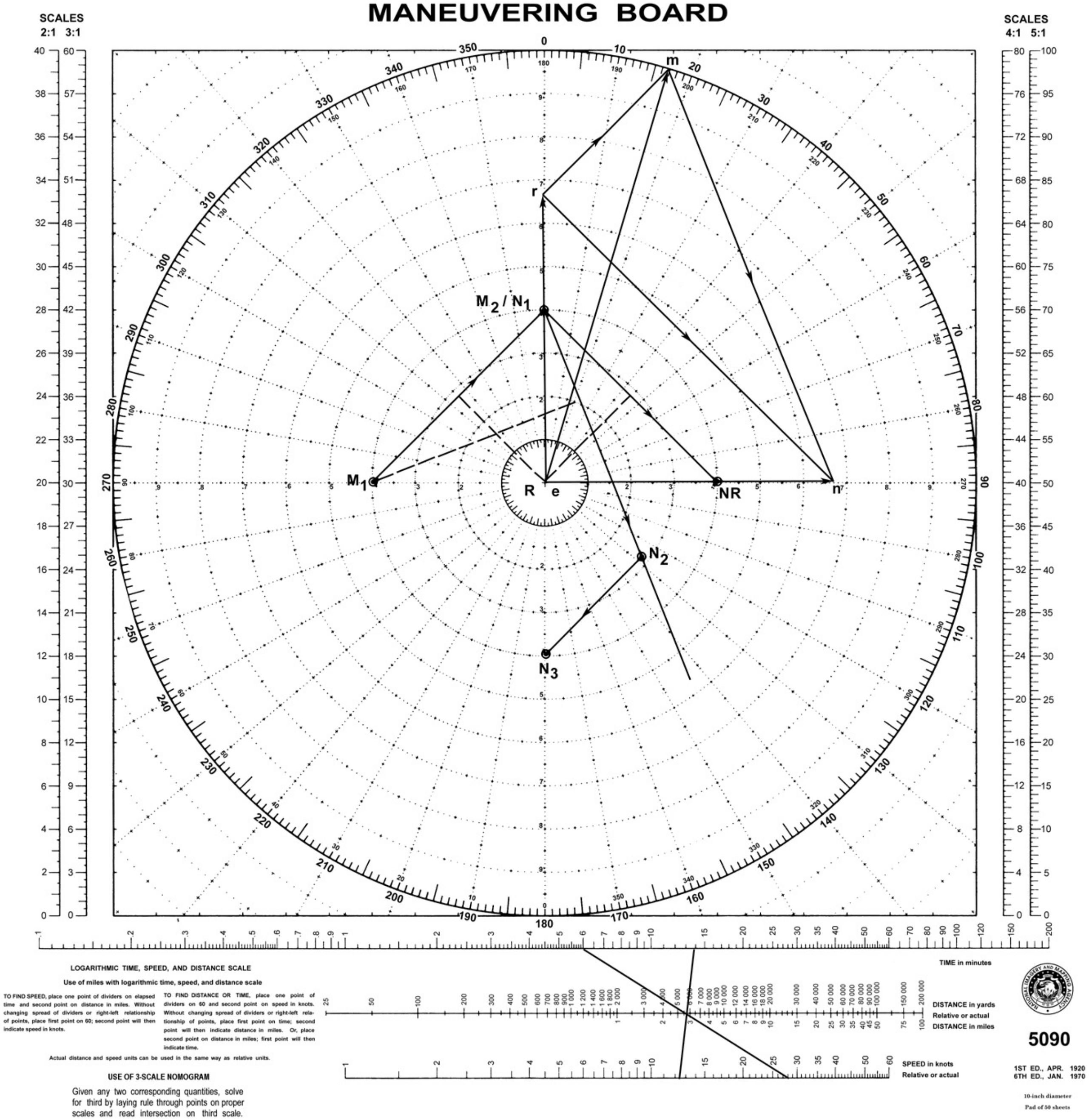
(5) The point at which *N* resumes formation course and speed N_2, is the maximum range of *N* from *M*; 6,500 yards.

Answer:

(1) *N*'s course 090˚, time 6 minutes.
(2) *M*'s course 017˚, time 14 minutes.
(3) CPA: *N* to *R* 2,850 yards at 045˚; *M* to *R* 2,850 yards at 315˚.
(4) CPA of *N* to *M* 5,200 yards at 069˚.
(5) Range 6,500 yards.

Explanation:

In solution step (4), the movement of *N* in relation to *M* is parallel to the direction of vector *mn* and from N_1 until such time that *N* returns to base course and speed. Afterwards, the movement of *N* in relation to *M* is parallel to vector *rm* and from N_2 toward that point, N_3, that *N* will occupy relative to *M* when the maneuver is completed.



GUIDE AT CENTER

EXAMPLE 30

Scale: Speed 3:1; Distance 1:1 yd.

EXAMPLE 31

COURSE AND SPEED TO PASS ANOTHER SHIP AT A SPECIFIED DISTANCE

Situation:

At 1743 own ship *M* is on course 190˚, speed 12 knots. Another ship *R* is observed bearing 153˚, 13,000 yards on course 287˚, speed 10 knots. It is desired to pass ahead of *R* with a CPA of 3,000 yards.

Required:

(1) Course of *M* at 12 knots.
(2) Bearing of *R* and time at CPA.

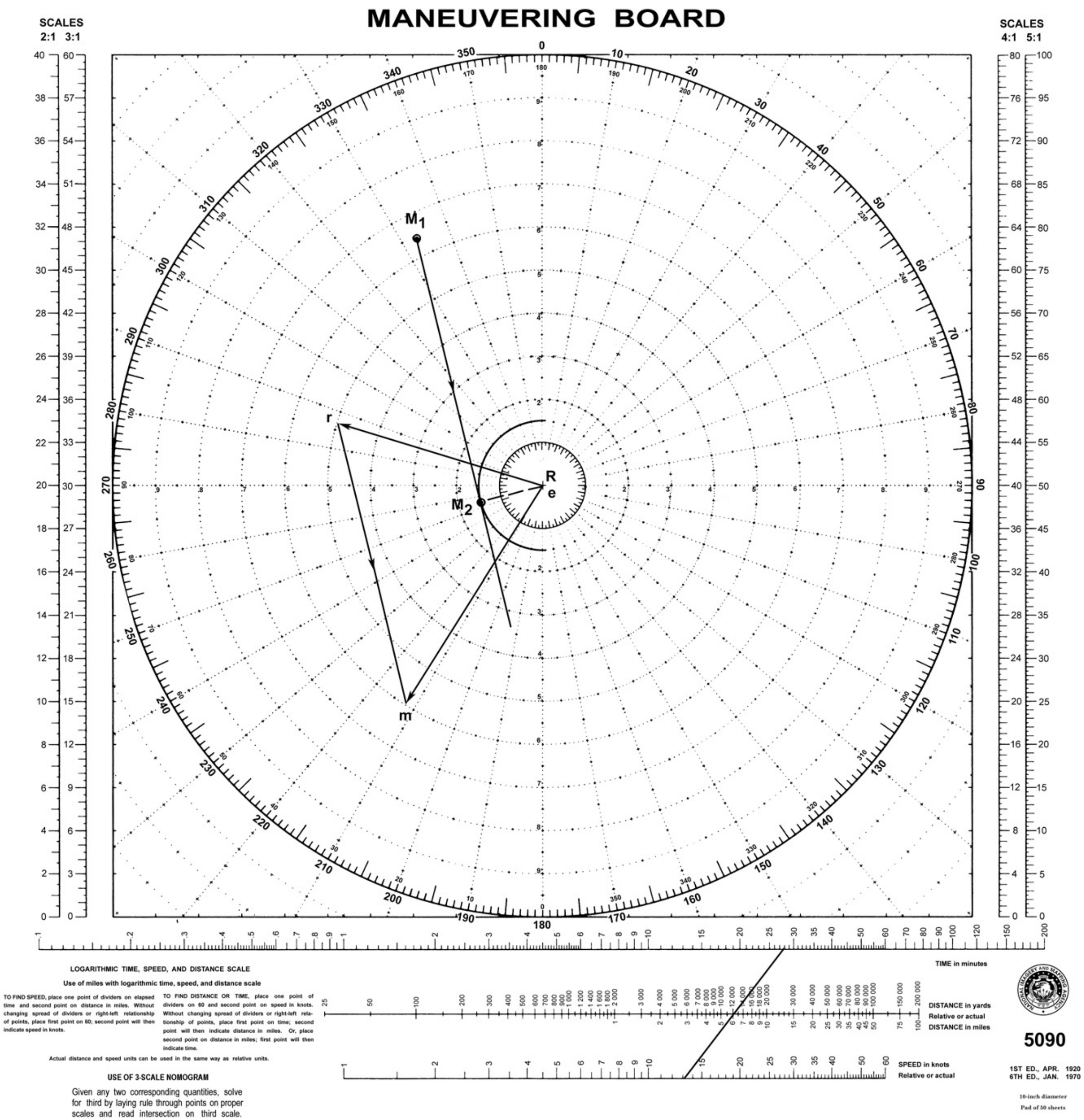
Solution:

(1) Plot *R* at the center of M_1 bearing 333˚, 13,000 yards from *R*. Draw the other ship's vector *er* 287˚, 10 knots. With *R* as a center, describe a circle of radius 3,000 yards. From M_1 draw a line tangent to the circle at M_2. This satisfies the requirement of passing with a CPA of 3,000 yards from *R*. From *r* draw a line parallel to and in the same direction as M_1M_2, intersecting the 12-knot speed circle at *m*. Draw *em*, own ship's vector 212˚, 12 knots.

(2) From *R* drop a perpendicular to M_2. When own ship reaches M_2, *R* will bear 076˚. Measure the relative distance M_1M_2, 12,600 yards, and the relative speed vector *rm*, 13.4 knots. Using this distance and speed, the elapsed time to CPA is obtained from the TDS scale: 28 minutes. The time at CPA is 1743 + 28 = 1811.

Answer:

(1) Course 212˚.
(2) Bearing 076˚, time at CPA 1811.



GUIDE AT CENTER

EXAMPLE 31

Scale: Speed 2:1;
Distance 2:1 yd.

EXAMPLE 32

COURSE AT SPECIFIED SPEED TO PASS ANOTHER SHIP AT MAXIMUM AND MINIMUM DISTANCES

Situation:

Ship *R* on course 300˚, speed 30 knots, bears 155˚, range 16 miles from own ship *M* whose maximum speed is 15 knots.

Required:

(1) *M*'s course at 15 knots to pass *R* at (a) maximum distance, (b) minimum distance.

(2) CPA for each course found in (1).

(3) Time interval to each CPA.

(4) Relative bearing of *R* from *M* when at CPA on each course.

Solution:

(1) Plot M_1 335˚, 16 miles from *R*. Draw the vector *er* 300˚, 30 knots. With *e* as the center, draw a circle with radius of 15 knots, the speed of *M*. From *r* draw the tangents rm_1 and rm_2 which produce the two limiting courses for *M*. Parallel to the tangents plot the relative movement lines from M_1. Course of own ship to pass at maximum distance is em_1: 000˚. Course to pass at minimum distance is em_2: 240˚.

(2) Through *R* draw RM_2 and RM'_2 perpendicular to the two possible relative movement lines. *R* bearing 180˚, 14.5 miles from M_2 is the CPA for course of 000˚. *R* bearing 240˚, 1.4 miles from M'_2 is the CPA for course 240˚.

(3) Measure M_1M_2: 6.8 miles, and $M_1M'_2$: 15.9 miles. *M* must travel these relative distances before reaching the CPA on each limiting course. The relative speed of *M* is indicated by the length of the vectors rm_1 and rm_2: 26 knots. From the TDS scale the times required to reach M_2 and M'_2 are found: 15.6 minutes and 36.6 minutes, respectively.

(4) Bearings are determined by inspection. *R* bears 180˚ relative because own ship's course is along vector em_1 for maximum CPA. *R* bears 000˚ relative when own ship's course is em_2 for minimum passing distance.

Note:

This situation occurs only when own ship *M* is (1) ahead of the other ship and (2) has a maximum speed less than the speed of the other ship. Under these conditions, own ship can intercept (collision course) only if *R* lies between the slopes of M_1M_2 and $M_1M'_2$. Note that for limiting courses, and only for these, CPA occurs when other ship is dead ahead or dead astern. The solution to this problem is applicable to avoiding a tropical storm by taking that course which results in maximum passing distance.

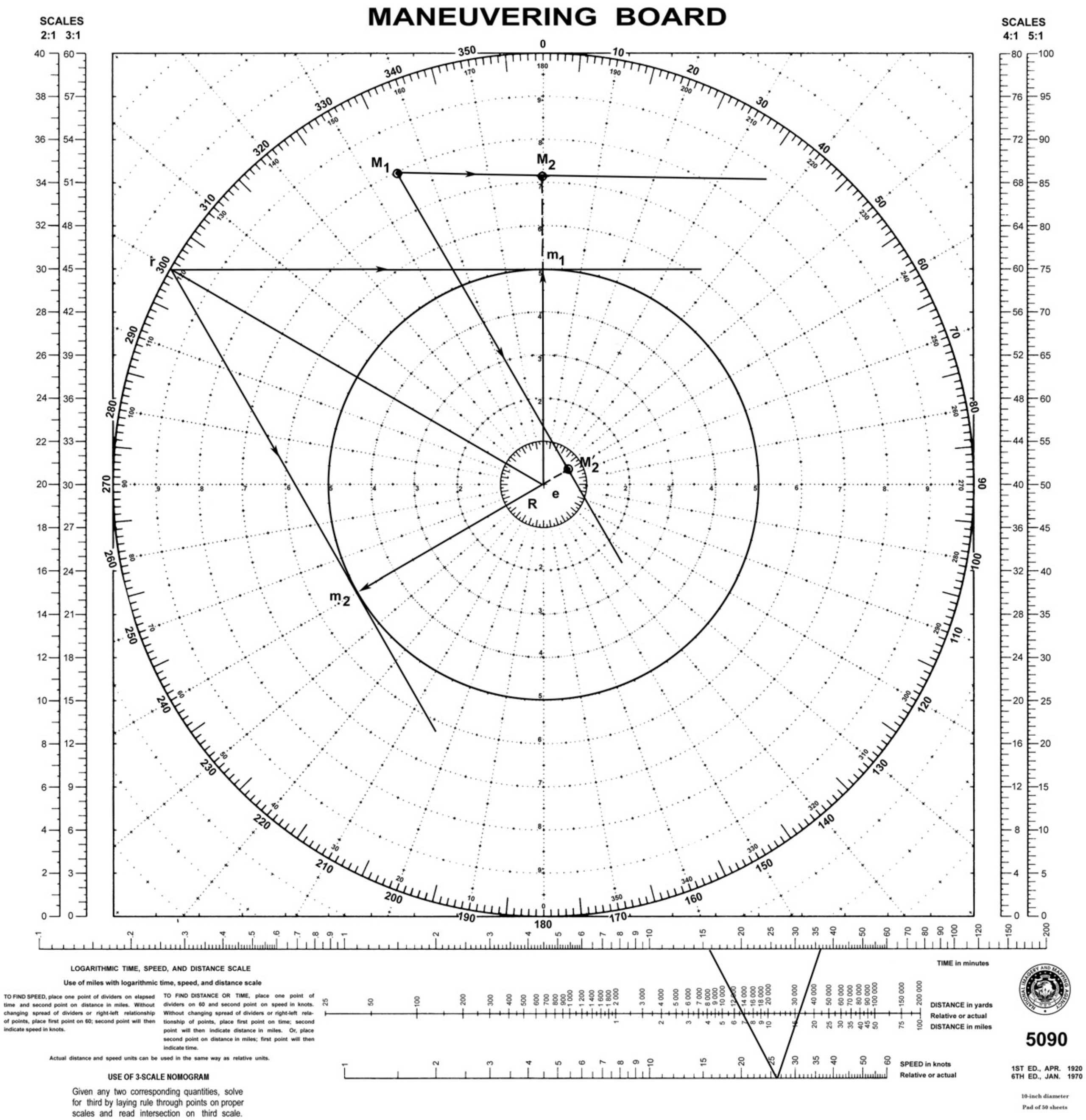
Answer:

(1) Course (a) 000˚; (b) 240˚.

(2) CPA (a) 180˚, 14.5 miles; (b) 240˚, 1.4 miles.

(3) Time (a) 16 minutes; (b) 37 minutes.

(4) Relative bearing (a) 180˚; (b) 000˚.



GUIDE AT CENTER

EXAMPLE 32

Scale: Speed 3:1;
Distance 2:1 mi.

EXAMPLE 33

COURSE CHANGE IN COLUMN FORMATION ASSURING LAST SHIP IN COLUMN CLEARS

Situation:

Own ship *D*1 is the guide in the van of a destroyer unit consisting of four destroyers (*D*1, *D*2, *D*3, and *D*4) in column astern, distance 1,000 yards. *D*1 is on station bearing 090˚, 8 miles from the formation guide *R*. Formation course is 135˚, speed 15 knots. The formation guide is at the center of a concentric circular ASW screen stationed on the 4-mile circle.

The destroyer unit is ordered to take new station bearing 235˚, 8 miles from the formation guide. The unit commander in *D*1 decides to use a wheeling maneuver at 27 knots, passing ahead of the screen using two course changes so that the CPA of his unit on each leg is 1,000 yards from the screen.

Required:

(1) New course to clear screen commencing at 1000.
(2) Second course to station.
(3) Bearing and range of *R* and *D*1 at time of coming to second course.
(4) Time of turn to second course.
(5) Time *D*1 will reach new station.

Solution:

(1) Plot the formation guide *R* at the center. Plot own ship *D*1 bearing 090˚, 8 miles from *R*. Plot the remaining three destroyers in column astern of *D*1, distance between ships 1,000 yards. Draw *er*, the speed vector of *R*, 135˚, 15 knots. It is required that the destroyer column clear *R* by a minimum of 9,000 yards (screen radius of 4 miles plus 1,000 yards). At the instant the signal is executed, only *D*1 changes both course and speed. The other destroyers increase speed to 27 knots but remain on formation course of 135˚ until each reaches the turning point. Advance *R* along the formation course the distance *R* would move at 15 knots while *D*4 advances to the turning point at 27 knots. The distance is equal to:

$$\frac{\text{Speed of } R}{\text{Speed of } D4} \times 3,000 \text{ yards} = 1,666 \text{ yards}$$

Draw a circle of radius 9,000 yards about the advanced position of the guide *R'*. Draw a line from *D*1 (the turning point) tangent to the circle. This is the relative movement line required for *D*4 to clear the screen by 1,000 yards on the first leg. Draw a line from *r* parallel to this line and intersecting the 27-knot circle at m_1. This produces em_1, the initial course of 194˚.2.

(2) Plot the final relative position of *D*1 at *D*1' bearing 235˚, 8 miles from *R*. Draw a line from *D*1' tangent to the 9,000 yard circle and intersecting the first relative movement line at *D*1". Draw a line parallel to and in the direction of *D*1"*D*1' from *r*. The intersection of this line and the 27-knot circle at m_2 is the second course required, em_2 252˚.8.

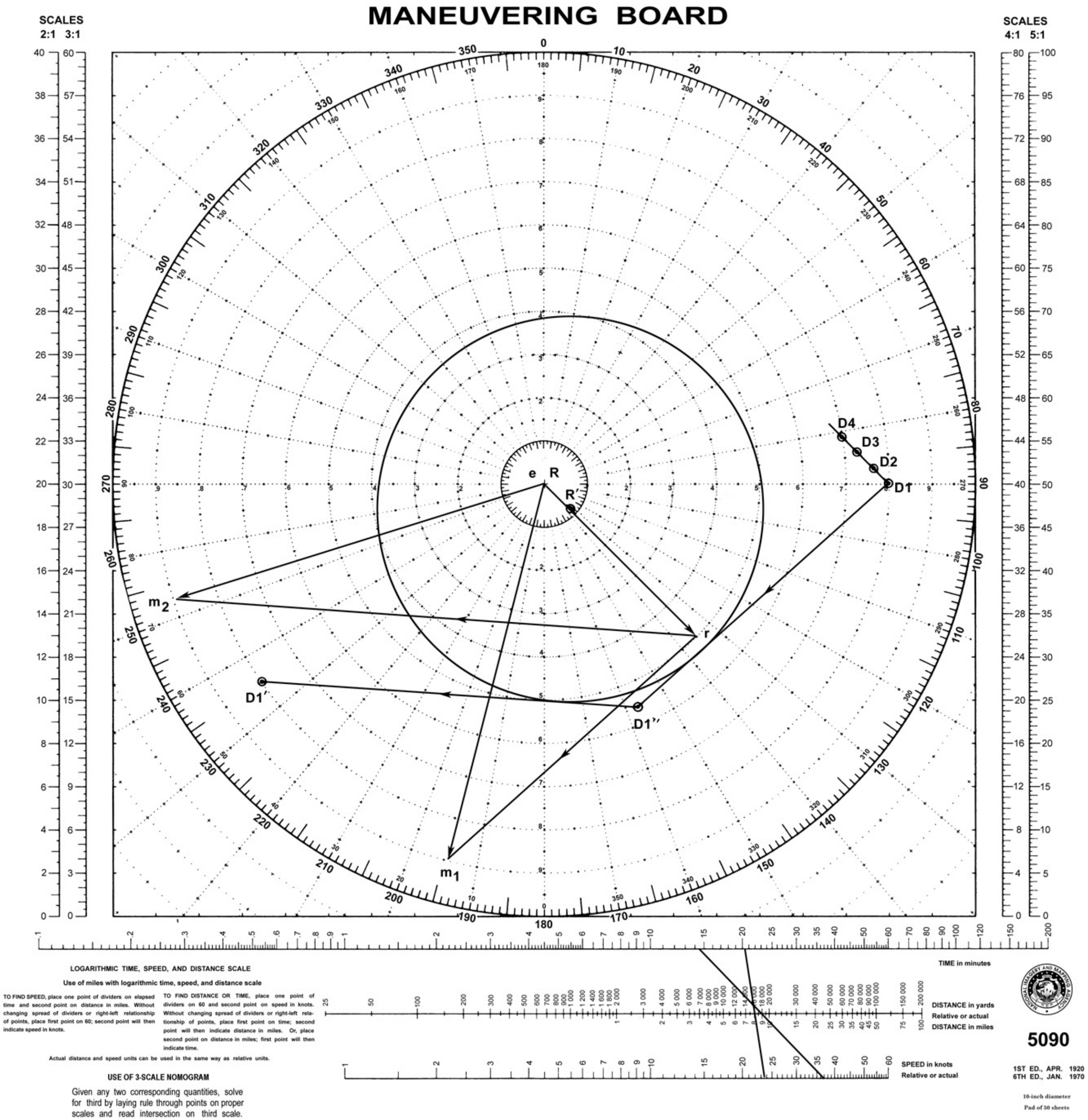
(3) Bearing and range of *R* from *D*1" is 337˚ at 11,250 yards.

(4) Time interval for *D*1 to travel to *D*1" is: $D1D1''/rm_1$ = 7.8 miles/23.2 knots = 20.2 minutes. Time of turn 1000 + 20 = 1020.

(5) Time interval for the second leg is: $D1''D1'/rm_2$ = 8.8 miles/36.5 knots = 14.2 minutes. *D*1 will arrive at new station at 1034.

Answer:

(1) Course 194˚.
(2) Course 253˚.
(3) Bearing 337˚, range 11,250 yards.
(4) Time 1020.
(5) Time 1034.



GUIDE AT CENTER

EXAMPLE 33

Scale: Speed 3:1; Distance 1:1 mi.

PRACTICAL ASPECTS OF MANEUVERING BOARD SOLUTIONS

The foregoing examples and their accompanying illustrations are based upon the premise that ships are capable of instantaneous changes of course and speed. It is also assumed that an unlimited amount of time is available for determining the solutions.

In actual practice, the interval between the signal for a maneuver and its execution frequently allows insufficient time to reach a complete, graphical solution. Nevertheless, under many circumstances, safety and smart seamanship both require prompt and decisive action, even though this action is determined from a quick, mental estimate. The estimate must be based upon the principles of relative motion and therefore should be nearly correct. Course and speed can be modified enroute to new station when a more accurate solution has been obtained from a maneuvering board.

Allowance must be made for those tactical characteristics which vary widely between types of ships and also under varying conditions of sea and loading. Experience has shown that it is impractical to solve for the relative motion that occurs during a turn and that acceptable solutions can be found by eye and mental estimate.

By careful appraisal of the PPI and maneuvering board, the relative movement of own ship and the guide during a turn can be approximated and an estimate made of the relative position upon completion of a turn. Ships' characteristic curves and a few simple thumb rules applicable to own ship type serve as a basis for these estimates. During the final turn the ship can be brought onto station with small compensatory adjustments in engine revolutions and/or course.

EXAMPLE 34

ADVANCE, TRANSFER, ACCELERATION, AND DECELERATION

Situation:

Own ship *M* is a destroyer on station bearing 020˚, 8,000 yards from the guide *R*. Formation course is 000˚, speed 15 knots. *M* is ordered to take station bearing 120˚, 8,000 yards from guide, using 25 knots.

Required:

(1) Course to new station.
(2) Bearing of *R* when order is given to resume formation course and speed.
(3) Time to complete the maneuver.

Solution:

(1) Plot *R* at the center with M_1 bearing 020˚, 8,000 yards and M_2 bearing 120˚, 8,000 yards. Draw guide's vector, *er*, 000˚, 15 knots.

By eye, it appears *M* will have to make a turn to the right of about 150˚, accelerating from 15 to 25 knots during the turn. Prior to reaching the new station a reverse turn of about the same amount and deceleration to 15 knots will be required. Assume that *M* averages 20 knots during each turn.

Using 30˚ rudder at 20 knots, a DD calibration curve indicates approximately 2˚ turn per second and a 600 yard diameter. Thus, a 150˚ turn will require about 75 seconds and will produce a transfer of about 600 yards. During the turn, *R* will advance 625 yards ($1^{1/4}$ minutes at 15 knots). Plotting this approximate off-set distance on the maneuvering board gives a new relative position of M_3 at the time the initial turn is completed. Similarly, a new off-set position at M_4 is determined where a left turn to formation course and reduction of speed to 15 knots should be ordered.

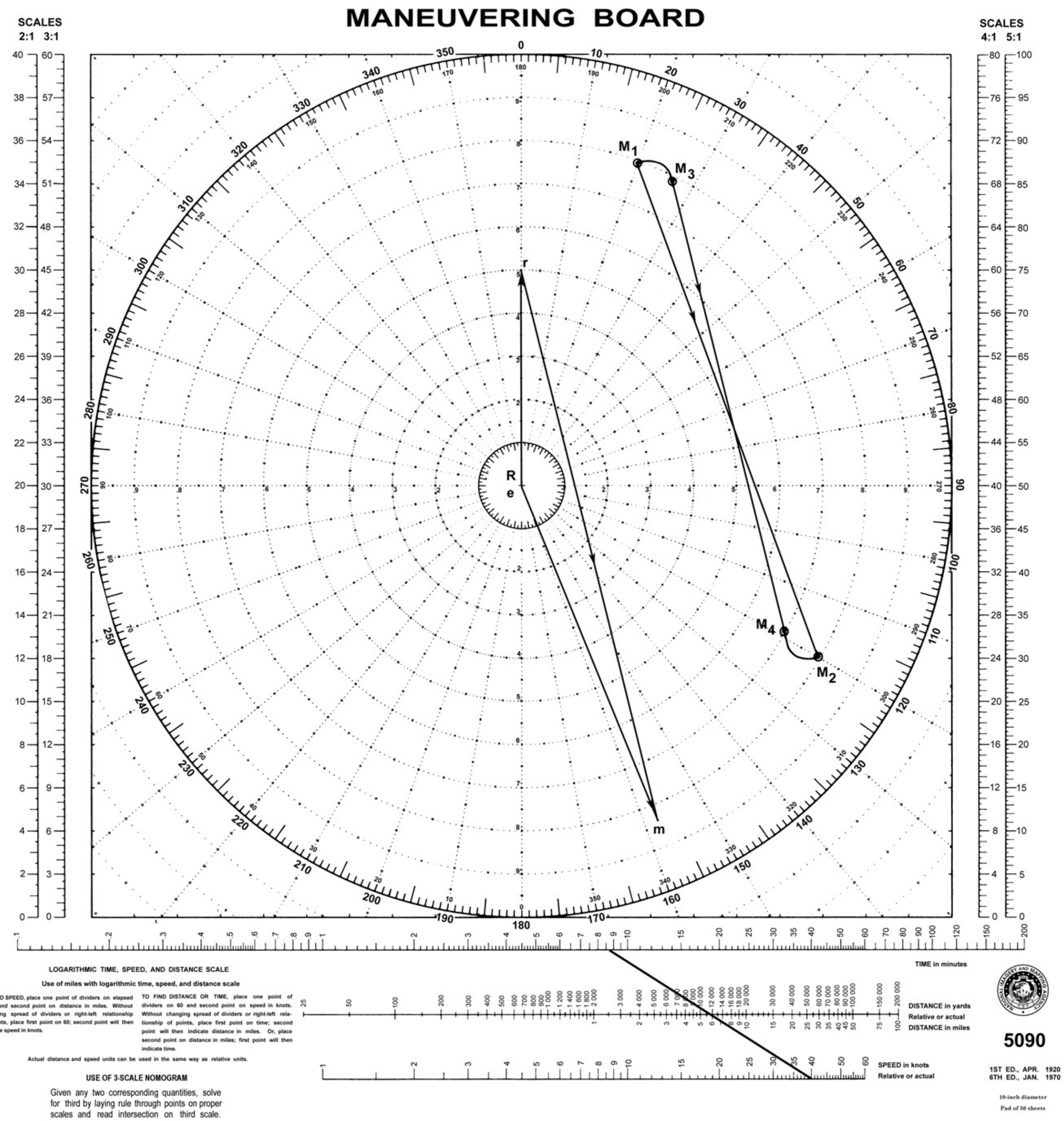
Draw a line from *r* parallel to M_3M_4 and intersecting the 25-knot speed circle at *m*. Vector *em* is the required course of 158˚.

(2) When *M* reaches point M_4 with *R* bearing 299˚, turn left to formation course using 30˚ rudder and slow to 15 knots.

(3) Time to complete the maneuver is M_3M_4/SRM + 2.5 minutes = 11,050 yards/39.8 knots + 2.5 minutes = 11 minutes.

Answer:

(1) Course 158˚.
(2) Bearing 299˚.
(3) Time 11 minutes.



GUIDE AT CENTER

EXAMPLE 34

Scale: Speed 3:1;
Distance 1:1 yd.

MANEUVERING BY SEAMAN'S EYE

In many circumstances it is impossible to use a maneuvering board in the solution of relative movement problems. When the distance between old and new stations is short and well abaft the beam, it may be impractical to attempt to complete the theoretically required turns and travel along an M_1M_2 path. In such cases, a reduction in speed, fishtailing, or various modifications of a fishtail may be required.

In the following example, it is assumed that a destroyer type ship is proceeding at formation speed and using standard rudder which yields a perfect turning circle of 1,000 yards diameter and 3,150 yards circumference. It is also assumed that a 13% reduction in speed is produced by large turns.

Based upon these assumptions, a ship using a 45˚ fishtail either side of formation course will fall behind old station by about 400 yards. By using a 60˚ fishtail, it will drop back about 700 yards. Approximate distances for any amount of course change can be computed if desired; however, the above quantities used as thumb rules should be sufficient. Repeated application of either will produce larger "drop backs" and also offer the advantage of not using excessive sea room.

If it is desired to move laterally as well as fall back, a turn of 45˚ to *one side only* and then immediate return to original course will produce a 300 yard transfer and a 200 yard drop back.

If time is not a consideration and the relative movement line is relatively very short, a reduction in speed may prove most desirable.

EXAMPLE 35

Situation:

Own ship M is on formation course 225˚, speed 15 knots, with guide R bearing 000˚, 3,000 yards.

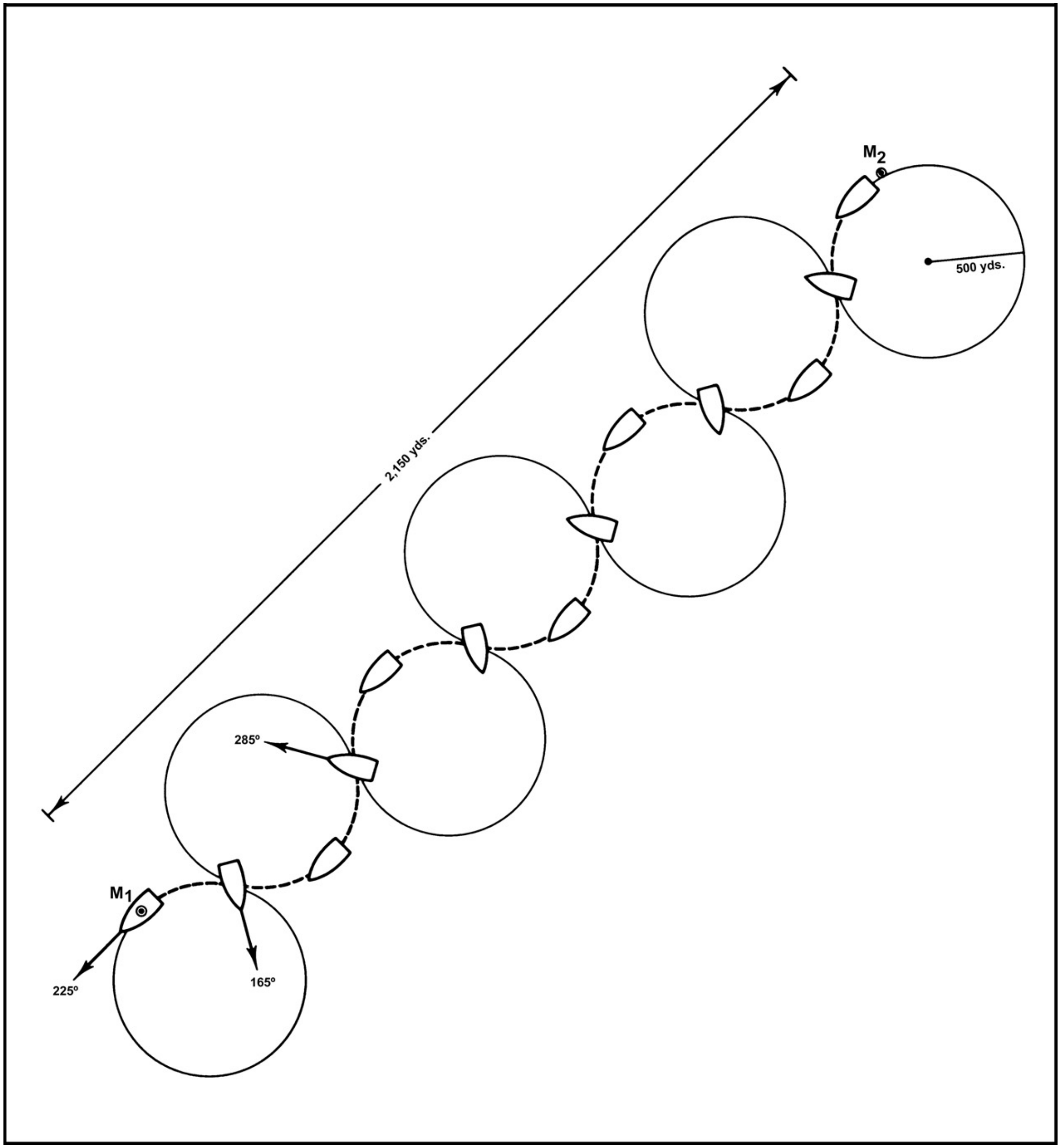
Required:

Take station 2,000 yards broad on the port beam of the guide.

Solution:

An attempt to solve this problem by normal maneuvering board procedures will prove impractical. M_2 is directly astern of M_1 at a distance of 2,150 yards. Any combination of course changes in an attempt to travel a line from M_1 to M_2 will result in own ship falling far astern of the new station. Even a simple 360˚ turn will drop own ship back 3,600 yards, almost twice the desired movement.

By fishtailing 60˚ to either side using courses of 165˚ and 285˚ three times per side, own ship will drop straight back approximately 2,000 yards, within 150 yards of station. Final adjustment to station can be effected by normal station keeping maneuvers such as rapidly shifting the rudder between maximum positions or reduction in engine revolutions.



CHANGING STATIONS BY FISHTAIL METHOD

EXAMPLE 35

EXAMPLE 36

FORMATION AXIS ROTATION—GUIDE IN CENTER

Situation:

The formation is on course 240˚, speed 15 knots. The formation axis is 130˚. The guide is in station Zero and own ship is in station 6330. The OTC rotates the formation axis to 070˚. Stationing speed is 20 knots.

Required:

(1) Course at 20 knots to regain station relative to the new formation axis, 070˚.

Solution:

(1) Mark the initial and new formation axes at 130˚ and 070˚, respectively. Plot the guide's station in the center (station Zero) and label as *R*. Plot own ship's initial position M_1 on circle 6 in a direction from the formation center 330˚ relative to the initial formation axis. Draw *er* corresponding to guide's course 240˚ and speed 15 knots.

(2) Plot own ship's new position M_2 oriented to the new axis. The original station assignments are retained, except the stations are now relative to the new axis.

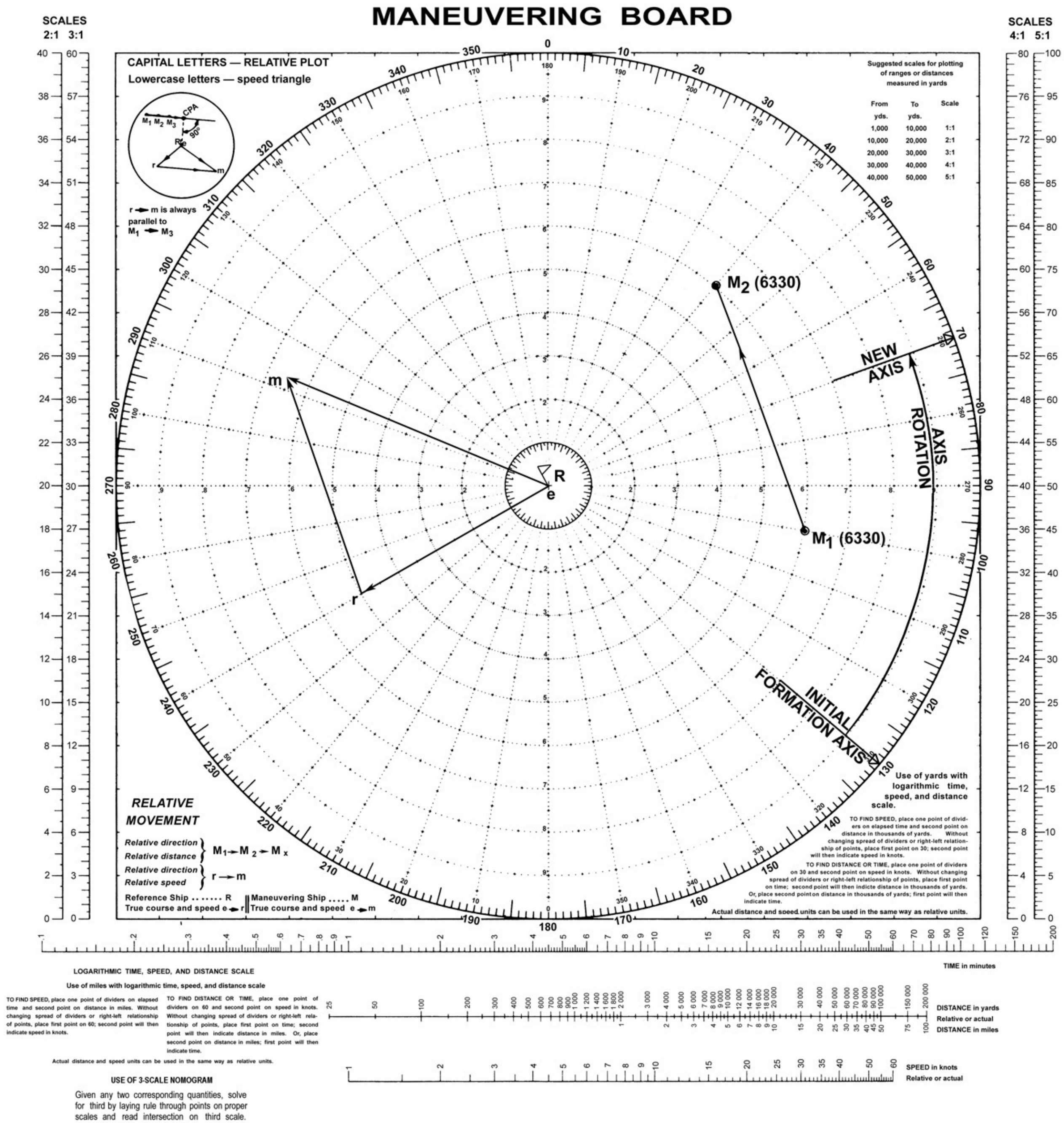
(3) Draw the direction of relative movement line (DRM) from M_1 through M_2.

(4) Through *r* draw a line in the direction of relative movement intersecting the 20-knot circle at *m*.

(5) Own ship's true vector is *em*: course 293˚, speed 20 knots.

Answer:

(1) Course 293˚ to regain station relative to the new axis.



GUIDE AT CENTER

EXAMPLE 36

Scale: Speed 3:1;
Distance 1:1 thousands of yds.

EXAMPLE 37

FORMATION AXIS ROTATION—GUIDE OUT OF CENTER FORMATION CENTER KEPT IN CENTER OF PLOT

Situation:

The formation is on course 275˚, speed 18 knots. The formation axis is 190˚. The guide is in station 3030 and own ship is in station 7300. The OTC rotates the formation axis to 140˚. Stationing speed is 20 knots.

Required:

(1) Course at 20 knots to regain station relative to the new formation axis, 140˚.

Solution:

(1) Mark the initial and new formation axes at 190˚ and 140˚, respectively. Plot the guide's initial station R_1 on circle 3 in a direction from the formation center 30˚ relative to the initial formation axis. Plot own ship's initial station S_1 on circle 7 in a direction from the formation center 300˚ relative to the initial formation axis. Draw *er* corresponding to guide's course 275˚ and speed 18 knots.

(2) Plot the guide's new station R_2 oriented to the new formation axis; plot own ship's new station S_2 oriented to the new formation axis.

(3) Measure the bearings and distances of S_1 and S_2 from R_1 and R_2, respectively.

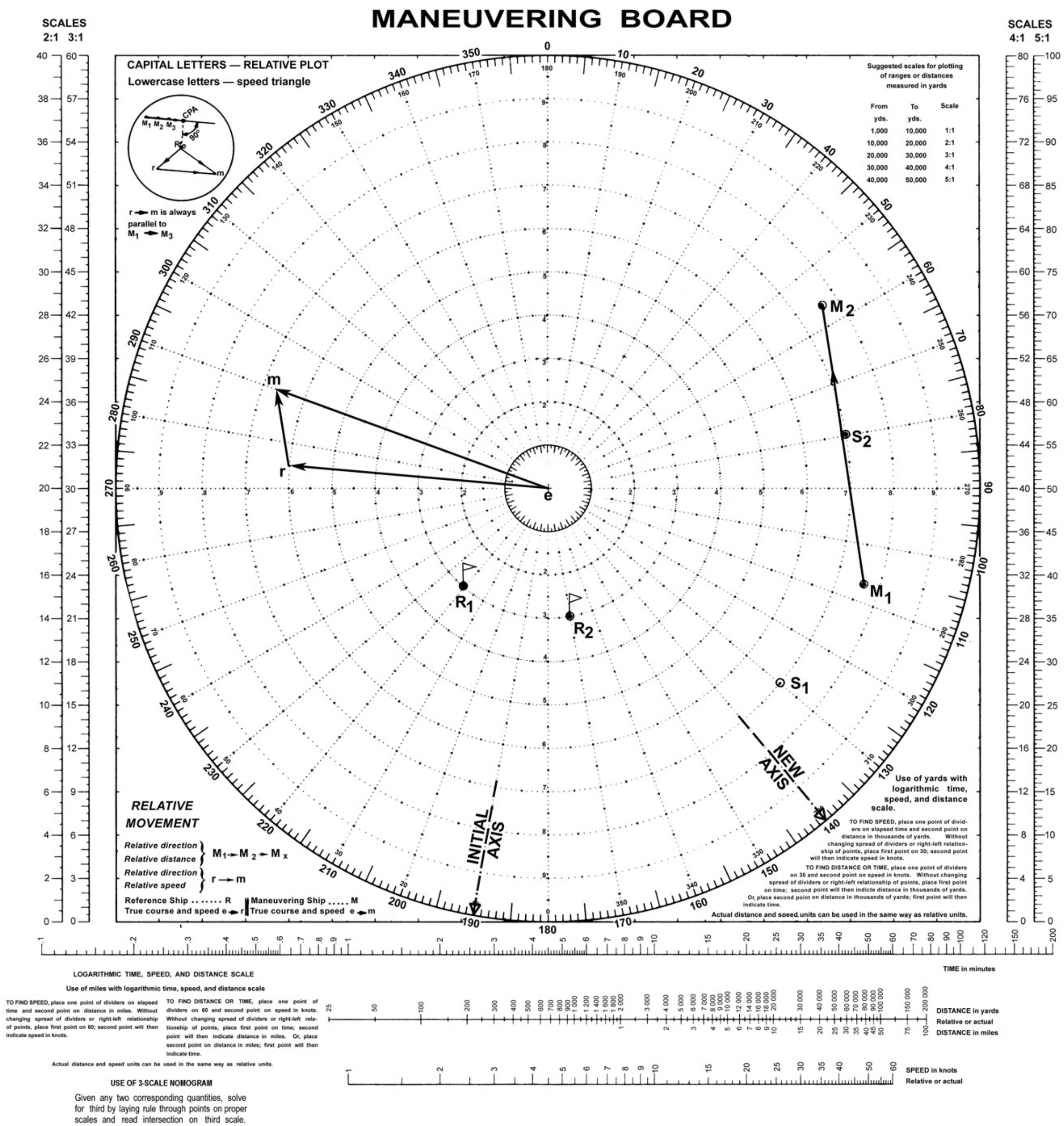
(4) From the center, plot the bearing and distance of S_1 from R_1 as M_1 and the bearing and distance of S_2 from R_2 as M_2.

(5) Since the line from M_1 to M_2 represents the required DRM for own ship to regain station relative to the new axis, draw a line through *r* in the direction of relative movement.

(6) Own ship's true vector is *em*: course 291˚, speed 20 knots.

Answer:

(1) Course 291˚ to regain station relative to the new axis.



GUIDE OUT OF CENTER

EXAMPLE 37

Scale: Speed 3:1;
Distance 1:1 thousands of yds.

EXAMPLE 38

FORMATION AXIS ROTATION—GUIDE OUT OF CENTER

Situation:

The formation is on course 275˚, speed 18 knots. The formation axis is 190˚. The guide is in station 3030 and own ship is in station 7300. The OTC rotates the formation axis to 140˚. Stationing speed is 20 knots.

Required:

(1) Course at 20 knots to regain station relative to the new formation axis, 140˚.

Solution:

(1) Mark the initial and new formation axes at 190˚ and 140˚, respectively. Plot the guide's station R_1 on circle 3 in a direction from the formation center 30˚ relative to the initial formation axis. Plot own ship's station M_1 on circle 7 in a direction from the formation center 300˚ relative to the initial formation axis. Draw *er* corresponding to guide's course 275˚ and speed 18 knots.

(2) Plot the guide's station, R_2, oriented to the new formation axis. Plot own ship's position M_3 oriented to the new axis. The original station assignments are retained, except the stations are now relative to the new axis.

(3) Shift the initial position of own ship's station at M_1 in the direction and distance of the fictitious shift of the guide to its position relative to the new axis. Mark the initial position so shifted as M_2.

(4) Draw the direction of relative movement lines (DRM) from M_2 through M_3.

(5) Through *r* draw a line in the direction of relative movement intersecting the 20-knot circle at *m*.

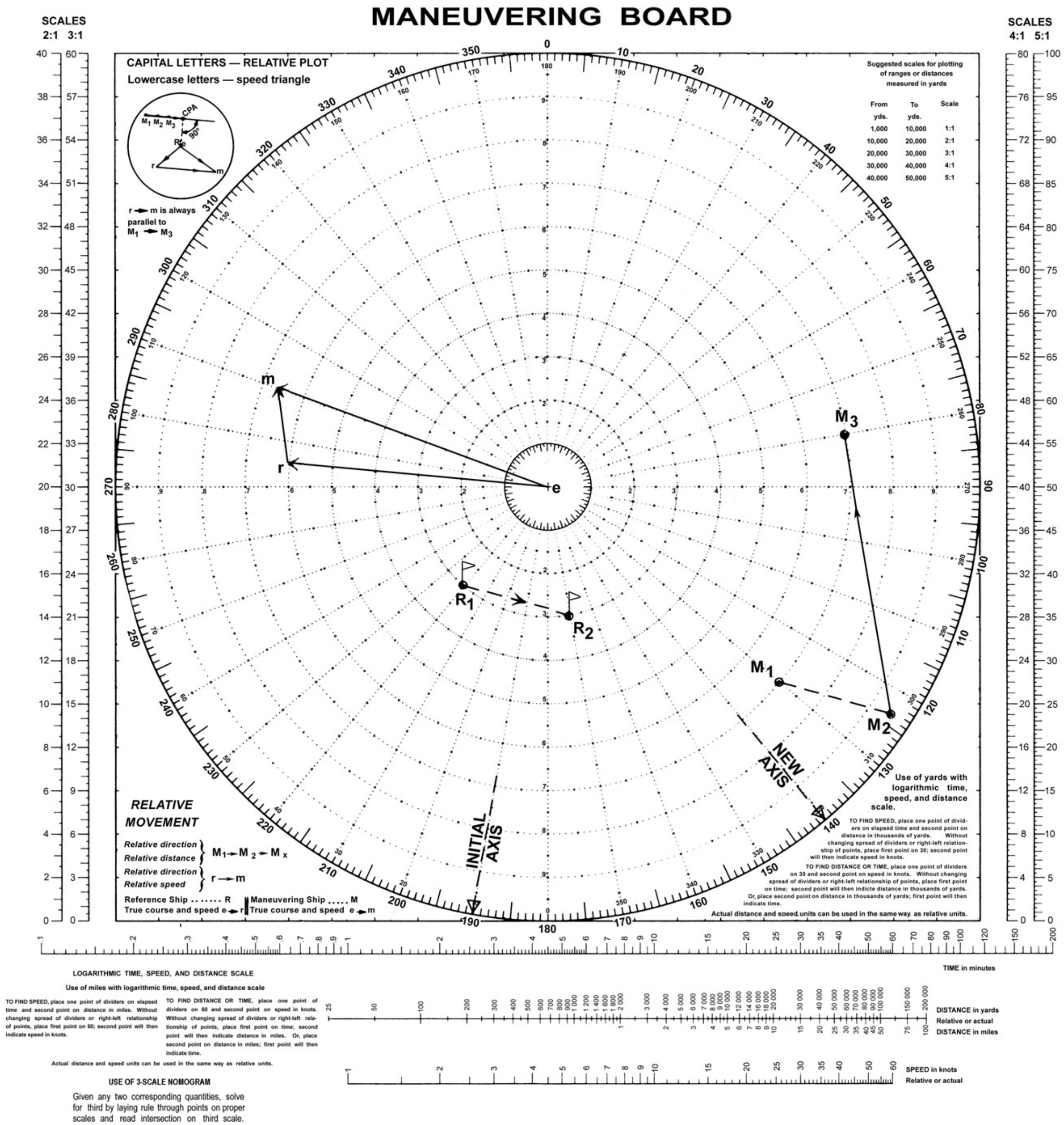
(6) Own ship's true vector is *em*: course 291˚, speed 20 knots.

Answer:

(1) Course 291˚ to regain station relative to the new axis.

Explanation:

Since the guide does not actually move relative to the initial formation center while maintaining course and speed during the formation maneuver, all initial positions of stations in the formation must be moved in the same direction and distance as the fictitious movement of the guide to its new position.



GUIDE OUT OF CENTER

EXAMPLE 38

Scale: Speed 3:1;
Distance 1:1 thousands of yds.

EXAMPLE 39

COURSE AND SPEED BETWEEN TWO STATIONS, REMAINING WITHIN A SPECIFIED RANGE FOR SPECIFIED TIME INTERVAL ENROUTE

Situation:

Own ship *M* is on station bearing 280˚, 5 miles from the guide *R* on formation course 190˚, speed 20 knots.

Required:

At 1500 own ship *M* is ordered to proceed to new station bearing 055˚, 20 miles, arriving at 1630 and to remain within a 10-mile range for 1 hour. The commanding officer elects to proceed directly to new station, adjusting course and speed as necessary to comply with the foregoing requirements.

(1) Course and speed to remain within 10 miles for 1 hour.

(2) Course and speed required at 1600.

(3) Bearing of *R* at 1600.

Solution:

(1) Plot the 1500 and 1630 positions of *M* at M_1 and M_3, respectively. Draw the relative motion line, M_1M_3, intersecting the 10-mile circle at M_2. Draw *er*. Measure M_1M_2: 13.6 miles. The time required to transit this distance is 1 hour at an SRM of 13.6 knots. Through *r* draw rm_1 13.6 knots in length, parallel to and in the direction M_1M_3. Vector em_1 is 147˚.5, 16.2 knots.

(2) Measure M_2M_3, 10.3 miles, which requires an SRM of 20.6 knots for one half hour. Through *r* draw rm_2. Vector em_2 is 125˚.5, 18.2 knots.

(3) By inspection, *R* bears 226˚ from M_2 at 1600.

Answer:

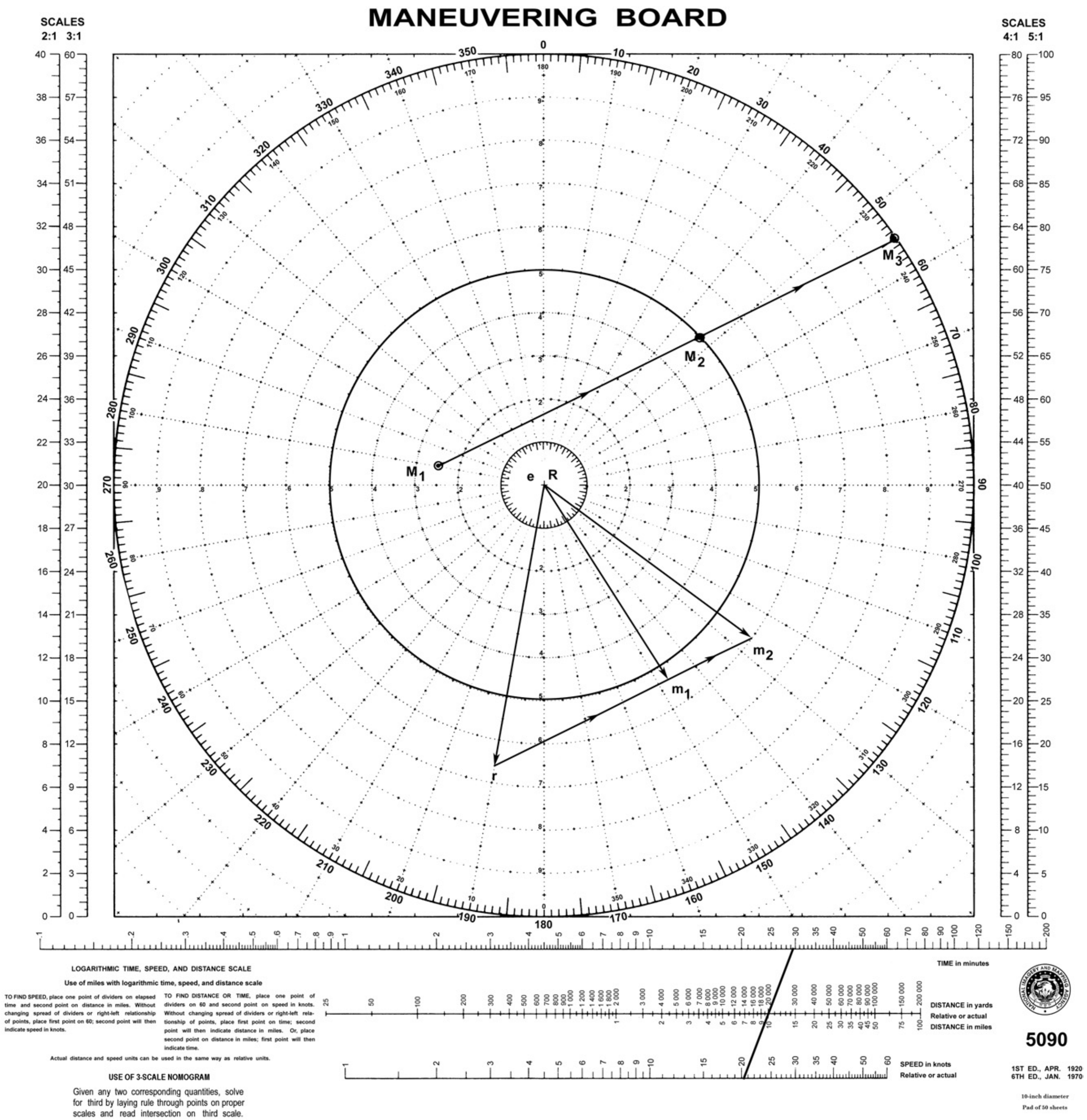
(1) Course 148˚, speed 16.2 knots.

(2) Course 126˚, speed 18.2 knots.

(3) Bearing 226˚.

Explanation:

Since own ship *M* must remain within 10 miles of the guide for 1 hour, *M* must not plot along M_1M_2 farther than M_2 prior to 1600. The required magnitudes of the relative speed vectors for time intervals 1500 to 1600 and 1600 to 1630 together with their common direction are combined with the true vector of the guide to obtain the two true course vectors for own ship.



GUIDE AT CENTER

EXAMPLE 39

Scale: Speed 3:1; Distance 2:1 mi.

EXAMPLE 40

COURSE AT MAXIMUM SPEED TO OPEN RANGE TO A SPECIFIED DISTANCE IN MINIMUM TIME

Situation:

Own ship *M* has guide *R* bearing 240˚, range 12 miles. The guide is on course 120˚, speed 15 knots. Own ship's maximum speed is 30 knots.

Required:

Open range to 18 miles as quickly as possible.

(1) Course at 30 knots.

(2) Time to complete the maneuver.

(3) Bearing of guide upon arrival at specified range.

Solution:

The key to this solution is to find that relative position (*M*') of the guide that could exist *before* the problem starts in order to be able to draw the RML through the given relative position (M_1) and *M'* to intersect the specified range circle.

(1) Plot *R* and M_1. About *R* describe a circle of radius 18 miles. Draw *er*. Along *R*'s course plot *M'* 9 miles from *R*.

$$\frac{\text{Speed of } R}{\text{Speed of } M} \times 18 \text{ miles} = 9 \text{ miles}$$

Draw a line through *M'* and M_1 and extend it to intersect the 18-mile range circle at M_2.

From *r* draw *rm* parallel to and in the direction M_1M_2. The intersection of *rm* and the 30-knot speed circle is the course required to complete the maneuver in minimum time. Vector *em* is 042˚.6, 30 knots.

(2) SRM is 30.5 knots. MRM is 7.5 miles. Time to complete the maneuver: 14.8 minutes.

(3) Upon reaching the 18-mile range circle, *R* is dead astern of *M* bearing 222˚.6.

Answer:

(1) Course 043˚.

(2) Time 15 minutes.

(3) Bearing 223˚.

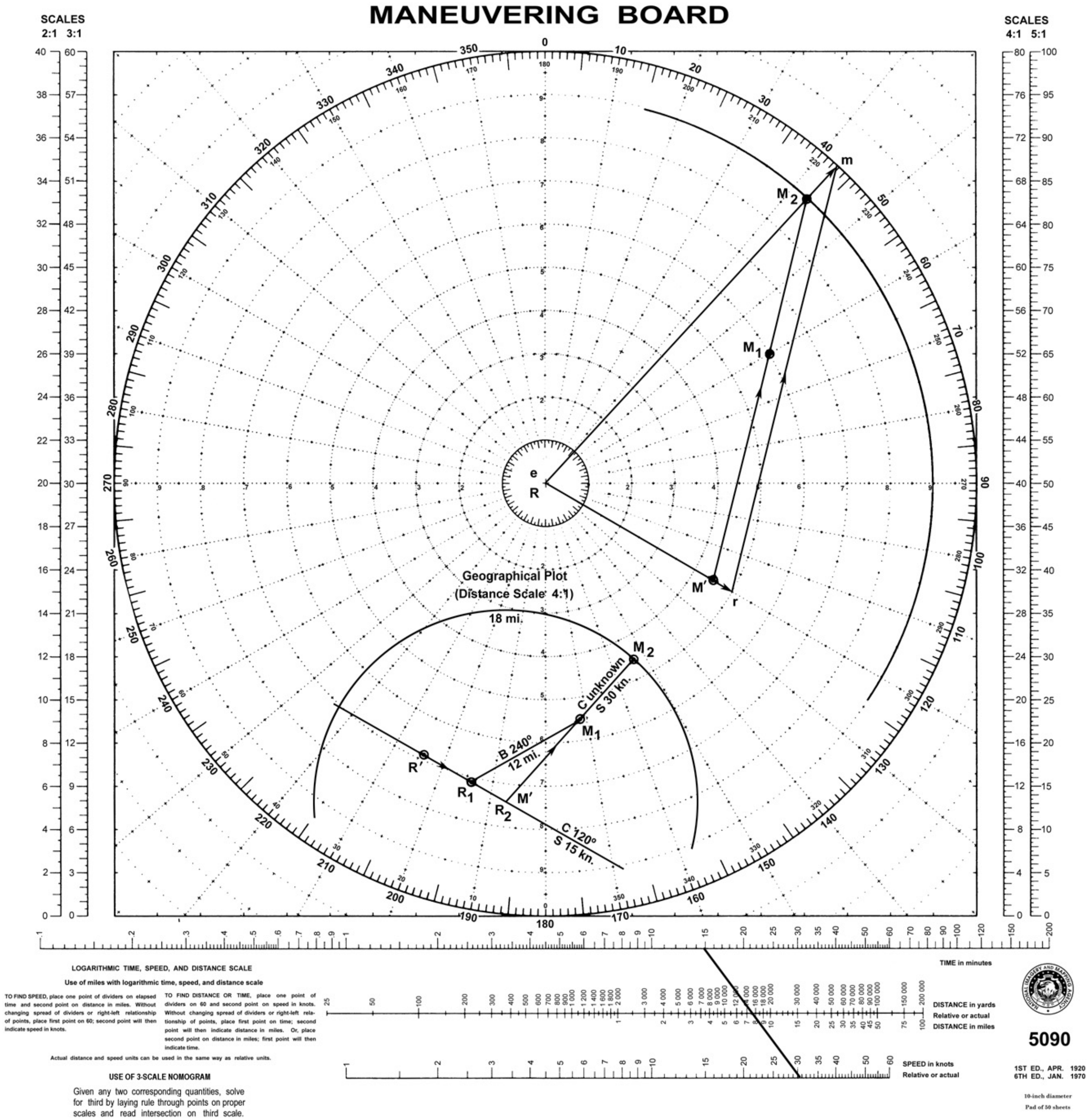
Explanation:

For *M* to open or close to a specified range in minimum time, *M* must travel the shortest geographical distance at maximum speed. The shortest distance is along the radius of a circle centered at the position occupied by *R* at the instant *M* reaches the specified range circle.

In the "opening range" problem, determine hypothetical relative positions of *M* and *R* that could exist *before the problem starts*. Referring to the **geographical plot**, assume *M* starts from position *M'* and proceeds outward along some radius 18 miles in length on an unknown course at 30 knots. If *R* moves toward its final position at R_2 along the given course of 120˚, speed 15 knots, it should arrive at R_2 the instant *M* reaches the 18-mile circle. At this instant, the problem conditions are satisfied by *M* being 18 miles distant from *R*. However, own ship's course required to reach this position is not yet known. During the time interval *M* opened 18 miles at 30 knots, *R* moved 9 miles at 15 knots from *R'* to R_2.

$$\frac{\text{Speed of } M}{\text{Speed of } R} \times 18 \text{ miles} = 9 \text{ miles}$$

This provides the needed second relative position of *M'* from *R'*, 9 miles bearing 120˚. This position is then transferred to the **relative plot**.



GUIDE AT CENTER

EXAMPLE 40

Scale: Speed 3:1;
Distance 2:1 mi.

EXAMPLE 41

COURSE AT MAXIMUM SPEED TO CLOSE RANGE TO A SPECIFIED DISTANCE IN MINIMUM TIME

Situation:

Own ship M has the guide R bearing 280˚, range 10 miles. The guide is on course 020˚, speed 15 knots. Own ship's maximum speed is 24 knots.

Required:

Close range to 2 miles as quickly as possible.

(1) Course at 24 knots.

(2) Time to complete the maneuver.

(3) Bearing of guide upon arrival at the specified range.

Solution:

The key to this solution is to find that relative position (M') of the guide that could exist *after* the problem starts in order to be able to draw the RML through the given relative position (M_1) and M' to intersect the specified range circle.

(1) Plot R and M_1. About R describe a circle of radius 2 miles. Draw *er*, guide's speed vector 020˚, 15 knots. On reciprocal of R's course plot M' 1.25 miles from R.

$$\frac{\text{Speed of } R}{\text{Speed of } M} \times 2 \text{ miles} = 1.25 \text{ miles}$$

Draw a line through M' and M_1. The intersection of this line and the 2-mile range circle is M_2.

From r draw a line parallel to and in the direction M_1M_2. The intersection of this line and the 24-knot speed circle at m is the course required to complete the maneuver in minimum time. Vector *em* 309˚.8, 24 knots.

(2) SRM is 23.6 knots. MRM is 8.3 miles. Time to complete the maneuver: 21.1 minutes.

(3) Upon reaching the 2-mile range circle, R is dead ahead of M on a bearing 309˚.8.

Answer:

(1) Course 310˚.

(2) Time 21 minutes.

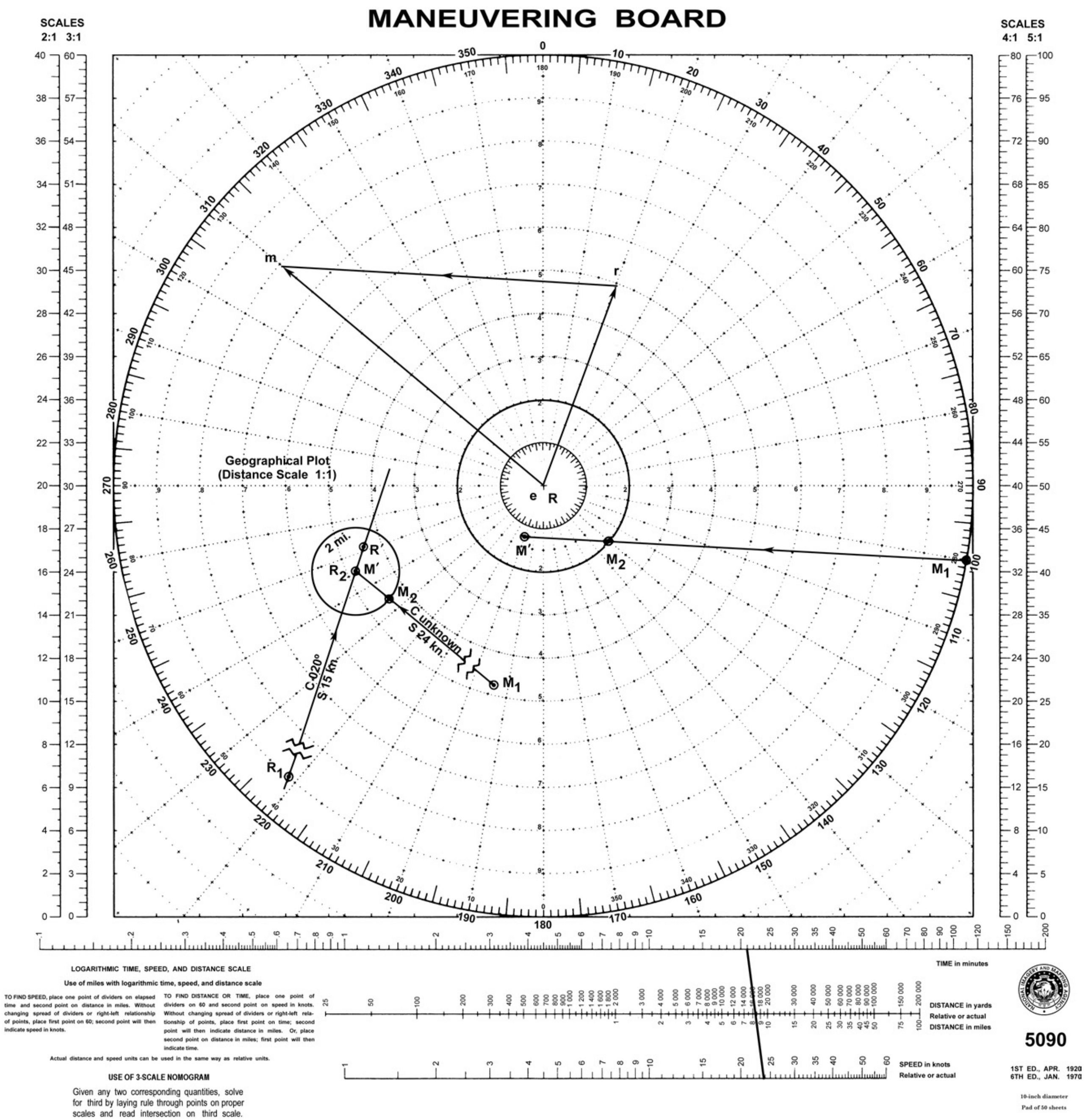
(3) Bearing 310˚.

Explanation:

Referring to the **geographical plot**, assume M starts from position M_1 and proceeds inward along some radius on an unknown course at 24 knots. If R moves toward its final position at R_2 along the given course 020˚, speed 15 knots, it should arrive at R_2 the instant M reaches the 2-mile circle. At this instant the problem conditions are satisfied although the solution for own ship's course is not yet known. Assume that M continues on the same course and speed through the 2 miles to M' at the center of the circle while R moves away from the center on course 020˚, speed 15 knots. During the time interval that M moves these 2 miles at 24 knots, R opens 1.25 miles.

$$\frac{\text{Speed of } R}{\text{Speed of } M} \times 2 \text{ miles} = 1.25 \text{ miles}$$

This provides the needed second relative position of M' from R': 1.25 miles, bearing 200˚. This position is then transferred to the **relative plot**.



GUIDE AT CENTER

EXAMPLE 41

Scale: Speed 3:1; Distance 1:1 mi.

EXAMPLE 42

COURSE AT MAXIMUM SPEED TO REMAIN WITHIN A SPECIFIED RANGE FOR MAXIMUM TIME

Situation:

Ship *R* bears 110˚, 4 miles from *M*. *R* is on course 230˚, 18 knots. Maximum speed of *M* is 9 knots.

Required:

Remain within a 10-mile range of *R* for as long as possible.
(1) Course at maximum speed.
(2) Bearing of *R* upon arrival at specified range.
(3) Length of time within specified range.
(4) CPA.

Solution:

(1) Plot *R* at the center and M_1 bearing 290˚, 4 miles from *R*. About *R* describe arcs of radius 9 knots and 10 miles. Draw *er* 230˚, 18 knots. Along the reciprocal of *R*'s course, plot *M'* 20 miles from *R*.

$$\frac{\text{Speed of } R}{\text{Speed of } M} \times 10 \text{ miles} = 20 \text{ miles}$$

Draw a line through *M'* and M_1. The intersection of $M'M_1$ and the 10-mile range circle is M_2, the point beyond which the specified or limiting range is exceeded. Through *r* draw a line parallel to and in the direction M_1M_2. The intersection of this line at point *m* on the 9-knot speed circle is the required course to remain within 10 miles of *R*. Vector *em* is 220˚.8, 9 knots.

(2) Upon arrival at limiting range at M_2, *R* is dead ahead of *M* bearing 220˚.8.

(3) The time interval within specified range is:

$$\frac{M_1M_2}{rm} = \frac{12 \text{ miles}}{9.1 \text{ knots}} = 78.8 \text{ minutes}$$

(4) Drop a perpendicular from *R* to M_1M_2. CPA is 148˚.9, 3.1 miles.

Note:

When *M*'s speed is equal to or greater than that of *R*, a special case exists in which there is no problem insofar as remaining within a specified range.

Answer:

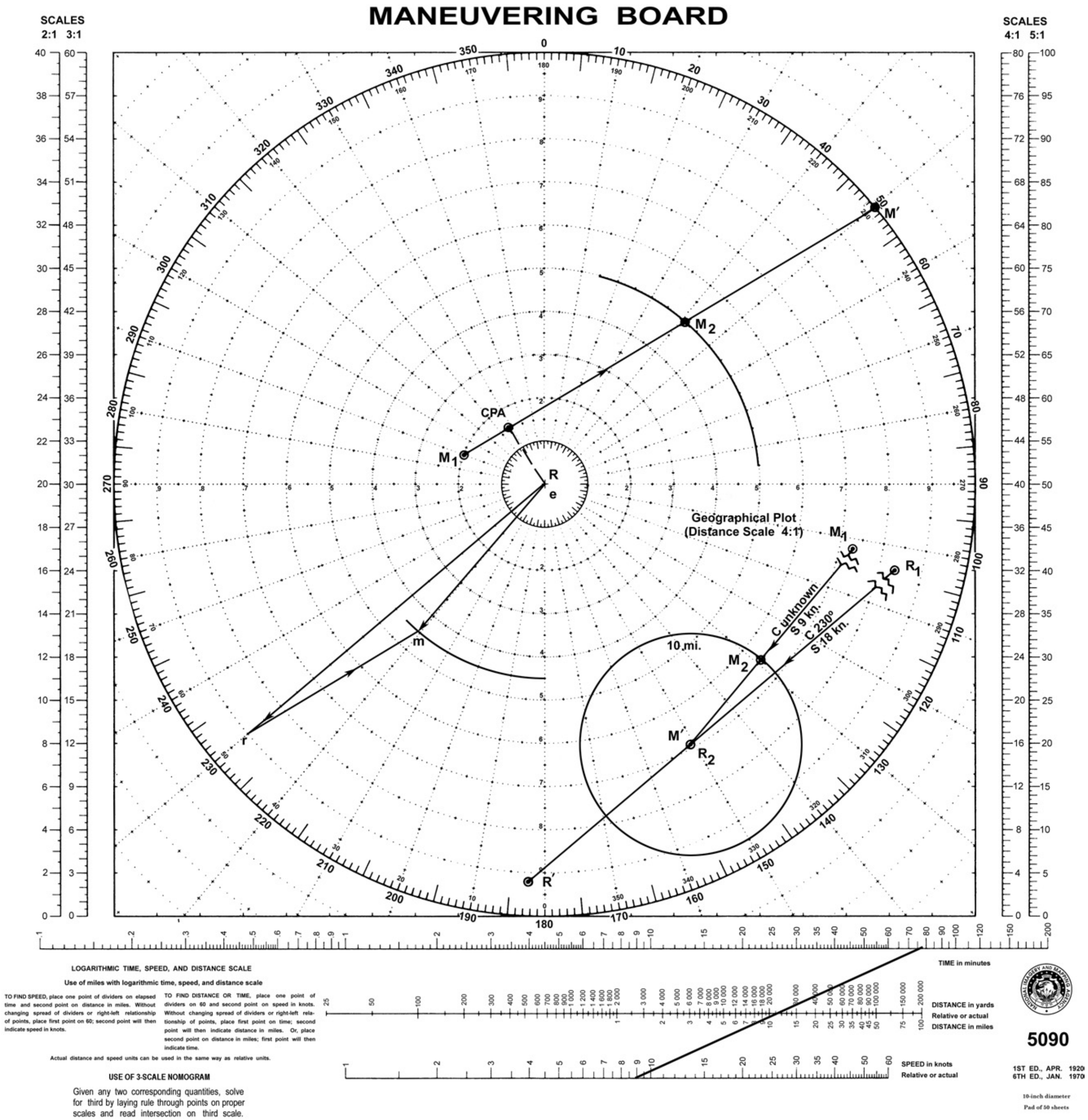
(1) Course 221˚.
(2) Bearing 221˚.
(3) Time 79 minutes.
(4) CPA 149˚, 3.1 miles.

Explanation:

As in the "closing range" problem, example 39, determine hypothetical relative positions of *M* and *R* that could exist *after the problem ends*. Referring to the **geographical plot**, assume *M* starts from position M_1 and proceeds inward along some radius on an unknown course at 9 knots. *R* is on course 230˚ at 18 knots. At the instant *R* passes through R_2, *M* reaches the 10-mile limiting range at M_2. At this instant the problem conditions are satisfied although the solution is not yet known. Assume that *M* continues on the same course and speed for 10 miles to the center of the circle while *R* moves away from the center on course 230˚, speed 18 knots. During the time interval *M* closes 10 miles toward the center, *R* opens 20 miles at 18 knots.

$$\frac{\text{Speed of } R}{\text{Speed of } M} \times 10 \text{ miles} = 20 \text{ miles}$$

This then gives us the needed second relative position of *R'* from *M'*, 20 miles bearing 230˚. This position is then transferred to the **relative plot**.



GUIDE AT CENTER

EXAMPLE 42

Scale: Speed 2:1;
Distance 2:1 mi.

EXAMPLE 43

COURSE AT MAXIMUM SPEED TO REMAIN OUTSIDE OF A SPECIFIED RANGE FOR MAXIMUM TIME

Situation:

Ship *R* bears 020˚, 14 miles from own ship *M*. *R* is on course 210˚, speed 18 knots. Maximum speed of *M* is 9 knots.

Required:

Remain outside a 10-mile range from *R* for as long as possible.
(1) Course at maximum speed.
(2) Bearing of *R* upon arrival at specified range.
(3) Time interval before reaching specified range.

Solution:

(1) Plot *R* at the center and M_1 bearing 200˚, 14 miles from *R*. About *R*, describe circles of radius 9 knots and 10 miles. Draw *er* 210˚, speed 18 knots. Along *R*'s course, plot *M'* 20 miles from *R*.

$$\frac{\text{Speed of } R}{\text{Speed of } M} \times 10 \text{ miles} = 20 \text{ miles}$$

Draw a line through *M'* and M_1 intersecting the 10-mile range circle at M_2. Through *r* draw a line parallel to and in the direction of M_1M_2 intersecting the 9-knot speed circle at *m*. Completion of the speed triangle produces *em*, the required course of 184˚.2 at 9 knots.

(2) Upon arrival at limiting range at point M_2, *R* is dead astern of *M* bearing 004˚.2.

(3) The time interval outside of specified range is:

$$\frac{M_1M_2}{rm} = \frac{5.2 \text{ miles}}{10.7 \text{ knots}} = 30 \text{ minutes}$$

Note:

Own ship can remain outside the limiting range indefinitely if M_1 falls outside the area between two tangents drawn to the limiting range circle from *M'* and if *R* remains on the same course and speed.

Answer:

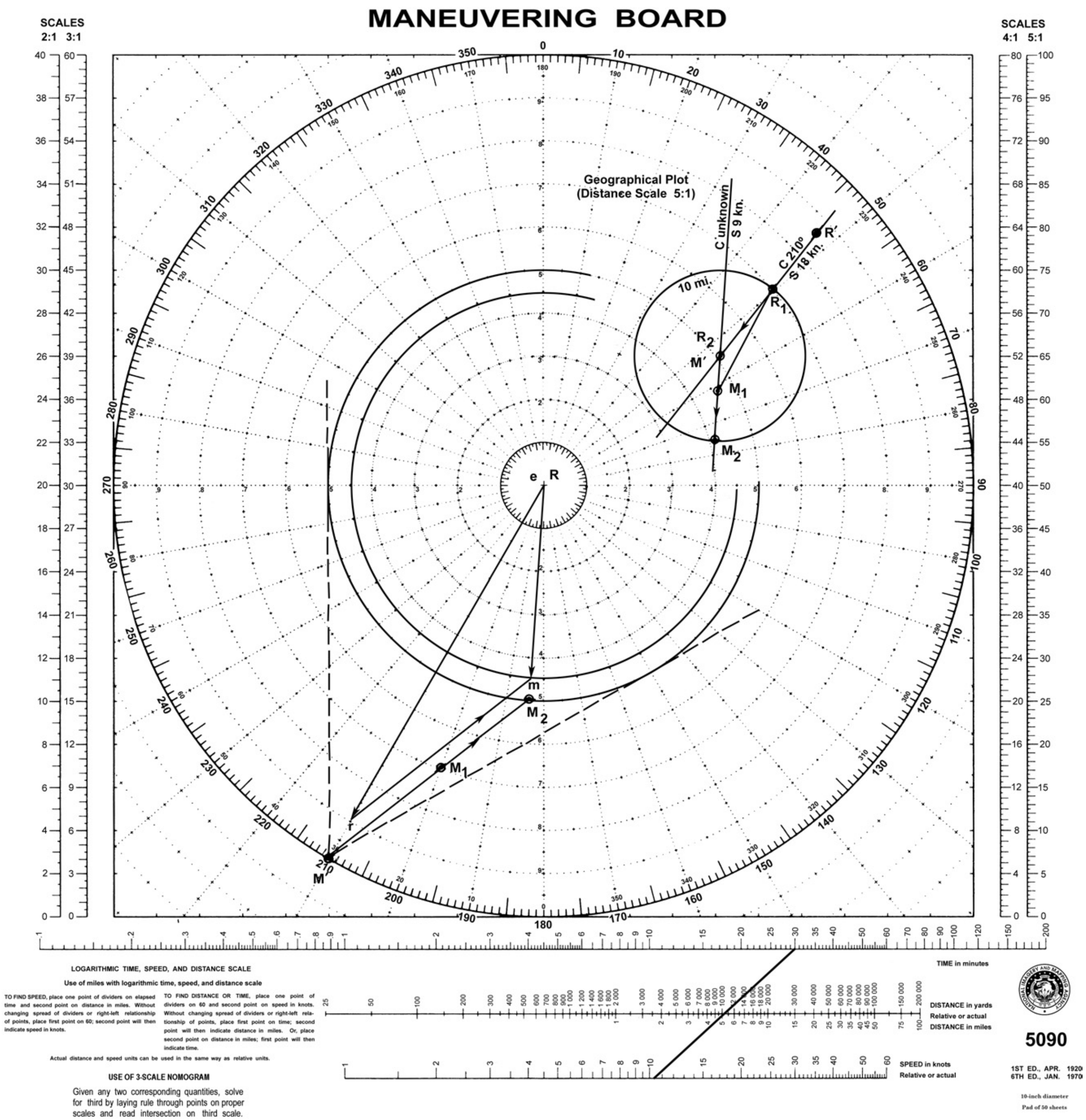
(1) Course 184˚.
(2) Bearing 004˚.
(3) Time 30 minutes.

Explanation:

To determine a course to remain outside of a given range for maximum time, determine hypothetical relative positions of *M* and *R* that could exist *before the problem starts*. Referring to the **geographical plot**, assume *M* starts from position *M'* and proceeds outward along some radius on an unknown course at 9 knots. If *R* moves toward its final position R_2 along the given course 210˚, speed 18 knots, it should arrive at R_2 the instant *M* reaches the 10-mile circle at M_2. At this instant the problem conditions are satisfied although the solution for own ship's course is not yet known. During the time interval required for *M* to move from *M'* to M_2, 10 miles at 9 knots, *R* moves from *R'* to R_2, 20 miles at 18 knots along the given course 210˚.

$$\frac{\text{Speed of } R}{\text{Speed of } M} \times 10 \text{ miles} = 20 \text{ miles}$$

This provides the needed second relative position, *M'* bearing 210˚, 20 miles from *R'*. This position is then transferred to the **relative plot**.



GUIDE AT CENTER

EXAMPLE 43

Scale: Speed 2:1;
Distance 2:1 mi.

USE OF A FICTITIOUS SHIP

The examples given thus far in PART TWO have been confined to ships that have either maintained constant courses and speeds during a maneuver or else have engaged in a succession of such maneuvers requiring only repeated application of the same principles. When one of the ships alters course and/or speed during a maneuver, a preliminary adjustment is necessary before these principles can be applied.

This adjustment consists, in effect, of substituting a **fictitious ship** for the ship making the alteration. This fictitious ship is presumed to:

(1) maintain a constant course and speed throughout the problem (this is the *final* course and speed of the actual ship).

(2) start and finish its run at times and positions determined by the conditions established in the problem.

For example, the course and speed of advance of a ship zig-zagging are considered to be the constant course and speed of a fictitious ship which departs from a given position at a given time simultaneously with the actual ship, and arrives simultaneously with the actual ship at the same final position. The principles discussed in previous examples are just as valid for a fictitious ship as for an actual ship, both in the relative plot and speed triangle. A **geographical plot** facilitates the solution of this type.

EXAMPLE 44

ONE SHIP ALTERS COURSE AND/OR SPEED DURING MANEUVER

Situation:

At 0630 ship *R* bears 250˚, range 32 miles. *R* is on course 345˚, speed 15 knots but at 0730 will change course to 020˚ and speed to 10 knots.

Required:

Own ship *M* take station 4 miles ahead of *R* using 12 knots speed.

(1) Course to comply.

(2) Time to complete maneuver.

Solution:

Determine the 0630 position of a fictitious ship *F* that, by steering course 020˚ at speed 10 knots, will pass through the 0730 position simultaneously with the actual ship. In this way the **fictitious ship** travels on a steady course of 020˚, speed 10 knots throughout the problem.

(1) Construct a **geographical plot** with *R* and R_1 the 0630 and 0730 positions respectively of ship *R* moving along course 345˚ at 15 knots. Plot *F*, the 0630 position of the fictitious ship bearing 200˚, 10 miles from R_1. By measurement, *F* bears 304˚, 8.8 miles from *R*. Transfer this position to a relative plot with *R* at the center.

Plot own ship at M_1 bearing 070˚, 32 miles from *R*. Draw *erf*, the fictitious ship's vector, 020˚, 10 knots. Lay off own ship's final position, M_2, 4 miles ahead of *F* along its final course 020˚. Draw the relative movement line M_1M_2 and, parallel to it, construct the relative speed vector from *rf* to its intersection with the 12-knot circle at *m*. This produces *em* the required course of 316˚.

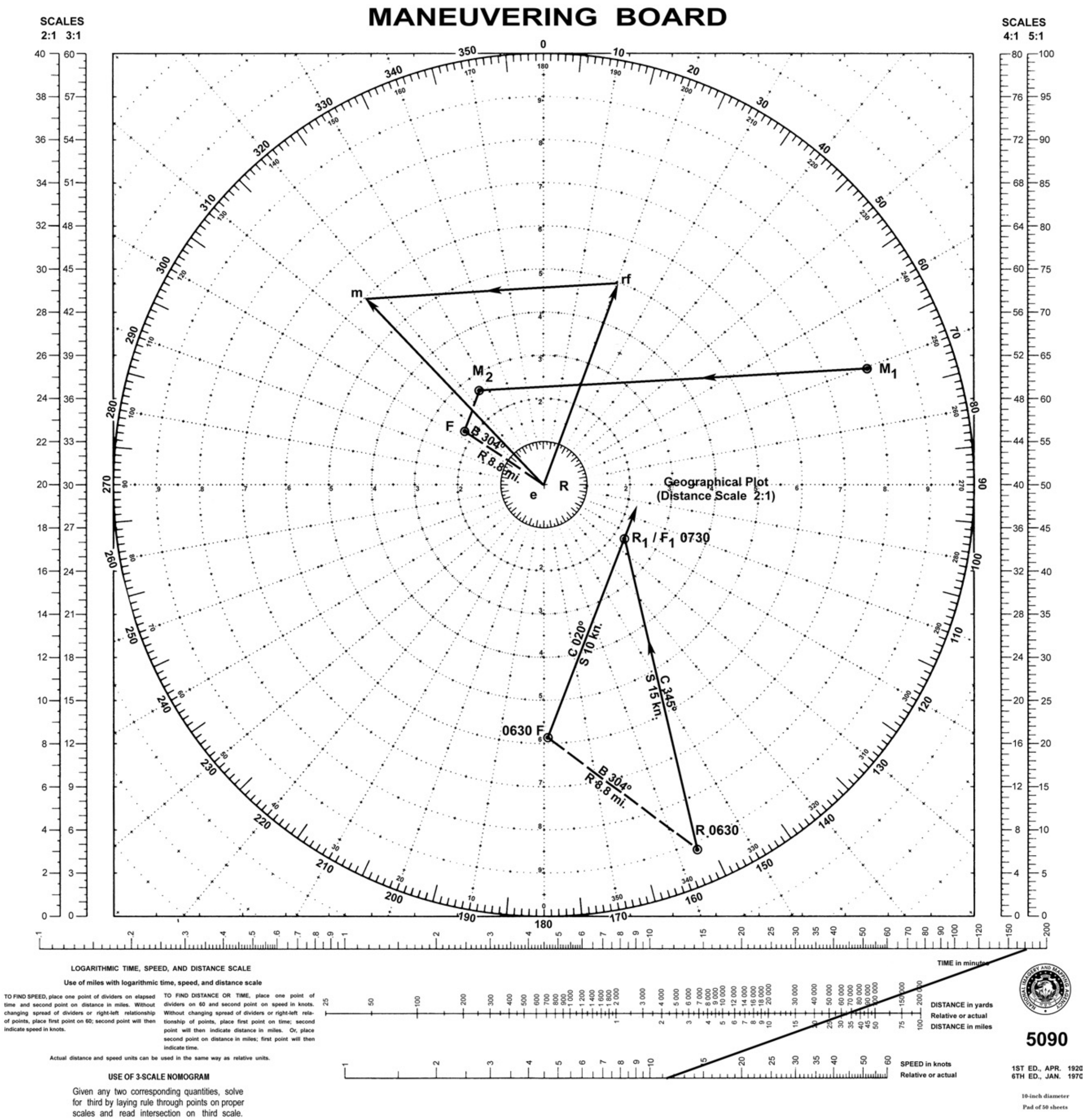
(2) The time to complete the maneuver can be obtained from the TDS scale using MRM of 36.4 miles and SRM of 11.8 knots which gives a time of 3.1 hours.

Answer:

(1) Course 316˚.

(2) Time 3 hours 6 minutes.

GUIDE AT CENTER



EXAMPLE 44

Scale: Speed 2:1;
Distance 4:1 mi.

EXAMPLE 45

BOTH SHIPS ALTER COURSE AND/OR SPEED DURING MANEUVER

Situation:

At 0800 *R* is on course 105˚, speed 15 knots and will change course to 350˚, speed 18 knots at 0930. Own ship *M* is maintaining station bearing 330˚, 4 miles from *R*. *M* is ordered to take station bearing 100˚, 12 miles from *R*, arriving at 1200.

Required:

(1) Course and speed for *M* to comply if maneuver is begun at 0800.

(2) Course for *M* to comply if *M* delays the course change as long as possible and remains at 15 knots speed throughout the maneuver.

(3) Time to turn to course determined in (2).

Solution:

Since the relative positions of *R* and *M* at the beginning and end of the maneuver and the time interval for the maneuver are given, the solution for (1) can be obtained directly from a **geographical plot**. Solve the remainder of the problem using a **relative plot**.

(1) Using a geographical plot, lay out *R*'s 0800-1200 track through points R_1, R_2, and R_3. Plot M_1 and M_3 relative to R_1 and R_3, respectively. The course 040˚ from M_1 to M_3 can be measured directly from the plot. *M* will require a speed of 10.8 knots to move 43.4 miles in 4 hours.

This solution may be verified on a relative plot by means of a fictitious ship. First, using a geographical plot, determine the 0800 position of a **fictitious ship** that, by steering 350˚, speed 18 knots, will pass through the 0930 position simultaneously with *R*. At 0800 own ship at M_1 bears 322˚, 45.7 miles from the fictitious ship at F_1. Transfer these positions to a relative plot, placing *F* at the center. Plot own ship's 1200 position at M_3 bearing 100˚, 12 miles from *F*. Draw the fictitious ship's vector erf_1 350˚, 18 knots. From rf_1, construct the relative speed vector parallel to M_1M_3 and 13.8 knots in length. (MRM of 55.2 miles/4 hours = 13.8 knots.) Draw em_1, the required course of 040˚, 10.8 knots.

(2) To find the two legs of *M*'s 0800-1200 track, use a relative plot. Draw em_2, own ship's vector which is given as 105˚, 15 knots. At this stage of the solution, disregard *R* and consider own ship *M* to maneuver relative to a *new* fictitious ship. Own ship on course 040˚, 10.8 knots from part (1) is the fictitious ship used. Label vector em_1 as erf_2, the fictitious ship's vector. From point m_2 draw a line through rf_2 extended to intersect the 15-knot speed circle at m_3. Draw em_3, the second course of 012˚ required by *M* in changing station.

(3) To find the time on each leg draw a time line from m_2 using any convenient scale. Through m_3 draw m_3X. Through m_1 draw m_1Y parallel to m_3X. Similar triangles exist; thus, the time line is divided into proportional time intervals for two legs. XY is the time on the first leg: 1 hour 22 minutes. The remainder of the 4 hours is spent on the second leg.

Answer:

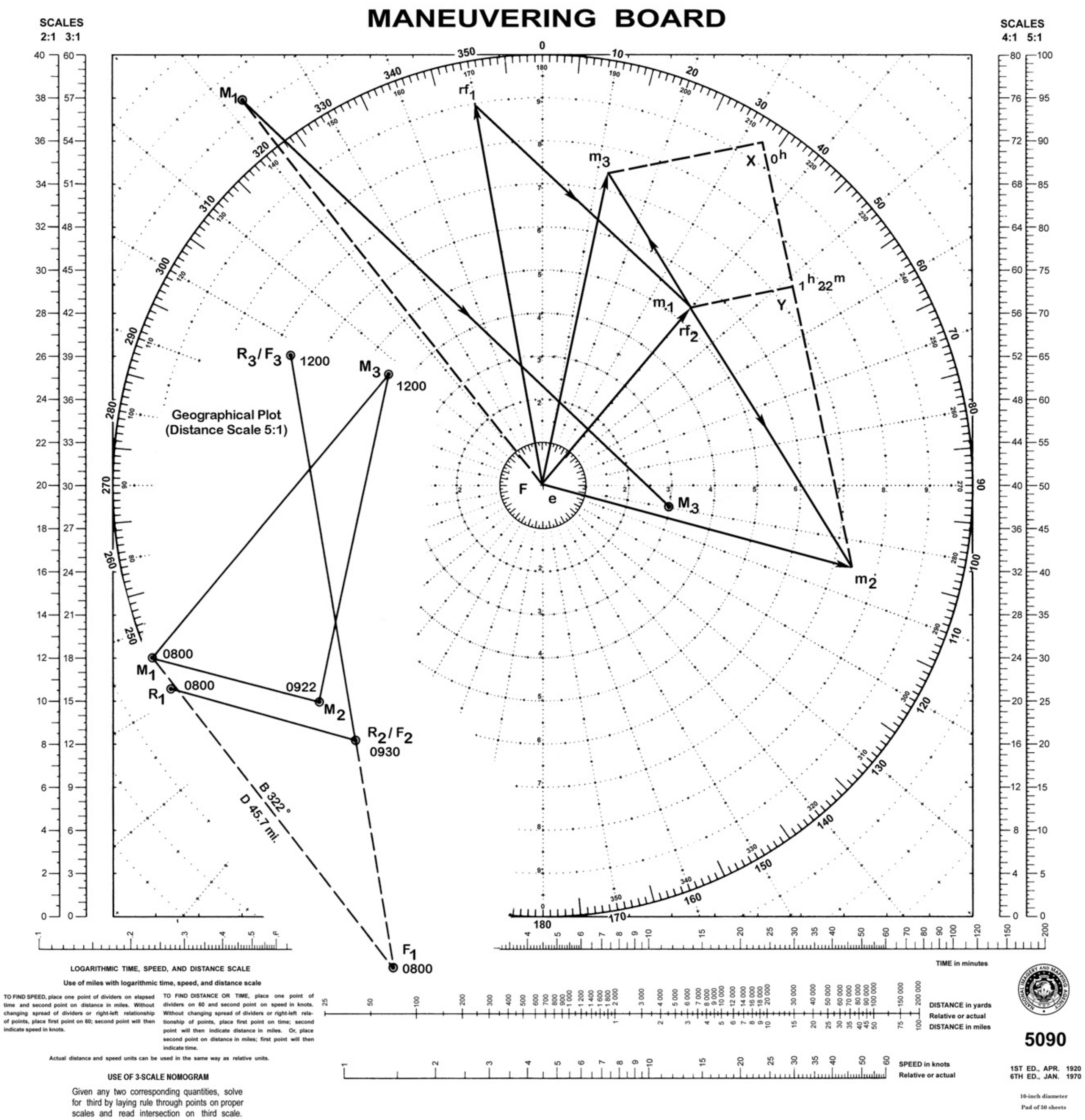
(1) Course 040˚, 10.8 knots.

(2) Course 012˚.

(3) Time 0922.

Note:

In the above example, an alternative construction of the time line as defined in the glossary is used so that the line can be drawn to a convenient scale. The proportionality is maintained by constructing similar triangles. See Note with example 47.



GUIDE AT CENTER

EXAMPLE 45

Scale: Speed 2:1; Distance 4:1 mi.

EXAMPLE 46

COURSES AT A SPECIFIED SPEED TO SCOUT OUTWARD ON PRESENT BEARING AND RETURN AT A SPECIFIED TIME

Situation:

Own ship *M* is maintaining station on the guide *R* which bears 110˚, range 5 miles. Formation course is 055˚, speed 15 knots.

Required:

Commencing at 1730, scout outward on present bearing and return to present station at 2030. Use 20 knots speed.

(1) Course for first leg.
(2) Course for second leg.
(3) Time to turn.
(4) Maximum distance from the guide.

Solution:

(1) Plot *R* at the center and M_1 bearing 290˚, 5 miles from *R*. Draw *er* 055˚, 15 knots. The DRM "out" is along the bearing of *M* from *R*. The DRM "in" is along the bearing of *R* from *M*. Through *r* draw a line parallel to the DRM's and intersecting the 20-knot circle at m_1 and m_2. Vector rm_1 is the DRM "out". Vector em_1 is 327˚.8, the course "out".

(2) Vector rm_2 is the DRM "in". Vector em_2 is 072˚, the course "in".

(3) To find the time on each leg, draw a time line from m_1 using any convenient scale. Through m_2 draw m_2X. Through *r* draw *r*Y parallel to m_2X. Similar triangles exist; thus, the time line is divided into proportional time intervals for the two legs. XY is the time on the first leg, 41 minutes. The remainder of the time is spent on the second leg returning to station.

(4) Range of *R* when course is changed to "in" leg is 21.7 miles. Initial range + (rm_1 **x** *time* on "out" leg).

Answer:

(1) Course 328˚.
(2) Course 072˚.
(3) Time 1811.
(4) Distance 21.7 miles.

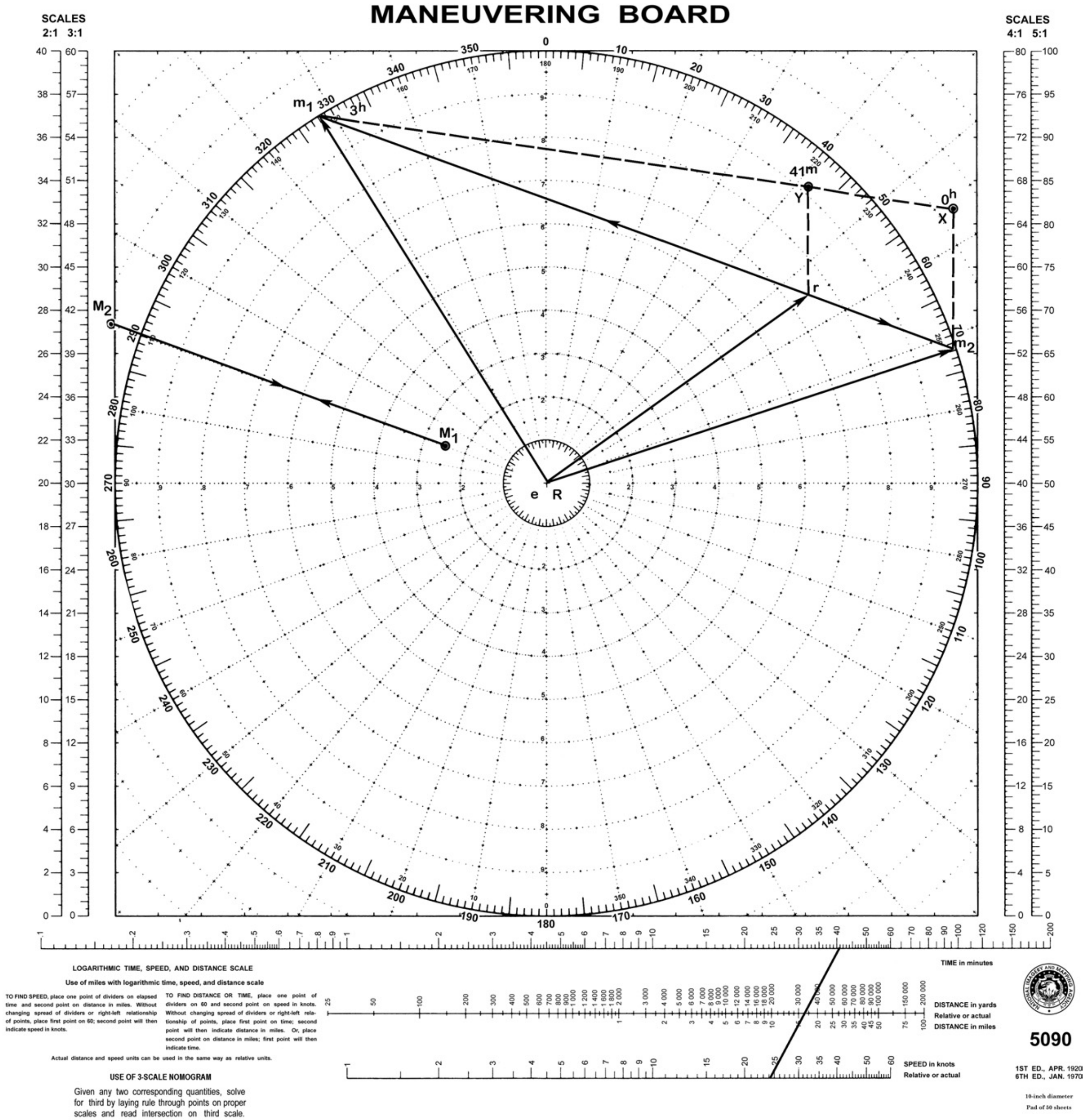
Explanation:

Since own ship *R* returns to present station, relative distances out and in are equal. In going equal distances, time varies inversely as speed:

$$\frac{\text{time (out)}}{\text{time (in)}} = \frac{\text{relative speed (in)}}{\text{relative speed (out)}} = \frac{rm_1\text{(in)}}{rm_2\text{(out)}}$$

Therefore, the time out part of the specified time (3^h) is obtained by simple proportion or graphically.

As defined in the glossary, the time line is the line joining the heads of vectors em_1 and em_2. This line is divided by the head of vector *er* into segments inversely proportional to the times spent by own ship *R* on the first (out) and second (in) legs. In the above example an alternative construction is used so that the line can be drawn to a convenient scale. The proportionality is maintained by constructing similar triangles.



GUIDE AT CENTER

EXAMPLE 46

Scale: Speed 2:1; Distance 2:1 mi.

EXAMPLE 47

COURSES AND MINIMUM SPEED TO CHANGE STATIONS WITHIN A SPECIFIED TIME, WHILE SCOUTING ENROUTE

Situation:

Own ship *M* bears 130˚, 8 miles from the guide *R* which is on course 040˚, speed 12 knots.

Required:

Proceed to new station bearing 060˚, 10 miles from the guide, passing through a point bearing 085˚, 25 miles from the guide. Complete the maneuver in 4.5 hours using minimum speed.

(1) First and second courses for *M*.

(2) Minimum speed.

(3) Time to turn to second course.

Solution:

(1) Plot M_1, M_2 and M_3 at 130˚, 8 miles; 085˚, 25 miles; and 060˚, 10 miles from *R*, respectively. Draw *er* 040˚, 12 knots. From *r* draw lines of indefinite length parallel to and in the direction of M_1M_2 and M_2M_3. Assume that a **fictitious ship**, *F*, departs M_1 simultaneously with *M* and proceeds directly to M_3 arriving at the same time as *M* which traveled through M_2 enroute. The fictitious ship covers a relative distance of 10.5 miles in 4.5 hours. SRM of the fictitious ship is 2.3 knots. Through *r* draw *rrf*, the relative speed vector, 2.3 knots parallel to and in the direction of M_1M_3. Vector *erf* is the true course and speed vector of the fictitious ship. With *rf* as a pivot, rotate a straight line so that it intersects the two previously drawn lines on the same speed circle. The points of intersection are m_1 and m_2. Vector em_1 is the course out: 049˚. Vector em_2 is the course in: 316˚.9.

(2) Points m_1 and m_2 lie on the 17.2 knot circle which is the minimum speed to complete the maneuver.

(3) From m_2 lay off a 4.5 hour time line using any convenient scale. Draw m_1X. Draw *rf*Y parallel to m_1X. The point Y divides the time line into parts that are inversely proportional to the relative speeds rfm_1 and rfm_2. XY the time “in” is 51 minutes. Ym_2 the time “out” is 3 hours 39 minutes. Time on each leg may also be determined mathematically by the formula MRM/SRM = time.

Answer:

(1) First course 049˚, second 317˚.

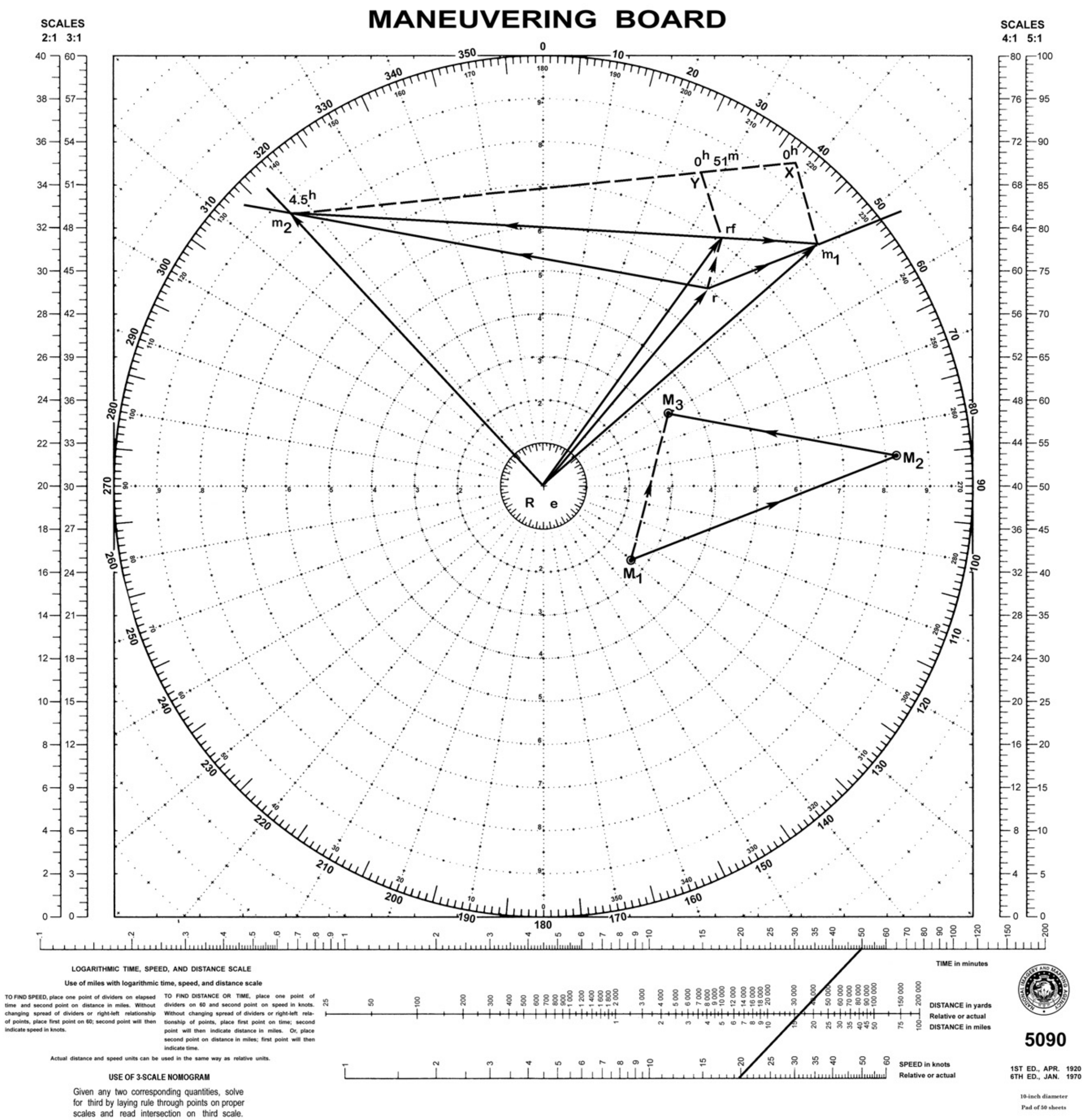
(2) Speed 17.2 knots.

(3) Time 3 hours and 39 minutes.

Note:

The *time line*, as defined in the glossary, is the line joining the heads of vectors em_1 and em_2 and touching the head of the fictitious ship vector *erf*. This time line is divided by the head of the fictitious ship vector into segments inversely proportional to the times spent by the unit on the first and second legs.

In the above example, an alternative construction of the time line is used so that the line can be drawn to a convenient scale. The proportionality is maintained by constructing similar triangles.



GUIDE AT CENTER

EXAMPLE 47

Scale: Speed 2:1; Distance 3:1 mi.

EXAMPLE 48

LIMITING LINES OF APPROACH

Situation:

A circular formation of ships 4 miles across, with guide *R* the center is proceeding on course 000˚, 15 knots. An enemy torpedo firing submarine is suspected to be in a position some distance ahead of the formation with a maximum speed capability corresponding to modes of operation of:

Submerged (SU) speed:	5 knots
Quiet (Q) speed:	8 knots
Snorkel (SN) speed:	10 knots
Surfaced (S) speed:	12 knots

Note:

The maximum speeds above were chosen for example purposes and should *NOT* be used as real estimates. Consult appropriate intelligence publications on individual submarines for correct speeds.

Required:

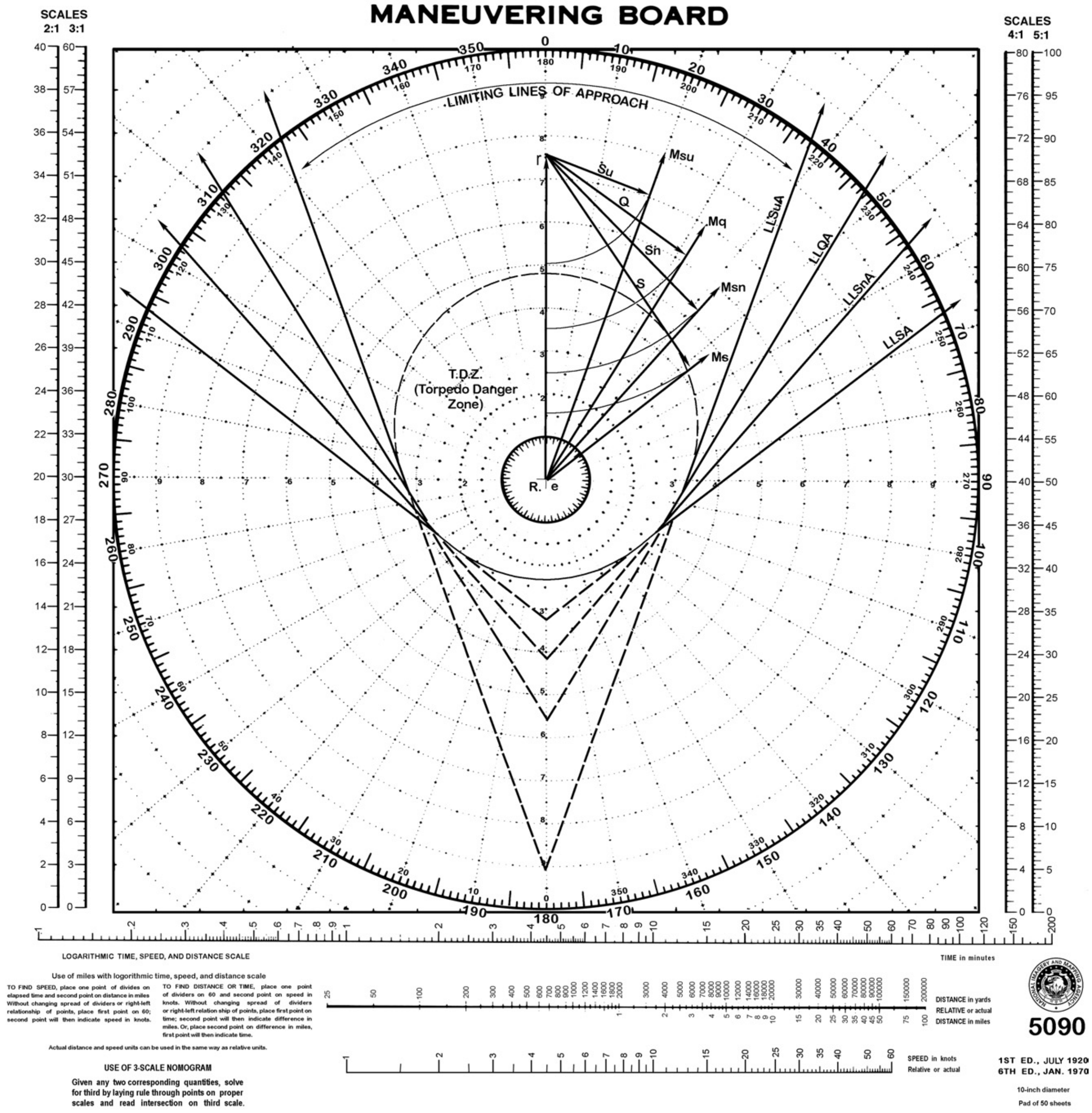
(1) Construct Limiting Lines of Submerged Approach (LLSUA).
(2) Construct Limiting Lines of Quiet Approach (LLQA).
(3) Construct Limiting Lines of Snorkel Approach (LLSNA).
(4) Construct Limiting Lines of Surfaced Approach (LLSA).

Solution:

(1) Plot *R* at the center of the maneuvering board and draw the vector "*er*" 000˚, 15 knots. Construct the TDZ for the assumed effective torpedo firing range (e.g., 5 miles) and torpedo speed (e.g., 30 knots). From "*r*" describe an arc (with radius of 5 knots), the assumed submerged speed. Draw the tangent vector *"emsu"* to the arc and parallel this vector to the TDZ. By extending the parallel vector until it intersects the formation course vector, the other limiting line to the TDZ can be constructed (the area enclosed by the Limiting Lines of Submerged Approach (LLSUA) and the aft perimeter of the TDZ defines the submarine Danger Zone). Solutions (2) through (4) use the similar construction principles as in solution (1) to construct the LLQA, LLSNA and LLSA using their respective assumed speeds.

Note:

This construction assumes the submarine maintains a constant speed throughout the approach.



GUIDE AT CENTER

EXAMPLE 48

Scale: Speed 2:1; Distance 4:1 mi.

EXAMPLE 49

TORPEDO DANGER ZONE (TDZ)

Situation:

A circular formation of ships 4 miles across, with guide *R* at the center is proceeding on course 000˚, at 15 knots. An enemy torpedo carrying submarine is suspected of being in the area with weapon parameters of:

Maximum effective torpedo firing range:	5 miles
Speed:	30 knots

Required:

Torpedo Danger Zone (TDZ)

Solution:

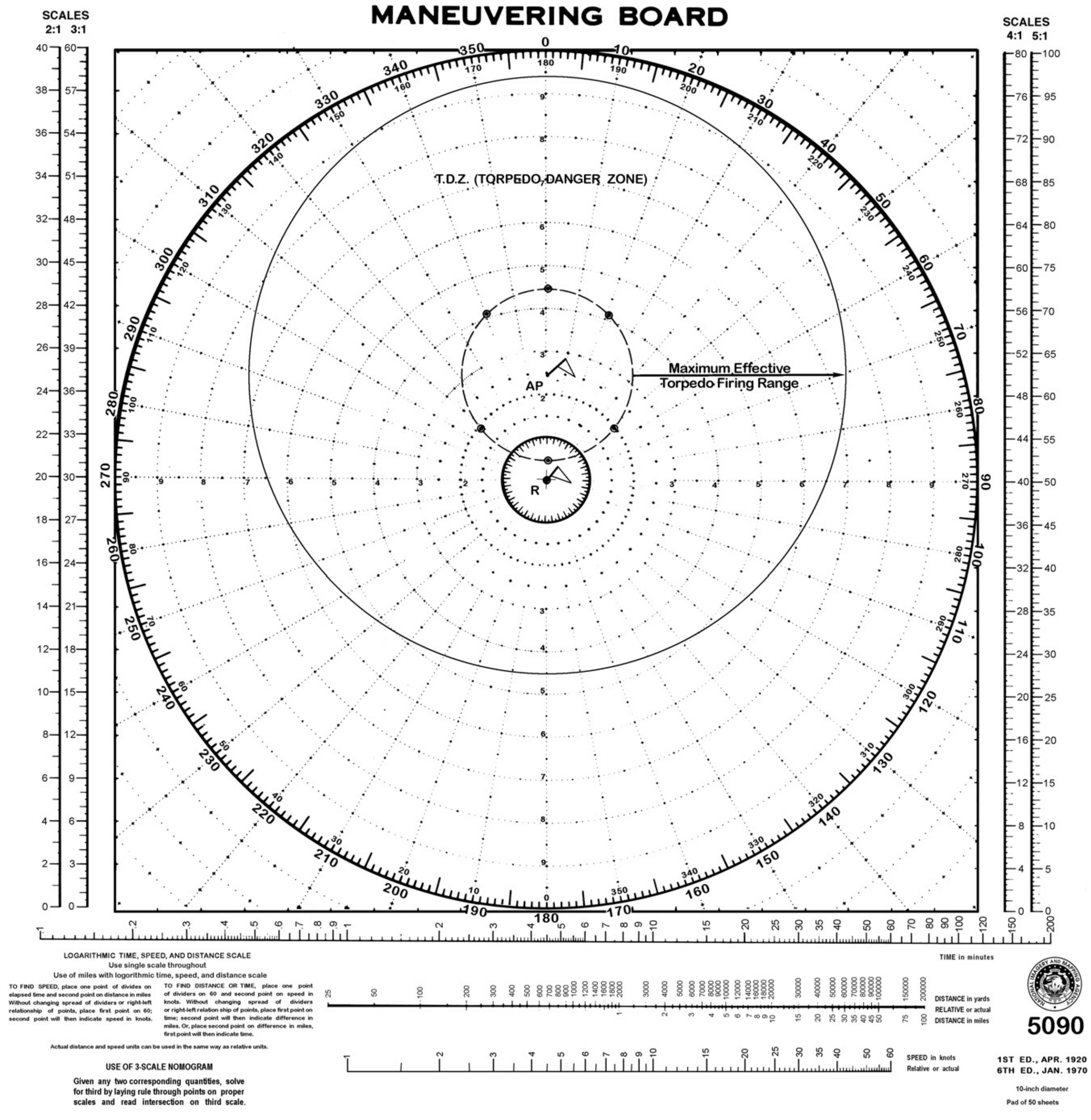
Plot *R* at the center of the maneuvering board. Calculate the formation's advanced position (i.e., *R*'s future position along the formation direction of advance if a torpedo is fired when *R* was located at board center) by:

$$\text{Advanced Position} = \frac{\begin{array}{c}\text{Maximum Effective Torpedo}\\ \text{Firing Range} \times \text{Formation Speed}\end{array}}{\text{Torpedo Speed}}$$

Label this position AP and plot the formation around AP. Construct the TDZ outer boundary by plotting points at a distance equal to the maximum effective torpedo firing range (e.g., 5 miles) from the perimeter of the formation. The area enclosed is the TDZ relative to the formation in its original position around *R*.

Note:

The torpedo range and speed were chosen for example purposes only and should not be used as real estimates. Consult appropriate intelligence publications on individual submarine torpedoes for correct ranges and speeds.



GUIDE AT CENTER

EXAMPLE 49

Scale: Speed 3:1; Distance 2:1 mi.

EXAMPLE 50

MISSILE DANGER ZONE (MDZ)

Situation:

A circular formation of ships 4 miles across with guide *R* at the center is proceeding on course 000˚ at 15 knots. An enemy missile carrying submarine is suspected of being in the area with weapon parameters of:

Maximum effective missile firing range:	20 miles
Speed:	600 mph

Required:

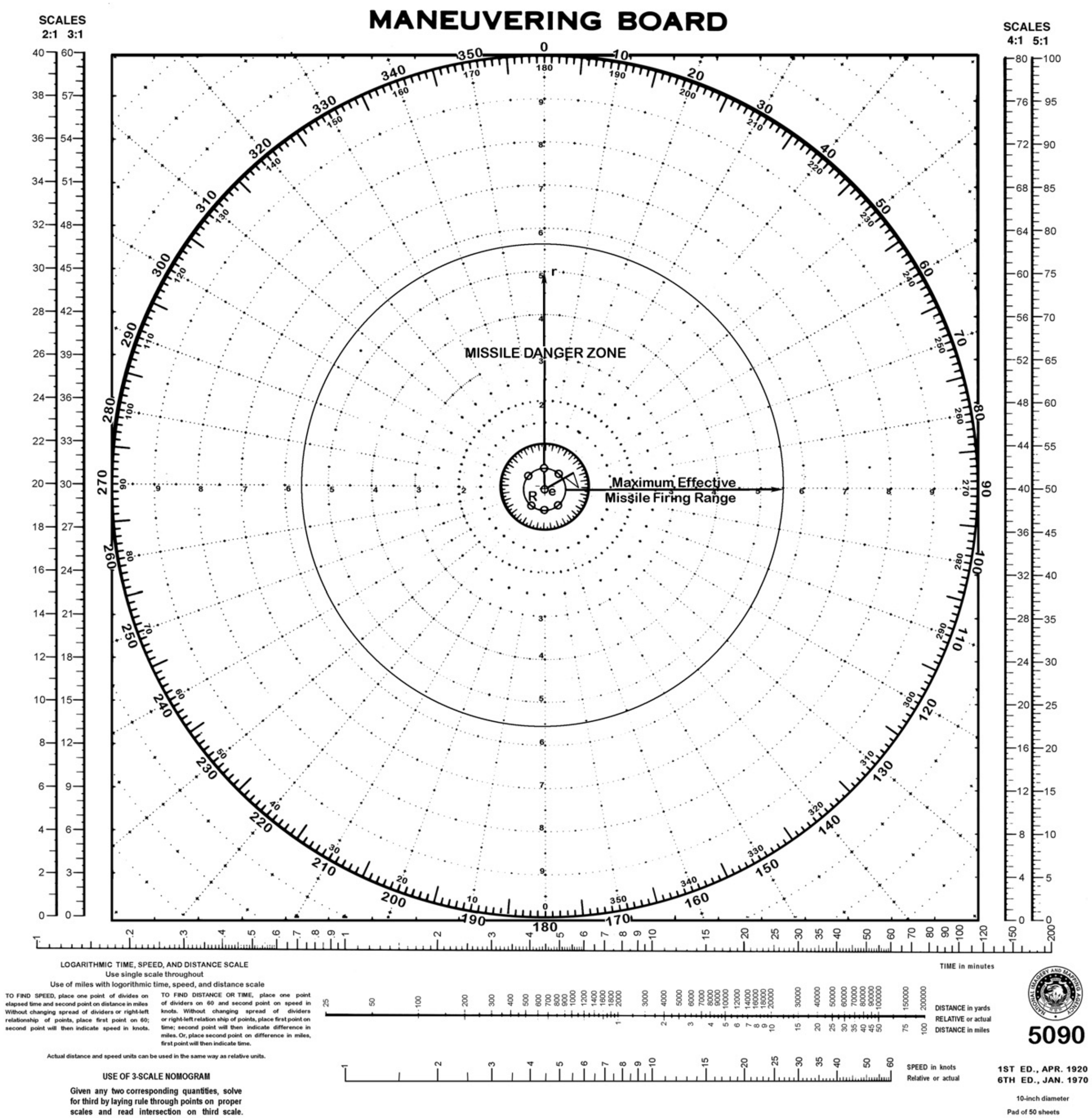
Missile Danger Zone (MDZ)

Solution:

Plot *R* at the center of the maneuvering board. Since the enemy's missile travels at 40 times the formation's speed, the formation will not appreciably advance during the missile's time of flight. The missile's maximum effective firing range (20 miles) is added to the perimeter of the formation and plotted around the formation. The area enclosed is the MDZ.

Note:

The missile range and speed were chosen for example purposes only and should not be used as real estimates. Consult appropriate intelligence publications on individual submarine missiles for correct ranges and speeds.



GUIDE AT CENTER

EXAMPLE 50

Scale: Speed 3:1;
Distance 8:1 mi.

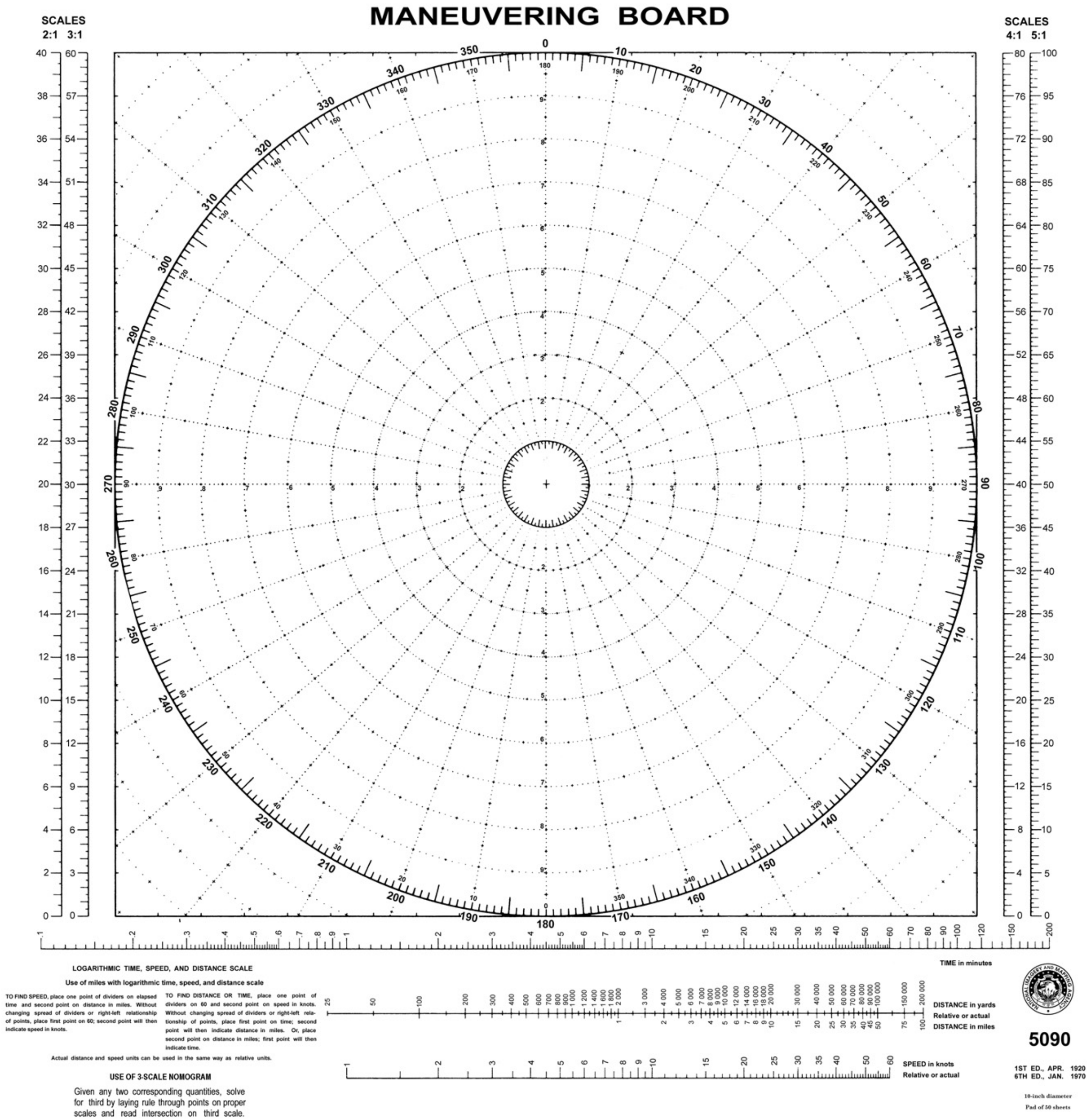
Space is provided for user's insertion of example according to his needs

Situation:

Solution:

Required:

Answers:



Scale: Speed :1;
Distance :1 thousands of yds.

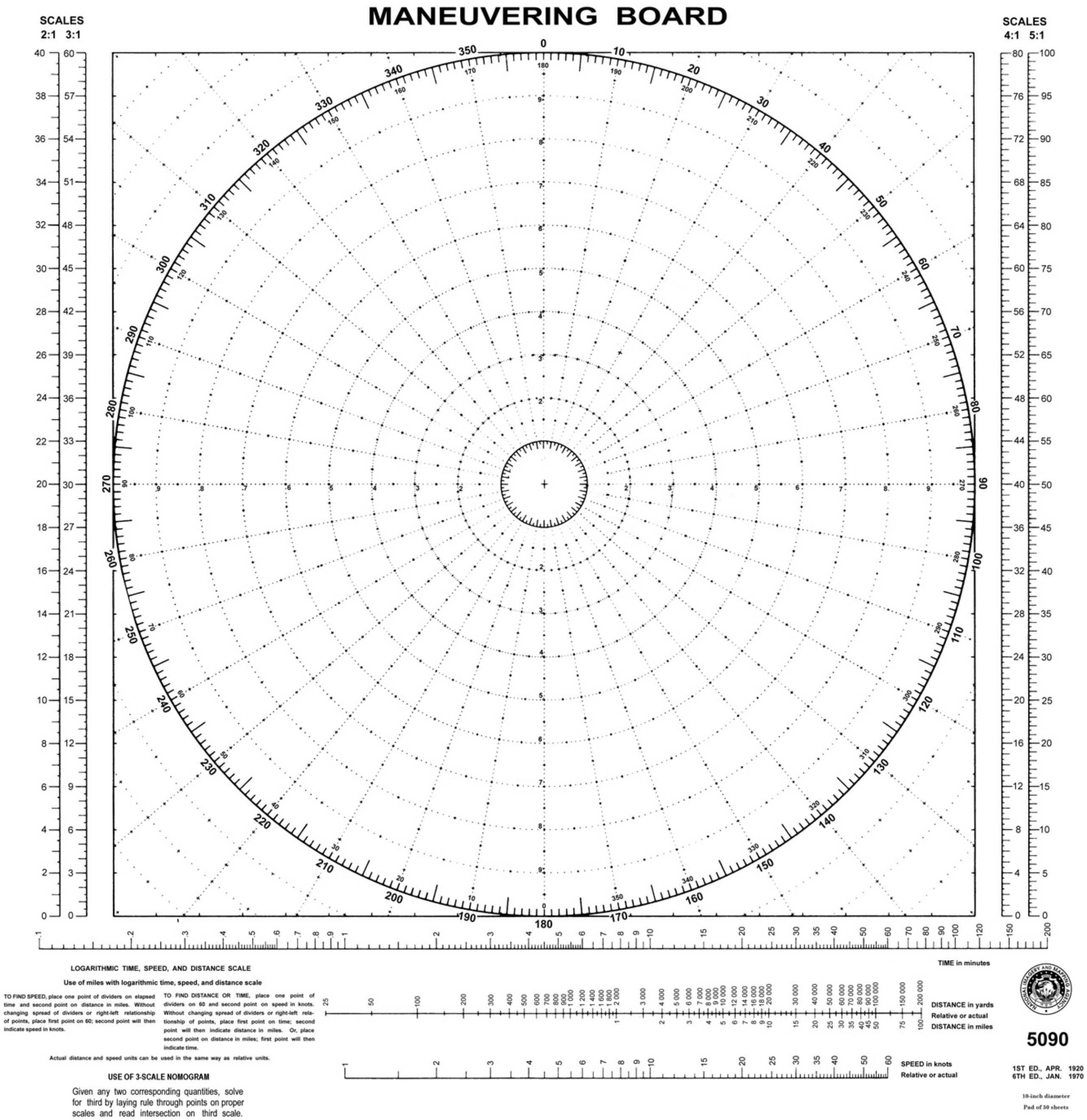
Space is provided for user's insertion of example according to his needs

Situation:

Solution:

Required:

Answers:



Scale: Speed   :1;
Distance   :1 thousands of yds.

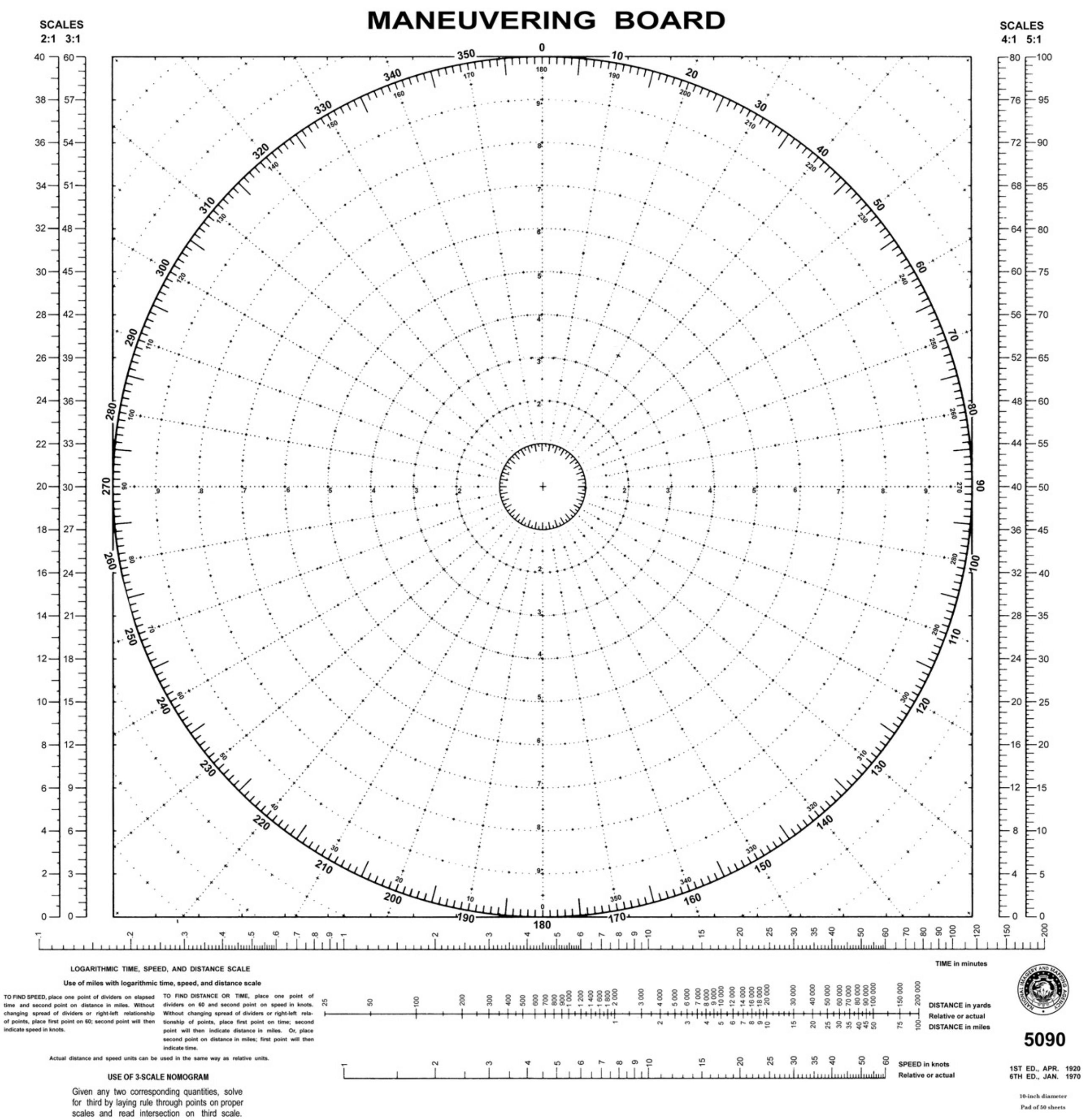
Space is provided for user's insertion of example according to his needs

Situation:

Solution:

Required:

Answers:



Scale: Speed   :1;
Distance   :1 thousands of yds.

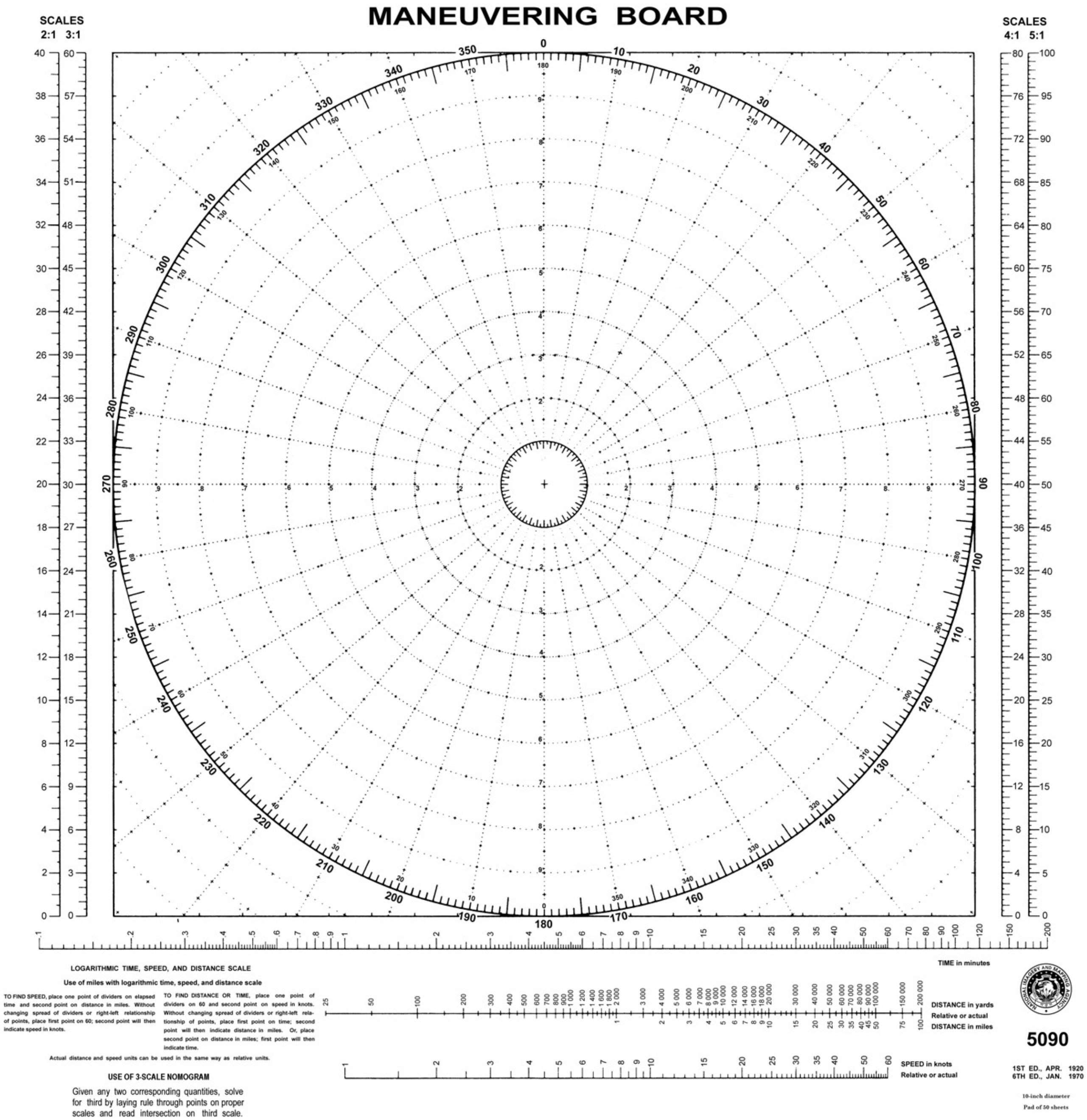
Space is provided for user's insertion of example according to his needs

Situation:

Solution:

Required:

Answers:



Scale: Speed :1;
Distance :1 thousands of yds.

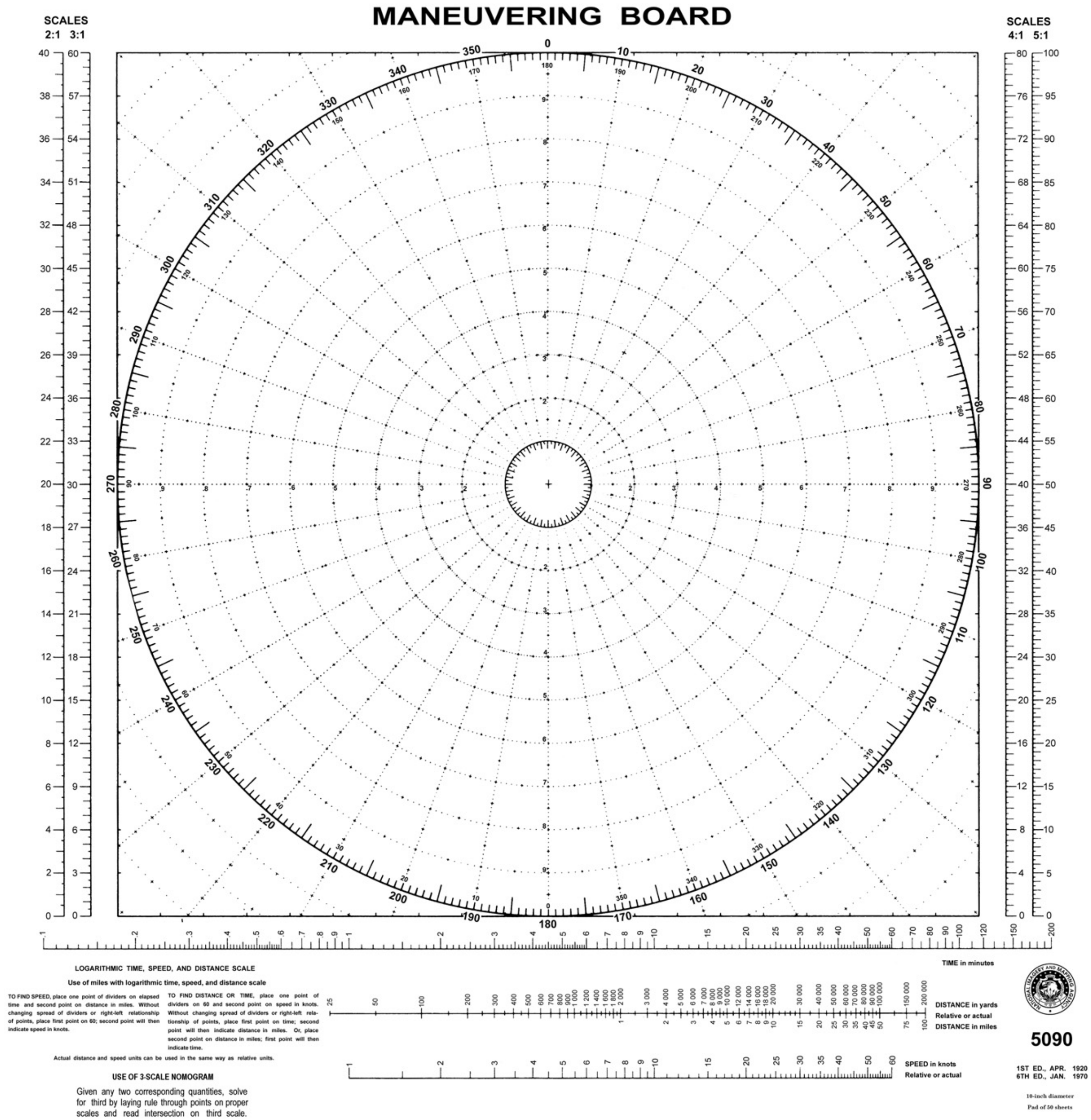
Space is provided for user’s insertion of example according to his needs

Situation:

Solution:

Required:

Answers:



Scale: Speed :1;
Distance :1 thousands of yds.

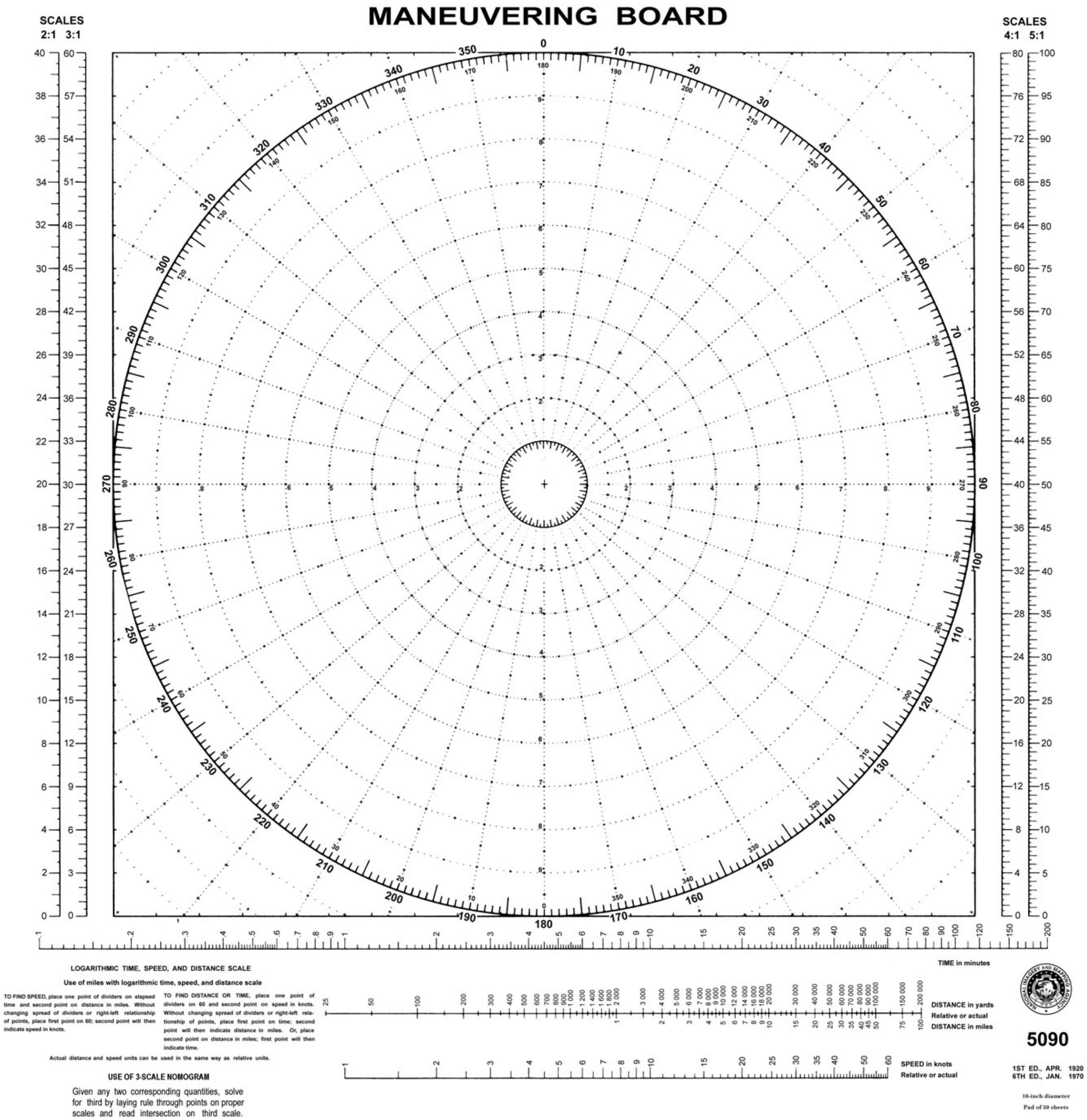
Space is provided for user's insertion of example according to his needs

Situation:

Solution:

Required:

Answers:



Scale: Speed   :1;
Distance   :1 thousands of yds.

APPENDIX A

EXTRACT FROM REGULATION 12, CHAPTER V OF THE IMO-SOLAS (1974) CONVENTION AS AMENDED TO 1983

THE REQUIREMENT TO CARRY RADAR AND ARPA

Ships of 500 gross tonnage and upwards constructed on or after 1 September 1984 and ships of 1600 gross tonnage and upwards constructed before 1 September 1984 shall be fitted with a radar installation.

Ships of 1000 gross tonnage and upwards shall be fitted with two radar installations, each capable of being operated independently of the other.

Facilities for plotting radar readings shall be provided on the navigating bridge of ships required by paragraph (g) or (h) to be fitted with a radar installation. In ships of 1600 gross tonage and upwards constructed on or after 1 September 1984, the plotting facilities shall be at least as effective as a reflection plotter.

An automatic radar plotting aid shall be fitted on:

1. Ships of 10,000 gross tonnage and upwards, constructed on or after 1 September 1984;
2. Tankers constructed before 1 September 1984 as follows:
   (a) If of 40,000 gross tonnage and upwards, by 1 January 1985;
   (b) If of 10,000 gross tonnage and upwards, but less than 40,000 gross tonnage, by 1 September 1986;
3. Ships constructed before 1 September 1984, that are not tankers, as follows:
   (a) If of 40,000 gross tonnage and upwards, by 1 September 1986;
   (b) If of 20,000 gross tonnage and upwards, but less than 40,000 gross tonnage, by 1 September 1987;
   (c) If of 15,000 gross tonnage and upwards, but less than 20,000 gross tonnage, by 1 September 1998.

(ii) Automatic radar plotting aids fitted prior to 1 September 1984 which do not fully conform to the performance standards adopted by the organization may, at the discretion of the administration, be retained until 1 January 1991.

(iii) the administration may exempt ships from the requirements of this paragraph, in cases where it considers it unreasonable or unnecessary for such equipment to be carried, or when the ships will be taken permanently out of service within two years of the appropriate implementation date.

EXTRACT FROM IMO RESOLUTIONS A222(VII), A278(VII), A477(XII)

Performance Standards for Navigational Radar equipment installed before 1 September 1984

INTRODUCTION

The radar equipment required by Regulation 12 of Chapter V should provide an indication in relation to the ship of the position of other surface craft and obstructions of buoys, shorelines and navigational marks in a manner which will assist in avoiding collision and navigation.

It should comply with the following minimum requirements:

Range Performance

The operational requirement under normal propagation conditions, when the radar aerial is mounted at a height of 15 meters above sea level, is that the equipment should give a clear indication of:

Coastlines:
At 20 nautical miles when the ground rises to 60 meters,
At 7 nautical miles when the ground rises to 6 meters.

Surface objects:
At 7 nautical miles a ship of 5,000 gross tonnage, whatever her aspect,
At 2 nautical miles an object such as a navigational buoy having an effective echoing area of approximately 10 square meters,
At 3 nautical miles a small ship of length 10 meters.

Minimum Range

The surface objects specified in paragraph 2(a) (ii) should be clearly displayed from a minimum range of 50 meters up to a range of 1 nautical mile, without adjustment of controls other than the range selector.

Display

The equipment should provide a relative plan display of not less than 180 mm effective diameter.

The equipment should be provided with at least five ranges, the smallest of which is not more than 1 nautical mile and the greatest of which is not less than 24 nautical miles. The scales should preferably of 1:2 ratio. Additional ranges may be provided.

Positive indication should be given of the range of view displayed and the interval between range rings.

Range Measurement

The primary means provided for range measurement should be fixed electronic range rings. There should be at least four range rings displayed on each of the ranges mentioned in paragraph 2(c)(ii), except that on ranges below 1 nautical mile range rings should be displayed at intervals of 0.25 nautical mile.

Fixed range rings should enable the range of an object, whose echo lies on a range ring, to be measured with an error not exceeding 1.5 per cent of the maximum range of the scale in use, or 70 meters, whichever is greater.

Any additional means of measuring range should have an error not exceeding 2.5 per cent of the maximum range of the displayed scale in use, or 120 meters, whichever is the greater.

Heading Indicator

The heading of the ship should be indicated by a line on the display with a maximum error not greater than +/- 1°. The thickness of the display heading line should not be greater than 0.5°.

Provision should be made to switch off the heading indicator by a device which cannot be left in the “heading marker off” position.

Bearing Measurement

Provision should be made to obtain quickly the bearing of any object whose echo appears on the display.

The means provided for obtaining bearings should enable the bearing of a target whose echo appears at the edge of the display to be measured with an accuracy of +/- 1° or better.

Discrimination

The equipment should display as separate indications, on the shortest range scale provided, two objects on the same azimuth separated by not more than 50 meters in range.

The equipment should display as separate indications two objects at the same range separated by not more than 2.5° in azimuth.

The equipment should be designed to avoid, as far as is practicable, the display of spurious echoes.

Roll

The performance of the equipment should be such that when the ship is rolling +/- 10° the echoes of the targets remain visible on the display.

Scan

The scan should be continuous and automatic through 360° of azimuth. The target data rate should be at least 12 per minute. The equipment should operate satisfactorily in relative wind speeds of 100 knots.

Azimuth Stabilization

Means should be provided to enable the display to be stabilized in azimuth by a transmitting compass. The accuracy of alignment with the compass transmission should be within 0.5 with a compass rotation rate of 2 r.p.m.

The equipment should operate satisfactorily for relative bearings when the compass control is inoperative or not fitted.

Performance Check

Means should be available, while the equipment is used operationally, to determine readily a significant drop in performance relative to a calibration standard established at the time of installation.

Anti-clutter Devices

Means should be provided to minimize the display of unwanted responses from precipitation and the sea.

Operation

The equipment should be capable of being switched on and operated from the main display position.

Operational controls should be accessible and easy to identify and use.

After switching on from the cold, the equipment should become fully operational within 4 minutes.

A standby condition should be provided from which the equipment can be brought to a fully operational condition within 1 minute.

Interference

After installation and adjustment on board, the bearing accuracy should be maintained without further adjustment irrespective of the variation of external magnetic fields.

Sea or Ground Stabilization

Sea or ground stabilization, if provided, should not degrade the accuracy of the display below the requirements of these performance standards, and the view ahead on the display should not be unduly restricted by the use of this facility.

Siting of the Aerial

The aerial system should be installed in such a manner that the efficiency of the display is not impaired by the close proximity of the aerial to other objects. In particular, blind sectors in the forward direction should be avoided.

Performance Standards for Navigational Radar equipment installed on or after 1 September 1984

Application

This Recommendation applies to all ships' radar equipment installed on or after 1 September 1984 in compliance with Regulation 12, Chapter V of the International Convention for the Safety of Life at Sea, 1974, as amended.

Radar equipment installed before 1 September 1984 should comply at least with the performance standards recommended in resolution A.222(VII).

General

The radar equipment should provide an indication, in relation to the ship, of the position of the other surface craft and obstructions and of buoys, shorelines and navigational marks in a manner which will assist in navigation and in avoiding collision.

All radar installations

All radar installations should comply with the following minimum requirements.

Range performance

The operational requirement under normal propagation conditions, when the radar antenna is mounted at a height of 15 meters above sea level, is that the equipment should in the absence of clutter give a clear indication of:

Coastlines:

At 20 nautical miles when the ground rises to 60 meters

At 7 nautical miles when the ground rises to 6 meters.

Surface objects:

At 7 nautical miles a ship of 5000 gross tonage, whatever her aspect

At 3 nautical miles a small ship of 10 meters in length

At 2 nautical miles an object such as a navigational buoy having an effective echoing area of approximately 10 square meters.

Minimum Range

The surface objects specified in paragraph 3.1.2 should be clearly displayed from a minimum range of 50 meters up to a range of 1 nautical mile, without changing the setting of controls other than the range selector.

Display

The equipment should without external magnification provide a relative plan display in the head up unstabilized mode with an effective diameter of not less than:

180 millimeters on ships of 500 gross tonnage and more but less than 1600 gross tonnage;

250 millimeters on ships of 1600 gross tonnage and more but less than 10000 gross tonnage;

340 millimeters in the case of one display and 250 millimeters in the case of the other on ships of 10000 gross tonnage and upwards.

Note: Display diameters of 180, 250 and 340 millimeters correspond respectively to 9, 12 and 16 inch cathode ray tubes.

The equipment should provide one of the two following sets of range scales of display:

1.5, 3, 6, 12, and 24 nautical miles and one range scale of not less than 0.5 and not greater than 0.8 nautical miles; or

1, 2, 4, 8, 16, and 32 nautical miles.

Additional range scales may be provided.

The range scale displayed and the distance between range rings should be clearly indicated at all times.

Range measurement

Fixed electronic range rings should be provided for range measurements as follows:

> Where range scales are provided in accordance with paragraph 3.3.2.1, on the range scale of between 0.5 and 0.8 nautical miles at least two range rings should be provided and on each of the other range scales six range rings should be provided; or
>
> Where range scales are provided in accordance with paragraph 3.3.2.2, four range rings should be provided on each of the range scales.

A variable electronic range marker should be provided with a numeric readout of range.

The fixed range rings and the variable range marker should enable the range of an object to be measured with an error not exceeding 1.5 per cent of the maximum range of the scale in use, or 70 meters, whichever is greater.

It should be possible to vary the brilliance of the range rings and the variable range marker and to remove them completely from the display.

Heading indicator

The heading indicator of the ship should be indicated by a line on the display with a maximum error not greater than +/- 1° .The thickness of the displayed heading line should not be greater than 0.5°.

Provision should be made to switch off the heading indicator by a device which cannot be left in the "heading marker off" position.

Bearing measurement

Provision should be made to obtain quickly the bearing of any object whose echo appears on the display.

The means provided for obtaining bearing should enable the bearing of a target whose echo appears at the edge of the display to be measured with an accuracy of +/-° or better.

Discrimination

The equipment should be capable of displaying as separate indications on a range scale of 2 nautical miles or less, two similar targets at a range of between 50% and 100% of the range scale in use, and on the same azimuth, separated by not more than 50 meters in range.

The equipment should be capable of displaying as separate indications two small similar targets both situated at the same range between 50 per cent and 100% of the 1.5 or 2 mile range scales, and separated by not more than 2.5° in azimuth.

Roll or pitch

The performance of the equipment should be such that when the ship is rolling or pitching up to +/- 10° the range performance requirements of paragraphs 3.1 and 3.2 continue to be met.

Scan

The scan should be clockwise, continuous and automatic through 360° of azimuth. The scan rate should be not less than 12 r.p.m. The equipment should operate satisfactorily in relative wind speed of up to 100 knots.

Azimuth stabilization

Means should be provided to enable the display to be stabilized in azimuth by a transmitting compass. The equipment should be provided with a compass input to enable it to be stabilized in azimuth. The accuracy of alignment with the compass transmission should be within 0.5° with a compass rotation rate of 2 r.p.m.

The equipment should operate satisfactorily in the unstabilized mode when the compass control is inoperative.

Performance check

Means should be available, while the equipment is used operationally, to determine readily a significant drop in performance relative to a calibration standard established at the time of installation, and that the equipment is correctly tuned in the absence of targets.

Anti-clutter devices

Suitable means should be provided for the suppression of unwanted echoes from sea clutter, rain and other forms of precipitation, clouds and sandstorms. It should be possible to adjust manually and continuously the anti-clutter controls. Anti-clutter controls should be inoperative in the fully anti-clockwise positions. In addition, automatic anti-clutter controls may be provided; however, they must be capable of being switched off.

Operation

The equipment should be capable of being switched on and operated from the display position.

Operational controls should be accessible and easy to identify and use. Where symbols are used they should comply with the recommendations of the organization on symbols for controls on marine navigational radar equipment.

After switching on from cold the equipment should become fully operational within 4 minutes.

A standby condition should be provided from which the equipment can be brought to an operational condition within 15 seconds.

Interference

After installation and adjustment on board, the bearing accuracy as prescribed in these performance standards should be maintained without further adjustment irrespective of the movement of the ship in the earth's magnetic field.

Sea or ground stabilization (true motion display)

Where sea or ground stabilization is provided the accuracy and discrimination of the display should be at least equivalent to that required by these performance standards.

The motion of the trace origin should not, except under manual override conditions, continue to a point beyond 75 per cent of the radius of the display. Automatic resetting may be provided.

Antenna system

The antenna system should be installed in such a manner that the design efficiency of the radar system is not substantially impaired.

Operation with radar beacons

All radars operating in the 3cm band should be capable of operating in a horizontally polarized mode.

It should be possible to switch off those signal processing facilities which might prevent a radar beacon from being shown on the radar display.

Multiple radar installations

Where two radars are required to be carried they should be so installed that each radar can be operated individually and both can be operated simultaneously without being dependent upon one another. When an emergency source of electrical power is provided in accordance with the appropriate requirements of Chapter II-1 of the 1974 SOLAS convention, both radars should be capable of being operated from this source.

Where two radars are fitted, interswitching facilities may be provided to improve the flexibility and overall radar installation. They should be so installed that failure of either radar would not cause the supply of electrical energy to the other radar to be interrupted or adversely affected.

APPENDIX B

GLOSSARY AND ABBREVIATIONS

across-the-scope
A radar contact whose direction of relative motion is perpendicular to the direction of the heading flash indicator of the radar. Also called LIMBO CONTACT.

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

AFC
Automatic frequency control.

aerial
Antenna.

afterglow
The slowly decaying luminescence of the screen of the cathode-ray tube after excitation by an electron beam has ceased. See PERSISTENCE.

amplify
To increase the strength of a radar signal or echo.

antenna
A conductor or system of conductors consisting of horn and reflector used for radiating or receiving radar waves. Also called AERIAL.

anti-clutter control
A means for reducing or eliminating interferences from sea return and weather.

apparent wind
See RELATIVE WIND.

ARPA
Automatic radar plotting aid.

attenuation
The decrease in the strength of a radar wave resulting from absorption, scattering, and reflection by the medium through which it passes (waveguide, atmosphere) and by obstructions in its path. Also attenuation of the wave may be the result of artificial means, such as the inclusion of an attenuator in the circuitry or by placing an absorbing device in the path of the wave.

automatic frequency control (AFC)
An electronic means for preventing drift in radio frequency or maintaining the frequency within specified limits. The AFC maintains the local oscillator of the radar on the frequency necessary to obtain a constant or near constant difference in the frequency of the radar echo (magnetron frequency) and the local oscillator frequency.

azimuth
While this term is frequently used for bearing in radar applications, the term azimuth is usually restricted to the direction of celestial bodies among marine navigators.

azimuth-stabilized PPI
See STABILIZED PPI.

beam width
The angular width of a radar beam between half-power points. See LOBE.

bearing
The direction of the line of sight from the radar antenna to the contact. Sometimes called AZIMUTH although in marine usage the latter term is usually restricted to the directions of celestial bodies.

bearing cursor
The radial line inscribed on a transparent disk which can be rotated manually about an axis coincident with the center of the PPI. It is used for bearing determination. Other lines inscribed parallel to the radial line have many useful purposes in radar plotting.

blind sector
A sector on the radarscope in which radar echoes cannot be received because of an obstruction near the antenna. See SHADOW SECTOR.

cathode-ray tube (CRT)
The radarscope (picture tube) within which a stream of electrons is directed against a fluorescent screen (PPI). On the face of the tube or screen (PPI), light is emitted at the points where the electrons strike.

challenger
See INTERROGATOR.

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

clutter
Unwanted radar echoes reflected from heavy rain, snow, waves, etc., which may obscure relatively large areas on the radarscope.

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

contact
Any echo detected on the radarscope not evaluated as clutter or as a false echo.

contrast
The difference in intensity of illumination of the radarscope between radar images and the background of the screen.

corner reflector
See RADAR REFLECTOR.

CPA
Closest point of approach.

course
Direction of actual movement relative to true north.

cross-band racon
A racon which transmits at a frequency not within the marine radar frequency band. To be able to use this type of racon, the ship's radar receiver must be capable of being tuned to the frequency of the cross-band racon or special accessory equipment is required. In either case, the radarscope will be blank except for the racon signal. See IN-BAND RACON.

CRT
Cathode-ray tube.

crystal
A crystalline substance which allows electric current to pass in only one direction.

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

definition
The clarity and fidelity of the detail of radar images on the radarscope. A combination of good resolution and focus adjustment is required for good definition.

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.

double stabilization The stabilization of a Heading-Upward PPI display to North. The cathode-ray tube with the PPI display stabilized to North is rotated to keep ship’s heading upward.

down-the-scope
A radar contact whose direction of relative motion is generally in the opposite direction of the heading flash indicator of the radar.

DRM
Direction of relative movement. The direction of movement of the maneuvering ship relative to the reference ship, always in the direction of $M_1 \rightarrow M_2 \rightarrow M_3 \rightarrow$...

duct
A layer within the atmosphere where refraction and reflection results in the trapping of radar waves, and consequently their propagation over abnormally long distances. Ducts are associated with temperature inversions in the atmosphere.

EBL
Electronic bearing line.

echo
The radar signal reflected back to the antenna by an object; the image of the reflected signal on the radarscope. Also called RETURN.

echo box
A cavity, resonant at the transmitted frequency which produces an artificial radar target signal for tuning or testing the overall performance of a radar set. The oscillations developed in the resonant cavity will be greater at higher power outputs of the transmitter.

echo box performance monitor
An accessory which is used for tuning the radar receiver and checking overall performance by visual inspection. An artificial echo as received from the echo box will appear as a narrow plume from the center of the PPI. The length of this plume as compared with its length when the radar is known to be operating at a high performance level is indicative of the current performance level.

face
The viewing surface (PPI) of a cathode-ray tube. The inner surface of the face is coated with a fluorescent layer which emits light under the impact of a stream of electrons. Also called SCREEN.

fast time constant (FTC) circuit
An electronic circuit designed to reduce the undesirable effects of clutter. With the FTC circuit in operation, only the nearer edge of an echo having a long time duration is displayed on the radarscope. The use of this circuit tends to reduce saturation of the scope which could be caused by clutter.

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

fluorescence Emission of light or other radiant energy as a result of and only during absorption of radiation from some other source. An example is the glowing of the screen of a cathode-ray tube during bombardment by a stream of electrons. The continued emission of light after absorption of radiation is called PHOSPHORESCENCE.

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.

FTC Fast time constant.

gain (RCVR) control
A control used to increase or decrease the sensitivity of the receiver (RCVR). This control, analogous to the volume control of a broadcast receiver, regulates the intensity of the echoes displayed on the radarscope.

geographical plot
A plot of the actual movements of objects (ships) with respect to the earth. Also called NAVIGATIONAL PLOT.

heading flash An illuminated radial line on the PPI for indicating own ship's heading on the bearing dial. Also called HEADING MARKER.

heading-upward display
See UNSTABILIZED DISPLAY.

in-band racon
A racon which transmits in the marine radar frequency band, e.g., the 3-centimeter band. The transmitter sweeps through a range of frequencies within the band to insure that a radar receiver tuned to a particular frequency within the band will be able to detect the signal. See CROSS-BAND RACON.

intensity control
A control for regulating the intensity of background illumination on the radarscope. Also called BRILLIANCE CONTROL.

interference
Unwanted and confusing signals or patterns produced on the radarscope by another radar or transmitter on the same frequency, and more rarely, by the effects of nearby electrical equipment or machinery, or by atmospheric phenomena.

interrogator
A radar transmitter which sends out a pulse that triggers a transponder. An interrogator is usually combined in a single unit with a responsor, which receives the reply from a transponder and produces an output suitable for feeding a display system; the combined unit is called an INTERROGATOR-RESPONSOR.

IRP
Image retaining panel.

kilohertz (kHz)
A frequency of one thousand cycles per second. See MEGAHERTZ.

limbo contacts
See ACROSS-THE-SCOPE.

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

lobe Of the three-dimensional radiation pattern transmitted by a directional antenna, one of the portions within which the field strength or power is everywhere greater than a selected value. The half-power level is used frequently as this reference value. The direction of the axis of the major lobe of the radiation pattern is the direction of maximum radiation. See SIDE LOBES.

maneuvering ship (*M*)
Any moving unit except the reference ship.

MCPA Minutes to closest point of approach.

megacycle per second (Mc)
A frequency of one million cycles per second. The equivalent term MEGAHERTZ (MHz) is now coming into more frequent use.

megahertz
A frequency of one million cycles per second. See KILOHERTZ.

microsecond
One millionth of 1 second.

microwaves
Commonly, very short radio waves having wavelengths of 1 millimeter to 30 centimeters. While the limits of the microwave region are not clearly defined, they are generally considered to be the region in which radar operates.

minor lobes
Side lobes.

missile danger zone
An area which the submarine must enter in order to be within maximum effective missile firing range.

MRM Miles of relative movement. The distance along the relative movement line between any two specified points or times. Also called RELATIVE DISTANCE.

nanosecond
One billionth of 1 second.

north-upward display
See STABILIZED DISPLAY.

NRML
New relative movement line.

paint
The bright area on the PPI resulting from the brightening of the sweep by the echoes. Also, the act of forming the bright area on the PPI by the sweep.

persistence
A measure of the time of decay of the luminescence of the face of the cathode-ray tube after excitation by the stream of electrons has ceased. Relatively slow decay is indicative of high persistence. Persistence is the length of time during which phosphorescence takes place.

phosphorescence
Emission of light without sensible heat, particularly as a result of, but continuing after, absorption of radiation from some other source. An example is the glowing of the screen of a cathode-ray tube after the beam of electrons has moved to another part of the screen. It is this property that results in the chartlike picture which gives the PPI its principal value. PERSISTENCE is the length of time during which phosphorescence takes place. The emission of light or other radiant energy as a result of and only during absorption of radiation from some other source is called FLUORESCENCE.

plan position indicator (PPI)
The face or screen of a cathode-ray tube on which radar images appear in correct relation to each other, so that the scope face presents a chartlike representation of the area about the antenna, the direction of a contact or target being represented by the direction of its echo from the center and its range by its distance from the center.

plotting head
Reflection plotter.

polarization
The orientation in space of the electric axis, of a radar wave. This electric axis, which is at right angles to the magnetic axis, may be either horizontal, vertical, or circular. With circular polarization, the axis rotate, resulting in a spiral transmission of the radar wave. Circular polarization is used for reducing rain clutter.

PPI
Plan position indicator.

pulse
An extremely short burst of radar wave transmission followed by a relatively long period of no transmission.

pulse duration
Pulse length.

pulse length
The time duration, measured in microseconds, of a single radar pulse. Also called PULSE DURATION.

pulse recurrence rate (PRR)
Pulse repetition rate.

pulse repetition rate (PRR)
The number of pulses transmitted per second.

racon
A radar beacon which, when triggered by a ship's radar signal, transmits a reply which provides the range and bearing to the beacon on the PPI display of the ship. The reply may be coded for identification purposes; in which case, it will consist of a series of concentric arcs on the PPI. The range is the measurement on the PPI to the arc nearest its center; the bearing is the middle of the racon arcs. If the reply is not coded, the racon signal will appear as a radial line extending from just beyond the reflected echo of the racon installation or from just beyond the point where the echo would be painted if detected. See IN-BAND RACON, CROSS-BAND RACON, RAMARK.

radar indicator
A unit of a radar set which provides a visual indication of radar echoes received, using a cathode-ray tube for such indication. Besides the cathode-ray tube, the radar indicator is comprised of sweep and calibration circuits, and associated power supplies.

radar receiver
A unit of a radar set which demodulates received radar echoes, amplifies the echoes, and delivers them to the radar indicator. The radar receiver differs from the usual superheterodyne communications receiver in that its sensitivity is much greater; it has a better signal to noise ratio, and it is designed to pass a pulse type signal.

radar reflector
A metal device designed for reflecting strong echoes of impinging radar signals towards their source. The *corner reflector* consists of three mutually perpendicular metal plates. Corner reflectors are sometimes assembled in clusters to insure good echo returns from all directions.

radar repeater
A unit which duplicates the PPI display at a location remote from the main radar indicator installation. Also called PPI REPEATER, REMOTE PPI.

radar transmitter
A unit of a radar set in which the radio-frequency power is generated and the pulse is modulated. The modulator of the transmitter provides the timing trigger for the radar indicator.

ramark
A radar beacon which continuously transmits a signal appearing as a radial line on the PPI, indicating the direction of the beacon from the ship. For identification purposes, the radial line may be formed by a series of dots or dashes. The radial line appears even if the beacon is outside the range for which the radar is set, as long as the radar receiver is within the power range of the beacon. Unlike the RACON, the ramark does not provide the range to the beacon.

range markers
Equally spaced concentric rings of light on the PPI which permit the radar observer to determine the range to a contact in accordance with the range setting or the range of the outer rings. See VARIABLE RANGE MARKER.

range selector
A control for selecting the range setting for the radar indicator.

RCVR
Short for RECEIVER.

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

reflection plotter An attachment fitted to a PPI which provides a plotting surface permitting radar plotting without parallax errors. Any mark made on the plotting surface will be reflected on the radarscope directly below. Also called PLOTTING HEAD.

refraction
The bending of the radar beam in passing obliquely through regions of the atmosphere of different densities.

relative motion display
A type of radarscope display in which the position of own ship is fixed at the center of the PPI and all detected objects or contacts move relative to own ship. See TRUE MOTION DISPLAY.

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.

remote PPI
Radar repeater.

resolution
The degree of ability of a radar set to indicate separately the echoes of two contacts in range, bearing, and elevation. With respect to:

range - the minimum range difference between separate contacts at the same bearing which will allow both to appear as separate, distinct echoes on the PPI.

bearing - the minimum angular separation between two contacts at the same range which will allow both to appear as separate, distinct echoes on the PPI.

elevation - the minimum angular separation in a vertical plane between two contacts at the same range and bearing which will allow both to appear as separate, distinct echoes on the PPI.

responder beacon
Transponder beacon.

RML
Relative movement line.

scan
To investigate an area or space by varying the direction of the radar antenna and thus the radar beam. Normally, scanning is done by continuous rotation of the antenna.

scanner
A unit of a radar set consisting of the antenna and drive assembly for rotating the antenna.

scope
Short for RADARSCOPE.

screen
The face of a cathode-ray tube on which radar images are displayed.

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.

sea return
Clutter on the radarscope which is the result of the radar signal being reflected from the sea, especially near the ship.

sensitivity time control (STC)
An electronic circuit designed to reduce automatically the sensitivity of the receiver to nearby targets. Also called SWEPT GAIN CONTROL.

shadow sector
A sector on the radarscope in which the appearance of radar echoes is improbable because of an obstruction near the antenna. While both *blind* and *shadow* sectors have the same basic cause, *blind* sectors

generally occur at the larger angles subtended by the obstruction. See BLIND SECTOR.

side lobes
Unwanted lobes of a radiation pattern, i.e., lobes other than major lobes. Also called MINOR LOBES.

speed triangle
The usual designation of the VECTOR DIAGRAM when scaled in knots.

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

stabilized display (North-Upward)
A PPI display in which the orientation of the relative motion presentation is fixed to an unchanging reference (North). This display is North-Upward, normally. In an UNSTABILIZED DISPLAY, the orientation of the relative motion presentation changes with changes in ship's heading. See DOUBLE STABILIZATION.

stabilized PPI
See STABILIZED DISPLAY.

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.

STC
Sensitivity time control.

strobe
Variable range marker.

sweep
As determined by the time base or range calibration, the radial movement of the stream of electrons impinging on the face of the cathode-ray tube. The origin of the sweep is the center of the face of the cathode-ray tube or PPI. Because of the very high speed of movement of the point of impingement, the successive points of impingement appear as a continuously luminous line. The line rotates in synchronism with the radar antenna. If an echo is received during the time of radial travel of the electron stream from the center to the outer edge of the face of the tube, the sweep will be increased in brightness at the point of travel of the electron stream corresponding to the range of the contact from which the echo is received. Since the sweep rotates in synchronism with the radar antenna, this increased brightness will occur on the bearing from which the echo is received. With this increased brightness and the persistence of the tube face, paint corresponding to the object being "illuminated" by the radar beam appears on the PPI.

swept gain control
Sensitivity time control.

TCPA
Time to closest point of approach.

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.

trace The luminous line resulting from the movement of the points of impingement of the electron stream on the face of the cathode-ray tube. See SWEEP.

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

transponder A transmitter-receiver capable of accepting the challenge (radar signal) of an interrogator and automatically transmitting an appropriate reply. See RACON.

transponder beacon
A beacon having a transponder. Also called RESPONDER BEACON.

trigger
A sharp voltage pulse usually of from 0.1 to 0.4 microseconds duration, which is applied to the modulator tubes to fire the transmitter, and which

is applied simultaneously to the sweep generator to start the electron beam moving radially from the sweep origin to the edge of the face of the cathode-ray tube.

true motion display

A type of radarscope display in which own ship and other moving contacts move on the PPI in accordance with their true courses and speed. This display is similar to a navigational (geographical) plot. See RELATIVE MOTION DISPLAY.

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.

unstabilized display (Heading-Upward)

A PPI display in which the orientation of the relative motion presentation is set to ship's heading and, thus, changes with changes in ship's heading. In this *Heading-Upward* display, radar echoes are shown at their relative bearings. A true bearing dial which is continuously set to ship's course at the 000 degrees relative bearing is normally used with this display for determining true bearings. This true bearing dial may be either manually or automatically set to ship's course. When set automatically by a course input from the gyrocompass, the true bearing dial is sometimes called a STABILIZED AZIMUTH SCALE. The latter term which appears in manufacturer's instruction books and operating manuals is more in conformity with air navigation rather than marine navigation usage. See DOUBLE STABILIZATION.

up-the-scope

A radar contact whose direction of relative motion is generally in the same direction as the heading flash indicator of the radar.

variable range marker

A luminous range circle or ring on the PPI, the radius of which is continuously adjustable. The range setting of this marker is read on the range counter of the radar indicator.

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).

VRM

Variable range marker.

VTS

Vessel traffic system.

XMTR

Short for TRANSMITTER.

APPENDIX C

RELATIVE MOTION PROBLEMS

RAPID RADAR PLOTTING PROBLEMS

1. Own ship, on course 311˚, speed 17 knots, obtains the following radar bearings and ranges at the times indicated, using a radar setting of 24 miles:

Time	*Bearing*	*Range (mi.)*
1136	280˚	16.0
1142	274˚	13.6
1148	265˚	11.4

Required:

(1) Range at CPA.

(2) Time at CPA.

(3) Direction of relative movement (DRM)

Solution:

(1) R 8.2 mi., (2) T 1204.5, (3) DRM 131˚.

2. Own ship, on course 000˚, speed 12 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 12 miles:

Time	*Bearing*	*Range (mi.)*
0410	035˚	11.1
0416	031˚	9.2
0422	025˚	7.3

Required:

(1) Distance at which the contact will cross dead ahead.

(2) Direction of relative movement (DRM).

(3) Speed of relative movement (SRM); relative speed.

(4) Range at CPA.

(5) Bearing of contact at CPA.

(6) Relative distance (MRM) from 0422 position of contact to the CPA.

(7) Time at CPA.

(8) Distance own ship travels from the time of the first plot (0410) to the time of the last plot (0422) of the contact.

(9) True course of the contact.

(10) Actual distance traveled by the contact between 0410 and 0422.

(11) True speed of the contact.

Solution:

Assuming that the contact maintains course and speed: (1) D 4.3. mi., (2) DRM 234˚, (3) SRM 20 kn., (4) R 3.5 mi., (5) B 324˚, (6) MRM 6.5 mi., (7) T 0441, (8) D 2.4 mi., (9) C 270˚, (10) D 3.2 mi., (11) S 16 kn.

3. Own ship, on course 030˚, speed 23 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 12 miles:

Time	*Bearing*	*Range (mi.)*
1020	081˚	10.8
1023	082˚	9.2
1026	083˚	7.7

Required:

(1) Range at CPA.

(2) Bearing of contact at CPA.

(3) Speed of relative movement (SRM); relative speed.

(4) Time at CPA.

(5) Distance own ship travels from the time of the first plot (1020) to the time of the last plot (1026) of the contact; distance own ship travels in 6 minutes.

(6) True course of the contact.

(7) Actual distance traveled by the contact between 1020 and 1026.

(8) True speed of the contact.

(9) Assuming that the contact has turned on its running lights during daylight hours because of inclement weather, what side light(s) might be seen at CPA?

Solution:

Assuming that the contact maintains course and speed: (1) R 1.0 mi., (2) B 167˚, (3) SRM 32 kn., (4) T 1041, (5) D 2.3 mi., (6) C 304˚, (7) D 2.2 mi., (8) S 22 kn., (9) starboard (green) side light.

4. Own ship, on course 000˚, speed 11 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 12 miles:

Time	*Bearing*	*Range (mi.)*
1100	080˚	12.0
1106	080˚	10.8
1112	080˚	9.6

Required:

(1) Range at CPA.

(2) Speed of relative movement (SRM); relative speed.

(3) Time at CPA.

(4) True course of contact.

Decision:

When the range to the contact decreases to 6 miles, own ship will change course so that the contact will pass safely ahead with a CPA of 2.0 miles.

Required:

(5) New course for own ship.

(6) New SRM after course change.

Solution:

Assuming that the contact maintains course and speed: (1) Nil; risk of collision exists, (2) SRM 12 kn., (3) T 1200, (4) 307˚, (5) 063˚, (6) New SRM 22 kn.

5. Own ship, on course 220˚, speed 12 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 12 miles:

Time	*Bearing*	*Range (mi.)*
0300	297˚	11.7
0306	296˚	10.0
0312	295˚	8.5

Required:

(1) Range at CPA.

(2) Speed of relative movement (SRM); relative speed.

(3) Time at CPA.

(4) True course of contact.

Decision:

When the range to the contact decreases to 6 miles, own ship will change course so that the contact will clear ahead, in minimum time, with a CPA of 3.0 miles.

Required:

(5) New course for own ship.

(6) New SRM after course change.

Solution:

Assuming that the contact maintains course and speed: (1) R 1.2 mi., (2) SRM 16.5 kn., (3) T 0343, (4) C 161˚, (5) Come right to 290˚, (6) New SRM 28 kn.

6. Own ship, on course 316˚, speed 21 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 12 miles:

Time	*Bearing*	*Range (mi.)*
1206	357˚	11.8
1212	358˚	10.2
1218	359˚	8.7

Required:

(1) Range at CPA.

(2) Speed of relative movement (SRM); relative speed.

(3) True course of contact.

(4) True speed of contact.

Decision:

When the range to the contact decreases to 6 miles, own ship will change course so that the contact will clear ahead, in minimum time, with a CPA of 3 miles.

Required:

(5) New course for own ship.

Solution:

Assuming that the contact maintains course and speed:(1) R 1.1 mi., (2) SRM 15.5 kn., (3) C 269˚, (4) S 12.5 kn., (5) C 002˚.

7. Own ship, on course 000°, speed 10 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 12 miles:

Time	*Bearing*	*Range (mi.)*
0400	010°	11.1
0406	010°	9.0
0412	010°	7.1

Required:

(1) Range at CPA.

(2) Speed of relative movement (SRM); relative speed.

(3) Time at CPA.

(4) True course of contact.

(5) True speed of contact.

Decision:

Own ship will change course at 0418 so that the contact will clear ahead (on own ship's port side), with a CPA of 2 miles.

Required:

(6) New course for own ship.

Solution:

Assuming that the contact maintains course and speed: (1) Nil., (2) SRM 20 kn., (3) T 0433, (4) C 200°, (5) S 10 kn., (6) C 046°.

8. Own ship, on course 052°, speed 15 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 24 miles:

Time	*Bearing*	*Range (mi.)*
0340	052°	14.9
0346	052°	11.6
0352	052°	8.3

Required:

(1) Range at CPA.

(2) True course of contact.

(3) Assuming that there are no other vessels in the area and that the contact is a large passenger ship, clearly visible at 0352, is this a crossing, meeting, or overtaking situation?

(4) True speed of contact.

Decision:

A decision is made to change course when the range to the contact decreases to 6 miles.

(5) New course of own ship to clear the contact port to port with a CPA of 3 miles.

Solution:

Assuming that the contact maintains course and speed: (1) Nil; risk of collision exists, (2) C 232°, (3) Meeting, (4) S 18 kn., (5) C 119°.

9. Own ship, on course 070°, speed 16 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 12 miles:

Time	*Bearing*	*Range (mi.)*
0306	015°	10.8
0312	016°	8.3
0318	017°	5.9

Required:

(1) Range at CPA.

(2) Time at CPA.

(3) True course of the contact.

(4) True speed of the contact.

Decision:

When the range to the contact decreases to 5 miles, own ship will change speed only so that contact will clear ahead at a distance of 3 miles.

Required:

(5) New speed of own ship.

Solution:

Assuming that the contact maintains course and speed: (1) R 0.5 mi., (2) T 0333., (3) C 152°, (4) S 21 kn., (5) S $3^1/_4$ kn.

10. Own ship, on course 093°, speed 18 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 12 miles:

Time	*Bearing*	*Range (mi.)*
0452	112°	5.9
0458	120°	4.2
0504	137°	2.7

Required:

(1) Range at CPA.

(2) Relative distance (MRM) from 0452 to 0504 position of contact.

(3) Speed of relative movement (SRM); relative speed.

(4) Direction of relative movement (DRM).

(5) Distance own ship travels from the time of the first plot (0452) to the time of the last plot (0504) of the contact.

(6) True course and speed of the contact.

Solution:

Assuming that the contact maintains course and speed: (1) R 1.9 mi., (2) MRM 3.6 mi., (3) SRM 18 kn., (4) DRM 273°, (5) D 3.6 mi., (6) The contact is either a stationary object or a vessel underway but with no way on.

11. Own ship, on course 315˚, speed 11 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 24 miles:

Time	*Bearing*	*Range (mi.)*
0405	319˚	17.8
0417	320˚	15.6
0429	321˚	13.4

Required:

(1) Range at CPA.

(2) True course and speed of the contact.

Decision:

When the range to the contact decreases to 8 miles, own ship will change course so that the contact will pass safely to starboard with a CPA of 3 miles.

Required:

(3) New course for own ship.

Solution:

Assuming that the contact maintains course and speed: (1) R 1.6 mi., (2) The contact is either stationary or a vessel with little or no way on. (3) C 303˚.

12. Own ship, on course 342˚ speed 11 knots, (half speed), obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 12 miles:

Time	*Bearing*	*Range (mi.)*
0906	287˚	12.0
0912	287˚	10.2
0918	288˚	8.4

Required:

(1) Range at CPA.

(2) True course of the contact.

(3) True speed of the contact.

(4) Is this a crossing, meeting, or overtaking situation?

Decision:

Own ship is accelerating to full speed of 18 knots and will change course at 0924 when the speed is 15 knots so that the contact will clear astern with a CPA of 2 miles.

Required:

(5) New course for own ship.

Solution:

Assuming that the contact maintains course and speed: (1) R 0.5 mi., (2) C 067˚, (3) S 15 kn., (4) Crossing, (5) C 006˚.

13. Own ship, on course 350˚, speed 18 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 12 miles:

Time	*Bearing*	*Range (mi.)*
0200	030˚	10.0
0203	029˚	8.7
0206	028˚	7.4

Required:

(1) Range at CPA.

(2) True course of the contact.

(3) True speed of the contact.

Decision:

When the range to the contact decreases to 6 miles, own ship changes course to 039˚.

Required:

(4) New range at CPA.

(5) Describe how the new time at CPA would be computed.

(6) New time at CPA.

(7) At what bearing and range to the contact can own ship safely resume the original course of 350˚ and obtain a CPA of 3 miles?

(8) What would be the benefit, if any, of bringing own ship slowly back to the original course of 350˚ once the point referred to in (7) above is reached?

Solution:

Assuming that the contact maintains course and speed: (1) R 1.0 mi., (2) C 252˚, (3) S 18.5 kn., (4) R 3.0 mi., (5) Determine the original relative speed (SRM); then using it, determine the time at Mx. Next, determine the new SRM; then using it, determine how long it will take for the contact to move in relative motion down the new RML from Mx to the new CPA. (6) T 0219, (7) When the contact bears 318˚, range 3.0 miles. (8) The slow return to the original course will serve to insure that the contact will remain outside the 3-mile danger or buffer zone after own ship is steady on 350˚.

14. Own ship, on course 330˚, speed 20 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 12 miles:

Time	*Bearing*	*Range (mi.)*
0608	300˚	12.0
0614	300˚	10.0
0620	300˚	8.0

Required:

(1) Range at CPA.

(2) Time at CPA.

(3) True course of the contact.

(4) True speed of the contact.

(5) What danger, if any, would be present if own ship maintained course and speed and contact changed course to 120˚ at 0620?

Decision:

Assume that the contact maintains its original course and speed and that own ship's speed has been reduced to 11.5 knots when the range to the contact has decreased to 6 miles.

Required:

(6) New range at CPA.

(7) Will the contact pass ahead or astern of own ship?

Solution:

(1) Nil; risk of collision exists. (2) T 0644, (3) C 045˚, (4) S 10.5 kn., (5) None, (6) R 2.0 mi., (7) Ahead.

15. Own ship, on course 022˚, speed 32 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 24 miles:

Time	*Contact A*	*Contact B*	*Contact C*
0423	070˚-23.2 mi.	170˚-23.8 mi.	025˚-22.6 mi.
0426	070˚-21.1 mi.	170˚-23.8 mi.	023˚-21.2 mi.
0429	070˚-19.1 mi.	170˚-23.8 mi.	020˚-19.0 mi.

The observations are made on a warm, summer morning. The weather is calm; the sea state is 0. From sea water temperature measurements and weather reports, it is determined that the temperature of the air immediately above the sea is 12˚ F cooler than the air 300 feet above the ship. Also, the relative humidity immediately above the sea is 30% greater than at 300 feet above the ship.

Required:

(1) Since the contacts are detected at ranges longer than normal, to what do you attribute the radar's increased detection capability?

(2) Ranges at CPA for the three contacts.

(3) True courses of the contacts.

(4) True speeds of the contacts.

(5) Which contact presents the greatest threat?

(6) If own ship has adequate sea room, should own ship come left or right of contact A?

Decision:

When the range to contact A decreases to 12 miles, own ship will change course so that no contact will pass within 4 miles.

Required:

(7) New course for own ship.

Solution:

Assuming that the contacts maintain course and speed: (1) Super-refraction, (2) Contact A-nil; Contact B-R 23.8 mi.; Contact C-R 9.2 mi., (3) Contact A-C 299˚; Contact B-C 022˚; Contact C-C 282˚, (4) Contact A-S 30 kn; Contact B-S 32 kn.; Contact C-S 19 kn., (5) Contact A; it is on collision course, (6) Come right, (7) C 063˚.

16. Own ship, on course 120˚, speed 12 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 12 miles:

Time	*Contact A*	*Contact B*	*Contact C*
0300	095˚-8.7 mi.	128˚-10.0 mi.	160˚-7.7 mi.
0306	093˚-7.8 mi.	128˚-8.3 mi.	164˚-7.0 mi.
0312	090˚-7.0 mi.	128˚-6.6 mi.	170˚-6.3 mi.

Required:

(1) Ranges at CPA for the three contacts.

(2) True courses of the contacts.

(3) Which contact presents the greatest danger?

(4) Which contact, if any, might be a lightship at anchor?

Decision:

When the range to contact B decreases to 6 miles, own ship will change course to 190˚.

Required:

(5) At what time will the range to contact B be 6 miles?

(6) New CPA of contact C after course change to 190˚.

Solution:

Assuming the contacts maintain course and speed: (1) Contact A-R 3.0 mi.; contact B-nil; contact C-R 4.3 mi., (2) contact A-C 138˚; contact B-C 329˚; contact C-C 101˚, (3) Contact B; it is on collision course, (4) None, (5) T 0314, (6) R 3.2 mi.

17. Own ship, on course 298°, speed 13 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 20 miles:

Time	*Bearing*	*Range (mi.)*
0639	267°	19.0
0651	266.5°	16.0
0709	265°	11.5
0729	261°	6.5
0735	255.5°	4.9
0737	252°	4.3
0741	242.5°	3.3

Required:

(1) Range at CPA as determined at 0729.

(2) Time at CPA as determined at 0729.

(3) Course of other ship as determined at 0729.

(4) Speed of other ship as determined at 0729.

(5) Range at CPA as determined at 0741.

(6) Time at CPA as determined at 0741.

(7) Course of other ship as determined at 0741.

(8) Speed of other ship as determined at 0741.

Solution:

(1) R 1.0 mi., (2) T 0755, (3) C 030°, (4) S 7.0 kn., (5) R 2.0 mi., (6) T 0749.5, (7) C 064°, (8) S 7.0 kn.

18. Own ship, on course 073°, speed 19.5 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 20 miles:

Time	*Bearing*	*Range (mi.)*
1530	343°	16.2
1540	343°	14.7
1546	343°	13.8
1558	343°	12.0
1606	342.5°	10.9
1612	341.5°	10.1
1624	339.5°	8.4
1632.5	336°	7.3
1644	328.5°	6.0
1657	315°	4.7

Required:

(1) Range at CPA as determined at 1558.

(2) Time at CPA as determined at 1558.

(3) Course of other ship as determined at 1558.

(4) Speed of other ship as determined at 1558.

(5) Range at CPA as determined at 1624.

(6) Time at CPA as determined at 1624.

(7) Course of other ship as determined at 1624.

(8) Speed of other ship as determined at 1624.

(9) Range at CPA as determined at 1657.

(10) Time at CPA as determined at 1657.

(11) Course of other ship as determined at 1657.

(12) Speed of other ship as determined at 1657.

Solution:

(1) R 0.0 mi., (2) T 1718, (3) C 098°, (4) S 21.5 kn., (5) R 2.0 mi., (6) T 1721, (7) C 098°, (8) S 20.0 kn., (9) R 3.7 mi., (10) T 1718, (11) C 098°, (12) S 18.0 kn.

19. Own ship, on course 140˚, speed 5 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 12 miles:

Time	*Bearing*	*Range (mi.)*
0257	142˚	10.5
0303	141.5˚	8
0308	141˚	6
0312	135˚	4.5
0314	126.5˚	4
0317	110.5˚	3.2

Required:

(1) Range at CPA as determined at 0308.

(2) Time at CPA as determined at 0308.

(3) Course of other ship as determined at 0308.

(4) Speed of other ship as determined at 0308.

(5) Range at CPA as determined at 0317.

(6) Time at CPA as determined at 0317.

(7) Course of other ship as determined at 0317.

(8) Speed of other ship as determined at 0317.

Solution:

(1) R 0.2 mi., (2) T 0322, (3) C 325˚, (4) S 20.0 kn., (5) R 3.0 mi., (6) T 0320, (7) C 006˚, (8) S 20.0 kn.

20. Own ship, on course 001˚, speed 15 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 15 miles:

Time	*Bearing*	*Range (mi.)*
2243	138˚	14.0
2255	137.5˚	12.6
2318	136˚	9.9
2332	140˚	8.0
2351	166.5˚	5.5
0002.5	191.5˚	5.0
0008	204˚	5.1
0014	214˚	5.1
0020	222˚	4.95
0026	230˚	4.85

Required:

(1) Range at CPA as determined at 2318.

(2) Time at CPA as determined at 2318.

(3) Course of other ship as determined at 2318.

(4) Speed of other ship as determined at 2318.

(5) Predicted range of other vessel as it crosses dead ahead of own ship as determined at 2318.

(6) Predicted time of crossing ahead as determined at 2318.

(7) Course of other ship as determined at 2351.

(8) Speed of other ship as determined at 2351.

(9) Predicted range of other vessel as it crosses dead astern of own ship as determined at 2351.

(10) Predicted time of crossing astern as determined at 2351.

(11) Direction of relative movement between 0002.5 and 0008.

(12) Relative speed between 0002.5 and 0008.

(13) Course of other ship as determined at 0026.

(14) Speed of other ship as determined at 0026.

Solution:

(1) R 1.2 mi., (2) T 0042, (3) C 349˚, (4) S 21.0 kn., (5) R 2.0 mi., (6) T 0056, (7) C 326˚, (8) S 21.0 kn., (9) R 5.1 mi., (10) T 2358, (11) DRM 281.5˚, (12) SRM 12.0 kn., (13) C 349˚, (14) S 21.0 kn.

21. Own ship, on course 196˚, speed 8 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 12 miles:

Time	*Bearing*	*Range (mi.)*
2303	016˚	11.0
2309	016˚	10.0
2318	016˚	8.5
2330	016˚	6.5
2340	011.5˚	4.9
2350	359.5˚	3.4
2400	333.5˚	2.2
0010.5	286˚	2.0
0020	247.5˚	2.5
0026	233.5˚	3.2

Required:

(1) Range at CPA as determined at 2318.

(2) Time at CPA as determined at 2318.

(3) Course of other ship as determined at 2318.

(4) Speed of other ship as determined at 2318.

(5) Range at CPA as determined at 2400.

(6) Time at CPA as determined at 2400.

(7) Course of other ship as determined at 2400.

(8) Speed of other ship as determined at 2400.

(9) Course of other ship as determined at 0026.

(10) Speed of other ship as determined at 0026.

Solution:

(1) R 0.0 mi., (2) T 0009, (3) C 196˚, (4) S 18.0 kn., (5) R 2.0 mi., (6) T 0006, (7) C 207˚, (8) S 18.0 kn., (9) C 196˚, (10) S 18.0 kn.

22. Own ship, on course 092˚, speed 12 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 16 miles:

Time	*Bearing*	*Range (mi.)*
1720	335˚	15.0
1750	334.5˚	11.7
1830	333˚	7.2
1854	325.5˚	4.5
1858	315.5˚	4.0
1902	303.5˚	3.6
1906	289.5˚	3.4
1914	263.5˚	3.3
1930	212.5˚	3.8
1950	184.5˚	6.8

Required:

(1) Range at CPA as determined at 1830.

(2) Time at CPA as determined at 1830.

(3) Course of other ship as determined at 1830.

(4) Speed of other ship as determined at 1830.

(5) Course of other ship as determined at 1906.

(6) Speed of other ship as determined at 1906.

(7) Course of other ship as determined at 1950.

(8) Speed of other ship as determined at 1950.

Solution:

(1) R 0.5 mi., (2) T 1935.5, (3) C 114˚, (4) S 16.0 kn., (5) C 147˚, (6) S 16.0 kn., (7) C 124˚, (8) S 20.0 kn.

23. Own ship, on course 080°, speed 12.5 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 16 miles:

Time	*Bearing*	*Range (mi.)*
0035	038°	14.5
0044	038.5°	13.2
0106	040°	10.0

Required:

(1) Range at CPA.

(2) Time at CPA.

(3) Course of other ship.

(4) Speed of other ship.

Decision:

When the range decreases to 8.0 miles, own ship will turn to the left to increase the CPA distance to 3.0 miles.

Required:

(5) Predicted time of change of course.

(6) Predicted bearing of other ship when own ship changes course.

(7) New course for own ship.

(8) Time at new CPA.

(9) Time at which own ship is dead astern of other ship.

Solution:

(1) R 1.0 mi., (2) T 0215, (3) C 124°, (4) S 9.0 kn., (5) T 0120, (6) B 041.5°, (7) C 064°, (8) T 0200, (9) T 0204.

24. Own ship, on course 251°, speed 18.5 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 20 miles:

Time	*Bearing*	*Range (mi.)*
0327	314°	16.2
0337	314.5°	14.7
0351	315°	12.6
0401	315.5°	11.1
0413.5	315°	9.1
0422	305°	6.7

Required: (As determined at 0401.)

(1) Range at CPA.

(2) Time at CPA.

(3) Course of other ship.

(4) Speed of other ship.

Decision:

Own ship will pass astern of other vessel, with a CPA of 4.0 miles and new direction of relative movement perpendicular to own ship's original course, maintaining a speed of 18.5 knots. The original course will be resumed when the other ship is dead ahead of this course.

Required:

(5) New direction of relative movement.

(6) Predicted time of change of course.

(7) Predicted bearing of other ship when own ship changes course.

(8) Predicted range of other ship when own ship changes course.

(9) New course for own ship.

(10) Predicted new relative speed.

(11) Predicted time at which other ship is dead ahead of own ship.

(12) Predicted range of other ship when it is dead ahead of own ship.

(13) Predicted time at CPA, as determined at 0422.

(14) Bearing of other ship when it is dead ahead of own ship's original course.

(15) Predicted time of resuming original course.

Solution:

(1) R 1.0 mi., (2) T 0515, (3) C 222°, (4) S 16.0 kn., (5) DRM 161°, (6) T 0411, (7) B 316.5°, (8) R 9.6 mi., (9) C 292°, (10) SRM 19.8 kn., (11) T 0428, (12) R 5.3 mi., (13) T 0438.5, (14) B 251°, (15) T 0438.5.

25. Own ship, on course 035°, speed 20 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 15 miles:

Time	*Bearing*	*Range (mi.)*
1900	035°	14.4
1906	035°	12.8
1915	035°	10.4
1924	035°	8.0
1933	035°	5.6
1941	030°	3.5
1947	015°	1.9

Required: (As determined at 1915.)

(1) Range at CPA.

(2) Time at CPA.

(3) Course of other ship.

(4) Speed of other ship.

Decision:

When the range decreases to 5.0 miles, own ship will change course to the right, maintaining a speed of 20 knots, to pass the other ship with a CPA of 1.0 mile. Original course of 035° will be resumed when the other ship is broad on the port quarter.

Required:

(5) Predicted time of change of course to the right.

(6) New course for own ship.

(7) Bearing of CPA as determined at 1935.

(8) Predicted time at 1.0 mile CPA as determined at 1935.

(9) Bearing of other ship when own ship commences turn to original course.

(10) Predicted time of resuming original course.

Solution:

(1) R 0.0 mi., (2) T 1954, (3) C 035°, (4) S 4.0 kn., (5) T 1935, (6) C 044°, (7) B 314°, (8) T 1952, (9) B 269°, (10) T 1957.

26. Own ship, on course 173˚, speed 16.5 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 20 miles:

Time	*Bearing*	*Range (mi.)*
2125.5	221˚	16.0
2130	220.5˚	15.0
2137.5	219˚	13.2
2142	218˚	12.2
2151.5	215.5˚	10.0
2158	205.5˚	8.3
2206	185˚	6.7

Required: (As determined at 2142.)

(1) Range at CPA.

(2) Time at CPA.

(3) Predicted range other ship will be dead ahead.

(4) Predicted time of crossing ahead.

(5) Course of other ship.

(6) Speed of other ship.

Decision:

When range decreases to 10 miles own ship will change course to the right to bearing of stern of other vessel (assume 0.5˚ right of radar contact).

Required:

(7) Range at new CPA.

(8) Time at new CPA.

(9) Direction of new relative movement line.

(10) New relative speed.

(11) New course of own ship.

Decision:

Own ship will resume original course when bearing of other vessel is the same as the original course of own ship.

Required:

(12) Predicted time of resuming original course.

(13) Distance displaced to right of original course line.

(14) Additional distance steamed in avoiding other vessel.

(15) Time lost in avoiding other vessel.

Solution:

(1) R 2.5 mi., (2) T 2233, (3) R 3.0 mi., (4) T 2225.5, (5) C 120˚, (6) S 14.7 kn., (7) R 6.3 mi., (8) T 2211.5, (9) DRM 075˚, (10) SRM 23.2 kn., (11) C 216˚, (12) T 2209.5, (13) D 3.4 mi., (14) D 1.3 mi., (15) t less than 5 min.

27. Own ship, on course 274°, speed 15.5 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 20 miles:

Time	*Bearing*	*Range (mi.)*
0815	008°	14.4
0839	006°	10.1
0853	004°	7.6

Required:

(1) Range at CPA.

(2) Time at CPA.

(3) Course of other ship.

(4) Speed of other ship.

Decision:

When the range decreases to 6.0 miles, own ship will commence action to obtain a CPA distance of 4.0 miles, with own ship crossing astern of other vessel.

Required:

(5) Predicted bearing of other ship when at a range of 6.0 miles.

(6) Predicted time when other ship is at 6.0 mile range, and own ship must commence action to obtain the desired CPA of 4.0 miles.

Decision:

Own ship may (1) alter course to right and maintain speed of 15.5 knots, or (2) reduce speed and maintain course of 274°.

Required:

(7) New course if own ship maintains speed of 15.5 knots.

(8) Predicted time when other vessel bears 274° and own ship's original course can be resumed.

(9) New speed if own ship maintains course of 274°.

(10) Predicted time when other vessel crosses ahead of own ship and original speed of 15.5 knots can be resumed.

Solution:

(1) R 1.1 mi., (2) T 0935, (3) C 242°, (4) S 20.0 kn., (5) B 002°, (6) T 0902, (7) C 019°, (8) T 0916, (9) S 8.2 kn., (10) T 0936.

28. Own ship, on course 052˚, speed 8.5 knots, obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 20 miles:

Time	*Bearing*	*Range (mi.)*
0542	052˚	18.5
0544	052˚	17.5
0549	052˚	15.0
0550	052˚	14.5

Required:

(1) Range at CPA.

(2) Time at CPA.

(3) Course of other ship.

(4) Speed of other ship.

Decision:

At 0555, own ship is to alter course to right to provide a CPA distance of 2.0 miles on own ship's port side.

Required:

(5) Predicted bearing of other ship when own ship changes course.

(6) Predicted range of other ship when own ship changes course.

(7) New course for own ship.

Own ship continues to track other ship and obtains the following radar bearings and ranges at the times indicated, using a radar range setting of 20 miles:

Time	*Bearing*	*Range (mi.)*
0559	050˚	10.0
0604.5	043.5˚	7.4
0606.5	040˚	6.5
0609	034˚	5.5

Required:

(8) Course of other ship as determined at 0609.

(9) Speed of other ship as determined at 0609.

(10) Range at CPA as determined at 0609.

Solution:

(1) R 0.0 mi., (2) T 0619, (3) C 232˚, (4) S 21.5 kn., (5) B 052˚, (6) R 12.0 mi., (7) C 086˚, (8) C 241˚, (9) S 21.5 kn., (10) R 3.0 mi.

APPENDIX D

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