PRACTICAL NAVIGATION
FOR OFFICERS OF THE WATCH

Practical Navigation for Officers of the Watch

BY

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FOREWORD

The new title of *Practical Navigation for Officers of the Watch* replaces two titles – *Practical Navigation for Second Mates (Five editions)* and *Principals and Practices of Navigation (First edition and reprinted many times)* and both have been extensively revised, extended and re-titled to reflect the changes in nautical education over the past decade. When this work was first written the knowledge required of the officer of the watch at sea tended to be artificially compartmentalized by the arbitrarily selected subject matter of the various examination papers for certification. Now the structure of Merchant Navy certification has been radically changed partly in the name of 'progress' and partly to comply with International Maritime Organisation requirements which are embodied in the STCW code. More radical however is the change in the way in which certificates are acquired. The aspiring officer of the watch can now achieve certification through NVQ or SVQ unit achievement ratified by MSA oral examination. The divisions between various elements within the overall spectrum of knowledge required have been blurred somewhat. Consequently this publication has been extended in scope to reflect these changes. Much theoretical matter which, although of great interest, has been excluded on the grounds that it is no longer examined in professional certification. What has been included and introduced is what is considered to be the foreground and background knowledge required by the officer of the watch to plan his voyage and navigate his vessel safely and intelligently, with some degree of professional satisfaction.

Marine navigation has seen many changes over the past two decades, the most noticeable of which is the rapid expansion of electronic aids to navigation. Radar has become an almost indispensable aid and any work on navigation can no longer ignore it. A section on radar information has therefore been included. One section of a publication however cannot claim to be a comprehensive and definitive work on such a vast subject and this section is necessarily confined to the practical use in its navigational role.

There is a great danger now that readily obtainable positional information from electronic navigational aids is accepted as an alternative to basic navigational techniques. It is the author's view however that, while it is obviously wrong to reject the benefits of technological advances it is it professionally inept to rely on such devices to the exclusion of basic principles and techniques tried and tested over many decades. It is also detrimental to the self esteem of the navigator to be dictated to by computer generated information. It is also the author's view therefore that the main subject matter of this publication is far from outdated and will remain so for the foreseeable future.

All practical problems used in the examples and exercises in this book may be worked using the extracts from the Nautical Almanac and the Admiralty Tide Tables included. Some chartwork examples and exercises have been worked using the series of reasonable priced practice charts published by the UK Hydrographic Office.

Trapp, Carmarthenshire January 2003 *A. Frost*

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INTRODUCTION

The Passage Plan

It is a foolhardy navigator who sets out without careful consideration of the voyage ahead. There is an abundance of good advice on the subject of voyage planning, most of which, to the competent navigator, is just good common sense. At the time of writing the Marine Guidance Note (MGN 166) brings to the attention of the navigator 'Guidelines for Voyage Planning' approved by the International Maritime Organisation, and the previous MGN 72 emphasises the need for systematic planning of all stages of a voyage, and also draws the attention of all navigators to two excellent works 'Bridge Team Management – A Practical Guide', published by the Nautical Institute and 'Bridge Procedures Guide' published by the International Chamber of Shipping. These should form part of the bridge equipment of every vessel, but invariably they are written on the assumption that the reader is familiar with basic techniques of navigation. It is therefore the intention of this work to explain these basic techniques and it is intended to give only a brief outline of the voyage planning process here as it affects this purpose.

The elements of voyage planning are formally divided into four distinct stages:

1. Appraisal
2. Planning
3. Execution
4. Monitoring

Appraisal

This first stage requires an assessment of the voyage and the particular dangers which it presents. It requires a consideration of all the information which is relevant to the voyage, and it is the responsibility of the navigator to be aware of what information is available and where it can be found. Most of this information has its primary source in the Admiralty publications issued by the UK Hydrograhic Office in Taunton, and all of these should be familiar to the navigator. The contents and use of the various publications are described in Module 1.2. All voyages to sea contain some element of risk. The appraisal stage should minimise the risk whilst weighing it against commercial considerations. Routeing information, climatic data, prevailing meteorological conditions and the possibility of ice, the advisability of weather routeing and general traffic patterns should be considered to establish the wide strategy of the voyage. A major consideration must be the nature of the voyage and its cargo, and the minimising of any potential risk to the environment. When the particular route is finally decided upon, as much general information as possible about the areas concerned and their navigational hazards should be assimilated.

Planning
Having made a full appraisal of the voyage the navigator can now make a detailed plan from berth to berth. This will require deciding upon and marking on charts the exact ground tracks which it is the intention to follow. These should be chosen with regard to the vessel's size and draft, and the margins of error that are necessary to account for inaccuracies in the monitoring of the vessel's movements and for the possibilities of equipment failure. Navigational hazards must be passed at safe distances with such failure in mind. Routeing advice must be considered and mandatory requirements in the form of traffic separation schemes followed. Tracks on charts should be marked with their true directions and possibly with the predicted compass error and the compass courses to steer to make good those tracks. The underpinning knowledge that is required for this is contained in Modules 1.1, 1.2, 1.3 and 1.4 which collectively cover the use of charts and compasses and compass errors.

At this stage of the voyage plan important decisions must be made as to how the progress of the vessel is to be monitored. What will be the primary and the backup methods of position fixing and what is the accuracy required at various stages of the voyage. The modern navigator must decide which will best serve his needs at each stage, choosing between visual position fixing, visual pilotage, radar position fixing or radar parallel indexing, position fixing by observation of celestial bodies or by electronic navigational aids such as Loran C or Navstar GPS. Whichever is used he will need a thorough knowledge of basic techniques. The theory of position fixing is covered in Module 1.5. Radar navigation is covered in Module 1.8, while ocean navigation is dealt with in Section 2.

Also decided at this point must be key elements of the voyage plan which should include:

(a) The safe speeds to negotiate each stage of the voyage, bearing in mind factors such as draught in relation to the depth of water, and the manoeuvring characteristics of the vessel. Factors such as squat at critical points in the passage should not be neglected.
(b) Speed adjustments to arrive at critical points of the voyage under the desired conditions of tide and daylight.
(c) Contingency plans in the event of emergency at critical stages, to maintain the vessel in safe water.
(d) Obligations for reporting in to traffic reporting schemes.

All these elements should be noted at appropriate places on the chart or in a bridge notebook which will be available for easy reference during the passage.

Execution
When the voyage plan is completed and approved by the master the plan can be executed when the final timing of the plan can be predicted. An overall ETA at the destination can be worked as well as ETA's at points in the passage where tidal or traffic conditions are critical.

Tidal streams can be predicted from charted information or from tidal stream atlases for various parts of the voyage. This is dealt with in Module 1.7. Allowance for tide is covered in Module 1.4.

The status and condition of navigational equipment can be checked and meteorological conditions predicted from available weather reports. The results of either of these checks may require a modification of the plan to account for unreliable equipment or adverse weather including expected limitations in visibility. Any changes to the normal composition of the watches can be decided upon and work schedules arranged so that those commencing the watchkeeping pattern are adequately rested.

Finally the bridge can be prepared before scheduled sailing time so that all equipment is tested, all ancillary equipment normally stowed away when not in use, is in good condition and arranged to hand. Radars and navigational aids can be switched on and set up.

Monitoring
This is the process of checking at each stage of the voyage that the agreed plan is being adhered to as closely as possible. After the

vessel sails, this is the responsibility of the officer of the watch. He is the master's representative on the bridge and he must ensure that the master's instructions in the form of the passage plan are carried out, and that any deviation from the plan is detected and corrective action initiated and if of a serious nature the master informed. It may be that a modification of the original plan is required and this can only be done with the agreement of the master. He must always use all available information and cross check that different sources of information agree. Any disagreement is often the first sign that things are going wrong, either that equipment is inaccurate or inoperative, or that the vessel is not where it should be. The causes of the disagreement must be investigated and decisions made as to which information is most reliable. The quality of the chartwork performed by the officer of the watch is most important. Chartwork is an important element in the recording of the voyage and complements the deck log. The master and other watchkeepers must be able to readily understand the chartwork, and in the event of accident the chartwork will be an important factor in establishing the events which led up to the mishap. For this reason charts should not be cleaned until the next time they are required. Chartwork practice and constructions are dealt with in Module 1.4. The methods of monitoring the vessel's position in coastal passages are dealt with in Modules 1.5, which covers the theory of position lines and visual position fixing, and Module 1.8 which deals with the use of radar. The practice of navigation during ocean passages is the subject of Section 2.

Personalising the passage plan

Finally it must be said that there is no such thing as the definitive passage plan. Different types of vessel, different types of trade, different areas of navigation may all require modifications to the standard that is set by publications devoted to the subject. The navigator must be urged to study the standard texts on passage planning and to use them as guidelines for the formulation of methods to suit his own circumstances. It may be that company instructions or masters standing orders already dictate what is required of his passage plan, but if not the individual navigator must develop his own techniques and routines. Going to sea is always a risky business and it is the task of the navigator to ensure that risks are kept to a minimum by adequate preparation and ensuring that he takes into account all the sound advice and information which is available for his benefit. It is hoped that this

work will go some substantial way towards providing the underpinning knowledge of basic techniques which will enable him to conduct his voyages successfully.

SECTION 1

Coastal Navigation

In this section we are concerned with the production and monitoring of a vessel's navigation plan when voyaging in the vicinity of coastlines and navigational hazards. Contact with the shore line may be visual or by radar, and by depth information from echo sounding equipment. Additional data may be provided by electronic position fixing aids, in the form of position, and also of course and distance information from waypoint navigation facilities.

Modules included in this section are:

1.1 Latitude and Longitude. Units of Distance.

1.2 The Use of Charts and Other Navigational Publications.

1.3 Compasses, Compass Errors. Courses and Bearings.

1.4 Chartwork Constructions. Allowance for Wind and Tide.

1.5 Position Lines. Position Fixing by Terrestrial Observation.

1.6 The Sailings.

1.7 Tides, Tide Tables and Other Tidal Information.

1.8 Radar Navigation.

MODULE 1.1

Latitude and Longitude. Units of Distance

Definitions

Great Circle. A circle drawn upon the surface of a sphere whose plane passes through the centre of the sphere. It will be the largest circle that can be drawn upon that sphere. Given any two points on the sphere which are not diametrically opposed there is only one great circle that may be drawn through the points.

Small Circle. Any circle drawn on the surface of a sphere which is not a great circle.

Poles. The two points where the rotation axis of the earth cuts the earth's surface.

Meridian. A semi great circle on the earth's surface between the two poles.

Equator. The great circle on the earth's surface the plane of which is at right angles to the axis of rotation, thus dividing the earth's surface into a northern and a southern hemisphere. Each point on the equator will be equidistant from the two poles.

Parallel of Latitude. A small circle on the earth's surface, the plane of which is parallel to the plane of the equator.

The shape of the earth (the geoid) approximates to the mathematical form called an oblate spheroid or ellipsoid. It is a sphere which is flattened at the poles due to the rotation about the polar axis. Thus the polar diameter is less than the equatorial diameter. However for many aspects of navigation the earth is considered as a sphere without undue error.

Position on this sphere is defined by two coordinates latitude and longitude. The reference from which latitude is measured is the equator.

The latitude of a position on the earth's surface is defined as the angle subtended at the centre of the earth by the position and the plane of the equator, or the arc of a meridian between the equator and the parallel of latitude through the position. Thus latitude may be measured from zero degrees at the equator to 90 degrees at the poles and must be expressed north or south of the equator. The latitude so defined is called the geocentric latitude.

The reference from which longitude is measured is arbitrarily defined as the prime meridian which is that meridian which passes through Greenwich. Longitude is measured and named east or west of Greenwich from 0 degrees to 180 degrees, and may be defined as the angle subtended by the plane of the Greenwich meridian that of the meridian which passes through the position, or alternatively as the lesser arc of the equator contained between the Greenwich meridian and the meridian under consideration.

In stating the latitude and longitude of a position by convention the latitude must always be given first to avoid any confusion in communications.

The measurement of latitude and longitude is complicated by the fact that the shape of the earth (the geiod) is irregular and only approximates to an oblate spheroid and not a sphere. In general these are considerations which must be taken into account by surveyors and chart makers but have little effect on marine navigation. It should be realised however that the mathematical figure or datum which describes the size and shape of the earth, which is used by the chart maker may be that which most closely fits the earth in the area which is being charted, and may or may

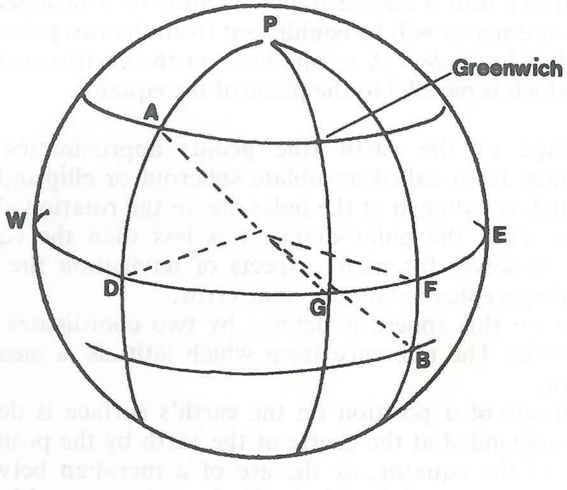


FIG. 1.1.1
Point A in north latitude (arc AD) and west longitude (arc DG).
Point B in south latitude (arc FB) and east longitude (arc GF).

not be the same as that used in the charting of other parts of the earth. It may not be that which is used by a satellite navigation system, and the navigator may find that latitudes and longitudes do not agree between charts produced using different datums, and between charts and satellite navigators which use different datums. There will also be discrepancies between his astronomical observations of positions based upon a spherical earth, and charted position based upon an oblate earth. There is usually provision within satellite navigator receivers to allow for the use of different datums in order to minimise these discrepancies and usually these are small enough to be insignificant. In situations where they may be significant latitude and longitude are of less importance to the navigator than his position relative to the dangers which he is trying to avoid, and he should be using methods of position monitoring that give this kind of information.

The marine navigator normally expresses latitude and longitude in degrees and minutes of arc, the minutes being stated to the nearest decimal point. (Unless extreme accuracy is required such as chart correcting where seconds of arc may be used.) The latitude should be annotated N or S, and the longitude E or W.

Thus	52° 14.1′ N	005° 43.7′ W
or	23° 54.8′ S	115° 34.9′ E

Distance

The unit of distance used in marine navigation is the International Nautical Mile. The length of this unit is adopted as 1852 metres.

The marine navigator, when defining position, or when making celestial observations to find his position, is primarily concerned with angular measurement, and the unit of distance most convenient to him is that distance occupied by one minute of arc on the earth's sphere. Thus the nautical mile was originally defined as the distance occupied by one minute of arc of a meridian. Although this is most convenient in celestial navigation this definition caused the minor inconvenience of being of different length due to the elliptical shape of a meridian. One minute of the flattened meridian at the poles is approximately 1861 metres whereas at the equator where the curvature is greater it is only approximately 1843 metres. The navigator's scale of distance on a nautical chart is the latitude scale and this variation is usually ignored with no significant error. Note that on a chart the divisions denoting minutes of latitude on charts which cover a large range of latitude may be noticeably of different length in different latitudes, but this is primarily as a result of the projection of the chart and this will be discussed later.

Speed

The unit of speed at sea is the knot which is defined as 1 nautical mile per hour.

Difference of Latitude. Difference of Longitude

When sailing between two positions on the earth's surface a knowledge of the necessary change in latitude and longitude is often required.

The difference of latitude (d'lat) between any two positions is the arc of a meridian which is contained between the two parallels of latitude which pass through the two positions. From Figure 1.1.2 it can be seen that if the two positions are on the same side of the equator (latitudes same name), then the d'lat will be the numerical difference between the two latitudes. If the two positions are on opposite sides of the equator (latitudes different names), then the d'lat will be the sum of the two latitudes. The d'lat is named according to the direction of travel.

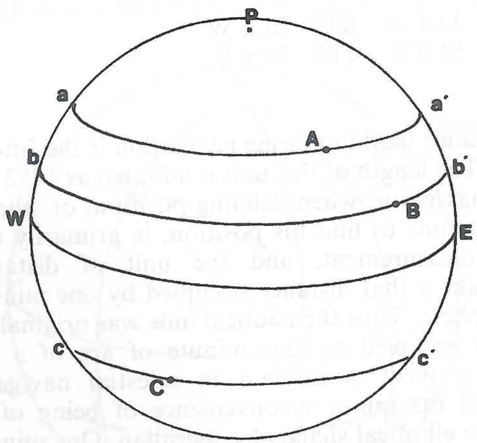


FIG. 1.1.2

WE = Equator
aa' = parallel of latitude through A
bb' = parallel of latitude through B
cc' = parallel of latitude through C
d'lat between A and B = Latitude A − Latitude B = arc ab
d'lat between A and C = Latitude A + Latitude C = arc ac
d'lat between B and C = Latitude B + Latitude C = arc bc

The difference of longitude (d'long) between any two positions is the lesser arc of the equator contained between the two meridians which pass through the positions. If the longitude of the positions lie on the same side of the prime meridian (longitudes same name), then the d'long will be the numerical difference between the two longitudes. If the positions lie on opposites sides of the prime meridian (longitudes opposite names), then the d'long will be the sum of the two longitudes. If however the sum is greater than 180° then the sum must be subtracted from 360°. The d'long is named according to the direction of travel.

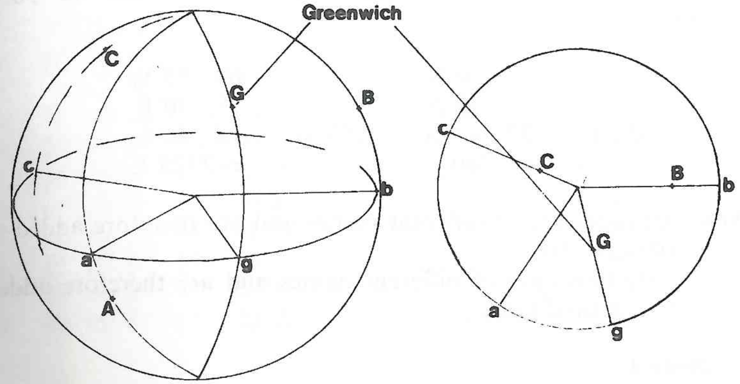


FIG. 1.1.3

Point A and point C are in westerly longitude.
Point B is in easterly longitude.
D'long between A and C = Long. A ~ Long. C = arc ac
D'long between A and B = Long. A + Long. B = arc ab
D'long between C and B = 360 − (Long. C + Long. B) = arc cb

D'lats and d'longs are usually required in minutes of arc and are therefore expressed as such in the following examples.

Example 1

Find the d'lat and d'long between the two positions 25° 46′ N 15° 28′ W and 52° 56′ N 39° 47′ W.

	25° 46′ N		15° 28′ W
	52° 56′ N		39° 47′ W
d'lat	27° 10′ N	d'long	24° 19′ W
	= 1630′ N		= 1459′ W

Example 2

Find the d'lat and d'long between the two positions 44° 25′ N 75° 46′ W and 36° 19′ S 09° 26′ W.

	44° 25′ N		75° 46′ W
	36° 19′ S		09° 26′ W
d'lat	80° 44′ S	d'long	66° 20′ E
	= 4844′ S		= 3980′ E

Example 3

Find the d'lat and d'long made good by a vessel which steams between the two positions 22° 10′ S 09° 15′ W and 15° 30′ N 29° 30′ E.

	22° 10′ S		09° 15′ W
	15° 30′ N		29° 30′ E
d'lat	37° 40′ N	d'long	38° 45′ E
	= 2260′ N		= 2325′ E

Note: latitudes are of different names and are therefore added to obtain d'lat.
longitudes are of different names and are therefore added to obtain d'long.

Example 4

A vessel steams from position 18° 40.0′ S 136° 40.6′ W to 31° 15.2′ S 126° 35.8′ E. Find the d'lat and d'long made good.

	18° 40.0′ S		136° 40.6′ W
	31° 15.2′ S		126° 35.8′ E
d'lat	12° 35.2′ S	d'long	263° 16.4′ E
			360°
			96° 43.6′ W
	= 755.2′ S		= 5803.6′ W

Note: The vessel is steaming from a west longitude across the 180° meridian to a position in east longitude and is therefore moving in a westerly direction.

Example 5

A vessel steams on a course which lies between north and east and makes good a d'lat of 925.8′ N and a d'long of 1392.6′ E. If the initial position is 25° 20.7′ N 46° 45.2′ W find the final position.

	25° 20.7′ N		46° 45.2′ W
d'lat	15° 25.8′ N	d'long	23° 12.6′ E
final latitude	40° 46.5′ N	final longitude	23° 32.6′ W

Note: The d'lat having the same name as the latitude is added. The d'long is of opposite name to the longitude and is therefore subtracted.

EXERCISE 1.1.1

Find the d'lat and d'long between the following positions.

	initial position		final position	
1.	40° 10′ N	9° 25′ W	47° 15′ N	21° 14′ W
2.	35° 15′ N	22° 12′ W	50° 25′ N	11° 37′ W
3.	10° 12′ N	5° 03′ E	5° 18′ S	7° 18′ W
4.	20° 40′ S	170° 09′ E	13° 06′ N	178° 51′ E
5.	30° 03′ N	152° 43′ W	42° 24′ N	174° 01′ W
6.	11° 31′ N	178° 00′ E	5° 14′ S	177° 00′ W
7.	8° 42′ S	162° 41′ W	7° 53′ N	135° 27′ E
8.	15° 20′ S	130° 35′ E	33° 10′ N	155° 40′ W
9.	52° 10′ S	171° 08′ E	27° 02′ S	34° 02′ E
10.	60° 40′ S	151° 23′ W	10° 57′ S	92° 47′ W

EXERCISE 1.1.2

1. Find the final position if a vessel steams from position 20° 50′ S 178° 49′ E and makes good a d'lat of 1994′ N and a d'long of 937′ E.

2. Find the final position if a vessel steams from position 39° 40′ N 9° 21′ W and makes good a d'lat of 237′ N and a d'long of 1627′ E.

3. If a vessel reaches a final position of 30° 10.6′ S 4° 40.3′ E having made good a d'lat of 4338.8′ S and a d'long of 2334.7′ E, find the departure position.

4. If a vessel steered a course between north and east and made good a d'lat of 2335.5′ and a d'long of 1241.8′, arriving in a position 21° 10.4′ N 168° 18.7′ W, find the departure position.

MODULE 1.2

The Use of Charts and Other Navigational Publications

Nautical publications necessary for any intended voyage are required to be carried under the 'Safety of Life at Sea Convention' (SOLAS). This requirement is given the force of law by Statutory Instrument which stipulates mandatory carriage of certain publications supplemented by a recommended list. The Merchant Shipping (Carriage of Nautical Publications) Regulations 1998 came into force on the 1st December 1998 and require UK registered ships anywhere in the world to carry charts and the following publications which are relevant to intended voyages:

Merchant Shipping Notices
Marine Guidance Notes
Marine Information Notes
Notices to Mariners
Lists of Radio Signals
Lists of Lights
Sailing Directions
The Mariner's Handbook
The Nautical Almanac
Navigation Tables
Tide Tables
Tidal Stream Atlases
Operating instructions for navigational aids carried.

All charts and publications must be the latest obtainable editions and maintained corrected up to date.

A list of current regulation nautical publications is published each year in the Annual Summary of Notices to Mariners.

Admiralty Charts

Admiralty charts, along with other Admiralty publications, are published by The United Kingdom Hydrographic Office based in Taunton, England, and distributed world wide through appointed Admiralty chart agents. Admiralty publications are catalogued in

the Admiralty Chart Catalogue, with a condensed version distributed free for United Kingdom and local European waters. The chart is arguably the most important of the navigational publications and contains a great deal of information. The use of the chart will be dealt with later.

Charts are now available in electronic form for display on a VDU and the use of such charts is increasing.

An Electronic Navigational Chart (ENC) means a database standardised as to content and format approved for use with an ECDIS by a government hydrographic office.

An Electronic Chart Display and Information System (ECDIS) means a navigational system with adequate backup for updating and which complies with SOLAS requirements by displaying selected chart information together with information from navigational sensors to enable the navigator to plan and monitor his routes. It must be type approved to IMO standards in order to satisfy SOLAS carriage of charts requirements.

A Raster Chart is a digitised version of a paper chart. The Admiralty publish charts on compact disc under the name of ARC or Admiralty Raster Charts. These are produced by scanning paper charts and storing the scans electronically, and will result in an image exactly the same as the paper chart. Such systems do not replace the requirement for carrying paper charts and the effectiveness depends to some extent on the quality of the commercial software which is used for displaying the information. Many would argue that it is more difficult to read the chart effectively from a VDU, in the same way as for most people a written publication displayed on a VDU can never rival a printed book. A VDU display usually either compromises scale or the extent of the visible area. It is more difficult to perform effective chartwork on an electronic display and this discourages good chartwork practices. Again this factor depends largely upon the software used. One advantage is that chart correction is made much easier for the navigator by electronic means. The Hydrographic Office offer various levels of service for provision and update of an ARC system.

Catalogue of Admiralty Charts and other Hydrographic Publications

This catalogue is published annually. The main section of the catalogue consists of outline maps of regions of the world for which charts are available with the limits of coverage of each chart within that area marked with the chart number. As well as being used for ordering charts it provides a most convenient way for a navigator to extract those charts from his folios which are available and required for a particular voyage. On the opposing page is a list of the charts contained on the map in order of the chart number, listing the chart title, the scale, the date of publication and the date of the last new edition. Other sections contain information about lists of chart agents, availability of Notices to Mariners, (for correction of charts), and lists of other Admiralty publications. The ship's officer should be familiar with the use of the catalogue for selecting and ordering nautical publications.

Chart Folios

Charts can be obtained in complete Standard Admiralty Chart Folios, the extent of coverage of which is shown in the chart catalogue. Alternatively charts are supplied individually or can be made up in non standard folios for individual users.

Admiralty Sailing Directions

These are volumes each of which cover a specific area defined in the title such as 'Dover Strait Pilot'. They are known therefore as the pilot books. Each contains information regarding the regulations governing the navigation of the area, and general and climatic information. The main part of each volume consists of detailed information on the navigation of the coastlines and navigational routes within the area, with specific details of pilotage, traffic signals, navigational dangers, reporting procedures, traffic management services, and facilities available at ports within the area. The information given is to supplement the information provided on charts. The appropriate pilot books should be consulted as part of the process of preparing and planning any voyage. A full list of available Sailing Directions is included in the Admiralty Chart Catalogue. Important corrections are issued through Notices to Mariners, while less important corrections are made through the issue of supplements, perhaps every two years or so. Any reference to a pilot book should be accompanied by a reference to its supplement if one has been issued and also Section IV of Notices to Mariners in which a list of corrections in force is given each month. Those in force at the end of the year are listed in the Annual Summary of Notices to Mariners.

Notices To Mariners

The SOLAS Convention requires all ships to carry up to date charts, sailing directions and lists of lights and tide tables etc.

necessary for any intended voyage. These publications, particularly charts, are subject to frequent change and these changes are promulgated in Notices to Mariners. These are issued daily as required to some chart agents, ports and other authorities, a list of which can be found in the Annual Summary of Notices to Mariners, and are available for inspection. Each week's notices are published in a Weekly Edition which can be obtained from Admiralty Chart Distributors.

Admiralty charts are despatched corrected to date. From then on it is the responsibility of the ship's master to maintain correction to the date of the last publication of Notices, of all the charts used on board. Many Chart Agents also provide a service for correcting charts. The ship's officer should be familiar with the methods of using Notices to Mariners to correct charts and other publications. (See Chart Correction).

Notices to Mariners Weekly Editions

Each week the notices issued are combined into a weekly edition and it is this convenient form which is normally used for correcting publications. These editions are discussed in detail under 'Chart Management and Correction'.

Annual Summary of Notices to Mariners

An Annual edition published at the start of each year contains the first Notices of the year. These are notices which are re-issued each year, perhaps with corrections, concerning important subjects of a semi permanent nature. Each year's edition should be consulted as soon as possible after publication. Examples of the subject matter of these notices are:

Corrections to Tide Tables
Lists of suppliers of Admiralty charts
Distress and rescue information
Traffic separation schemes in force
etc.

It also contains a reprint of all Admiralty and Australian and New Zealand Temporary and Preliminary Notices which are in force and a list of all corrections to Admiralty Sailing Directions which have been promulgated in Weekly Editions.

Admiralty Tide Tables

These are published annually in four volumes. Volume 1 covers United Kingdom, Ireland and European channel ports. Volume 2 covers European, Mediterranean and Atlantic Ocean ports. Volume 3 covers the Indian Ocean and South China Sea ports, and Volume 4 covers the Pacific Ocean. Each contains information on times and heights of high and low waters throughout the year at selected standard ports with information on secondary ports to enable the same information to be derived. The use of the tide tables will be covered in Module 1.7.

Admiralty Tidal Stream Atlases

These are booklets covering the waters of the British Isles and a few other areas, which contain information about tidal stream directions and rates through the tidal cycle.

The information is in the form of maps, one for each hour of the tidal cycle relative to the time of the nearest high water at a standard port, with arrows representing the direction of tidal streams. The strength of the stream is indicated by the thickness of the arrows and numbers associated with some of the arrows show the neap and spring rates. They are particularly useful for gaining an overall view of the tides which will be encountered throughout a passage.

Admiralty List of Radio Signals

At present these are published in nine volumes with some volumes having two parts covering different geographical areas.

ALRS Volume 1

This contains coast radio stations with their frequencies and the services that they offer. These include Medical Advice by Radio, arrangements for Quarantine Reports, Locust Reports and Pollution Reports, Inmarsat, GMDSS, Ship Reporting Systems and Piracy and Robbery Reports. Part 1 covers Europe, Africa and Asia and Part 2 covers Indonesia, Australasia and the Americas.

ALRS Volume 2

This includes Radio Beacons and Aero Marine Beacons, RDF finding stations, Radar Beacons (Racons and Ramarks), Radio Time Signals, electronic position fixing systems and DGPS correction transmitting beacons.

ALRS Volume 3

This covers Radio Weather Services and Navigational Warnings together with other Maritime Safety Information (MSI) broadcasts including Navtex, and radio facsimile broadcasts. Part 1 covers Europe, Africa and Asia and Part 2 covers Indonesia, Australasia and the Americas.

ALRS Volume 4

This contains a list of meteorological observation stations.

ALRS Volume 5

This covers the Global Maritime Distress and Safety System (GMDSS) including Navtex, Information on Distress, Search and Rescue procedures and regulations and services to assist vessels using GMDSS.

ALRS Volume 6

This gives radio procedures to assist vessels requiring pilots and/or entering port. It also contains small craft marina and harbour VHF facilities. Part 1 covers Europe and the Mediterranean. Part 2 covers Africa, Asia, Australasia, the Americas and Greenland and Iceland.

ALRS Volume 7

This covers Vessel Traffic Services and Reporting Systems. This complements Volume 6 and is divided into two parts as for Volume 6.

ALRS Volume 8

This covers all aspects of Satellite Navigation Systems including Navstar GPS and Glonass, with error sources and DGPS beacons.

ALRS Volume 9

This is a small craft edition covering UK, Europe and the Mediterranean and containing small craft related extracts from the other volumes.

Admiralty Lists of Radio Signals are corrected from Section VI of Admiralty Notices to Mariners Weekly Editions which give quarterly a cumulative list of stations which have been corrected with the relevant Weekly Edition number.

Admiralty List of Lights and Fog Signals

These volumes contain details of navigational lights, daymarks and fog signals for the world. Lights on navigational buoys over 8 metres in height are included. UK waters and the north coast of France are covered in Volume A, with the rest of the world being covered in a further 10 volumes from B to L. Corrections to these volumes are contained in the Weekly Editions of Notices to

Mariners Section V with the corresponding chart correction in Section II but possibly in a later edition. Insignificant or temporary corrections may not be included in Section II, so that this list should be consulted if details of any lights is required rather than rely on charted information.

Ocean Passages for the World

This contains details of commonly used ocean routes between major ports. Distances, climatic and current information, details of weather routeing and load line rules are given.

The Navigational Chart

Definitions

The Rhumb Line. This is a curve on the earth's surface which represents a line of constant course, thus crossing all meridians at the same angle. It will appear on the earth's surface as a spiral towards the poles. It represents the track which a navigator normally uses when steaming between two points, having calculated or measured the course from a chart.

The Mercator's projection is used for the majority of navigational charts. Portraying a portion of a spherical surface on a flat chart must result in some form of distortion of the charted features. Just what form this distortion takes depends upon the projection used. Mercator's projection is used for the navigator's chart because the nature of the distortion produced by this projection has little effect upon the use to which the chart is to be put and the properties of the projection are most advantageous to the navigator.

A most important and essential requirement of a navigator's chart is that the rhumb line is portrayed on the chart as a straight line and that the direction of the rhumb line may be measured directly from the chart. This means firstly that the meridians must be shown as straight parallel lines. Any line of constant course crossing each meridian at the same angle must therefore appear also as a straight line. The property of showing the course angle correctly is only achieved by stretching the latitude scale by the same amount by which the chart is distorted in the east west direction by showing the converging meridians as parallel lines. This distortion increases with an increase in latitude, varying as the secant of the latitude. On the earth meridians converge to a

point at the poles, and Mercator's projection is not suitable for showing regions of high latitude because of the excessive distortion. The stretching of the meridians in the north south direction results in the dimensions of the latitude scale along the meridians increasing towards the poles. On a chart covering only a moderate range of latitude this distortion can be seen by measuring a minute of latitude at the bottom of the chart with a pair of dividers and comparing it with a minute of latitude at the top. The inequality in the latitude scale is undesirable but is tolerable, and on charts which have a reasonably small range of latitude, which is usually the case, it is hardly noticeable. It is usually said that distances should be measured against the latitude scale as near as possible in their own latitude, but large distances should be calculated mathematically by methods to be described later.

For large scale charts and plan charts other projections are often used but the areas covered are small, distortions insignificant, and the projection used is of little or no importance to the navigator.

The Latitude Scale

The latitude scale down the western and eastern sides of the chart is used for taking off or plotting the latitude of a position on the chart. It is also used as the scale of distance, one minute of the scale being by definition one nautical mile. More detail about these processes is given in Module 1.4.

The Longitude Scale

This is the only constant scale on a Mercator chart, and is only used for taking off or plotting the longitude of a position.

The Natural Scale

This is given in the title block of the chart and is the fraction represented by a measured distance on a chart divided by the distance on the earth's surface which it represents. Admiralty charts are published in a range of natural scales which is listed in the catalogue against the chart. There is no practical use other than to give the navigator a general idea of the range and scale of the chart. It should be noted that because of the distortion of the latitude scale of the chart the natural scale will apply to only one latitude within the range of the chart and this is usually somewhere in the middle. The latitude to which the natural scale applies is stated against the scale in the chart title block.

Definitions (See Module 1.7 for a more rigorous treatment)

Chart Datum. This is the level from which charted depths are measured.

Mean High Water Springs. The mean value of sea level at high water on spring tides over a period of time.

The navigator's chart contains a wealth of information and must necessarily show much of the information in symbolic and abbreviated form. The key to the symbols and abbreviations is contained in Chart 5011 which is in fact in booklet form. Many of the symbols soon become well known to the navigator through usage and because of the large number of them it is not practical to commit them all to memory. Chart 5011 therefore should always be available for reference. However the common symbols and those which represent features of a hazardous nature should be known. The ability to read and understand the chart is only gained by use and familiarity and it would serve no purpose to describe the chart fully at this stage. Some comments about the main features depicted on the chart may be found useful however and are given here.

Coastlines

The coastline as represented by the level of Mean High Water Springs (MHWS) is shown with the land shaded yellow. Below this level will be an area which is sometimes covered and sometimes uncovered by the tidal rise and fall. This area is shaded green. Below this level will be areas which are always covered and this area is shaded blue down to the 20 metre contour and then white. The coastline will be the boundary between the yellow and the green areas on the chart. The level of chart datum will be the boundary between the blue and the green areas.

Soundings

Depths of water are indicated by depth contours and by spot soundings and are expressed in metres: Depth contours may be shown for example for the 5, 10, 20 metres etc. Spot soundings are given in metres or in metres and decimals of a metre. Drying heights found in the area between the levels of chart datum and MHWS may be thought of as negative soundings and are given in the same way as spot soundings but with a bar underneath. At any position where a drying height is given that position will cover when the height of the water surface is above chart datum by the value of the drying height.

Depth of water is obviously one of the most important items

of information shown on a chart. Soundings are however probably the least accurate of the charted information. The accuracy will depend upon the quality of the survey which produced the information and some indication of this may be gleaned from the density of the spot soundings in a unit area and also the date of the survey. For this reason there is usually a small inset map showing areas covered by different surveys and the date at which they were done. In general the more frequented the area the more up to date the survey is likely to be and European waters are very well surveyed. There are areas however even around UK waters where the survey is surprisingly early, and there are even some areas which have not been adequately surveyed. Also it should be remembered that a spot sounding can only show the depth at a specific point and lesser depths may appear between spot soundings which have been missed by the survey especially in the case of early surveys which would have been conducted by lead and line. It should also be remembered that some types of bottom such as sand move, and changes to depths since the survey may have occurred. All this leads to the conclusion that depth contours and soundings should be treated with respect and not trusted implicitly, particularly when navigating in areas which are less frequented. This consideration also means that the prudent navigator passes the coastline at a well considered distance and does not cut corners to save steaming time.

Navigational marks

All marks intended as aids to navigation will be shown symbolically on the chart. These marks will include lights, buoys, beacons etc. with the key to the symbology given in Chart 5011. Of all charted features these are the most subject to change particularly floating marks.

Heights

All charted heights on land including those of lights, bridges, mountains etc. are given above Mean High Water Springs.

Symbols and Abbreviations used on Admiralty Charts

This publication is usually known as Chart 5011 although it is in booklet form. It contains details and explanations of all symbols and abbreviations found on charts. The more important symbols, and those which are encountered regularly, should be known. These include navigational mark and light abbreviations, depth information, wrecks and underwater obstructions, traffic routeing information and tidal information. Other less critical symbols and abbreviations, of which there are a great many, may become familiar by constant use of the chart but Chart 5011 should always be available as a reference. More detail on charted tidal information is given in Module 1.7.

Chart Management and Correction

A systematic approach is necessary to keep charts and other publications up to date. This applies whether a world wide coverage of Standard Admiralty Folios is carried or just a few charts of a local area. Advice can be obtained from the Mariner's Handbook on the maintenance of comprehensive charts outfits but a system may be tailored to suit the needs of particular vessels. The minimum requirements however are provision to obtain regularly the Weekly Editions of Notices to Mariners and a log to list the charts and publications carried and systematically record corrections made to them. There is a standard chart correction log (NP 133a) which is available.

Notices to Mariners are issued by the Hydrographic Office and are numbered consecutively from the beginning of each year. These Notices are issued to some chart agents, ports and other authorities, a list of which can be found in the Annual Summary of Notices to Mariners, and are available for inspection. Relevant Notices are broadcast through Navtex and other Radio Navigational Warnings..Each week's Notices are combined in a Weekly Edition and these editions should be obtained and used to keep charts and other Admiralty publications up to date. The Weekly Edition contains six sections.

Section I Indexes to Section II and charts affected
This contains some explanatory notes, an index of Notices, an index of charts affected by this weeks notices, and a geographical index.

Section II Notices to Mariners. Chart Corrections
This consists of:

A list of new charts and new editions and any that have been withdrawn with announcements of any forthcoming new charts or editions. New editions of, or supplements to, Admiralty Sailing directions are announced and also new editions of other Admiralty publications.

A list of permanent Admiralty, Australian and New Zealand Notices followed by any Temporary or Preliminary notices. These are suffixed (T) or (P).

Section III Radio Navigational Warnings
This consists of a list of Navarea I messages in force and reprints of any issued during the week.

Section IV Corrections to Admiralty Sailing Directions
This consists of a list of corrections to Admiralty Sailing Directions issued during the week. A list of corrections in force is included monthly.

Section V Corrections to Admiralty List of Lights and Fog Signals
This consists of a list of corrections to Admiralty List of Lights and Fog Signals.

Section VI Corrections to Admiralty List of Radio Signals
This consists of a list of corrections to Admiralty List of Radio Signals.

On receipt of any Weekly Editions of Notices to Mariners the serial numbers should be checked against those already received to ensure continuity. They should be used in the following way.

Using the Index to Charts Affected in Section I enter in the chart correction log the numbers of the relevant notices against the charts which are carried.

Amend the entries in the log concerning any temporary or preliminary notices to charts carried by consulting the week's (T) and (P) notices at the end of Section II.

Extract each chart affected from its folio and correct the chart for the relevant Notice for each new entry in the log. The new Notice will give at the end, the number of the last correction to the chart. The chart should be checked to see if this last correction has been made. If not it should be made and the previous correction checked.

Note any relevant New Charts or New Editions in the log and order them at the first opportunity.

Detach Section III (Radio Warnings) and include in the file of Radio Warnings.

Detach Section IV and include in the appropriate file. A list of current corrections is published monthly in Section IV and this may be used as a file of such corrections.

Detach Section V, cut up individual corrections and use to correct the List of Lights and Fog Signals.

Detach Section VI, cut up and use to correct Admiralty List of Radio Signals.

Correction from permanent notices should be made in magenta ink using symbols given in Chart 5011. Obsolete information should be crossed through and not erased. Temporary and preliminary information should be done in pencil with preliminary notices made in ink when they become permanent. Complicated corrections may be made easier by the provision of a block to be cut out and pasted carefully over the chart. These blocks are included in Weekly Editions between Sections V and VI. As each correction is made the number of the correction should be added to a list along the bottom left hand margin of the chart. This list should contain the year followed by a list of corrections made during that year. It can be seen at a glance from this list the date of the last correction made as a check on whether the chart is corrected to date.

MODULE 1.3

Compasses, Compass Errors. Courses and Bearings

Three Figure Notation

Direction from an observer is expressed in three figure notation in which the observer is imagined to be at the centre of his compass and the direction of the north geographical pole taken to be the reference direction of 000°. The observer's horizon is divided into 360° and any direction from the observer is expressed as an angle or arc of the horizon measured from north, clockwise around the compass from 0° to 360°.

This notation is used to express:

Course (Track). The direction of movement or intended movement of a vessel.

Head. The direction in which a vessel's fore and aft line is aligned at any time.

Bearing. The direction of an object from the observer.

It is convention that the courses and bearings when spoken or written always include the three figures with any leading zeros.

Quadrantal Notation

Often the results of calculations to obtain a course result in an answer in quadrantal notation in which the course is defined as an angle between 0° and 90° measured from the direction of north, either east or west, or from the direction of south either east or west. It is therefore often convenient to retain this quadrantal notation although to conform to standard practice such courses should be converted to three figure notation. Thus for a quadrantal notation in the NE quadrant the three figure notation will be the same as the quadrantal angle. The leading zero should be inserted. For the SE quadrant the quadrantal angle should be subtracted from 180°. For the SW quadrant the quadrantal angle should be added to 180° and for the NW quadrant the quadrantal angle should be subtracted from 360°.

The instruments in common use at sea to measure course or bearing are the gyroscopic compass and the magnetic compass. The most favoured, (and the most expensive), is the gyro compass because of its accuracy, steadiness and its suitability for interfacing with other navigational aids. The gyro compass however is a complex mechanical instrument and more prone to breakdown and malfunction than the magnetic compass, which unlike the gyro does not require a power source. The magnetic compass therefore should never be underestimated or neglected, even though in many vessels it is now only used as a backup to the gyro.

The Compass Error

If the north reference of a compass card does not point towards true north then the compass will have an error which must be evaluated and allowed for in the use of the compass. This is true of a gyro compass as well as a magnetic compass.

The Gyro Compass

The basis of a gyro compass is a wheel or rotor which is spinning at a relatively high rate. This is mounted in gimbals such that it has freedom to turn in any direction and align itself with the spin axis pointing in any direction.

Such an arrangement is called a free gyro and has two very important properties.

(i) Once set spinning with the spin axis aligned in any given direction it will remain pointing in that direction unless some external force disturbs it. This is referred to as gyroscopic inertia, the degree of which will depend upon the mass of the rotor and its rate of spin.

(ii) If an external force or moment acts upon the gyro spin axis, it will precess. That is the spin axis will change the direction in which it is pointing. The direction of change however will be in a plane at right angles to that of the precessing moment, as if the force were carried around through 90° in the direction of the spin.

The free gyro spin axis will point to a constant direction but this direction will be constant relative to space. This is best understood by considering that the direction of a star can be considered to be a constant direction in space, and if set pointing to a star then the spin axis will follow that star as the earth rotates, describing a circle in the sky.

In order for it to point north consistently the free gyro must be controlled and damped in order for it to firstly seek the meridian and then for it to remain in the meridian with the spin axis substantially horizontal. This process of finding the meridian when the gyro is first switched on is called settling, and while settling the gyro spin axis will execute an oscillation about the meridian. The damping causes the oscillations to get smaller and the spin axis therefore spirals towards a settling position where the oscillations are infinitely small. This settling position will not be perfectly in the meridian. In fact in the northern hemisphere it will be slightly to the east of the meridian with the spin axis north end tilted upwards. In the southern hemisphere it will be to the west of the meridian with the north end of the spin axis tilted downwards.

Each oscillation of the spiral towards the meridian takes between 84 minutes and 120 minutes depending on the design of the specific gyro and usually it takes several oscillations before the spin axis is stable enough to use as a compass. This will be evident on the compass by the ship's head as indicated by the lubber line oscillating either side of the correct heading. The settling period may be reduced by manually pointing the spin axis near the meridian after running up the wheel. In modern gyros there may be controls provided to electrically precess the spin axis to enable this to be done. Such controls are called slew controls, one for slew in azimuth and one for slew in tilt. When starting the gyro these are used to set the compass pointing near to the correct heading and horizontal. A spirit level will be attached to help achieve this. It will never be possible to achieve the exact settling position by this method and the gyro will now still need to settle but the oscillations will be much smaller and it will take much less time before it can be used.

There are two main errors to which the marine gyro is subject, although most gyro compasses will have an error correction system to enable these errors to be substantially removed. Such a system will have controls to be set by the navigator.

The main errors associated with a gyro compass are:

Settling error. (Latitude error)

This is the error associated with the settling position already discussed. It is an easterly error in north latitude and a westerly error in south latitude. Its value varies as the latitude, being zero at the equator and in the order of 2 degrees in 50 N and S. Its value gets very large in high latitudes.

Course Latitude and Speed Error. (Steaming Error)
This is an error which depends upon:

(a) The course. The error varies as the cosine of the course, being zero on east and west and maximum on north and south.
(b) The latitude. The error is minimum at the equator and infinitely large at the poles.
(c) The speed.

The error will be westerly if the vessel is steaming northerly, and easterly if the vessel is steaming southerly. For a vessel at 20 knots in latitude 60° North steaming north it will be typically about 2 degrees, but again the error gets very large in high latitudes.

There will be controls associated with the error correction system. There may be two controls, one for setting in the vessel's latitude and one for setting in the vessel's speed. These should be maintained approximately correct to keep the gyro error to an acceptable minimum. It should however be remembered that there will usually be small residual errors and these should be monitored and allowed for. It is easy to maintain the latitude correct to within a few degrees but it is not possible to keep changing the speed setting, particularly when manoeuvring. It is practice therefore to either set the speed to the vessel's normal service speed or to set it at a medium setting. This will depend upon the nature of the work of the vessel in which the compass is mounted. It should be remembered that errors will result in conditions where the vessel's speed is different from the setting on the compass.

Gyro Compass Errors
Whether the gyro compass errors are corrected or not any error or residual error must be monitored by comparing a gyro bearing of an object with the known true bearing. If the gyro bearing is greater than the true bearing then the gyro is said to be reading high and the value of the error will have to be subtracted from the gyro bearing. If the gyro bearing is less than the true bearing then the gyro is said to be reading low and the error will have to be added to the gyro bearing. In a corrected gyro system these errors should be small, perhaps never more than a degree if the correction system controls are set accurately. In an uncorrected gyro or if the correction system controls are not adjusted properly they may be several degrees increasing rapidly in higher latitudes. As with a magnetic compass in very high latitudes the errors become large enough to render the marine gyro compass unusable.

The Magnetic Compass

Terrestrial Magnetism
The earth's magnetic field is considered to be that associated with a short bar magnet located near the earth's centre.

Figure 1.3.1 shows the lines of magnetic force associated with the earth's magnetism. The lines of force represent the direction in which a freely suspended magnetic needle will align itself within the earth's field. The convention is that the earth's northern magnetic pole is denoted as a blue pole where the lines of force enter the magnet and the earth's south magnetic pole as a red pole where the lines of force emerge. A magnetic needle suspended within the earth's field will have its red pole attracted towards the earth's blue pole and its blue pole attracted towards the earth's red pole. Thus the 'red' end of a magnetic needle is said to be the 'north seeking' end.

Definitions
Magnetic Poles. These are the points on the earth's surface where the lines of force are vertical. They are situated in approximate positions 75° N 100° W and 67° S 140° E. They move slowly on the earth's surface.

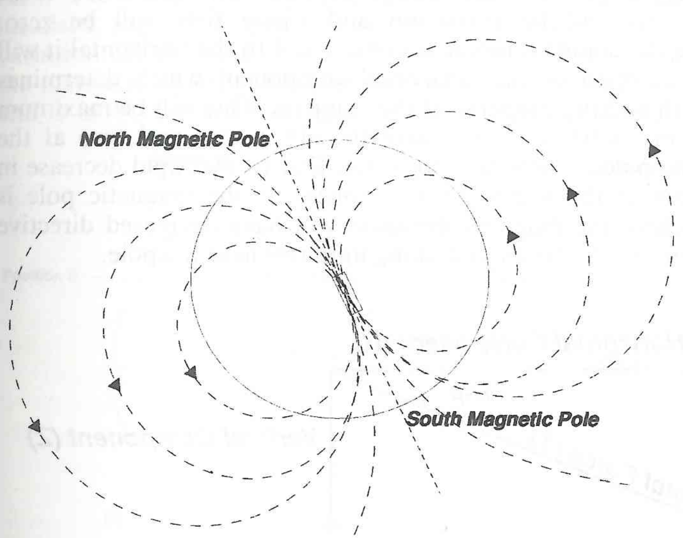


FIG. 1.3.1

Magnetic Equator. The line around the earth's surface where the lines of force are horizontal. Also called the Aclinic Line. This will not be a great circle due to the irregular nature of the earth's field but will approximate to one.

Magnetic Meridian. The vertical plane at any place in which a freely suspended magnetic needle will align itself within the earth's field. The direction of this plane will not necessarily be that of the magnetic pole due to the irregularity of the earth's field. The direction of the magnetic meridian is called Magnetic North.

Variation. The angle between the true meridian and the magnetic meridian. It is named West if the north seeking end of the magnetic needle lies to the west of the true meridian and East if it lies to the east of the true meridian.

Vertical, Horizontal, and Total Components of the Earth's Field

The freely suspended magnetic needle will align itself with the direction of the total earth's field which can be seen from Figure 1.3.1 to have a vertical component at all places except on the magnetic equator. The total strength of the field at any point may be resolved or separated into a horizontal component and a vertical component as shown in the Figure 1.3.2. The depression of the total field below the horizontal is referred to as the Magnetic Dip. Consider where on the earth's surface these components will be maximum and where they will be zero. Because the compass needle is constrained to the horizontal it will be the strength of the horizontal component which determines the north seeking property of the compass. This will be maximum on the magnetic equator, where the dip is zero and zero at the magnetic poles, where the dip is 90°. Due to the rapid decrease in the value of the horizontal component as the magnetic pole is approached, the magnetic compass will have decreased directive power in high latitudes, becoming unusable near the pole.

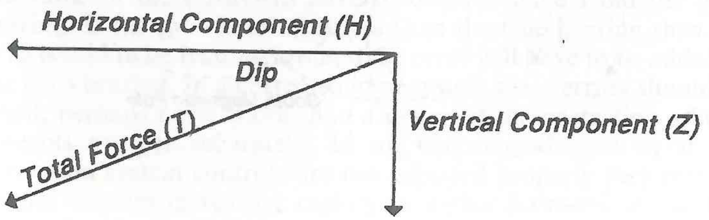


Fig. 1.3.2

Changes in the Earth's Magnetic Field

The most important change is the secular change which is caused by the movement of the earth's magnetic poles. They presently appear to be describing a circle around the true poles but observations do not go back in time long enough for any movement to be properly analysed. The movement causes the value of the variation at any place on the earth's surface to change slowly from maximum west to maximum east and back again but the period is very long. This is the main cause of the change in the value of the variation indicated on Admiralty charts.

There are other less important short term changes in the variation, the greatest of which is the solar daily change. These have no effect on the practical use of compasses. There are also irregular disturbances caused by magnetic storms associated with sunspot activity, and local disturbances due to the irregular make up of the earth's crust. These tend to occur near land where there are large concentrations of metallic rock, and are called magnetic anomalies. They will be marked on charts if they significantly affect navigation.

Changes in the variation with position on the earth's surface

The variation over the earth's surface changes in an apparently irregular way due to the irregular nature of the earth's magnetic field. There are however observations that may be made if an idealised regular magnetic field is considered. In general the variation will decrease with a decrease of latitude to a minimum at the magnetic equator. This can be seen by considering positions 1 and 2 in Figure 1.3.3. Figure 1.3.3(a) shows a meridian in the

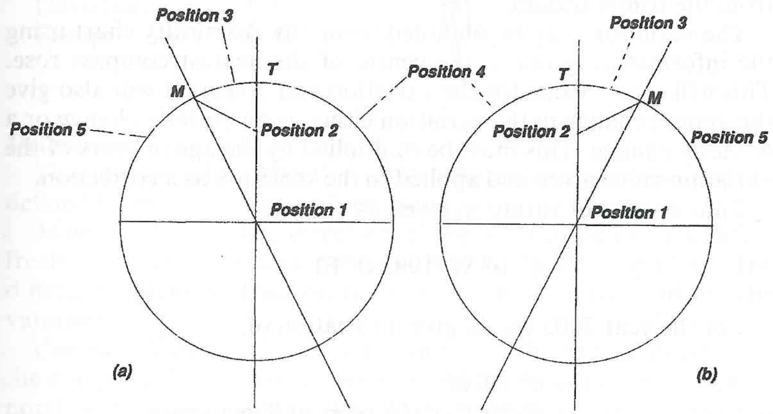


Fig. 1.3.3

Atlantic Ocean where there will be a westerly variation. Figure 1.3.3(b) shows a meridian in the Pacific Ocean where there will be an easterly variation. The variation changes with longitude and there will be meridians in the longitude of the magnetic poles and their opposite meridians on which the magnetic and true poles will be in line and the variation will be zero, unless of course the position is between the north magnetic pole and the true north pole or between the south magnetic and the south true pole in which case the variation will be 180°. These observations can be seen from inspection of the small scale variation charts but they are masked somewhat by the highly irregular nature of the magnetic field.

Magnetic compass errors

Variation

It has been shown that a magnetic compass which is under the influence of the earth's magnetic field only, will not indicate true north due the fact that the earth's magnetic poles are not coincident with the true geographical poles. The north magnetic pole is in northern Canada and it is towards this point that the lines of the earth's magnetic field converge. The direction of magnetic north at any place is the direction of the vertical plane of the earth's magnetic field at that place and it will be to this direction that the magnetic needle of the compass is drawn. The angle between this direction and the direction of true north is called the Variation. This is named East or West depending on the direction of disturbance of the north end of the compass needle from the true meridian.

The variation may be obtained from any Admiralty chart using the information given in the centre of the nearest compass rose. This will give a value for the variation and a year. It will also give the annual change in the variation either as an easterly change or a westerly change. This must be multiplied by the age in years of the variation value given and applied to the variation as a correction.

Thus a value of variation given as:

6° 10′ W 1993 (8′ E)

For the year 2003 would give a variation of:

6° 10′ W
1° 20′ E (10 years at 8′ per year)
4° 50′ W

Deviation

A compass needle will be disturbed from the direction of magnetic north by the magnetic influences of the ship itself. The amount of disturbance from the direction of magnetic north is called the Deviation, and is named East or West indicating the direction of disturbance of the north end of the compass needle from magnetic north.

A deviation card produced at the last compass adjustment must be displayed for each magnetic compass showing the value of the deviation for each ship's head by compass, usually at intervals of ten degrees. The deviation may be found by reference to this card.

The magnetic compass error in a properly installed compass will be the resultant of the variation and the deviation. If they are of the same name then the error will be the sum of the two and will take the same name as the variation and the deviation. If they are of different names then the compass error will be the difference between the two taking the name of the greater.

Example 1

Variation	10° E
Deviation	5° E
Compass Error	15° E

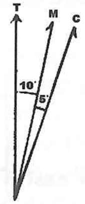


FIG. 1.3.4

Example 2

Variation	9° W
Deviation	3° E
Compass error	6° W

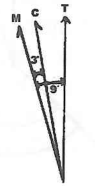


FIG. 1.3.5

Definitions

True North. The direction of the north geographical pole as defined by the earth's axis of rotation.

Magnetic North. The direction of the vertical plane in which a freely suspended magnetic needle will align itself at any place. The difference between true north and magnetic north will be the variation.

Compass North. The direction indicated by the north point of the compass. The difference between magnetic north and compass north will be the deviation. The difference between true north and compass north will be the compass error.

True Course (Bearing). The angle at the observer or the arc of the observer's horizon, between the directions of true north and that of the direction being measured, expressed clockwise from true north.

Magnetic Course (Bearing). The angle at the observer or the arc of the observer's horizon, between the directions of magnetic north and that of the direction being measured, expressed clockwise from magnetic north.

Compass Course (Bearing). The angle at the observer or the arc of the observer's horizon, between the directions of compass north and that of the direction being measured, expressed clockwise from compass north.

Any course or bearing indicated by a compass must be corrected to true before being marked on a chart. If the compass error is east then the compass course or bearing will be less than the true course or bearing, and the compass error must be added to give true.

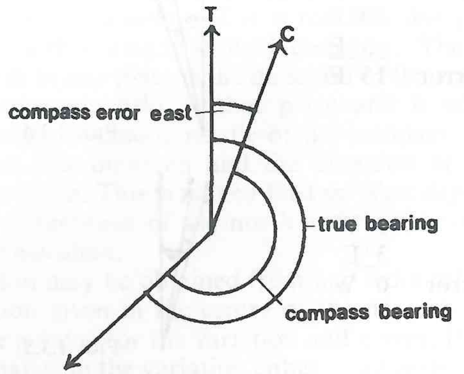


FIG. 1.3.6

If the compass error is west then the compass course or bearing will be greater than the true and the compass error must be subtracted to give true.

The mnemonic Error WEST compass BEST, Error EAST compass LEAST may be found useful.

This means that when the error is west the value of the compass bearing or compass course must always be greater than the true value. When the error is east the value of the compass bearing or compass course must always be less than the true value. This is

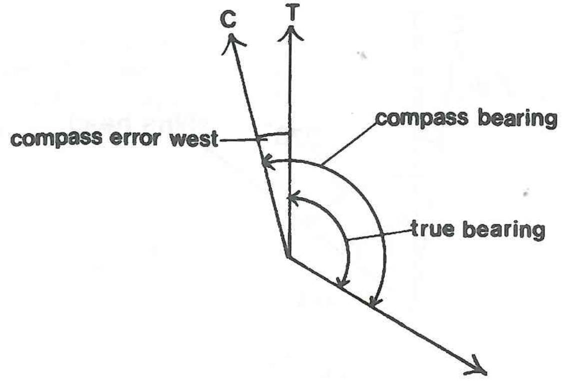


FIG. 1.3.7

valid whether the conversion is being made from compass to true or from true to compass.

Note that in practice the deviation varies mainly with the ship's head, and that for any one heading it can be considered constant over a short period of time. Therefore on a constant heading the same deviation may be used. In practice the compass error may be obtained by combining the variation obtained from the chart, and the deviation obtained from the compass deviation card or it may be obtained directly by observation by comparing the observed compass bearing of an object with the known true bearing. (See 'Observing the Compass Error'). The latter method is preferable and should be used at all times if possible. Because of the probable inaccuracies inherent in the deviation card the first method should only be used when the compass error cannot be observed directly.

Example 1

A vessel is steering 070° by compass. Deviation for the ship's head is 2° E. Variation is 9° W. Find the true course.

Variation	9° W
Deviation	2° E
Compass error	7° W
Compass Course	070° C
True course	063° T

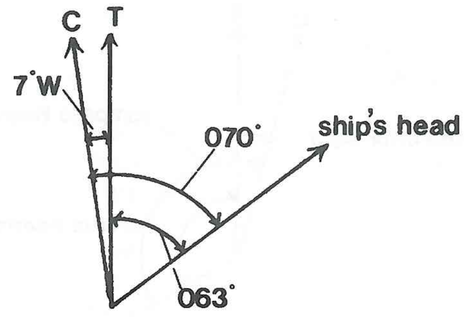


FIG. 1.3.8

Example 2
Find the compass course to steer to make good a true course of 340° if the variation is 5° E and the deviation 6° E.

Variation	5° E
Deviation	6° E
Compass error	11° E
True course	340° T
Compass course	329° C

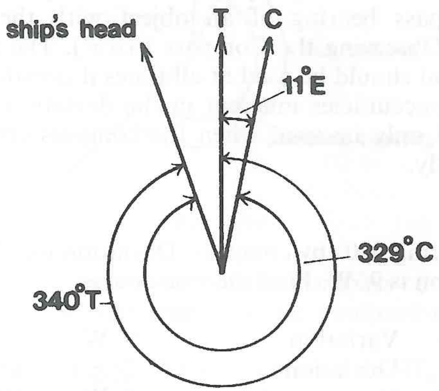


FIG. 1.3.9

Example 3
The compass bearing of the sun was observed to be 221° C. At the same time the true bearing was calculated to be 225° T. If the variation was 8° E, find the compass error and the deviation for the ship's head.

Compass bearing	221° C
True bearing	225° T
Compass error	4° E
Variation	8° E
Deviation	4° W

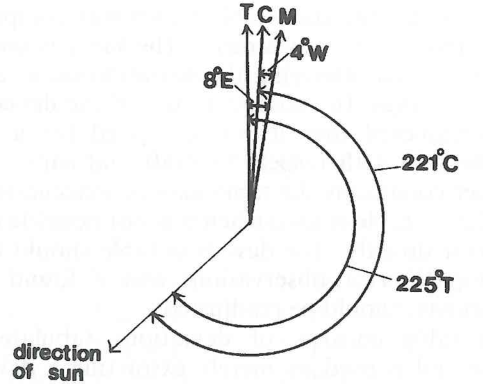


FIG. 1.3.10

Relative Bearings
In some circumstances it is necessary to measure bearings relative to the ship's head. This is the case when using unstabilised radar for position fixing or if a pelorus or dummy compass card is used. In this case the reference from which the bearing is measured is the ship's head along the direction parallel to the fore and aft line. A relative bearing must be converted to a true bearing before laying off on a chart and this is done by adding the ship's head at the time of taking the bearing. If the result is more than 360 degrees then 360° is subtracted.

true bearing = relative bearing + true ship's head
(−360° if necessary)

Example 4
The relative bearing of a lightship was measured from a radar

display as 248° R. The ship's head at the time was 176° C. Variation was 3° E and deviation 2° E. Find the true bearing.

Ship's head	176° C
Compass error	5° E
Ship's head	181° T
Relative bearing	248° R
True bearing	429° T
	360°
True bearing	069° T

Deviation Tables

A ship must carry the deviation table which was compiled at the last compass correction or adjustment. The table is compiled by swinging the vessel and observing the deviation on a selection of equally spaced headings. In subsequent use of the deviation table it must be remembered that it was compiled for a particular condition of the ship with respect to draft and cargo on board, and that in other conditions the table may be inaccurate. For this reason the deviation table is used when it is not possible to observe the compass error directly. The deviation table should be verified by regular compass error observations and if found to be inaccurate the compass should be readjusted.

A deviation table consists of deviations tabulated against compass course and is used by merely extracting a deviation for the ship's head at the time, interpolating if necessary. If the task is to find a deviation when the ship's head is known, then it is a simple matter of entering the table with the compass head. If the task is to correct a true course to find a compass course to steer then there is the complication that the compass course with which to enter the table is not yet known and the true course, or magnetic course must be used. This could lead to an inaccurate result unless the deviation obtained is checked against the compass course calculated. If there is a discrepancy then the table should be re-entered with the compass course calculated and a new deviation taken. Thus by this process of reiteration an accurate deviation is obtained. With a well adjusted compass the deviations should be small and this task is easier than it may appear.

Example 1

Using the specimen deviation table provided (page 45) find the compass course to steer to make good a course of 150° if the variation is 4° W.

True course	150° T
Variation	4° W
Magnetic course	154° M
Deviation	4° W (from deviation table to nearest degree)
Compass course	158° C

Enter the deviation table with compass course 158° and extract deviation 5° W and re-work the compass course.

Magnetic course	154° M
Deviation	5° W
Compass course	159° C

This compass course would again give 5° W if the deviation table was re-entered so 5° W is accepted as the deviation.

EXERCISE 1.3.1

Find the compass error in the following cases.

1.	Dev 5° W,	Var 6° E	5.	Dev 10° W,	Var 7° W
2.	Dev 9° E,	Var 5° E	6.	Dev 7° E,	Var 5° E
3.	Dev 3° W,	Var 8° E	7.	Dev 7° W,	Var 5° E
4.	Dev 2° E,	Var 3° W	8.	Dev 4° E,	Var 5° W

EXERCISE 1.3.2

Using the deviation table provided to obtain deviation to the nearest half degree, find the true course in the following cases.

	Compass Course	Variation
1	226	10° W
2.	010	5° W
3.	358	8° E
4.	267	6° W
5.	034	8° E
6.	332	4° E
7.	002	7° W
8.	084	7° E

EXERCISE 1.3.3

Using the deviation table provided to obtain deviation to the nearest half degree, find the compass course in the following cases.

	True Course	Variation
1	234	8° W
2.	000	7° W
3.	356	3° E
4.	258	6° W
5.	035	1° E
6.	323	0° E
7.	077	5° W
8.	256	7° E

EXERCISE 1.3.4

Using the deviation table provided to obtain deviation to the nearest half degree, find the true bearing in the following cases.

	Relative Bearing	Ship's Head	Variation
1.	234	123° C	5° W
2.	000	345° C	6° E
3.	356	167° C	2° E
4.	258	358° C	1° W
5.	035	200° C	0°
6.	323	103° C	8° W
7.	077	001° C	9° E
8.	256	309° C	4° W

Specimen Deviation Card

Own Ship 1.	
Compass Co	Deviation
000	2 W
010	1 W
020	0
030	0
040	1 E
050	2 E
060	3 E
070	4 E
080	3 E
090	2 E
100	1 E
110	1 E
120	0
130	1 W
140	2 W
150	4 W
160	5 W
170	4 W
180	3 W
190	2 W
200	1 W
210	0
220	1 E
230	2 E
240	2 E
250	3 E
260	4 E
270	3 E
280	2 E
290	1 E
300	0
310	1 W
320	2 W
330	3 W
340	4 W
350	3 W

The azimuth mirror
This is a device which enables bearings to be taken accurately from a gyro or magnetic compass, and is therefore an essential part of the bridge equipment. It consists of a brass ring which fits over the compass bowl in a manner which enables it to be rotated. The ring carries at one edge, a prism or mirror which itself can be rotated about its horizontal axis. On the opposite side of the ring a sight is provided for the navigator to look through at the prism. The wheel which rotates the prism has an arrow engraved on it and the instrument can be used in either of two ways, with the arrow pointing up or with the arrow pointing down. The former is used for taking bearings of high altitude objects such as astronomical bodies, and the latter is used for taking bearings of terrestrial objects.

In the arrow down position the navigator looks through the sight and across the top of the compass at the mirror and at the object he is observing beyond it. The prism is then adjusted so that the image of the compass card is reflected horizontally into the eye and the object can then be seen superimposed on the image of the compass card. In the arrow up position the navigator looks down onto the prism and the compass card and adjusts the prism so that the image of the observed body is reflected through the prism up into the eye and is seen superimposed on the compass card.

The azimuth mirror should be checked by taking bearings of a low altitude body in both arrow up and down positions. If they do not agree the alignment of the prism can be adjusted by small screws.

Observing the Compass Error
It has been stated that any compass error used should if possible have been obtained from direct observation rather that relying on a deviation taken from a deviation card. Any observed compass error should be used to check the accuracy of the deviation card.

In general the compass error is observed by comparing a compass bearing of an object with a known true bearing. Various methods of ascertaining the true bearing are available to be used in various circumstances. Each time the vessel is placed on a new course the navigator should take the earliest opportunity to establish the compass error for that course. On long passages when the vessel is on the same course for long periods of time the compass error should be checked at least once per watch. Each time a compass error is observed the results should be recorded in

a compass record book with the methods and circumstances under which it was observed, and comments on the accuracy with which the deviation agrees with the deviation card.

Transit bearings
Perhaps the easiest method of observing the compass error is to note the compass bearing of two objects in transit. The true bearing is taken from the chart by laying parallel rulers through the two charted objects and measuring the bearing from the compass rose. When making a coastal passage reasonably close to the land there is usually an abundance of transits which can be used. If the vessel is following a channel by using leading marks, then the compass bearing will be the ship's head when the vessel is on the lead with the leads right ahead.

Bearing of a distant object
If the compass bearing of a distant object is observed, the true bearing can be taken from the chart. The accuracy of this method however relies on the vessel's position being known to some degree of accuracy, which will depend upon the distance of the object. If the vessel's position has been fixed using the compass whose error is not certain then clearly this method may be suspect. If the position can be fixed independently of the compass error such as by horizontal angles, (see Module 1.5) then this method is valid.

Bearing of an astronomical body
Astronomical methods are used when not in sight of land. They are less convenient as they require some amount of calculation. The methods commonly used are stated here and are described fully in Modules 2.3 and 2.8

(i) Finding the true bearing by azimuth problem.
(ii) Finding the true bearing by amplitude problem.
(iii) Finding the true bearing by the pole star problem.

MODULE 1.4

Chartwork Constructions. Allowance for Wind and Tide

Chartwork is the use of the chart for planning, monitoring and recording the intended voyage. Good chartwork forms a very important supplement to the main permanent record of the ship's voyage which is the deck log. For this reason chartwork should not be erased until the charts are required again. Chartwork also provides a means of communication between those involved in the execution of the navigation plan and each should be able to easily understand the work of other team members. The chartwork should therefore be neat, legible and use standard symbology. The quality of his chartwork is an indication of the competence and the professionalism of the navigator.

Plotting Positions

The first basic requirement for chartwork is to be able to plot a position given in terms of latitude and longitude on the chart. This requires a familiarity and dexterity with parallel rulers and dividers which comes only with practice. Latitudes and longitudes are normally given in degrees and minutes and decimals of a minute thus:

52° 43.6′ N 005° 31.3′ W

The latitude and longitude scales are marked in units of minutes of latitude or longitude with alternate minutes highlighted. Each minute is divided into subunits of 0.1 of a minute. A convenient way of plotting the position is to line up the parallel rulers with a convenient parallel to get an east west reference and run the rulers to the required latitude. A light line can then be drawn in the vicinity of the given longitude. The longitude may be marked in a similar way but a more convenient way is to set the dividers correctly from the required longitude to a convenient meridian on the longitude scale. The dividers can then be used from the same meridian to mark a point on the parallel which has just been marked. There are variations on this method which are a matter of personal choice.

In many instances a position is given in terms of bearing and distance from a known and charted point. Note the difference between the statements 'a point is bearing 040°' and 'a position is 040° from a point'. The first terminology is the usual way in which a position is defined but confusing the two will result in a reciprocal bearing being laid off. The compass rose is used to line up the parallel rulers with the given bearing and then moved to pass through the point stated. The distance is then marked off with dividers or compasses. Note that all bearings and courses marked on a chart must be true, that is measured from the true meridian.

The next requirement is for the course and distance between two positions to be marked and annotated. A straight line between two plotted positions will represent the rhumb line which, except for long ocean passages vessels always follow. It is the line of constant course which may be measured directly from the chart by aligning the parallel rulers with it and transferring them to a compass rose. The value of the true course should be marked neatly against the course line to be followed. The distance can then be measured with dividers against the latitude scale.

Part of the navigator's voyage planning process is to use these skills to mark on the charts the tracks which he intends to follow. This should be done before the voyage is commenced. After all necessary charts have been collected together the complete voyage tracks should be marked and annotated. This will require decisions to be made regarding how far to pass off land or submerged dangers, what underwater clearance is required, what traffic routeing schemes must be followed etc. It will require a consultation of sailing directions, passage planning charts if applicable, and the appropriate volumes of ALRS for information on position fixing systems and pilot and Traffic Management services available. It may be necessary to calculate steaming times and ETA's at various points perhaps to anticipate tidal conditions. It will be necessary to calculate the overall steaming time to enable ETA's to be given for the destination.

Waypoints along the track should be marked with diamonds and these should if possible be chosen so that the position can be easily monitored at the waypoint. These are often chosen as the points where headlands and lights are abeam for this reason, or perhaps where a convenient transit occurs. It is a good idea to mark on the track places where change of engine status or change of speed may be necessary, and highlight particular dangers.

Position Fixing

The next consideration is how the vessel's position is going to be established when monitoring its progress along the tracks.

The possible methods which may be used are, dead reckoning, visual observations, radar observations and the use of electronic position fixing systems. The wise navigator makes use of all methods which are available to him, but he must decide which are going to be his primary and secondary methods. Visual position fixing is discussed in Module 1.5, and radar navigation in Module 1.8.

Dead Reckoning

This means establishing a position by consideration of courses and distances steamed since the last known position with or without consideration of tidal streams and/or wind effects. Fixing position by dead reckoning is used with caution when other means of direct observation are not available, and for predicting the vessel's position at some future time. Each time the ship's position is fixed, a DR position should be predicted for the time when it is expected to fix the position again. When the new fix is obtained it should not differ from the DR by more than can be attributed to wind and tide effects, thus providing a check on the validity of the fix and also a means of estimating wind and tide effects.

Definitions

DR (Dead Reckoning) position. This is a position which has been established by applying course and distance steamed since a previous known position. It is marked on the chart as a cross (+) The course steered is marked with one arrow.

EP (Estimated Position). This is a position which has been established by applying course and distance steamed and also estimated tidal set and drift since a previous known position. It is marked on the chart as a small triangle with a dot in the centre. The tidal vector is marked with three arrows.

Ground Track (Course Made Good). This will be the track drawn from the start position to the arrival position, that is the track relative to the sea bed. This track is marked with a double arrow.

Rate of the tide. This is the speed of the tidal stream in knots.

Drift of the tide. This is the total distance moved by the tidal stream in a given time.

Finding the DR position (or EP)

Example

Find the course and speed made good by a vessel steering 035° T at 12 knots through a tide setting 110° T at 2.5 knots.

Procedure (refer to Figure 1.4.1)

1. Lay off from the departure point the course steered and mark off the distance by log for any convenient interval of time. Mark this line with a single arrow.
2. From the position reached in 1, lay off the direction of the tidal set, and mark off a distance along this line equal to the drift for the interval chosen in 1. This tidal vector is marked with three arrows.

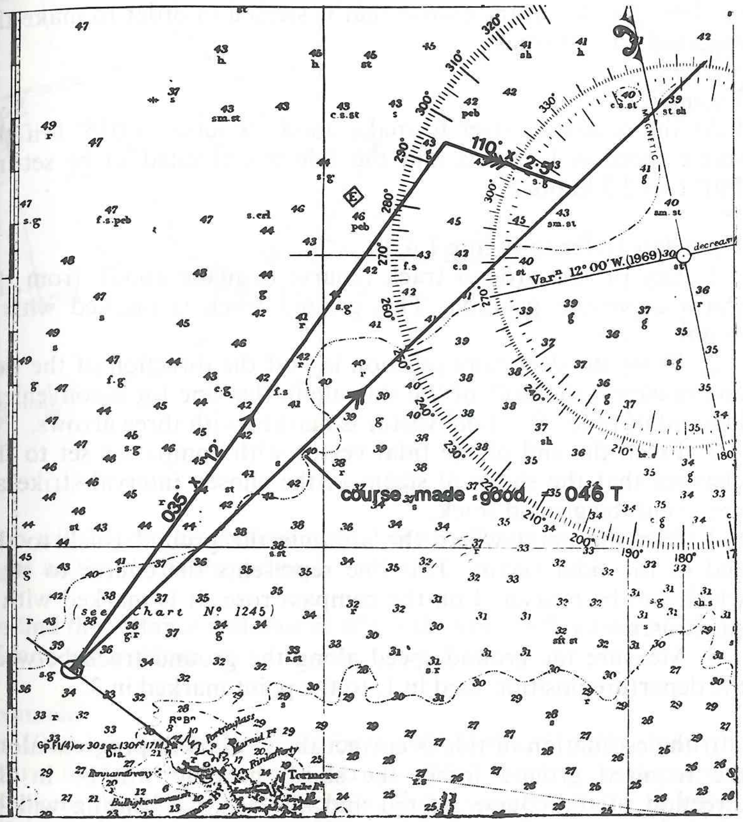


FIG. 1.4.1

3. Join the point reached in 2, to the original departure position to represent the vessel's ground track. This is marked with a double arrow. The length of this line will represent the distance made good by the vessel in the chosen interval and hence the speed made good may be found.

The DR position for any time will be found by projecting ahead the course steered which was laid off in 1 using the log speed. The EP can be found by projecting ahead the ground track and using the ground speed found in 3 for the required time interval.

Counteracting the tide
If an estimation of the tide has been made it would be preferable to allow for this in the course that is steered in order to make the required ground track.

Example
Find the course to steer to make good a course of 035° T if the ship's speed is 12 knots and the tide is estimated to be setting 110° T at 2.5 knots.

Procedure (refer to Figure 1.4.2)

1. Lay off the ground track (course to make good), from the ship's departure position. This ground track is marked with a double arrow.
2. From the departure position lay off the direction of the tide and mark off the drift of the tide along this line for a convenient interval of time. This tidal vector is marked with three arrows.
3. From the end of the tidal vector with compasses set to the distance that the ship will steam in the chosen interval strike an arc to cut the ground track.
4. Join the point where the arc cuts the ground track to the end of the tidal vector. This line represents the course to steer which can be measured on the compass rose. It is marked with a single arrow.
5. Measure the ground speed along the ground track between the departure position used in 1, to the point marked in 3.

If the estimation of tide is correct the vessel will progress along the required ground track, the ship's heading will be in the direction of the course steered and any relative bearing will be relative to the ship's head. Particular note should be taken of this when finding the position where a point of land will be abeam. The

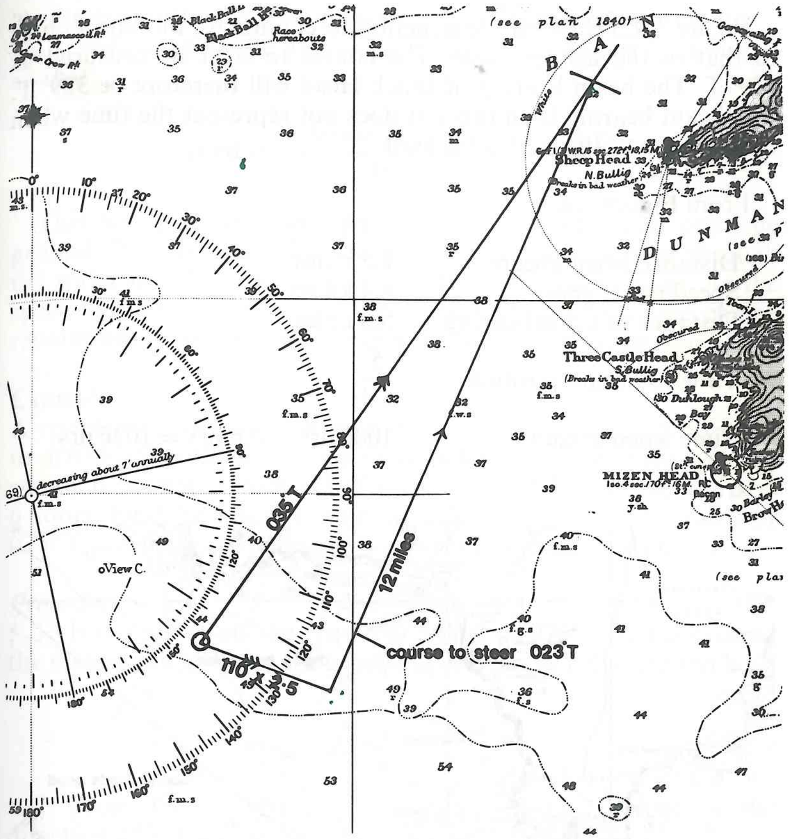


FIG. 1.4.2

ship will be on the ground track but the beam bearing will be at right angles to the ship's head.

To find the distance and time at which the vessel will pass a point of land when abeam

Example
At 1000 hrs Lizard Point Lt bore 000° T by 2.5 miles. Find the course to steer to make good a track of 050° T while counteracting a current setting 280° T at 2 knots. Ship's speed by log is 10 knots. Find the distance off Black Head when it is abeam and the time when this occurs.

Figure 1.4.3 shows a construction to counteract the tide similar to that in the last example. The course to steer is measured as 059° T. The beam bearing of Black Head will therefore be 329° T. The beam bearing is shown but does not represent the time when the distance to Black Head is least.

From Figure 1.4.3:

Distance when abeam	1.5 miles
Speed made good	8.4 knots
Distance to beam bearing	5.0 miles
Time to abeam position	$\frac{5}{8.4}$
Time when abeam	1000 hrs + 0.6 hrs = 1036 hrs.

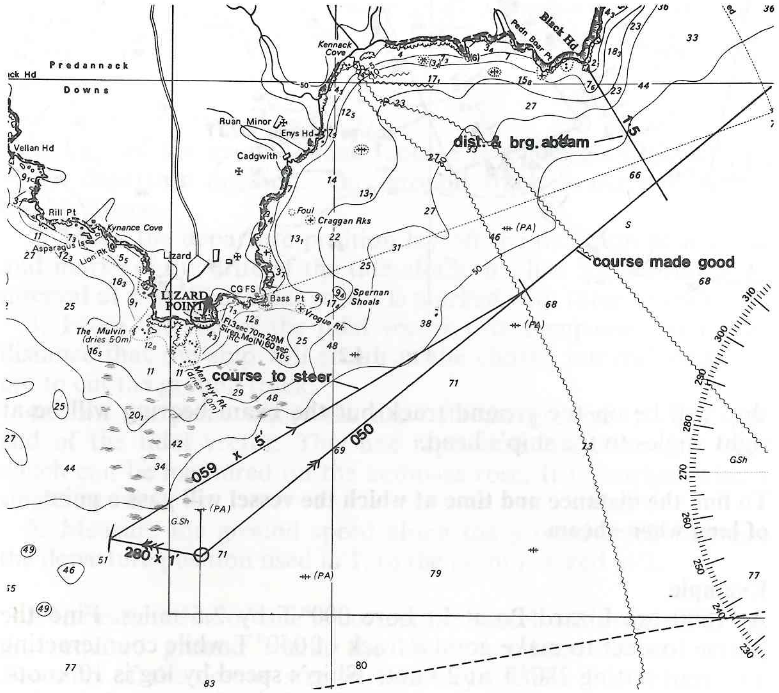


Fig. 1.4.3

To reach a position at a required time while counteracting a current

To arrive at a position at a given time the speed must be adjusted so that:

$$\text{speed} = \frac{\text{distance to steam to position}}{\text{time interval}}$$

This will give the speed which must be made good over the ground. If there is a tidal stream, the vessel's log speed through the water may be more or less than the speed made good. As the speed through the water or log speed will determine the engine revolutions required, then it is this speed which must be found.

Example

A vessel observes Fastnet Rock to bear 340° T by 7 miles. She wishes to arrive off Cork, a distance of 48 miles in 6 hours time. A tidal stream is estimated to set 285° T at an average 1.3 knots over the next 6 hours. Find the course to steer to make good a required course of 075° T, and the speed necessary to cover the 48 miles in six hours.

Procedure

1. Having laid off the required course of 075° T and measured the distance of 48 miles the ground speed can be calculated to be:

$$\frac{48}{6} = 8 \text{ knots}$$

2. From the departure position lay off the current in the direction 285° T and mark off the rate 1.3 miles.
3. From the departure position mark off the ground speed along the ground track.
4. Join the end of the tidal vector to the end of the ground speed marked in 3. The direction of this line will give the course to steer, and its length will give the speed to make good through the water, that is the speed to use when determining the engine revolutions to order.

To find the set and drift of the tide between two observed positions

When monitoring a vessel's progress along an intended navigation plan each time the vessel's position is found by observation a DR position should be predicted for the next time that it is intended to fix the ship's position. When this observed position is obtained the difference between it and the DR position will give the actual tide experienced.

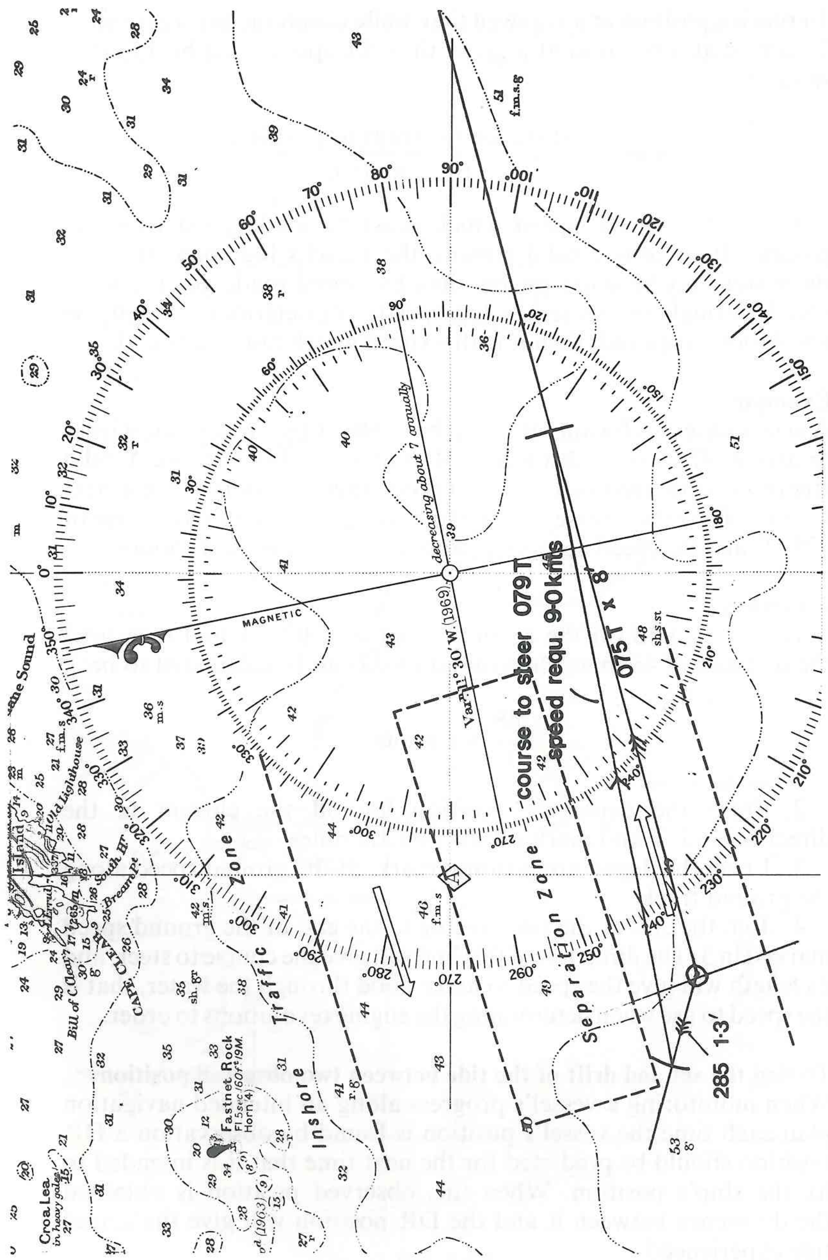


Fig. 1.4.4

Example

At 0800 Bull Lt. is observed to bear 120° T by 5 miles. At 0830 the same point of land was observed to bear 220° T by 6.5 miles.

Find the set and rate of the tide in the interval if the course steered throughout was 078° T, log speed 20 knots.

Procedure (refer to Figure 1.4.5)

1. Plot the two observed positions and label them with their respective times.
2. From the first observed position lay off the course steered and mark the distance steamed by log in the interval. This will give the DR position at the time of the second observation. Mark the line with a single arrow.
3. Join the DR position to the second observed position. Mark the line with three arrows. This direction will be the set and the length will be the drift.

Effect of Wind. Leeway

A vessel may be deviated from her track by the effect of a wind force on one side. The change in the water track due to the effect of the wind is called leeway. The ground track including wind effect may be found by applying the leeway angle to the course steered in the down wind direction. The leeway is applied to the course steered before laying it off on the chart. The effect of the wind may be counteracted by applying the leeway angle up into the wind. The leeway is applied to the course to be steered after allowing for any tide.

The leeway angle may be observed as the angle between a vessel's wake and the fore and aft line.

Example

A vessel is steering 135° T. Wind is SW leeway 5°. Find the water track.

Course	135° T	
Leeway	5°	
Water track	130°	(Wind on starboard side, subtract leeway).

Example (refer to Figure 1.4.6)

Find the course to steer to make good 120° T counteracting a current setting 085° T at 1.5 knots, and a SW'ly wind causing a leeway of 4°. Ship's speed 10 knots.

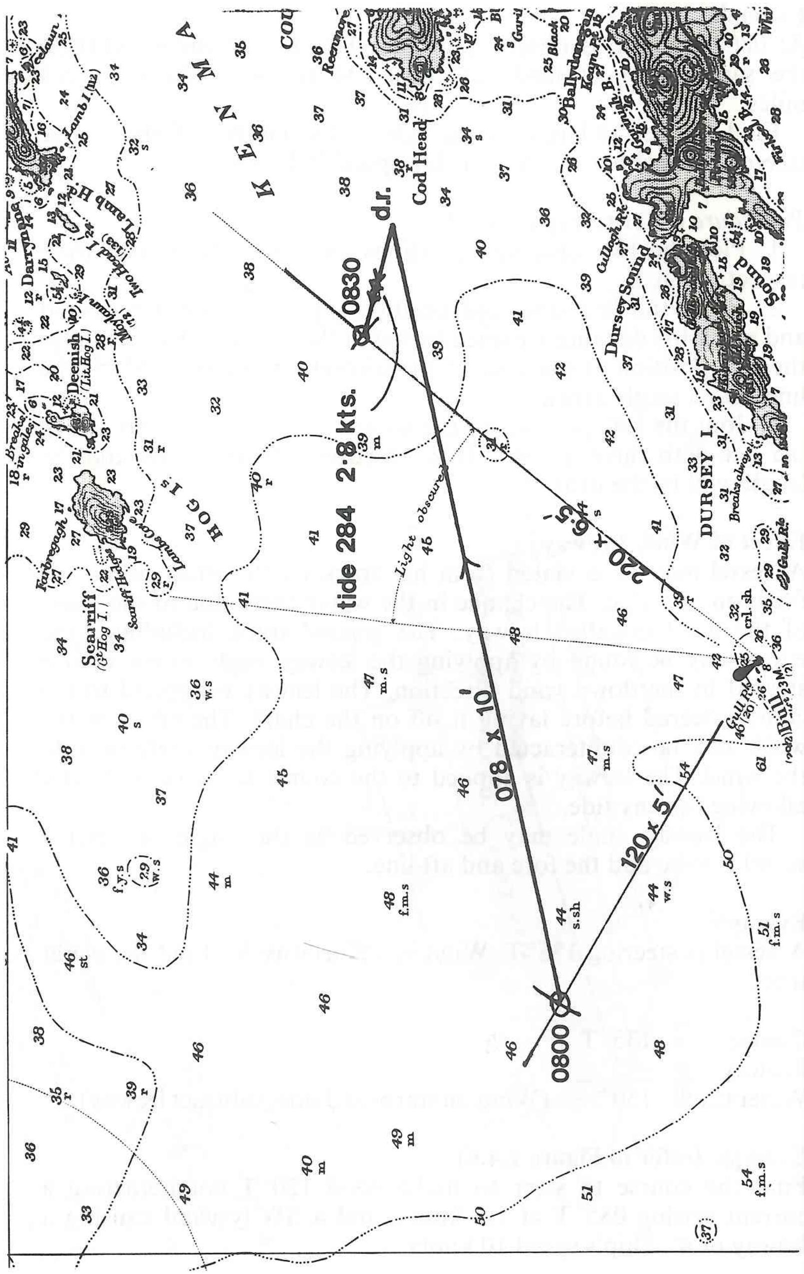


FIG. 1.4.5

From Figure 1.4.6 the course to counteract the tide is measured to be 125° T.

Course	125° T	
Leeway	4°	
Course to steer	129° T	(wind on starboard side, add leeway).

EXERCISE 1.4.1

In each of the following cases find the true water track.

	Course	Deviation	Variation	Leeway	Wind
1.	055° C	3° E	5° W	4°	NNW
2.	140° C	4° W	6° W	5°	SW
3.	246° C	2° E	3° E	4°	NW
4.	330° C	3° W	8° W	3°	SW
5.	104° C	6° E	4° W	7°	NE
6.	084° C	2° W	4° E	5°	N
7.	354° C	5° W	5° E	6°	W
8.	190° C	0°	6° W	10°	ESE
9.	240° C	3° E	5° E	8°	WNW
10.	280° C	1° W	6° W	4°	NNW

EXERCISE 1.4.2

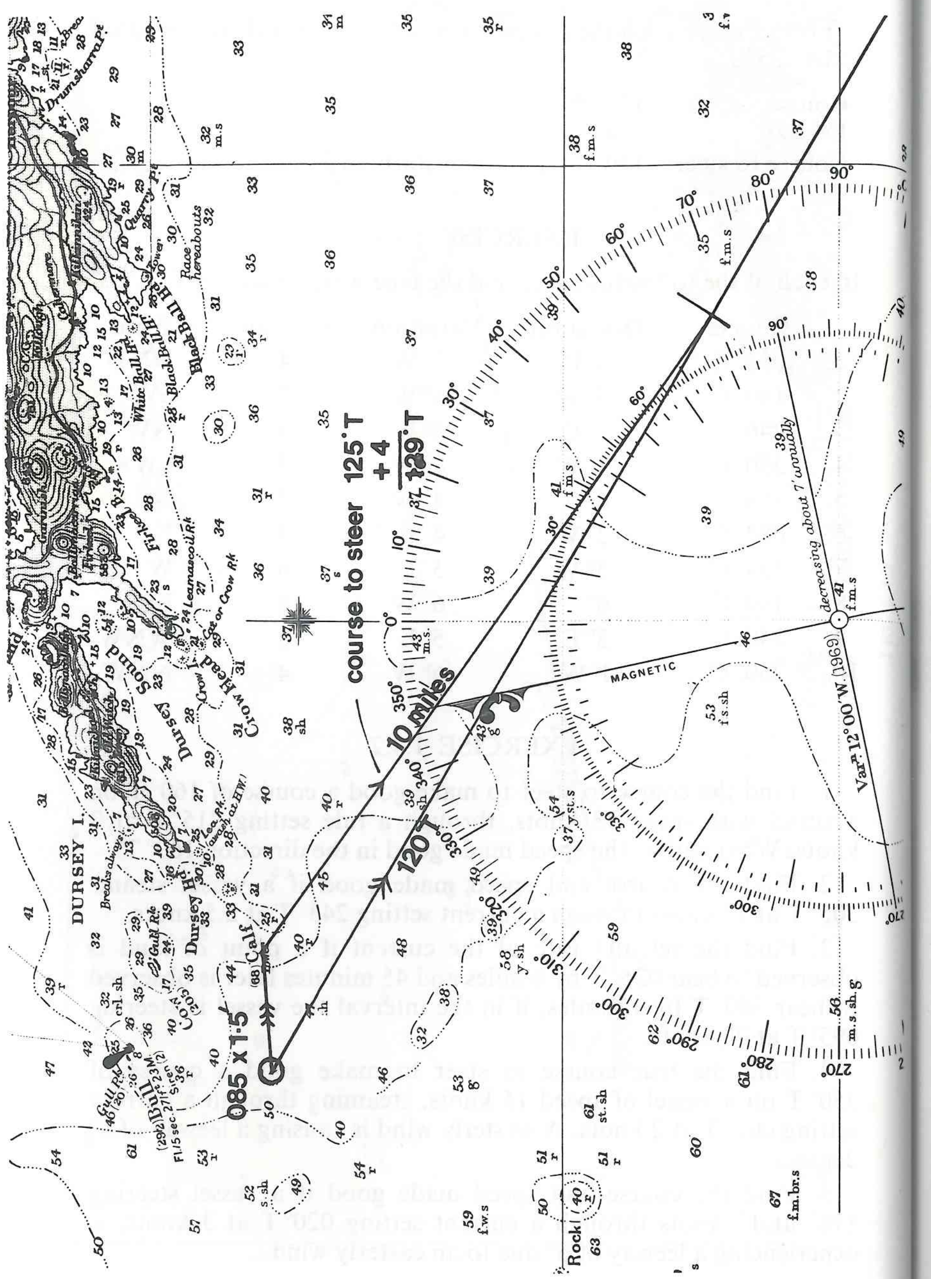
1. Find the course to steer to make good a course of 160° T on a vessel with speed 18 knots, through a tide setting 215° T at 3 knots. What will be the speed made good in the direction 160° T?

2. Find the course and speed made good if a vessel steams 305° T at 12 knots through a current setting 243° T at 2.5 knots.

3. Find the set and rate of the current if a point of land is observed to bear 025° T by 6 miles and 45 minutes later is observed to bear 300° T by 12 miles, if in the interval the vessel is steering 095° T at 20 knots.

4. Find the true course to steer to make good a course of 350° T on a vessel of speed 15 knots, steaming through a current setting 005° T at 2 knots. A westerly wind is causing a leeway of 5° degrees.

5. Find the course and speed made good if a vessel steering 176° at 17 knots through a current setting 020° T at 3 knots, is experiencing a leeway of 5° due to an easterly wind.



MODULE 1.5

Position Lines. Position Fixing by Terrestrial Observation

Definition

Position Line. A line drawn upon the chart to represent the line on the earth's surface upon which the vessel must be, consistent with some item of observed information.

Position lines on the earth's surface generally take the form of part of a great circle, a small circle or a hyperbola depending on the nature of the information observed. However that part of the position line which runs near to the vessel's DR position may very often be considered as, and represented on a chart as, a straight line without any considerable error. When such a line is drawn on a chart the observing vessel is then assumed to lie on that line. To fix the position two non coincident position lines must be drawn to intersect, the point of intersection defining the observer's position.

Lines of Bearing

The most commonly used position line at sea is that derived from the bearing of a known and charted object. The bearing may be obtained visually, by radar or by the direction of a radio signal transmitted from the observed object. This is not inherently the most accurate way of fixing as any error contained in the observation is exaggerated by the diverging nature of lines of bearing, but in the past bearing information has always been the easiest to obtain.

In all cases the bearing of an object will define a position line on the earth's surface which is the great circle which passes through the object and the observer. A great circle appears as a curve on a navigator's Mercator chart, but over the small distances which are involved with visual and radar bearings the curvature is small enough to be ignored and a bearing line is drawn as a straight line from the observed object, that is the rhumb line. If lines of bearing are drawn over large distances the error in doing this can be considerable, particularly in high latitudes, and a correction must be applied to the observed bearing. This is the case when taking bearings of a radio signal transmitted from a station. The correction of great circle bearings to rhumb line bearings is given in Module 1.6. In practice now bearings are rarely taken over distances such that the bearing requires correction.

A vessel's position can be fixed quickly and accurately by observation of the bearing of two terrestrial marks such as lighthouses, headlands etc. This requires the use of a compass with an azimuth mirror (see Module 1.3). A position line of bearing may be drawn directly onto the chart after application of any compass error. Any observation is likely to contain unknown errors and in this case the errors may be due to misalignment of the azimuth mirror, unknown compass errors, or personal errors caused by the observer. Two lines of bearing therefore should be checked with at least one other. Any error will cause the three position lines to form a small triangle at their intersection rather than a perfect cross. The size of this triangle may be used as a general indication of the quality of the bearings. The navigator must judge whether the three position lines cross accurately enough to give an acceptable observed position. A good indicator is the size of the triangle compared with the distance of the vessel from the nearest points of danger. If it is decided to accept the observation then the ship's position should be considered to be in the centre of the triangle.

Note that the ship's true position is as likely to be outside the triangle as it is to be inside and if doubt as to the actual position causes any concern then the fix is of little value and should be rejected.

Transit Bearing

Bearings may also be obtained by observing without the aid of a compass, two objects which are in line or in transit. A position line on the chart may be drawn by drawing a line through the two observed objects.

Radar Observations

Position lines of bearing may also be obtained from radar and used in the same way as visually observed bearings, usually with less accuracy. Radar also provides a means of observing ranges which will give a position circle centred upon the observed object. The choice depends upon what features are identifiable on the radar display. Clearly defined headlands or isolated radar targets

are generally suitable for both but it must be remembered that the charted coastline which is the level of MHWS is probably not the coastline that the radar will detect and the navigator must consider the effect that this will have on the accuracy of his position lines. A steep to coast for example will be suitable for ranging whereas a large tidal range with a gently shelving shore line will give poor range accuracy. In general a range will give a more accurate fix than a bearing because a position circle which contains an error does not diverge from the true position circle whereas the diverging nature of lines of bearing tends to accentuate any error. Also radar technology is such that ranges are inherently more accurate than bearings taken from a radar. The use of radar for position fixing should be used to supplement visual observations if they are available.

Horizontal Angles

A position circle may be obtained by observation of the horizontal angle subtended by two charted objects. The horizontal angle may be taken as the difference between the two compass bearings of the objects, or a more accurate result may be obtained by measurement with a sextant. The advantage of using the two observed compass bearings in this way, rather than treating them as lines of bearing, is that the position line is obtained independently of the compass error, and indeed after fixing the position with two sets of horizontal angles the compass error may be obtained by taking the true bearings from the chart for comparison with the compass bearings.

The angle subtended by the chord of a circle at the circumference is the same at all points on the circumference. The straight line between the two points observed is used as the chord and the circle which corresponds to the observed horizontal angle is constructed. The centre of the circle is found thus:

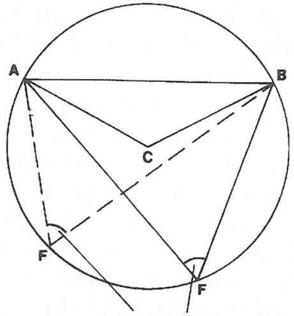
In Figure 1.5.1 the angle ACB = 2 × angle AFB

also angle CAB = angle CBA

$$= \frac{180^\circ - \text{angle ACB}}{2}$$

$$= \frac{180^\circ - (2 \times \text{angle AFB})}{2}$$

$$= 90^\circ - \text{angle AFB}$$



HORIZONTAL ANGLE BETWEEN A & B

FIG. 1.5.1

To find the angles CAB and CBA the measured horizontal angle is subtracted from 90° (if the horizontal angle is less than 90°). These angles can then be constructed on the chord which is drawn on the chart between the two observed positions. The intersection will give the centre of the circle.

Procedure (refer to Figure 1.5.1)

1. Join the charted positions of the two points between which the angle has been measured with a straight line AB.
2. Construct the angles CBA and CAB at the positions observed on the side of the line on which the observer lies. The value of both angles will be (90° – horizontal angle). The centre of the position circle will be given by the intersection at C, of the two lines constructed.
3. Draw a position circle centred upon C to pass through the two positions A and B.
4. Repeat the process for a second horizontal angle. The intersection of the two circles drawn is the ship's position.
5. If required measure the true bearings of the positions observed and compare with the compass bearings to find the compass error.

Example

The following compass bearings were observed. Find the ship's position and the error of the compass.

Great Skellig Lighthouse	307° C
Bolus Head	022° C
Great Hog Island (Scarrif)	067° C (Highest point 829)

The horizontal angles are:

Between Great Skellig Lighthouse and Bolus Head	75°
between Bolus Head and Scarrif	45°

Angles to construct = 90° – 75° = 15° and 90° – 45° = 45°

Refer to Figure 1.5.2 and follow the procedure outline above. The position measured is 51° 41.8′ N 10° 24.8′ W.

	Great Skellig	Bolus Head	Scarrif
True bearings	313° T	028° T	073° T
Compass bearings	307° C	022° C	067° C
Compass error	6° E	6° E	6° E

By checking the compass error with the three bearings the accuracy of the construction is verified.

If the horizontal angle measured is greater than 90 degrees then the observer lies in the smaller segment of the circle. In this case the angle to construct on the chord is given by the (horizontal angle –90°). This angle is constructed on the chord at the two positions as before, but on the opposite side of the chord to the observer. In all other respects the construction is the same as described.

Example (refer to Figure 1.5.3)

The following compass bearings were observed. Draw a position circle by horizontal angle method.

Galley Head	050° C
Castle Haven Lt	295° C
Horizontal angle	115°
Angles to construct	115° – 90° = 25°

If the observed horizontal angle is 90 degrees then the centre of the circle lies on the straight line between the two observed points. This straight line is in fact a diameter of the circle.

A poor angle of cut between two position circles constructed by this method will result if the two centres coincide or almost coincide. In this case all the observed points lie on the circumference of the same circle. This condition should be checked for using the ship's DR position when deciding on points to observe.

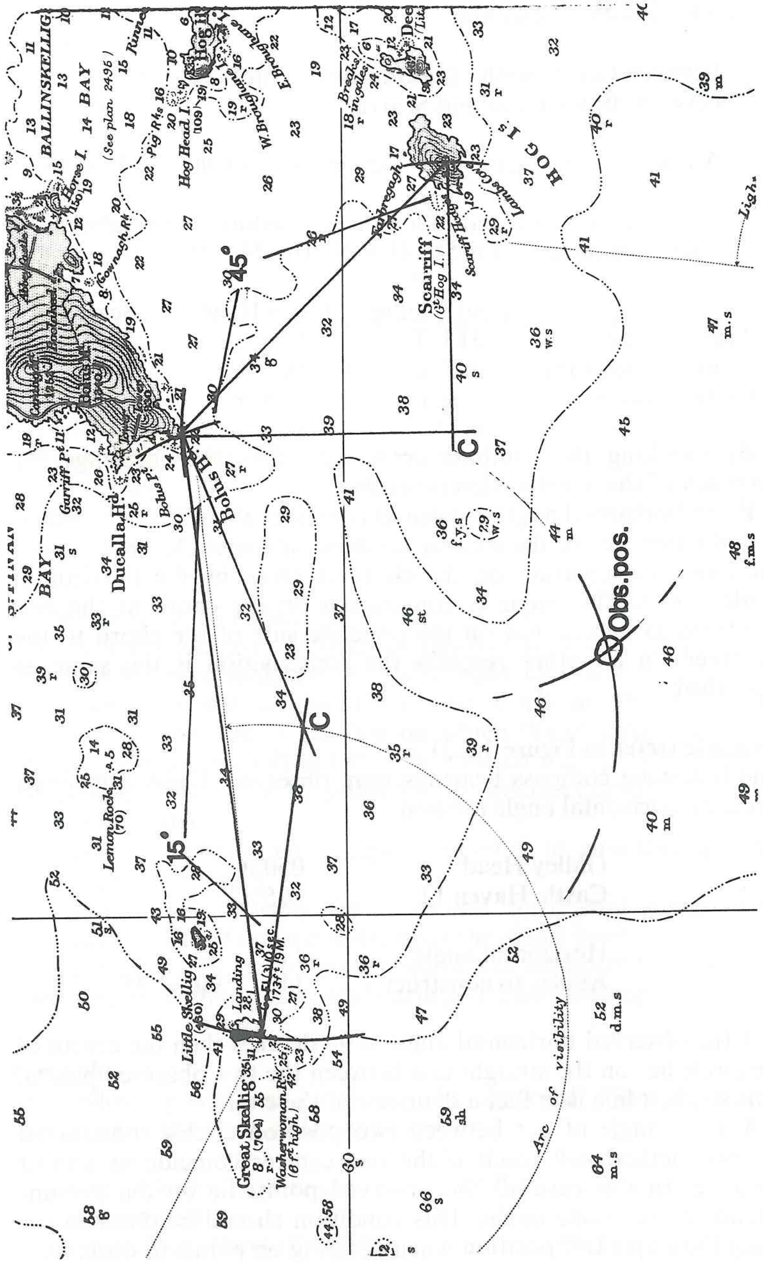


FIG. 1.5.2

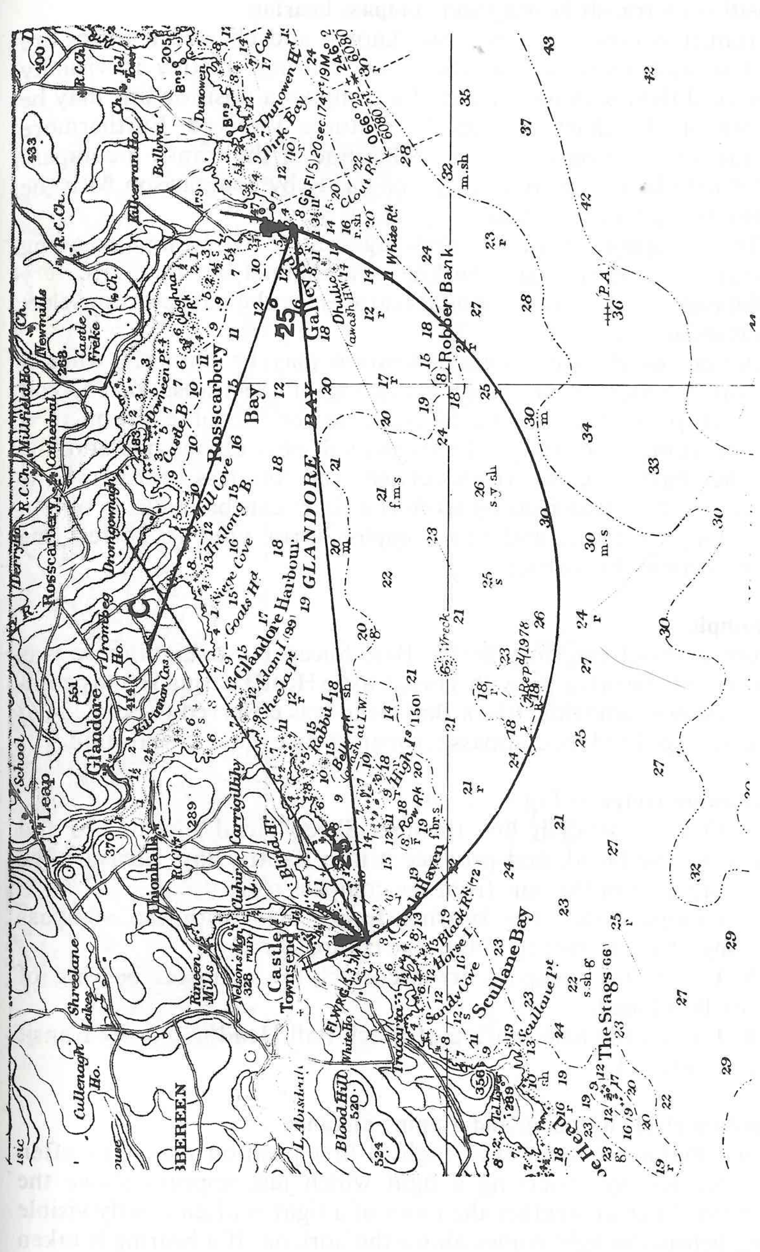


FIG. 1.5.3

Position by transit bearing and compass bearing

A transit is observed when two known and charted features are in line and therefore on the same bearing. If this is visually observed then without the aid of a compass a position line may be drawn on the chart through the features observed. Furthermore by taking a compass bearing at the time of the transit a compass error may be obtained quickly and easily by comparison with the true bearing from the chart.

Transits are used widely in pilotage waters by setting up leading marks or lights to mark the line of a channel but there are very often enough natural prominent features for the navigator to select his transits when fixing.

A very quick and accurate position may be obtained when a transit is observed, a compass bearing of the transit taken, and another prominent feature is available for the observation of a second compass bearing. The transit will provide one position line on the chart. A comparison between the compass bearing of the transit and its true bearing from the chart can be made to obtain the compass error, and this compass error used to correct the second compass bearing.

Example

From a vessel entering Bantry Bay, Sheep Head Lighthouse was observed to be in transit with Three Castle Head bearing 168° by compass. At the same time Black Ball Head was observed to bear 264½° by compass. Find the compass error and hence the ship's position.

Procedure (refer to Figure 1.5.4)

1. Draw a straight line through Sheep Head Lighthouse and Three Castle Head, and produce it into Bantry Bay. Measure the true direction of this line from the compass rose.
2. Compare the true bearing found in 1 with the compass bearing of the transit to obtain the compass error.
3. Using this compass error correct the compass bearing of Black Ball Head.
4. Lay off the true bearing of Black Ball Head to cut the transit line drawn in 1.

Position circle by rising and dipping distance

When making a landfall at night a first position may very often be obtained by observing a light which just appears above the horizon. In clear weather the loom of a light is often clearly visible long before the light comes above the horizon. If a bearing is taken

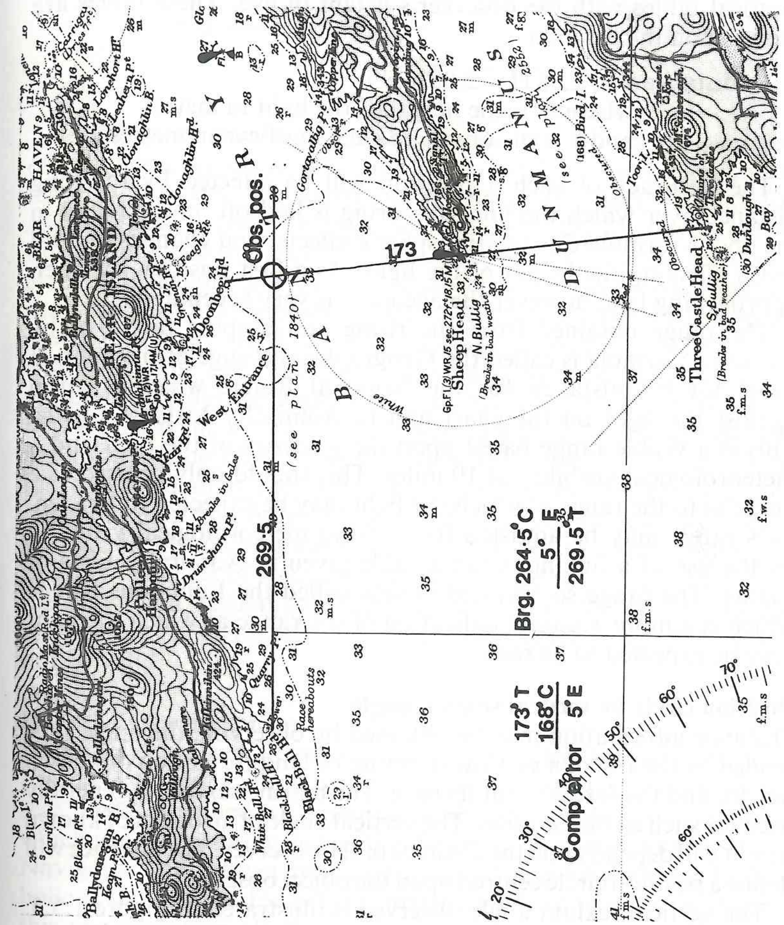


Fig. 1.5.4

when the light flash first appears, then a position may be obtained by crossing this bearing with a position circle obtained from a distance off. The height of the light must be obtained from the chart and used to enter tables of rising and dipping distances in nautical tables with the observer's height of eye. These tables are based upon the formula:

$$\text{distance} = \sqrt{2.08\,H} + 2.08\,h$$

where H is the height of the light in metres
and h is the observer's height of eye in metres

The accuracy of such a position will be affected by the long distance over which the line of bearing is laid off, inaccuracies in the above formula due to atmospheric effects, and changes in tidal levels affecting the height of the light. As a first position fix when approaching land however the accuracy is very acceptable.

The range obtained from the rising and dipping tables or by the above formula is called the Geographical Range of the light. It must not be mistaken for the Nominal Range which is given against the light on the chart and in Admiralty Lists of Lights. This is a visible range based upon the intensity of the light and a meteorological visibility of 10 miles. This should only be used as a guide as to the range at which the light may be expected to be seen. This range may be adjusted for varying meteorological visibility by the use of a luminous range table given in Admiralty Lists of Lights. The range so adjusted is then called the Luminous Range which is a more accurate indication of the range at which the light may be expected to be seen.

Position circle by vertical sextant angle

Distance information may be obtained by observing the angle subtended by the top of a vertical structure or land formation of known height, and the foreshore at its base. The marine sextant is generally used for such an observation. The vertical angle of an object of known height will depend upon the distance of the observer. The distance will define a position circle centred upon the object observed.

The vertical sextant angle observed is illustrated in Figure 1.5.5. This is considered to be equal to angle LCD without undue error. The triangle LCD which is right angled at C can be solved to find distance CD.

$$CD = CL \times \text{Tan vertical angle.}$$

The distance off may also be obtained from vertical sextant tables in nautical tables.

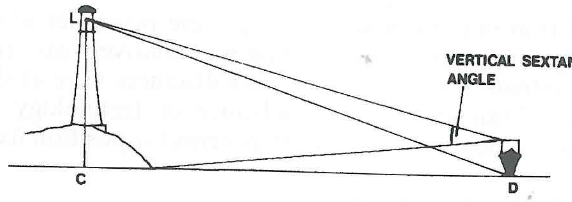


Fig. 1.5.5

The distance must be measured on the chart from the position of the point observed and not from the foreshore. Heights of features on land are given on charts above MHWS and for accurate results these heights should be adjusted for the height of tide. In practice the uncorrected heights are used, as the unknown error will usually put the vessel closer to the position observed than the vessel's true position. This will in most cases fix the vessel closer to danger and leave the navigator a margin of safety. This will not be the case however if a danger exists on the side of the vessel away from the point observed. If the height of tide is above MHWS then the above will be reversed and if the nearest danger lies towards the object observed then the vessel will be closer to the danger than is indicated. The accuracy of this method also depends upon the base of the point observed at sea level being visible. At distances greater than that of the sea horizon for the observer's height of eye, the base will not be visible and the angle measured will be that subtended by the top of the object and the sea horizon. If this is the case the vertical sextant angle tables will not be valid.

Hyperbolic position lines

Hyperbolic position lines are usually provided by the terrestrial based electronic position fixing systems which are in general use at sea. These assumed an importance during the past few decades which is now declining as position fixing systems such as the Decca Navigator and Omega are superseded. At present the main hyperbolic system in use for general marine navigation is Loran C and this remains as an alternative to satellite based systems. However the hyperbolic nature of the position lines is usually transparent to the navigator as invariably receivers process the raw measurements in order to give a latitude and longitude readout and seldom are the lattice overlaid charts used.

A hyperbolic position line is obtained from measurement of the difference in the distances from the receiver to two known fixed points or transmitters. Systems using these principles arose from the fact that this type of information was relatively easy to obtain in radio systems, whereas the absolute distances were at that time not easily obtained. With the advance of technology distance information is now used in satellite systems for position fixing.

Transferring the Position Line

The term transferring the position line refers to moving an observed position line along the direction of advance of a vessel at a known speed to give a position line at some later time. This is also known as running up a position line. This process is used in coastal navigation and also in astronomical navigation. The accuracy of the transferred position line will depend upon the accuracy of the course and speed information used and also on the length of time over which the position line is transferred. In coastal navigation this length of time is normally no longer than half an hour, while in astronomical navigation in the open sea it may be as much as several hours. The transferred position line may be obtained by graphical construction on the chart as is usually the case in coastal navigation or by calculation. The present discussion will be confined to the graphical methods used in coastal chartwork.

The Running Fix

The transferred position line will normally be used to cross with a second observed position line to obtain a fix. The second observation may be of the same object as the original position line or of a different object which has been brought into view in the interval. This chartwork construction is known as the running fix and is often used when there is only one object in view which is suitable for observation.

Example

At 0800 Galley Head was observed to bear 040° T. At 0840 it was observed to bear 310° T. Find the position of the vessel at 0840 if a course and distance of 075° T by 8 miles was estimated between the two observations.

Procedure (refer to Figure 1.5.6)

1. Lay off the position line given by the bearing of 040° T at 0800 from Galley head.
2. From any convenient point on this position line lay off the course of 075° T and mark the distance of 8 miles from the point chosen.

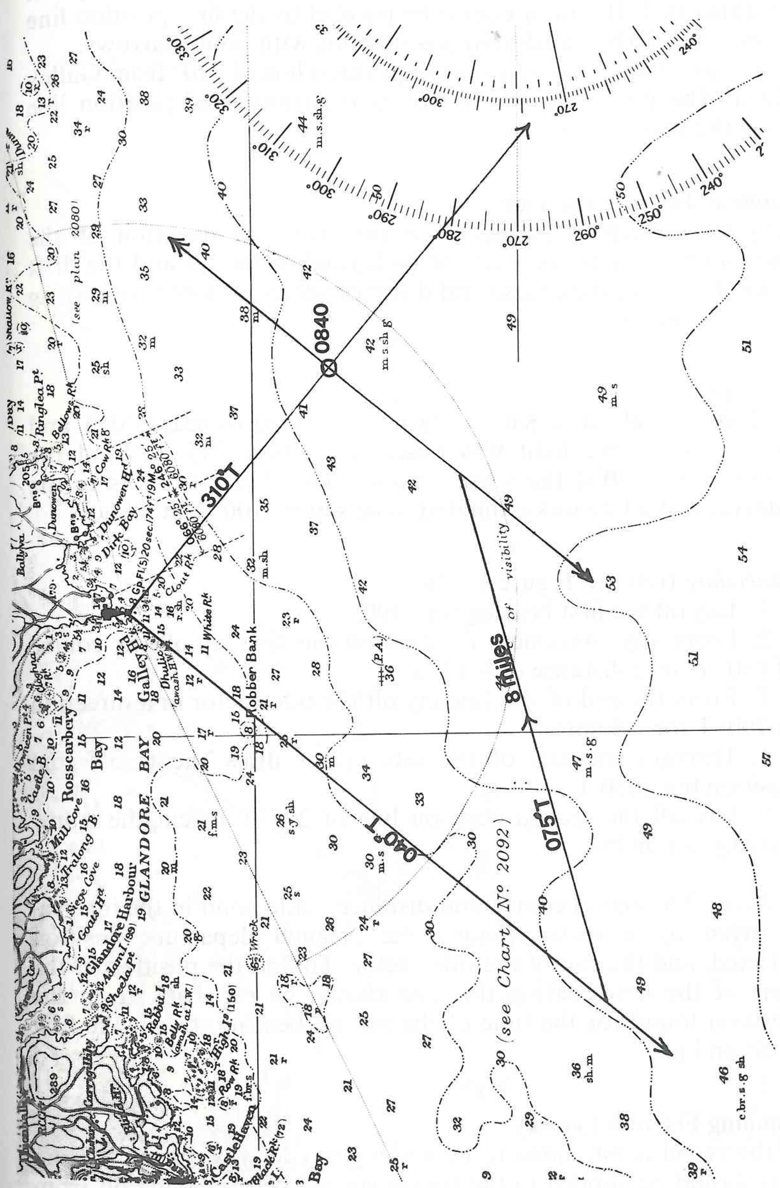


FIG. 1.5.6

3. Draw the transferred position line (040°) through the point obtained in 2. It will of course be parallel to the first position line drawn. Mark the transferred position line with double arrows.

4. Lay off the second observed position line of 310° from Galley Head. The point where this crosses the transferred position line gives the vessel's position.

Running Fix with the Tide

Any tide which is estimated to run over the duration of the running fix may be allowed for by laying off the set and the drift from the end of the course and distance vector, before transferring the position line.

Example

At 1300 Old Head of Kinsale Lt was observed to bear 030° T and at 1330 the same light was observed to bear 295° T. Find the position at 1330 if the vessel steamed 080° T at 16 knots in the interval and a tide was estimated to be setting 100° T at 3 knots.

Procedure (refer to Figure 1.5.7)

1. Lay off the first bearing for 1300.
2. From any convenient position on this line lay off the course of 080° T for a distance of 8 miles.
3. From the end of this line lay off the tide vector in a direction of 100° T for 1.5 miles.
4. Through the end of the tide vector draw the transferred position line (030°).
5. Lay off the second position line of 295° T to cut the transferred position line.

Note: The actual course and distance made good in the interval is given by a vector joining the original departure position selected, and the end of the tide vector. To find the position at the time of the first bearing this line should be run back from the position found for the time of the second bearing, to cut the first position line.

Running Fix with Leeway

If the vessel is estimated to be making any leeway during the run this should be applied to the course steered before laying off from the first bearing.

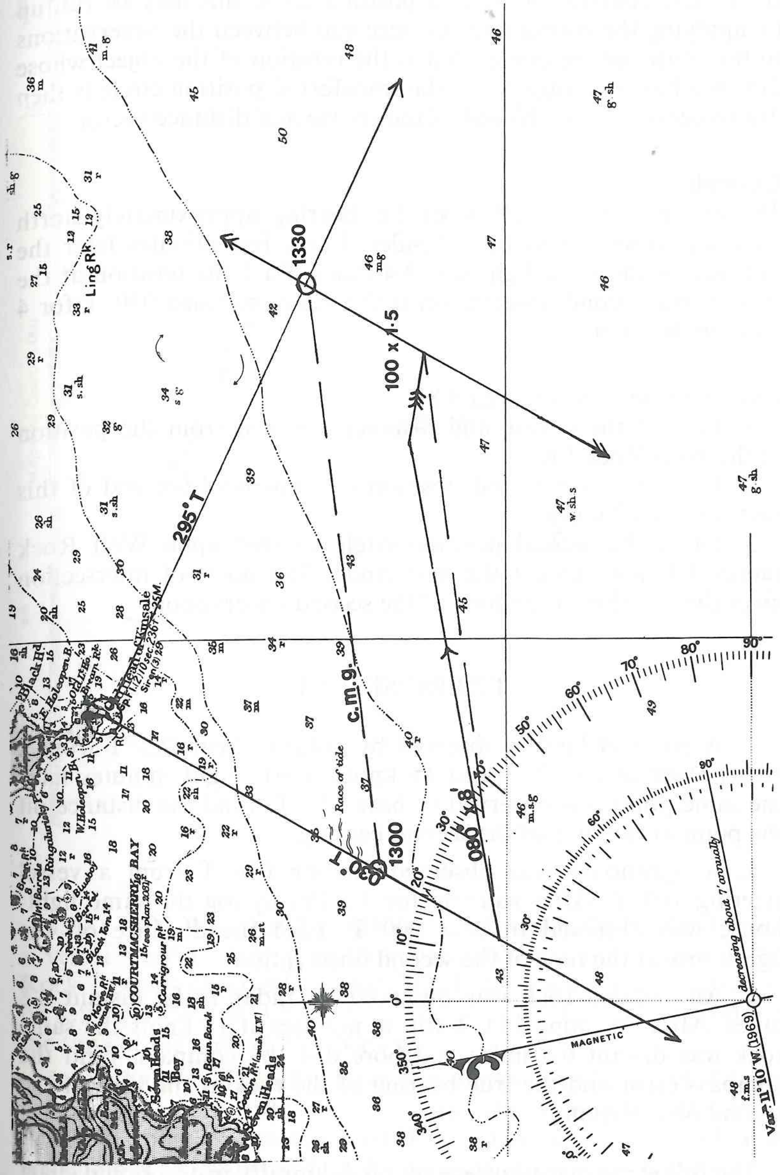


FIG. 1.5.7

Transferring a Position Circle

If the first observation gives a position circle this may be run up by applying the course and distance run between the observations to the centre of the circle, that is the position of the object whose distance has been observed. The transferred position circle is then drawn centred upon the end of the course and distance vector.

Example

The distance from Wolf Rock Lt. bearing approximately north west was observed to be 3.0 miles. Forty five minutes later the distance of the same light was 3.4 miles. Find the position at the time of the second observation if the vessel steamed 030° T for 4 miles in the interval.

Procedure (refer to Figure 1.5.8)

1. Lay off the course and distance steamed from the position of the Wolf Rock Lt.
2. Draw the transferred position circle around the end of this vector radius 3 miles.
3. Draw the second position circle centred upon Wolf Rock radius 3.4 miles to cut the first circle. The point of intersection gives the position at the time of the second observation.

EXERCISE 1.5.1

1. A point of land is observed by radar to bear 205° T from a vessel steering 248° T, speed 15 knots. Forty-eight minutes later the same point was observed to bear 147° T. Find the distance off the point at the time of the second bearing.
2. A lighthouse was observed bearing 050° T from a vessel steering 100° T. After running for 7 miles by log the same lighthouse was observed to bear 000° T. Find the distance off the lighthouse at the time of the second observation.
3. An isolated rock was observed by radar to be distant 6.8 miles. After steaming 174° T for 40 minutes at 11 knots the same rock was distant 6.8 miles and bore 054° by compass. Find the compass error and the true bearing of the rock at the time of the second observation.

The following questions are set on Admiralty instructional chart 5051 (Lands End to Falmouth).

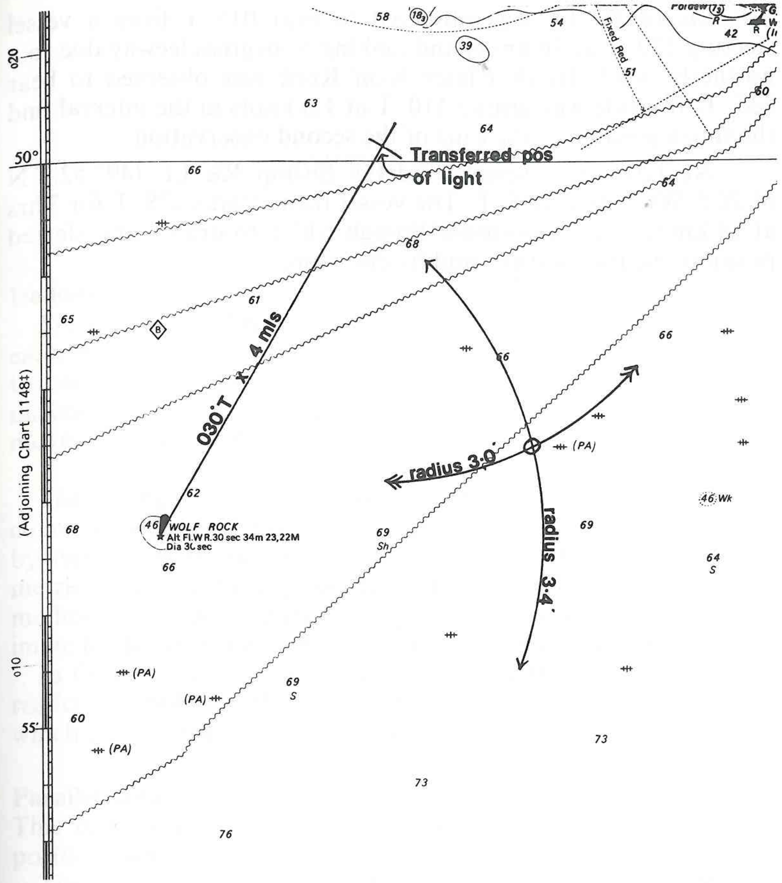


Fig. 1.5.8

4. At 0800 Wolf Rock Light was observed to bear 048° T from a vessel steering 085° T at 16 knots. Twelve minutes later Wolf Rock Lt. was observed to bear 337° T. If a tide was estimated to be setting 155° T at 3.5 knots in the interval, find the position at the time of the second observation.
5. At 2000 hrs Tater Du light was observed to bear 338° T from a vessel steaming 250° T at 18 knots. Thirty minutes later Wolf Rock was observed to bear 260° T. If a tide was setting 145° T at 2.5 knots in the interval, find the position at the time of the second bearing.

6. Lizard Pt. Lt. was observed to bear 015° T from a vessel steering 270° T at 16 knots and making 5° degrees leeway due to a northerly wind. 1h 18m later Wolf Rock was observed to bear 335° T. If a tide was setting 110° T at 1.0 knots in the interval find the ship's position at the time of the second observation.

7. At 1200 hrs a vessel observes Bishop Rk Lt. (49° 52.2′ N 6° 26.5′ W) to bear 035° T. The vessel then steams 278° T for 3 hrs at 15 knots. Find a position through which to draw a transferred position line for 1500 hrs, and its direction.

MODULE 1.6

The Sailings

Definitions

Rhumb Line. This is a line on the earth's surface which crosses each meridian at the same angle. A complete rhumb line from pole to pole would appear as a spiral towards each pole. If a vessel makes good a constant course between two positions then she will move along the rhumb line.

The sailings is the name given to the problems of finding the course and distance between two positions on the earth's surface by mathematical calculation, and in general they are done trigonometrically assuming a spherical earth. Courses obtained using the methods described, apart from great circle sailing, will approximate to the rhumb line tracks between the two positions.

In the examples contained in this module it is assumed that the reader is familiar with the use of a calculator to solve equations which contain trigonometrical functions.

Parallel sailing

This may be used to find the course and distance between two positions which are on the same parallel of latitude.

The distance measured along a parallel of latitude between any two given meridians decreases as the latitude increases and the meridians converge towards the poles. It will be maximum at the equator and zero at the poles. The distance between two meridians measured along a parallel is called the departure, and is expressed in nautical miles. The relationship between the departure and the difference of longitude is:

$$\text{departure} = \text{difference of longitude} \times \text{cosine latitude.}$$

This is shown in Figure 1.6.1.

In Figure 1.6.1 LL′ is the parallel whose latitude is angle ACD. The departure in miles is the distance ED. The lines CA, CB and CD are radii of the earth.

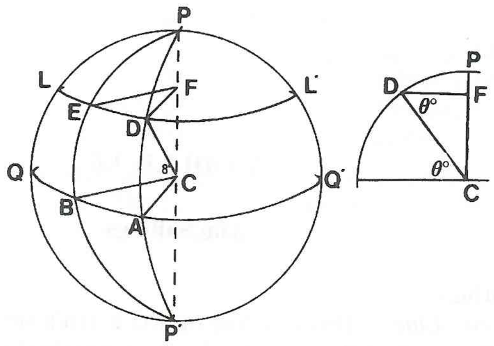


FIG. 1.6.1

By circular measure, the length of an arc which subtends any given angle at its centre is proportional to its radius.

Thus $\frac{DE}{DF} = \frac{AB}{AC}$ where DE is the departure and AB the difference of longitude.

Therefore $\frac{DE}{AB} = \frac{DF}{AC}$

and as DC and AC are both radii of the earth,

$$\frac{DE}{AB} = \frac{DF}{DC}$$

Thus $\frac{DE}{AB}$ = cosine angle FDC

and $\frac{\text{departure}}{\text{d'long}}$ = cosine latitude.

This is known as the parallel sailing formula.

Example 1

Find the distance to steam between the two positions 51° 20′ N 48° 30′ W and 51° 20′ N 38° 10′ W.

	51° 20′ N		48° 30 W	
	51° 20′ N		38° 10′ W	
d'lat	0	d'long	10° 20′ E = 620′	

and departure = d'long × cosine latitude
= 620 × cosine 51° 20′
= 387.4 miles

Example 2

In what latitude will a difference of longitude of 3° 40′ correspond to a departure of 120 nautical miles.

departure = d'long × cosine latitude

120 = 220 × cosine latitude

$$\text{cosine latitude} = \frac{120}{220}$$

latitude = 56° 56.7′ N or S

Example 3

A vessel steams 090° T from position 41° 20′ S 35° 25′ W. Find the arrival position if she steams for 294 miles.

departure = d'long × cosine latitude

294 = d'long × cosine 41° 20′

$$\text{d'long} = \frac{294}{\text{cosine } 41° 20'} = 391.5$$

departure longitude	=	35° 25′ W
d' long	=	6° 31.5′ E
arrival longitude	=	28° 53.5′ W

Example 4

A vessel steams from a position in latitude 60° N, in a direction of 000° T for a distance of 90 miles.

She then steams 090° T for 90 miles, 180° T for 90 miles and 270° T for 90 miles. How far is the vessel from her original position?

The distance steamed in a northerly direction gives a difference of latitude of 90′ or 1° 30′. She will therefore arrive in a latitude of 61° 30′ N after the first leg. The same difference of latitude is made on the southerly leg so that she will arrive back in the original latitude. A distance of 90 miles in the higher latitude will give a larger difference of longitude than in the southerly latitude and so she will not reach her original longitude when she sails westwards. Her distance from the original position will be the difference in the departures, for the two latitudes, which correspond to the difference of longitude made good on the easterly leg.

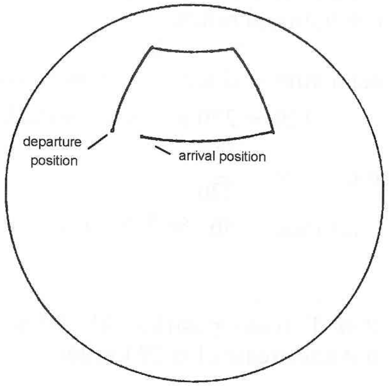


FIG. 1.6.2

Thus in latitude 61° 30′ N

$$\begin{aligned}\text{departure} &= \text{d'long} \times \text{cosine latitude}\\ 90 &= \text{d'long} \times \text{cosine } 61° \ 30'\\ \text{d'long} &= 90 \times \text{secant } 61° \ 30'\\ &= 188.62'\end{aligned}$$

in latitude 60°

$$\begin{aligned}\text{departure} &= 188.62 \times \text{cosine } 60°\\ &= 94.31\end{aligned}$$

Thus the vessel will be 94.31 − 90 miles from her original position

$$= \underline{4.31 \text{ miles}}$$

Example 5

At what speed in knots is a position on the parallel of 50° 56′ being carried around by the earth's rotation?

In 24 hours the position will be moved through 360°. This can be considered the difference of longitude. Thus in 1 hour its d'long will be 15°.

Thus the distance in miles moved in one hour will be:

$$\begin{aligned}\text{departure} &= 15 \times 60 \times \text{cosine } 50° \ 56'\\ &= 900 \times \cos 50° \ 56'\\ &= 567.2 \text{ miles}\end{aligned}$$

$$\text{speed} = 567.2 \text{ knots}$$

EXERCISE 1.6.1

1. In what latitude will a departure of 300 miles correspond to a difference of longitude of 6° 40′?

2. On a certain parallel the distance between two meridians is 250 miles, while the difference of longitude between two meridians is 12° 30′. Find the latitude.

3. In latitude 50° 10′ N the departure between two meridians is 360 miles. Find the difference of longitude.

4. A vessel steams on a course of 090° T from a position 23° 30′ N 59° 10′ E to a position 23° 30′ N 65° 30′ E. Find the distance steamed.

5. If a vessel steams 000° T for 50 miles and then 090° T for 100 miles, making good a difference of longitude of 3° 10′, find the original latitude.

6. From a position 44° 15′ N 10° 20′ W a vessel steams 270° T for 550 miles, and then 180° T for 753 miles. Find the arrival position.

7. On a certain parallel of latitude, the distance between two meridians is 150 miles. On the equator the distance between the same two meridians is 235 miles. Find the latitude of the parallel.

8. The distance between two meridians in latitude 48° 12′ N is 250 miles. Find the difference of longitude.

9. A vessel steams 470 miles along a parallel from a longitude of 15° 35′ W to the meridian of 27° 20′ W. Find the latitude of the parallel.

10. From position 39° 00′ N 33° 10′ W a vessel steams 270° T at 10 knots for 3 days 8 hours. Find the DR position.

EXERCISE 1.6.2

1. If the distance between two meridians is 427 nautical miles in latitude 50° 20′ N, find the angle at the pole between the two meridians.

2. If two ships are on the same parallel of 17° S and are 55 nautical miles apart, what would their distance apart be if they both steam 180° to the parallel of 30° S?

3. Two ports are both in the northern hemisphere. On the parallel of one the distance between their meridians is 250 miles. On the parallel through the other it is 350 miles, whilst on the equator the distance between their meridians is 400 miles. What are the latitudes of the two ports?

4. At what rate in knots is an observer in latitude 50° 20′ carried around by the earth's rotation?

5. A vessel in latitude 48° 30′ N steams 270° T at 10 knots for 24 hours. By how much does the vessel change the longitude?

6. In latitude 50° 20′ N a vessel steams from longitude 15° 46′ W to longitude 31° 18′ W. What distance was made good?

7. A ship steams 090° T for 200 miles in latitude 49° 10′ N. By how much should her clocks be advanced?

Plane Sailing (Mean Latitude Sailing)

Plane Sailing may be used to find the course and distance between two positions which are not in the same latitude. The method has inherent inaccuracies and should be used over small distances only. It is rarely used in practice as the alternative method of Mercator sailing produces greater accuracy with slightly less working.

Given the latitude and longitude of the two positions the difference of latitude (d'lat) and the difference of longitude (d'long) can be readily found.

The d'lat and the distance are measured in the same units and can be graphically represented by the two sides of a right angled triangle the distance being the hypotenuse and the angle between the two sides the course as shown in Figure 1.6.3.

The third side of the triangle may be thought of as the departure and can be found by the parallel sailing formula:

$$\text{departure} = \text{d'long} \times \text{cosine latitude.}$$

The latitude is changing however and the question of which latitude to use arises. There will be one value of departure when used in the triangle in Figure 1.6.3, to solve for the course, will give the correct value for the course and we would wish to use a latitude in the parallel sailing formula, which will give this value.

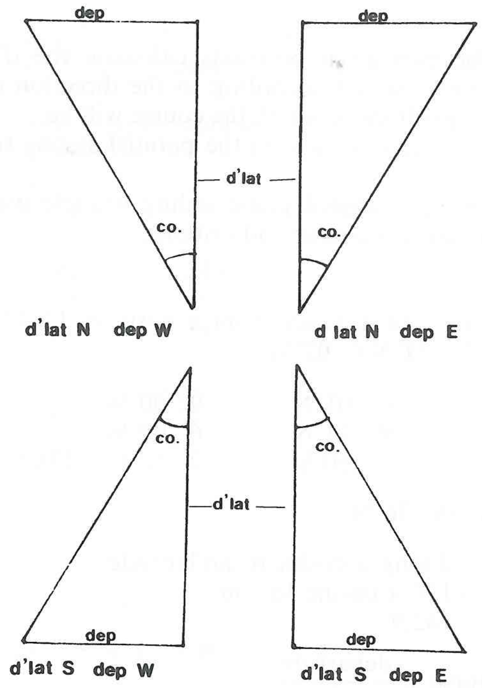


FIG. 1.6.3

This latitude however is not known at this stage and as an approximation the mean latitude is used. Thus the formula may be modified to read:

$$\text{departure} = \text{d'long} \times \text{cosine mean latitude}$$

When this is used to solve for the departure, the departure can then be used in the plane sailing triangle to first solve for course by:

$$\frac{\text{departure}}{\text{d'lat}} = \text{tangent course}$$

and then for the distance by:

$$\text{distance} = \text{d'lat} \times \text{secant course}$$

Procedure

1. From the two given positions calculate the d'lat and the d'long. These are named according to the direction of sailing to determine the quadrant in which the course will lie.
2. Using the mean latitude in the parallel sailing formula, find the departure.
3. Solve the right angled plane sailing triangle using the d'lat and the departure, for course and distance.

Example 1

Find the course and distance from a position 37° 01′ N 9° 00′ W to a position 36° 11′ N 6° 02′ W.

37° 01′ N	9° 00′ W
36° 11′ N	6° 02′ W
50′ S	2° 58′ E = 178′ E

Mean lat = 36° 36′ N

departure = d'long × cosine mean latitude
= 178 × cosine 36° 36′
= 142.9

$$\text{tangent course} = \frac{\text{departure}}{\text{d'lat}}$$

$$= \frac{142.9}{50}$$

= 70 43′ Course is in SE quadrant as determined by the names of the d'lat and the d'long

= S $70\frac{3}{4}$ E

distance = d'lat × secant course
= 50 × secant 70° 43′
= 151.4

Note that when using a calculator the first two steps can be combined as the value of the departure is not required. Thus:

$$\text{tangent course} = \frac{\text{d'long} \times \text{cosine mean latitude}}{\text{d'lat}}$$

Answer course = S $70\frac{3}{4}$ E, distance 151.4 miles

Example 2

From a position 50° 28′ N 7° 23′ W a vessel steams 334° T for 345 miles. Find the arrival position.

d'lat = distance × cosine course
= 345 cosine 334°
= 310.1
= 5° 10.1′ N

original latitude	50° 28.0′ N
d'lat	5° 10.1′ N
arrival latitude	55° 38.1′ N

mean latitude = 53° 03′ N

departure = distance × sine course
= 345 × sine 334°
= −151.2

$$\text{d'long} = \frac{\text{departure}}{\text{cosine mean lat}}$$

$$= \frac{-151.2}{\text{cosine } 53° \ 03}$$

= −251.6 = 4 11.6′ W

final longitude = 11° 34.6′ W

final position = 55° 38.1′ N 11° 34.6′ W

EXERCISE 1.6.3

1. Find the course and distance by plane sailing between the following positions.

35° 12′ N 178° 12′ W
37° 06′ N 177° 00′ E

2. A vessel leaves position 45° 12′ N 161° 12′ W and steams 213° T for 406 miles. Find by plane sailing the arrival position.

3. Find the course and distance by plane sailing between the following positions.

5° 21′ N 168° 17′ E
16° 38′ S 153° 48′ W

4. A vessel leaves position 40° 30′ S 175° 45′ E and steams 050° T for 506 miles. Find the arrival position.

Middle Latitude Sailing

For greater accuracy the mean latitude in the plane sailing problem should be corrected to obtain what is called the middle latitude, and a table of corrections is given for this purpose in nautical tables. This solution is rarely used now as the alternative solution by Mercator sailing involves less calculation and gives the same accuracy as middle latitude sailing.

Mercator Sailing

Definitions

The *meridional parts* for any latitude is the length along a meridian on a Mercator chart between the equator and that parallel of latitude expressed in units of the longitude scale.

The *difference of meridional parts* between any two latitudes is the length of a meridian on a Mercator chart between the two parallels expressed in units of the longitude scale.

Mercator Sailing may be used to find the course and distance between any two positions on the earth's surface.

The Mercator sailing triangle may be imagined to be drawn on a Mercator chart. The hypotenuse of this right angle triangle represents the rhumb line distance between the two positions, one side represents the meridian through one of the positions and the other side the parallel through the other position as shown in Figure 1.6.4. The angle between the meridian and the hypotenuse will be the course angle. The adjacent and opposite sides must be expressed in the same units if they are to be used in the solution. The side opposite the course angle along a parallel can be expressed as the difference of longitude. The side adjacent to the course angle, that is the side along the meridian through one of the positions can be expressed in units of the longitude scale by taking the difference in the meridional parts (DMP) between the two latitudes. This is illustrated in Figure 1.6.4.

The meridional parts for all latitudes are tabulated in nautical tables. The meridional parts for the two latitudes must be extracted and the difference of meridional parts (DMP) found from them. The DMP will be the difference between the two meridional parts if the latitudes carry the same name and will be the sum if they carry opposite names. This will be the same rule as for finding the d'lat.

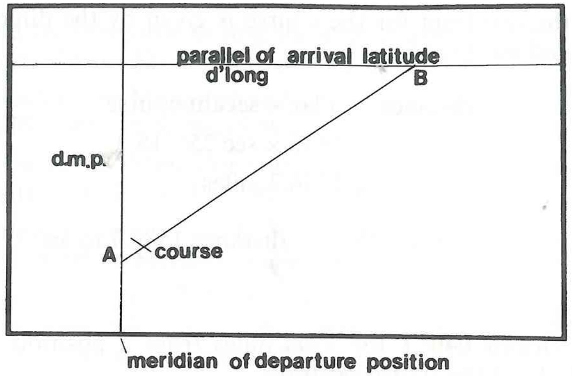


FIG. 1.6.4

The course is found by trigonometry in the Mercator sailing triangle by:

$$\frac{\text{d'long}}{\text{DMP}} = \text{tangent course}$$

The distance can then be solved in units of nautical miles by:

$$\text{distance} = \text{d'lat} \times \text{secant course.}$$

Example 1

By Mercator sailing find the true course and distance between the positions 49° 10′ N 12° 30′ W and 25° 15′ N 26° 50′ W.

lat	49° 10′ N	MP	3379.6	long	12° 30′ W
	25° 15′ N	MP	1556.6	long	26° 50′ W
d'lat	23° 55′ S	DMP	1823.0	d'long	14° 20′ W
	= 1435′ S				= 860′ W

Note: the values for meridional parts are taken from the table of Meridional Parts for the Terrestrial Spheroid in Norie's Nautical Tables.

$$\text{Tan course} = \frac{\text{d'long}}{\text{DMP}}$$

$$\text{course} = \frac{860}{1823}$$

$$= \text{S } 25° \ 15.3' \text{ W}$$

$$= 205\tfrac{1}{4}°$$

Note: the quadrant for the course is given by the directions of the d'lat and the d'long:

$$\text{distance} = \text{d'lat} \times \text{secant course}$$
$$= 1435 \times \sec 25° \; 15.3'$$
$$= 1586.7 \text{ miles}$$

Answer course 205° distance 1586.7 miles

Example 2
A vessel steams 040° T for 2300 miles from a position 39° 37′ S 47° 28′ W. Find the arrival position.

$$\text{d'lat} = \text{distance} \times \text{cosine course}$$
$$= 2300 \times \cos 40°$$
$$= 1761.9$$
$$= 29° \; 21.9'$$

initial latitude	39° 37.0′ S	MP 2577.82
d'lat	29° 21.9′ N	
final latitude	10° 15.1′ S	MP 614.15
		DMP 1963.67

$$\text{d'long} = \text{DMP} \times \tan \text{course}$$
$$= 1963.57 \times \tan 40°$$
$$= 1647.7$$
$$= 27° \; 27.7' \text{ E}$$

initial longitude	47° 28.0′ W
d'long	27° 27.6′ E
final longitude	20° 00.4′ W

final position 10° 15.1′ S 20° 00.4′ W

EXERCISE 1.6.4

1. Find the DMP between the following pairs of latitudes:

(a) 40° 00.0′ N and 50° 00.0′ N
(b) 20° 10.0′ N and 10° 35.0′ S
(c) 53° 15.0′ S and 24° 47.0′ S
(d) 22° 18.0′ S and 39° 53.0′ N.

2. Find by Mercator sailing the true course and distance from position 20° 14′ N 22° 17′ W to position 11° 35′ S 41° 05′ W.

3. Calculate by Mercator sailing the true course and distance from position 40° 10′ N 9° 45′ W to position 10° 15′ N 18° 11′ W.

4. Calculate by Mercator sailing the true course and distance from position 41° 13′ N 173° 50′ W to position 7° 50′ S 79° 55′ W.

5. A vessel steams 210° T 750 miles from position 29° 30′ N 162° 20′ E. Find by Mercator sailing the final position.

6. A vessel steers 017° T from position 10° 12′ S 35° 05′ W and arrives in longitude 28° 29′ W. Find by Mercator sailing the distance steamed and the final latitude.

7. A vessel steams 225° T a distance of 800 miles, and then 135° T 800 miles from an initial position of 10° 00′ S 00° 00′. Find the final position by Mercator sailing.

8. A vessel steams 065°T 1850 miles from position 20° 12′ N 178° 40′ E. Find by Mercator sailing the arrival position.

9. Find by Mercator sailing the true course and distance from position 5° 20′ N 79° 05′ E to position 24° 20′ S 112° 03′ E.

10. Find by Mercator sailing the true course and distance from position 37° 03′ N 13° 20′ E to position 31° 20′ N 29° 55′ E.

Great Circles and Great Circle Sailing
The plane trigonometrical methods of finding course and distance so far described will result in the rhumb line course and distance (or a good approximation to it). The shortest distance between two positions on the sphere is measured along the great circle which passes through the positions. Over long ocean passages the difference between the great circle distance and the rhumb line distance may be considerable and common practice is to use great circle sailing in these situations. The disadvantage of the great circle route is that the course is not constant but will vary as the great circle changes direction at successive meridians. In practice this will involve working a new course at regular intervals. With the use of modern navigational aids providing position observations when required, a new course would be calculated at each position fix.

The solution may be worked using spherical trigonometry. If a calculator is used the most convenient formula for this is the spherical cosine formula and this is given without proof. Napier's Rules for the solution of right angled or right sided spherical triangles are also used. These rules are also given without proof.