15 How is the figure for UERE derived?
16 The use of DGPS offers improved fix accuracy. Over what range would you expect to receive DGPS data?
17 Why does a GPS antenna need a ground plane?
18 Why is the C/A code generated (or held in memory) in a receiver and applied to the correlator?
19 Autocorrelation is used in the signal processing stages of a GPS receiver. Why is this?
20 The Russian Federation satellite navigation system, GLONASS, offers similar features and accuracy of position fixing to the GPS. Are the two systems compatible?

Chapter 6
Integrated bridge systems

6.1 Introduction

The 20th century saw many milestones in terms of nautical events and much was learnt from such events for the benefit of those seafarers that came afterwards. Starting with events such as the sinking of the Titanic in 1912 with its impact on the Safety of Life at Sea, the use of wireless telegraphy and, continuing throughout the century, the increasing use of electronics and satellites for navigation and communication purposes.

During that time there was a realization for the need to set up international bodies with a view to the harmonization, and the international recognition, of standards for ships involved in international trading. Bodies set up during the 20th century to monitor and influence these trends included the following.

6.1.1 International Maritime Organization (IMO)

Originally set up as the Inter-Governmental Maritime Consultative Committee (IMCO) in 1958, the name was changed in 1982. Its first task was to adopt a new version of the International Convention for the Safety of Life at Sea (SOLAS) and this was completed in 1960. The best known of the responsibilities of the IMO is the adoption of maritime legislation. About 40 conventions and protocols have been adopted by the organization and amended as necessary to keep pace with the changes in world shipping. The IMO has 158 member states and is based in London, England.

6.1.2 The International Standards Organization (ISO)

This is a non-governmental organization established in 1947 with a view to promoting the development of standardization in the world, facilitating the international exchange of goods and services, and developing co-operation in the areas of intellectual, scientific, technological and economic activity. The work of the organization results in international agreements, which are published as International Standards. There are more than 130 countries represented within the organization which is based in Geneva, Switzerland.

6.1.3 The International Electrotechnical Commission (IEC)

Established in 1906, the organization has more than 50 member countries covering 85% of the world's population. Standards established are used in more than 100 countries and there are approximately 200 Technical Committees (TCs) of which TC80 is an important part (see Section 6.3). The IEC collaborates with the ISO in matters of mutual interest and both organizations co-operate on a joint basis with the International Telecommunications Union (ITU). Like the ISO, the IEC is a non-governmental body while the ITU is part of the United Nations organization with governments as its members. The IEC is based in Geneva, Switzerland.

6.2 Design criteria

In the 1960s Planned Ships Bridges were available from at least one manufacturer and fitted on some vessels. This was probably the first attempt to construct a bridge within design concepts that took into consideration the operational requirements of the vessel. Integrated navigation systems and integrated bridge systems have evolved from those days and the concept is now accepted, with a variety of systems available from many different manufacturers.

Certain classification societies have initiated terms of carriage requirements if particular notations are specified for a vessel. A leading influence has been Det Norske Veritas (DNV) of Norway, a member of the International Association of Classification Societies (IACS). The Association was formed in 1968 and claims that 'At the heart of ship safety, classification embodies the technical rules, regulations, standards, guidelines and associated surveys and inspections covering the design, construction and through-life compliance of a ship's structure and essential engineering and electrical systems.' More than 90% of the world's merchant tonnage is classed by the 10 members and two associates of IACS. IACS members include the American Bureau of Shipping (ABS), Germanischer Lloyd and Lloyds Register of Shipping, together with societies from China, France, Italy, Japan, Korea, Norway and Russia. IACS has held consultative status with the IMO since 1969 and is the only non-government organization with observer status able to develop rules. The DNV rules for ships are as follows.

- To reduce the risk of failure in bridge operation, causing collisions, groundings and heavy weather damages and to minimize the consequences to ship and complement, should an accident occur.
- To include relevant requirements and recommendations from the IMO.
- To include relevant international standards within the rules or indicating the points in which they differ.

The various classification societies have adopted different standards although discussions on establishing international performance standards for integrated bridge systems have progressed under the direction of the IEC's Technical Committee 80 (TC80). Progress has been made on type approval and system notation.

The integrated bridge system should be designed and installed as a physical combination of equipment or systems using interconnected controls and displays. Workstations should provide centralized access to all nautical information. The type of operational function carried out from the bridge would include navigation, communications, automation and general ship operation. Manufacturers can provide shipbuilders and potential shipowners with computer-generated drawings of how a particular bridge layout would look when installed. One such diagram produced by Litton Marine Systems is shown in Figure 6.1.

In the absence of any internationally-agreed operating standards, from either the IMO or national authorities, reliance must be placed on industry guidelines and standards which do exist for bridge layout and equipment. These include the ISO standard for 'bridge layout and associated equipment.'

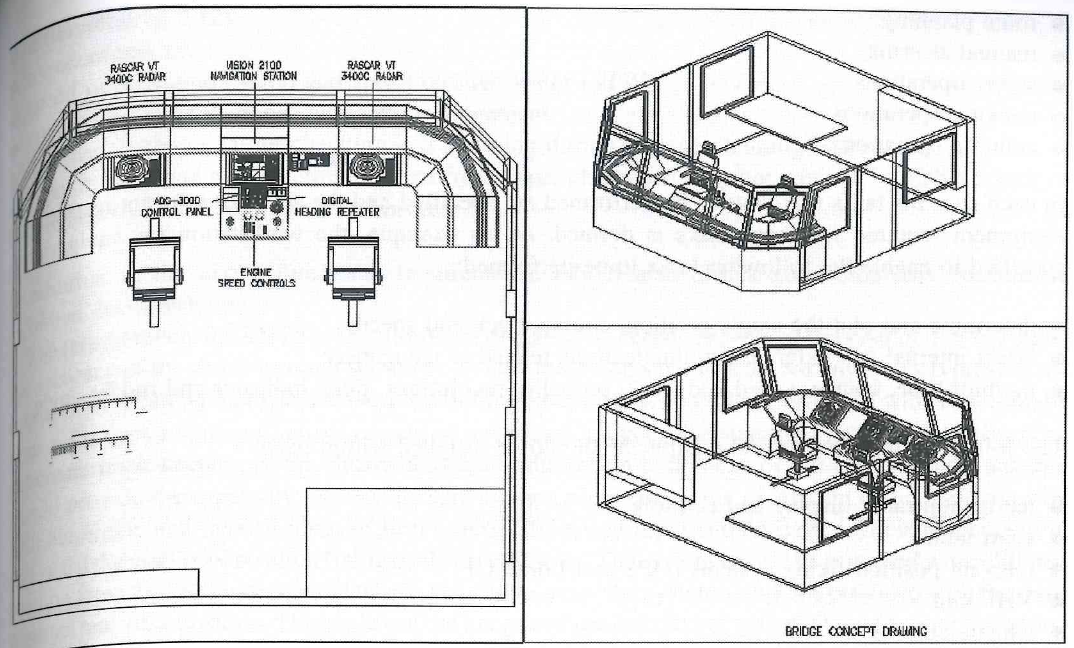


Figure 6.1 Line drawing of an integrated bridge system. (Reproduced courtesy of Litton Marine Systems.)

An IEC definition of an integrated bridge system states that such a system must be capable of carrying out at least two of the following functions:

- navigation planning
- passage execution and manoeuvring
- collision and stranding avoidance
- communications
- machinery control and monitoring
- loading and discharge of cargo
- safety and security
- management.

The integrated bridge system that meets these requirements must provide: redundancy in the event of system failure; the use of standardized equipment interfacing; the centralization of all nautical data and alarms; and the use of suitable displays to allow the monitoring of sensor data. The fact that current trends involve a reduction in manning levels suggests that the few members of a crew on the bridge must be capable of interpreting and responding to the multitude of information and alarms being presented to them. This would involve improvements in training and system documentation for the crews.

The DNV rules specify design criteria for particular workstations namely:

- traffic surveillance/manoeuvring
- navigation

- route planning
- manual steering
- safety operations
- docking operations
- conning operations.

In each case the tasks that have to be performed are specified and the siting of relevant instruments/equipment required for those tasks is defined. As an example, the workstation for navigation is specified to enable the following tasks to be performed:

- determine and plot the ship's position, course, track and speed;
- effect internal and external communications related to navigation;
- monitor time, course, speed and track, propeller revolutions, pitch indicator and rudder angle.

The following instruments and equipment should be installed within reach:

- navigation radar display and controls
- chart table
- relevant position fixing systems (GPS and Loran-C)
- VHF unit
- whistle control.

Instruments, indicators and displays providing information considered essential for the safe and efficient performance of tasks at the navigation workstation should be easily readable from the workstation. These instruments, indicators and displays should include:

- gyro repeater
- rudder angle indicator
- depth indicator
- clock
- propeller RPM indicator
- pitch indicator (where fitted)
- speed and distance indicator.

Means to be used at intervals for securing safe course and speed in relation to other ships and safety of bridge operation should also be easily accessible from the navigation workstation. Such means include:

- instruments and equipment installed at the workstation for traffic surveillance/manoeuvring
- internal communications equipment
- central navigation alarm panel (if provided)
- wipers and wash controls for the windows within the required field of vision.

DNV specification for one-man bridge systems in an unbounded voyage area, known as DNV-W1, requires an Automatic Navigation and Track-keeping System known as ANTS. The specification requires integration of the following:

- Electronic Chart Display and Information System (ECDIS)
- automatic steering system (including software for calculation/execution of adjustments for the maintenance of pre-planned routes)

- differential GPS (2)
- gyrocompass (2)
- speed over ground (SOG) and speed through water (STW)
- course alteration warnings and acknowledgement
- automatic safety contour checking and alarming during voyage planning and execution
- capacity to create own electronic charts from paper charts for areas not covered by ENCs issued or certified by official sea chart authorities.

In addition to the above functional requirements, ANTS also places great emphasis on suitable technical documentation.

The requirements for ANTS place additional demands on certain aspects of the system. For example, the accuracy of the ship's heading should be a value that has been corrected for any errors typical of the source of the heading input, and at least one of the gyrocompasses should be provided with an automatic system for the correction of errors caused by speed and latitude. The steering system should also keep automatic track-keeping of the ship within the limits set on both sides of the pre-planned track and should provide the capability to steer the ship along a route consisting of straight and curved lines by both automatic and manual input of turn orders. The speed input should have sufficient accuracy to safeguard the quality of position fixing by dead reckoning. The system should be provided with a filtered position from the GPS receiver and when performing turns, the system should be provided with the most accurate real-time position. The quality of the integrated position fixing system should be monitored and a warning should appear if the quality is below an acceptable limit.

The need for integration has meant that there has been a tendency to move away from sourcing equipment from a variety of manufacturers and attempts to integrate disparate pieces of equipment, to single-sourcing a package of equipment from just one manufacturer. Many manufacturers, aware of the requirement, now offer complete systems with all the necessary interfacing requirements guaranteed. The use of standard modules and interfaces, not only for navigation but also for other bridge functions, such as communications, engine monitoring and control, power supply etc., is likely to produce cost savings and reduce the amount of equipment required. Factors such as the reduced number of consoles, reduced installation and interfacing costs, more cost-effective design, installation and testing requirements have to be taken into account.

6.3 Standards

Those organizations involved in the production of world standards are the International Standards Organization (ISO), the International Electrotechnical Commission (IEC), and the International Telecommunications Union (ITU). The first two organizations work closely together and, as they both have their headquarters in Geneva, some facilities have been amalgamated.

The International Maritime Organization (IMO) is responsible for defining the requirements for marine equipment but it does not provide sufficient specification detail for manufacturers to design specified equipment or for national maritime authorities to provide test and approval facilities for the equipment. Thus, the IEC and ISO standards are designed to allow the necessary specification requirements for design, testing and approval.

The IEC has several Technical Committees working in specialized technical areas. The IEC Technical Committee 80 (IEC TC80) covers the area of 'Marine Navigation and Radio communication Equipment and Systems' and was formed in 1980. IEC TC80 responsibility is to concern itself with the development of international technical standards for the navigation and radio communication equipment designated by the IMO for mandatory carriage on vessels covered by the SOLAS (Safety of Life at Sea) Conventions.

IEC TC80 currently has 10 working groups:

- WG1 radar and ARPA
- WG1A Track control
- WG4 Terrestrial position-fixing aids
- WG4A Global Navigation Satellite Systems (GNSS)
- WG5 General requirements
- WG6 Digital interfaces
- WG8 Global Maritime Distress and Safety System (GMDSS)
- WG8A Automatic shipborne Identification Systems (AIS)
- WG10 Integrated navigation systems
- WG11 Voyage data recorders.

Until fairly recently there were two other TC80 working groups: WG7 Electronic chart display and information system (ECDIS) and WG9 Integrated bridge systems for ships. The latter group was responsible for the publication in April 1999 of IEC 61209 'Maritime navigation and radio communication equipment and systems – Integrated bridge systems (IBS) – operational and performance requirements, methods of testing and required test results'. This document covers features such as: data exchange, displayed information, system configuration, human factors, alarms, training facilities, power supplies and failure analysis. This latter point is doubly important as it has implications in other areas such as training facilities.

6.4 Nautical safety

All aspects of bridge operation have evolved because of the requirement for the safety of the ship, crew and, where applicable, the passengers. The safety philosophy is encapsulated within the rules of Det Norske Veritas (DNV) and the following is reproduced from the DNV rules, part 6, chapter 8 with their kind permission.

6.4.1 Safety philosophy

To achieve optimum safety and efficiency in bridge operation the rules address the total bridge system, which is considered to consist of four essential parts.

- The technical system which deduces and presents information as well as enabling the proper setting of course and speed.
- The human operator who is to evaluate available information, decide on the actions to be taken and execute the decisions.
- The man/machine interface which safeguards that the technical system is designed with due regard to human abilities.
- The procedures which shall ensure that the total bridge system performs satisfactorily under different operating conditions.

6.4.2 Scope of rule requirements

These are set out in each section of the Rules for Nautical Safety and reflect the different factors that affect the performance of the total bridge system and are intended to regulate the following areas.

- Design of workplace, based on the analysis of functions to be performed under various operating conditions and the technical aids to be installed.
- Bridge working environment, based on factors affecting the performance of human operators.
- Range of instrumentation, based on information needs and efficient performance of navigational tasks.
- Equipment reliability applicable to all types of bridge equipment, based on common requirements to ensure their suitability under various environmental conditions.
- Specific requirements to different types of bridge equipment, based on the facilities required for the performance of their specific functions.
- Man/machine interface, based on the analysis of human limitations and compliance with ergonomic principles.
- Qualifications, based on the competence required for mastering rational navigational methods and relevant technical systems installed on board the ship.
- Operating procedures, based on the work organization needed to make the bridge system function under different operational situations.
- Information on the ship's manoeuvring characteristics, based on the manoeuvres commonly used in various operational situations.
- Tests and trials for new ships, based on the need to ensure that technical systems perform in accordance with their specifications before being relied upon and used in practical operation.
- Reporting system, from ships in service, on bridge instrument failures, based on the information needed to detect their factual reliability level.
- Survey schemes for ships in service, based on the follow-up and testing required to safeguard that bridge systems maintain their reliability.

6.5 Class notations

The Rules for Nautical Safety are divided into three class notations. Two class notations represent the minimum requirements within bridge design, instrumentation and procedures whereby NAUT-C covers bridge design and W1-OC, in addition, includes instrumentation and bridge procedures. The third class notation, W1, extends the basic requirements for bridge design and instrumentation and additionally requires information on the manoeuvring characteristics of the ship and an operational safety manual for safe watchkeeping and command of the ship.

NAUT-C covers bridge design, comprising the following main areas:

- mandatory and additional workstations
- field of vision from workstations
- location of instruments and equipment.

W1-OC covers bridge design, instrumentation and bridge procedures comprising the following main areas:

- NAUT-C
- range of instrumentation
- instrument and system performance, functionality and reliability
- equipment installation
- monitoring and alarm transfer system
- procedures for single-man watchkeeping.

W1 covers W1-OC and extensions within the following areas of W1-OC:

- design of one-man workstation
- field of vision astern
- range of instrumentation
- instrument performance
- automation level
- qualifications.

Also covered is information on the manoeuvring characteristics of the ship comprising the following main items:

- speed at different settings
- steering ability
- turning ability
- stopping ability.

There is also a requirement for an operational safety manual comprising the following main items:

- bridge organization and responsibilities
- watchkeeping procedures
- system fall-back procedures
- accident and emergency procedures.

6.6 Bridge working environment

Ships requesting class notation NAUT-C, W1-OC or W1 should comply with rules for bridge working environment which specifies vibration levels, noise, lighting, temperature, ventilation, surfaces, colours and the safety of personnel.

6.6.1 Equipment carriage requirements

Ships requesting class notation W1-OC are equipped with the following systems:

- course information systems (two gyrocompasses or one gyro + one TMC)
- steering systems (manual and automatic steering)
- speed measuring system (water speed, > 40 000 tons gross, dual axis)
- depth measuring system (over 250 m length, two transducers)
- radar systems (two radars, at least one X-band)
- traffic surveillance systems (ARPA)
- position fixing systems (Loran-C, GPS)
- watch monitoring and alarm transfer system
- internal communication systems
- nautical safety radio communication systems
- sound reception system (technical device to receive signals).

Additional equipment required for class notation W1 includes:

- steering system with rate of turn indicator
- course information system, which should have two independent gyrocompasses
- speed measuring system, through the water, which should provide information for traffic surveillance system
- Electronic Chart Display and Information System (ECDIS)
- Automatic Navigation and Track-keeping System (ANTS)
- conning information display
- central alarm panel
- wind measuring system.

6.6.2 General bridge equipment requirements

The rules specify the following:

- environmental conditions
- location and installation of equipment
- electrical power supply, alarms, performance confirmation and failure protection
- computer-based systems and software quality.

6.6.3 Specific requirements for different types of bridge equipment

Ships requesting class notation W1-OC shall comply with specific requirements for the following systems:

- course information system (speed and latitude correction)
- steering systems (manual override control and rate of turn display)
- speed measuring system (if bottom track then up to 200 m depth)
- depth measuring system
- radar systems (two floating EBLs, interswitch, ship track monitoring)
- traffic surveillance systems (ARPA with two guard zones)
- position fixing systems (performance standards)
- watch monitoring and alarm transfer system
- internal communication systems
- nautical communication systems
- sound reception system.

Class notation W1 requires in addition the following systems:

- Electronic Chart Display and Information System (ECDIS)
- Automatic Navigation and Track-keeping System (ANTS)
- conning information display
- central alarm panel.

6.6.4 Man/machine interface

Ships requesting class notation W1-OC or W1 must comply with the rules in this section. All instruments must be logically grouped according to their functions within each workstation. Their location and design should give consideration to the physical capabilities of the human operator and comply with accepted ergonomic principles. The amount of information to be presented for conducting the various tasks, as well as the methods of displaying the information needed, should give consideration to the capabilities of the human operator to understand and process the information made available. The rules specify the following:

- instrument location and design
- illumination and individual lighting of instruments
- requirements for the man/machine dialogue of computer-based systems.

6.7 Ship manoeuvring information

Ships requesting class notation W1 must comply with rules for manoeuvring information. Information about the ship's manoeuvring characteristics, enabling the navigator to safely carry out manoeuvring functions, shall be available on the bridge. This section deals with: the manoeuvring information to be provided, and the presentation of the manoeuvring information.

The provision of manoeuvring information should include:

- speed ability
- stopping ability
- turning ability
- course change ability
- low-speed steering abilities
- course stability
- auxiliary manoeuvring device trial
- man-overboard rescue manoeuvre.

The presentation of manoeuvring information should include:

- pilot card
- wheelhouse poster
- manoeuvring booklet.

6.8 Qualifications and operational procedures

Class notation W1-OC specifies responsibilities of shipowner and ship operators, qualifications and bridge procedures. Class notation W1 has extensions to responsibilities, qualifications, bridge procedures, and a special requirement for operational safety standards.

6.8.1 Operational safety manual

This is a requirement for class notation W1 to obey the following guidelines.

1 Organization:
- general
- bridge organization
- responsibilities of shipowners and ship operators
- responsibilities of the master
- responsibilities of the officer in charge of single-man watchkeeping
- qualifications of bridge personnel
- manning
- safety systems – maintenance and training.

2 Daily routines:
- general
- look-out
- changing of the watch
- periodic checks of navigational equipment
- log-books
- communications and reporting.

3 Operation and maintenance of navigational equipment:
- general
- radars/ARPA
- automatic pilot
- gyro and magnetic compasses
- echo sounder
- speed/distance recorder
- electronic position fixing aid
- electronic navigational chart
- automatic navigation and track-keeping system
- hydrographic publications
- emergency navigation light and signal equipment.

4 Departure/arrival procedures:
- general
- preparation for sea
- preparation for arrival in port
- embarkation/disembarkation of pilot
- master/pilot information exchange.

5 Navigational procedures:
- general
- helmsman/automatic pilot
- navigation with pilot embarked
- navigation in narrow waters
- navigation in coastal waters
- navigation in ocean areas
- navigation in restricted visibility
- navigation in adverse weather
- navigation in ice
- anchoring.

6 System fall-back procedures:
- general
- bridge control/telegraph failure
- gyrocompass failure
- steering failure
- auxiliary engine failure
- main engine failure.

6.8.2 Contingency and emergency manual

1 Contingency and emergency organization:
- general
- duties and responsibilities.

2 Accident procedures:
- general
- collision
- grounding
- fire/explosion
- shift of cargo
- loss of buoyancy/stability.

3 Security procedures:
- general
- sabotage threat/sabotage
- hijacking threat/hijacking
- piracy
- local war situation
- criminal act committed on board
- detention/arrest.

4 Emergency procedures:
- general
- emergency notification
- abandon ship preparations
- lifeboat evacuation
- helicopter evacuation
- use of other evacuation equipment.

5 Miscellaneous:
- general
- dead or injured person aboard
- man overboard
- search and rescue actions
- stowaways
- political refugees
- missing or lost person
- documentation and reporting
- press releases.

6.9 Bridge equipment tests

Ships requesting class notation W1-OC or W1 must comply with rules for equipment tests. After installation of equipment, on-board testing shall be performed in order to ascertain that the equipment, as installed, operates satisfactorily.

It should be noted that reliable figures for all aspects of equipment performance/accuracy cannot be established by the on-board testing required for classification. Hence, to ensure that equipment performance is in accordance with specifications, shipowners are advised to choose equipment that is type approved.

A detailed test programme for the on-board testing of equipment should be submitted for approval at the earliest possible stage before sea trials. The following systems are tested according to general requirements for testing of equipment:

- gyrocompass
- automatic steering system
- rudder indicator(s)
- rate-of-turn indicator
- speed log
- echo sounder
- radar system
- ARPA system
- electronic position fixing systems
- watch monitoring and alarm transfer system
- internal communication systems
- nautical communication system
- sound reception system
- computer system(s)
- Electronic Chart Display and Information System (ECDIS)
- Automatic Navigation and Track-keeping System (ANTS)
- conning display.

6.10 Examples of integrated bridge systems

A variety of manufacturers offer a range of integrated bridge systems that can be tailored to fit the requirements of the user. Some of these systems will be described in this section. The systems selected come from leading manufacturers in this field.

6.10.1 Voyager by Furuno Electric Co. Ltd

An automatic navigation system designed by Furuno to meet the requirements for one-man bridge operation and the new ECDIS standards is the Voyager Integrated Bridge System. The system was designed to meet the class notation W1-OC of DNV, Norway. The system is modular which allows it to be set up to meet the requirements of the user and to provide capability for future expansion of the system as necessary. The complete system requirement comes from a single supplier with the claimed benefits of:

- increased safety
- increased cost-effectiveness
- increased navigation efficiency.

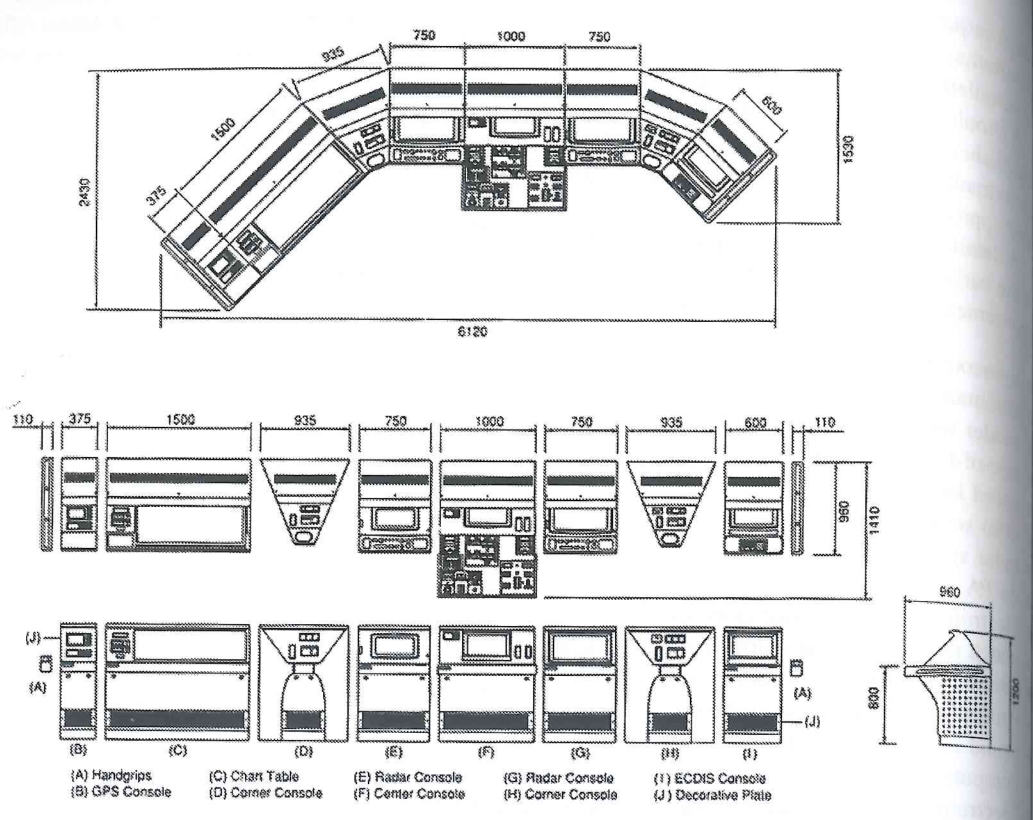


Figure 6.2 Components of the Voyager integrated bridge system. (Reproduced courtesy of Furuno Electric Co. Ltd.)

The modular nature of the system components can be seen from Figure 6.2 which shows a possible bridge layout using the Voyager system. Figure 6.3 shows one module, that of the ARPA/Radar which is module E/G in Figure 6.2.

Main functions of Voyager

There are three main functions of the system:

- electronic chart display and user interface
- position calculation and track steering
- automatic steering of the vessel.

Each of the main functions is performed using an individual processor as indicated in Figure 6.4. This guarantees real time data processing for critical applications such as positioning and steering.

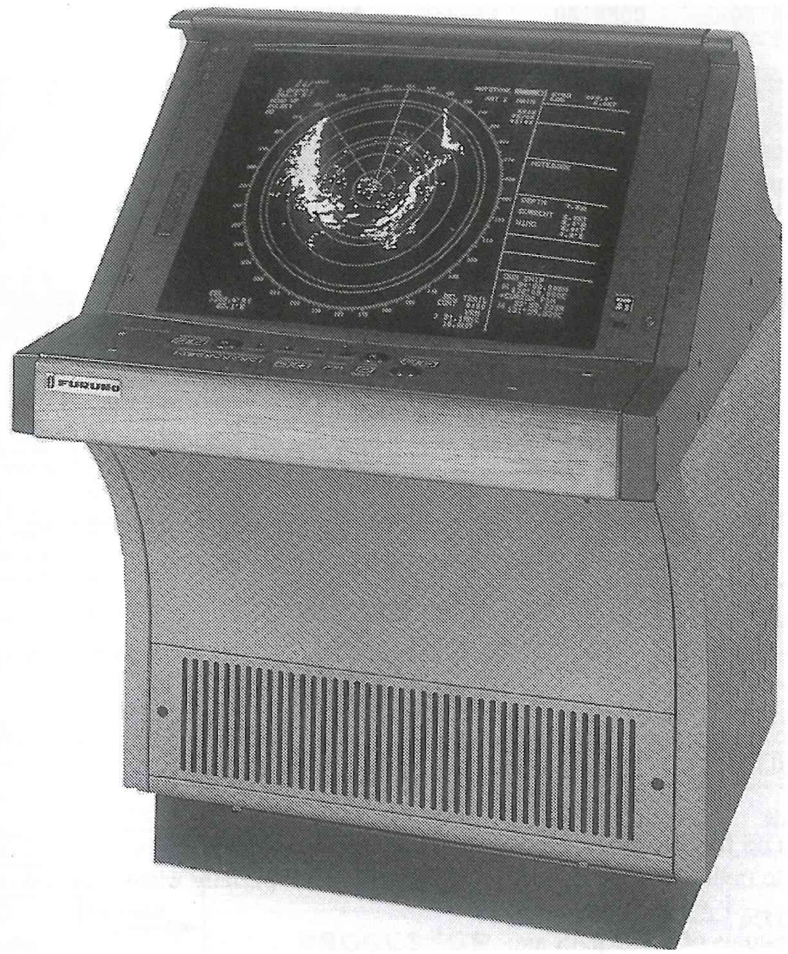


Figure 6.3 Voyager ARPA console. (Reproduced courtesy of Furuno Electric Co. Ltd.)

The system has built-in dual displays to satisfy the requirement for separate ECDIS and conning monitors. The ECDIS monitor provides the main display and user interface for the navigation system, while the conning monitors display the most important navigational sensor data in a graphical form, i.e. gyrocompass, speed log etc.

The navigation system is operated through a control panel that has dedicated function and execute keys for fast, easy operation. The steering functions are performed on their own operation control panel that integrates all functions for automatic steering. A block diagram that shows these control panels and also indicates all inputs to the navigation and track-keeping processor is shown in Figure 6.5. Figure 6.5 also indicates the type of interface connection that exists between a particular sensor and the processor.

Electronic chart display and user interface

For this system the electronic chart functions are designed to meet the performance standards for the ECDIS as laid down by the IMO and the IHO. More details on these requirements can be found in

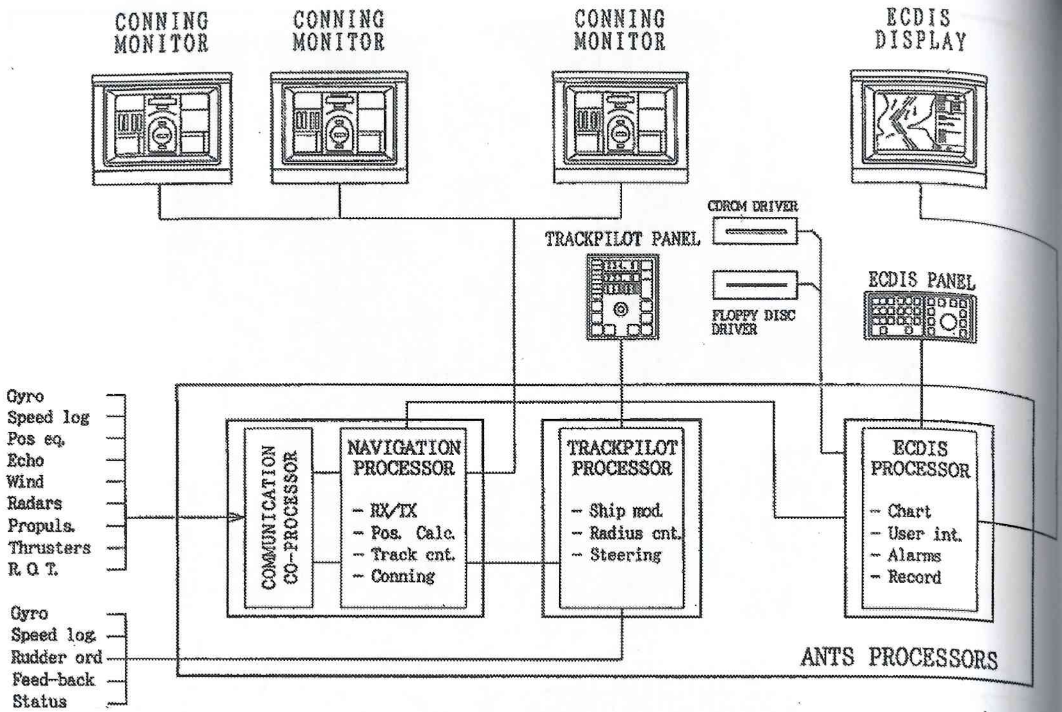


Figure 6.4 Block diagram of the Voyager integrated bridge system. (Reproduced courtesy of Furuno Electric Co. Ltd.)

Chapter 7. ECDIS functions are performed on their own computer unit, housed in the same electronic cabinet, so as to optimize graphical performance and cost, especially when a second chart display is necessary.

The main features of the ECDIS are:

- presentation of an electronic version of a sea chart, based on the latest ENC format using a 21- (or 29-) inch high resolution colour display
- multiple navaid interface for GPS/DGPS, gyrocompass, speed log, echo-sounder etc.
- capable of use with both ENC and ARCS
- route planning and route monitoring
- primary and secondary route planning facilities
- grounding warnings
- user generated navigational safety lines which are overlaid on the radar screen
- user selectable chart layer presentation
- navigational tools such as VRM, EBL, track-ball
- display of ARPA targets
- voyage recording to meet standards
- user generated information note-books
- display of alarms
- MOB and event functions
- dedicated function keys for scale up/down, standard display, TM-reset and other functions which are the most often used functions.

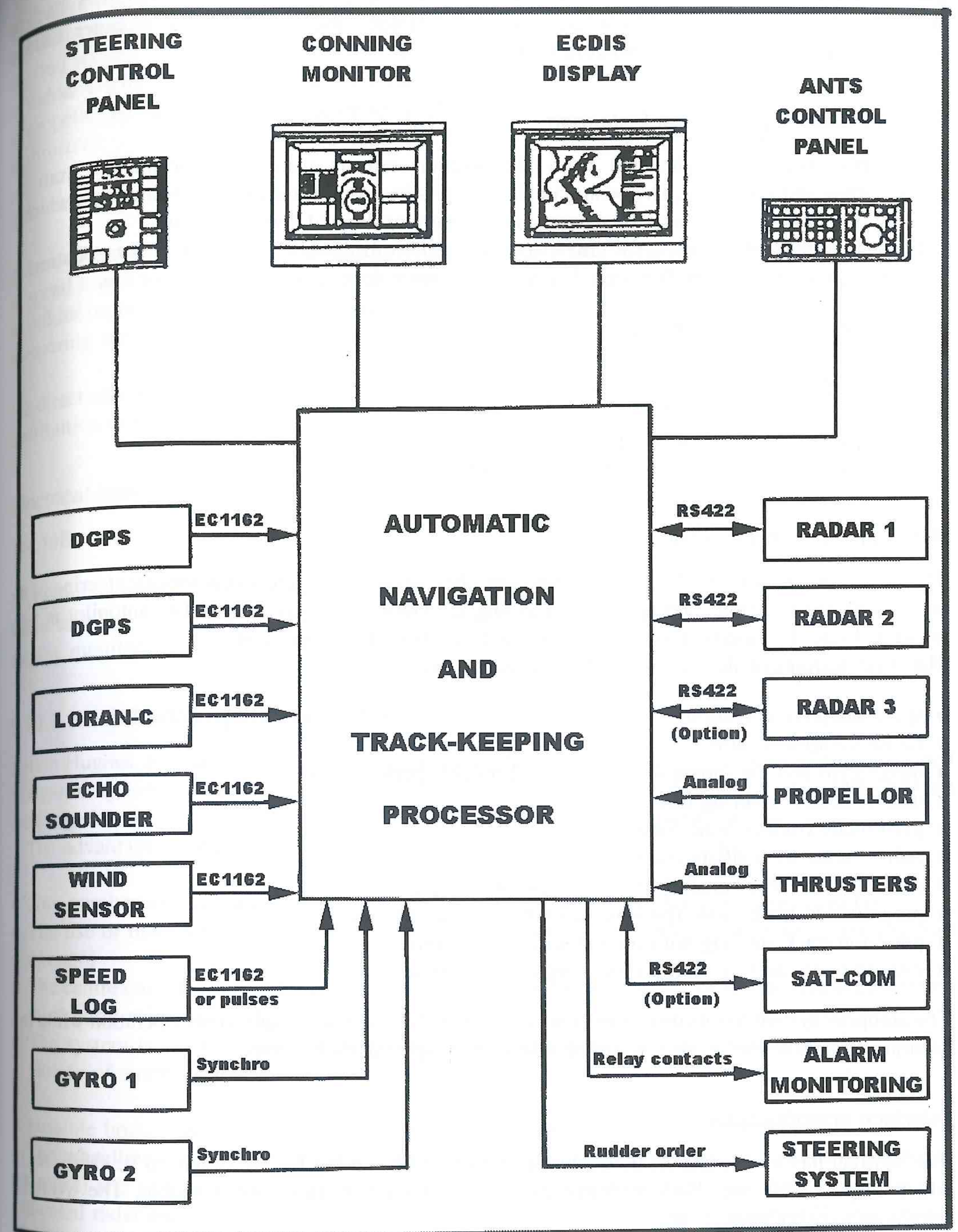


Figure 6.5 Block diagram of Voyager automatic navigation and track-keeping system (ANTS). (Reproduced courtesy of Furuno Electric Co. Ltd.)

The option of fitting a second ECDIS computer and display, to meet the required back-up arrangements in case of an ECDIS failure, is available. If fitted, the second ECDIS computer is linked to the first through a local area network (LAN).

Position calculation and track steering

The ship's position is calculated from the position sensors using the information from the gyrocompass and speed log. The position calculation is based on Kalman filter technology, which is capable of using different types of sensors and in operator-defined configurations.

Because of the need to allow for time-critical operations in position calculation and track steering, a separate processor is used for these functions. The main features of this processor are:

- interface to all external devices
- position calculation based on Kalman filter technology
- position quality calculation and alarm
- off-track calculation and alarm
- waypoint pre-warning and waypoint alarm
- graphical process and display for conning information.

Automatic steering function

The system includes a complete radius/track controlled autopilot for safe and automatic steering of the vessel with the functions and operations meeting the DNV-W1 requirements. The autopilot is fully integrated into the system allowing it to be easily controlled and operated.

The main features of the automatic steering system are:

- speed adaptive operation
- radius controlled turns
- direct gyro and log inputs for accurate and reliable performance
- user selectable steering modes
- gyro mode (rudder limit controlled)
- radius mode (immediate course change)
- programmed radius mode (programmed course change)
- programmed track mode (position referenced course change)
- precision track steering with pre-memorized waypoints
- relaxed track steering with pre-memorized waypoints.

The autopilot system has its own operation control panel for logical, simple to use operation while two separate operation control panels can be installed for special applications.

Interface specifications

The Voyager has a wide and flexible interface structure that allows for the system to be easily set up and configured for use. Both analogue and serial digital interfaces are available. The available interfaces to other systems are:

- gyrocompass: one analogue and one serial (NMEA) or two serial (NMEA)
- rate-of-turn gyro: analogue or serial (NMEA)
- speed log: pulse type or serial (NMEA)

- position receivers: up to five serial inputs (NMEA)
- echo sounder: serial input (NMEA)
- wind sensor: serial input (NMEA)
- rudder angle: analogue or serial (NMEA)
- propeller RPM/pitch: analogue or serial (NMEA)
- thrusters: up to four analogue inputs.

The autopilot interface requirements are:

- gyrocompass: two 1:1 synchros or high update rate serial inputs (NMEA)
- speed log: 200 p/nautical miles pulses or serial input (NMEA)
- rudder order: analogue output (0.25 V/degree) or solid-state solenoid outputs
- steering status: galvanically isolated contacts.

If a direct solenoid type of steering order is required then an optional feedback unit and solenoid drive distribution box is required.

Electrical specifications

The following supplies are required with battery back-up in case of supply failure:

navigation system	24 V d.c. supply (250 W approx.)
alarm supply	24 V d.c. supply (10 W approx.)
display monitors	230 V a.c. or 110 V a.c.

6.10.2 NINAS 9000 by Kelvin Hughes

Kelvin Hughes, the Naval and Marine division of Smiths Industries Aerospace, offer a fully integrated navigation system. Units from the Kelvin Hughes Nucleus Integrated Navigation System (NINAS) are used together with ancillary navigational equipment from specialist manufacturers.

The advantages claimed for the NINAS 9000 system include the following.

- Any number of auxiliary consoles can be added to the basic radar and navigation displays
- The use of modules gives flexibility in the final arrangement adopted by the ship owner and ship operator
- The centre consoles can be adapted to accept equipment from a number of Kelvin Hughes preferred third party suppliers
- The system is based around the proven nucleus2 6000 radar systems which are available with a variety of antennas and transmitters.

A possible bridge layout for a large passenger-carrying vessel is shown in Figure 6.6.

The wheelhouse layout consists of a centre-line steering console, two mid-position (manoeuvring and pilot) and two enclosed bridge wing consoles. The manoeuvring and pilot stations consist of a dedicated radar and a dedicated ECDIS/conning display, both being type approved CRT equipment. The centre-line station has two multifunctional LCD displays, which connect to any of three radar processors, for use as a remote operating station for either of the two ECDIS displays or as a remote operating station for any other function as required. The two stations at each wing bridge perform a similar function to that of the centre-line station.

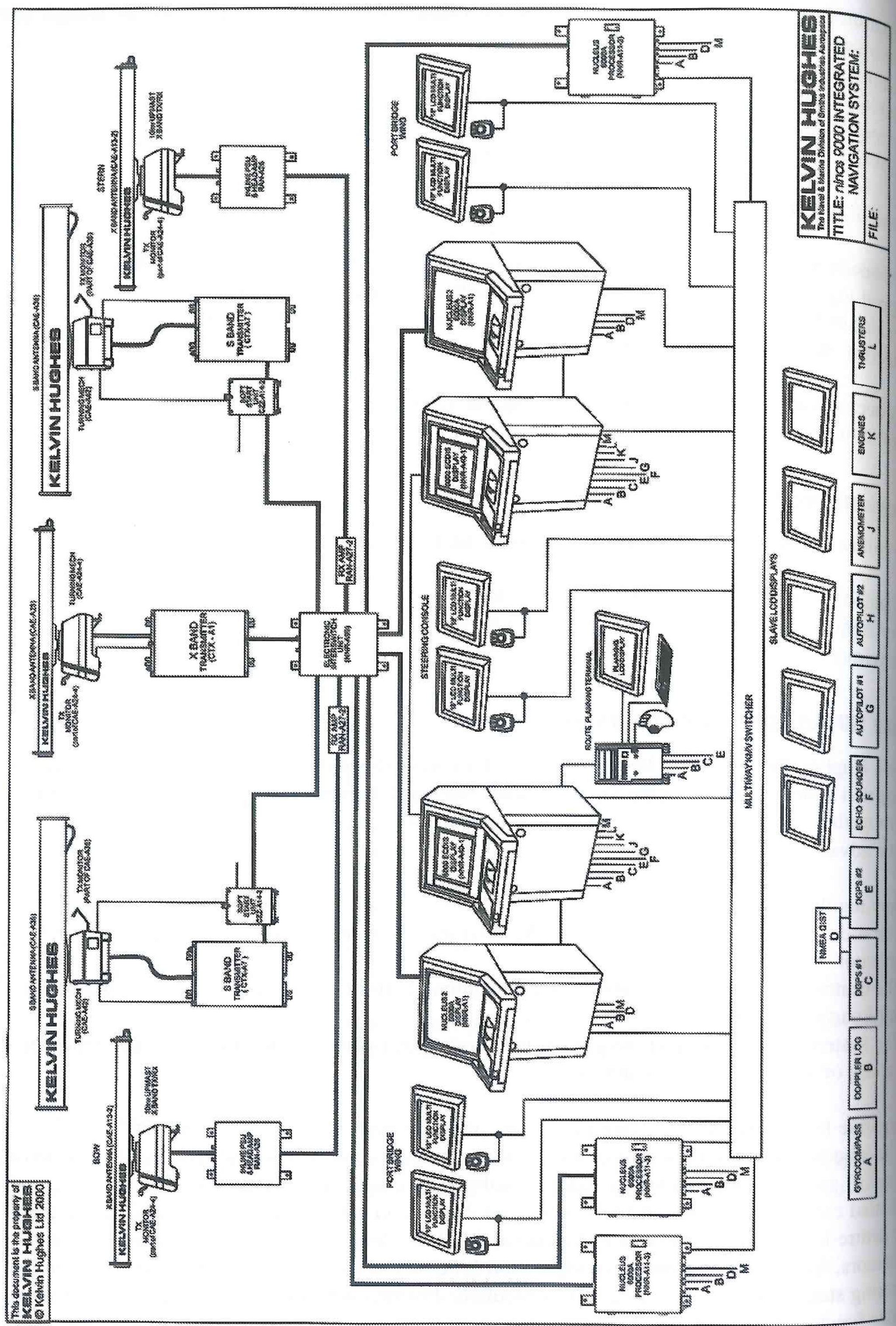


Figure 6.6 NINAS 9000 integrated bridge system. (Reproduced courtesy of Kelvin Hughes.)

Display systems

1 Radar displays

The two radar displays are 26-inch PPI, rasterscan ARPA radar displays with 10 range scales 0.25–96 nautical miles presented in relative motion, true motion and centred display true motion. There is auto tracking capability for up to 50 targets with a choice of manual or auto acquisition of targets using guard zones or footprint acquisition. The display has as standard parallel index lines, a flexible mapping system with a map storage capacity of 64K byte showing, for example, 100 maps of 80 elements.

The display has an interfacing capability of two RS232 bi-directional serial links and four NMEA opto-isolated inputs. The input capabilities are:

- GPS/Loran; waypoints; route; chart 'puck' position
- steering sequence; man overboard position; turning radius data
- serial link data from navigation display.

Output capabilities are tracker ball position and target data to ECDIS. A tracker ball and three buttons control all the radar display functions with external tracker-ball capability from each bridge wing.

2 ECDIS displays

The two ECDIS displays are IEC 1174 type approved 20-inch displays with the following functions.

- Operates with Windows-NT operating software with multi-window display showing S57 ed.3 ENC vector charts and/or ARCS/NOAA (BSB) raster charts. These may be viewed simultaneously or independently in variably sized windows.
- Graphic overlay of ownship symbol, route, waypoints, target vectors and trails on chart.
- Radar interlay of radar target echoes on chart. The interlay technique places the radar information video plane below that of the overlay to avoid obstruction of essential information.
- The ECDIS display can also act as a slave radar display by having its own radar video processing functions that allow independent control of the radar image on the ECDIS.
- North-up, course-up and head-up ENC chart presentation.
- Route safety zone function which provides a three-dimensional guard zone around own ship to monitor ship draft against chart depths and ships air draft against chart clearances to improve safety when on passage or route planning.
- Automatic plotting of time on chart with plot-on-demand function for special events.
- Passage calculator that allows route planning from the ECDIS screen. This allows calculation of distances, ETA, required speed for specific ETA and other navigational computations. This may be carried out locally or at a networked optional route planning workstation.
- Planning may be carried out visually with waypoints being dragged to modify legs and to allow the route to pass around obstacles.
- Uses ENC chart embedded database for interrogation feature, which allows the operator to request pop-up window information for any buoy, light etc. Also menu selection allows ECDIS or traditional chart symbols to be viewed for buoys and lights. There are six ENC colour palettes for optimal viewing in all light conditions.
- Continuous display of own ship heading, speed, position and depth on right side of the screen.
- Automatic Navigation and Tracking System (ANTS) interface to autopilot, allowing automated route sailing and constant radius turns.
- ECDIS display may be controlled either from the local tracker ball and three-button screen control unit (SCU) or from the remote display.

Additional functions within the ECDIS systems include a conning display, featuring the display of real-time vessel's position upon the chart in use, while displaying navigational and dynamic data in side panels. Data displayed includes:

- position
- heading
- speed (dual axis)
- depth
- wind (true and relative)
- route data
- engine RPM
- engines and thrusters.

3 Centre line console multi-function displays
Two 20-inch LCD displays that are capable of operating in the following modes.

- Fully independent radar displays capable of controlling any one of the five main radar transmitters.
- Remote radar displays capable of controlling any one of four main radar transmitters via another display (in the event of failure of the unit's own processor).
- Remote ECDIS/Conning display.

Additional functions that could also be allowed include:

- CCTV
- control and command monitoring
- alarm monitoring.

4 Bridge wing multi-function displays
Two 18-inch LCD displays that are capable of operating in the following modes.

- Fully independent radar displays capable of controlling any one of the five main radar transmitters.
- Remote radar displays capable of controlling any one of four main radar transmitters via another display (in the event of failure of the unit's own processor).
- Remote ECDIS/conning display.

Additional functions that could also be allowed include:

- CCTV
- control and command monitoring
- alarm monitoring.

5 Route planning terminal
A 17-inch LCD display with a dedicated processor designed in the same manner as an IEC 1174 type approved ECDIS display. The route planning terminal is installed as a slave unit to allow off-line route planning at the chart table position. The unit includes dedicated interfaces to log, gyro and GPS to allow it to act as a back-up ECDIS in the event of failure of the main units. Features are as for the type approved ECDIS, with the exception of radar interlay and target data.

Other components of the total system include the following.

- *Radar transmission system*. This comprises a five-way interswitched X and S band system allowing independent control of individual systems and complete interswitching of all radars.
- *Autopilot and steering system*. A system with full ANTS functionality when connected to the ECDIS. The system has inputs for both gyrocompass and magnetic compass heading data. During the normal operating mode the headings from both gyrocompass and magnetic compass are produced in the independent course monitor. In the event of a gyrocompass failure all major receivers of the gyrocompass heading, such as radar, Satcomm, GPS and digital repeaters, can be switched over immediately to the heading from the magnetic compass from the course monitor.
- *Gyrocompass system*. This is a microprocessor-controlled digital system designed as a single unit with control and display unit in the front cover. The control and display unit can be removed from the housing and installed at a position (e.g. a bridge console) remote from the gyrocompass. The gyrocompass has an integrated TMC function, gives a rate-of-turn (ROT) output, has seven independent RS 422 and NMEA 0183 serial outputs and complies with DNV-W1.
- *Magnetic compass*. The system includes aluminium alloy binnacle, magnetic flat glass compass, a fluxgate pick-off with an integrated sine/cosine interface, bypass arrangements, azimuth devices, electronic compasses, and magnetic compass autopilots (TMC). Variation correction, gyro/TMC changeover etc. is incorporated in the gyrocompass monitor/changeover system. System uses gyro repeaters for indication when TMC is selected at the compass monitor.
- *Dual axis Doppler log*. The log is a two-axis system, the data obtained from the speed log is longitudinal and transversal bottom-track speed and depth, and longitudinal water-track speed. The log provides simultaneous W/T and B/T speeds of ±30 knots with 0.1 knot scale and depth. Bottom-track speed and depth are displayed from 3 to 300 m. Data from the log is transmitted to the log processing unit (LPU) which serves as a data concentrator/distributor in the system. The LPU is programmed according to the geometry of the ship and the position of the transducer. With this information the LPU computes transversal speeds of bow and stern. The system comprises two independent log systems each with a dedicated display at the chart table. Log selection for output to other repeaters, integrated bridge system etc. is via a selector switch at this position.
- *Echo sounder*. This unit can be operated as a single or dual frequency unit with up to four transducers. The display offers five basic ranges between 0 and 2000 m. The high resolution LCD display allows continuous observation of bottom recordings and shows all relevant navigation data. The display includes continuous indication of digital depth and range. Bottom alarm can be set at any required depth. The unit can store the last 24 h data together with the position so that a printout can be made if required.
- *DGPS*. The receiver automatically locates the strongest transmitting beacon station and lock on in seconds. In the case of signal loss it automatically switches over to an alternative station ensuring a strong signal at all times. A navtalk NMEA distribution unit is included which is fed with the output from both DGPS receivers and supplies 10 buffered outputs. In the event of failure of the primary DGPS the system automatically switches to the secondary.
- *Loran-C*. The system uses the Furuno LC-90 Mk-II receiver. Full details of this receiver can be found in Chapter 4.
- *Bridge alarm system*. This is a central alarm/dead man system which meets the highest current classification society bridge alarm specification. The system is capable of handling 40 opto-isolated switched inputs. Alarms are managed and displayed in order of priority. It is connected interactively to the integrated navigation system to allow the alarms to be repeated on the ECDIS.

6.10.3 Sperry Marine Voyage Management System – Vision Technology (VMS-VT)

The Sperry VMS-VT system, provided by Litton Marine Services, is a computer-based navigation planning and monitoring system which typically consists of two or more computer workstations connected by a local area network (LAN). A typical arrangement for a VMS-VT system is shown in Figure 6.7.

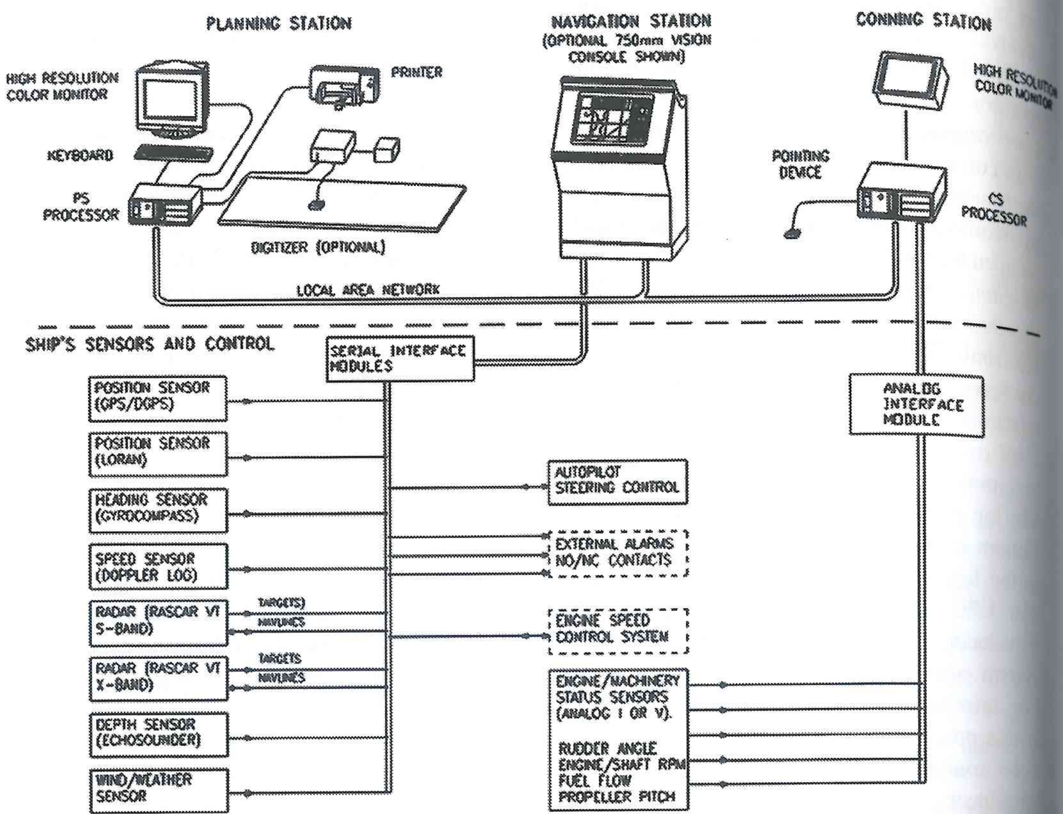


Figure 6.7 Typical arrangement for the Voyage Management System – Vision Technology (VMS-VT). (Reproduced courtesy of Litton Marine Systems.)

Figure 6.7 shows three workstations, providing a navigation station, a planning station and a workstation designated as a conning station. The navigation station is usually located in the conning position. All VMS-VT functions are available at this station except chart digitizing and chart additions.

The planning station is usually located in the chart room and has a high-resolution monitor and printer which can provide hard copies of voyage data. Separating the planning station from the navigation station allows an operator to effect voyage planning or chart editing at the planning station without interfering with conning operations at the navigation station. The display at the navigation station is also available at the planning station so that the ship's position can be monitored at either location. A typical VMS-VT main display is shown in Figure 6.8.

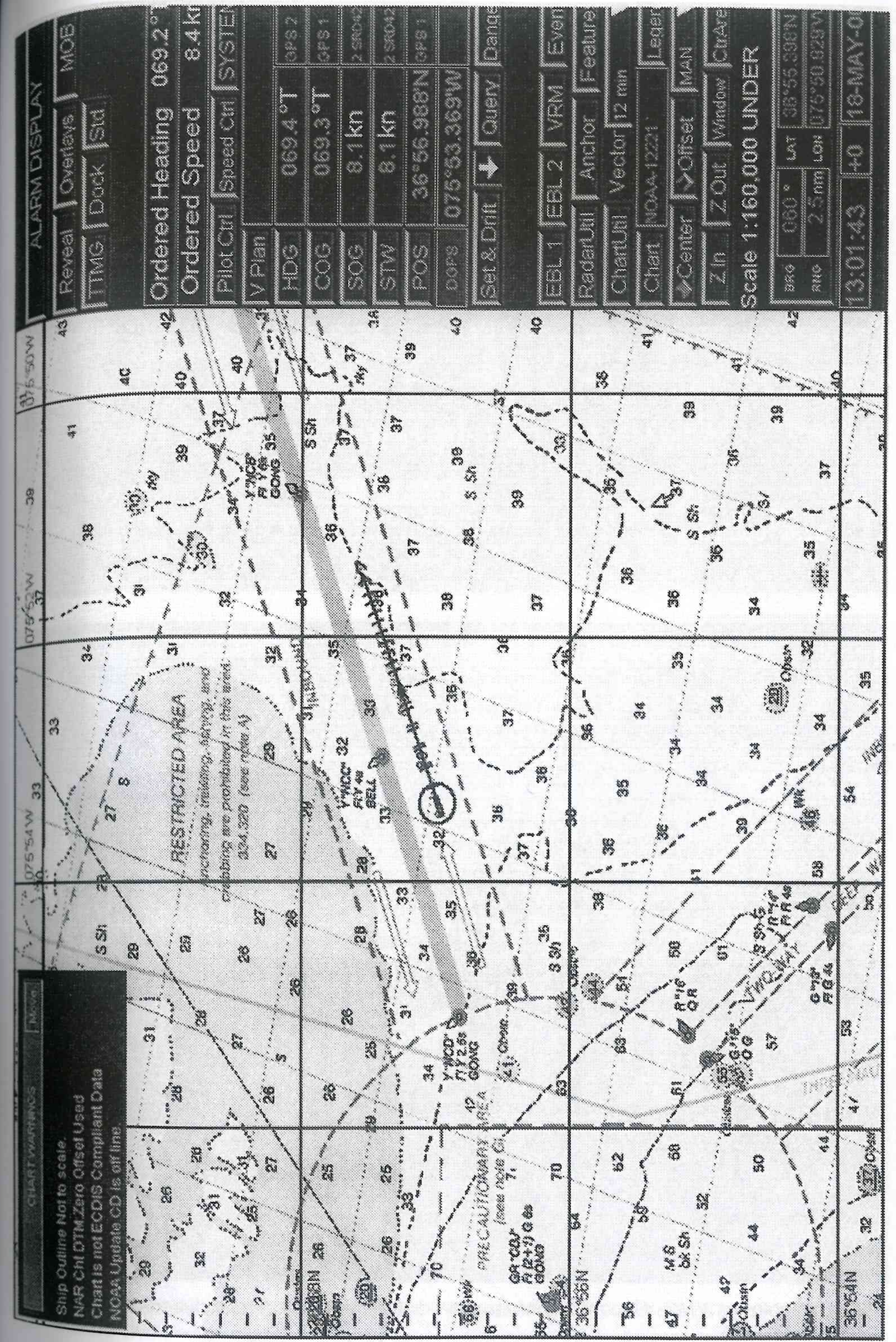


Figure 6.8 VMS-VT main display screen showing own ship's position, heading and speed using an electronic chart. (Reproduced courtesy of Litton Marine Systems.)

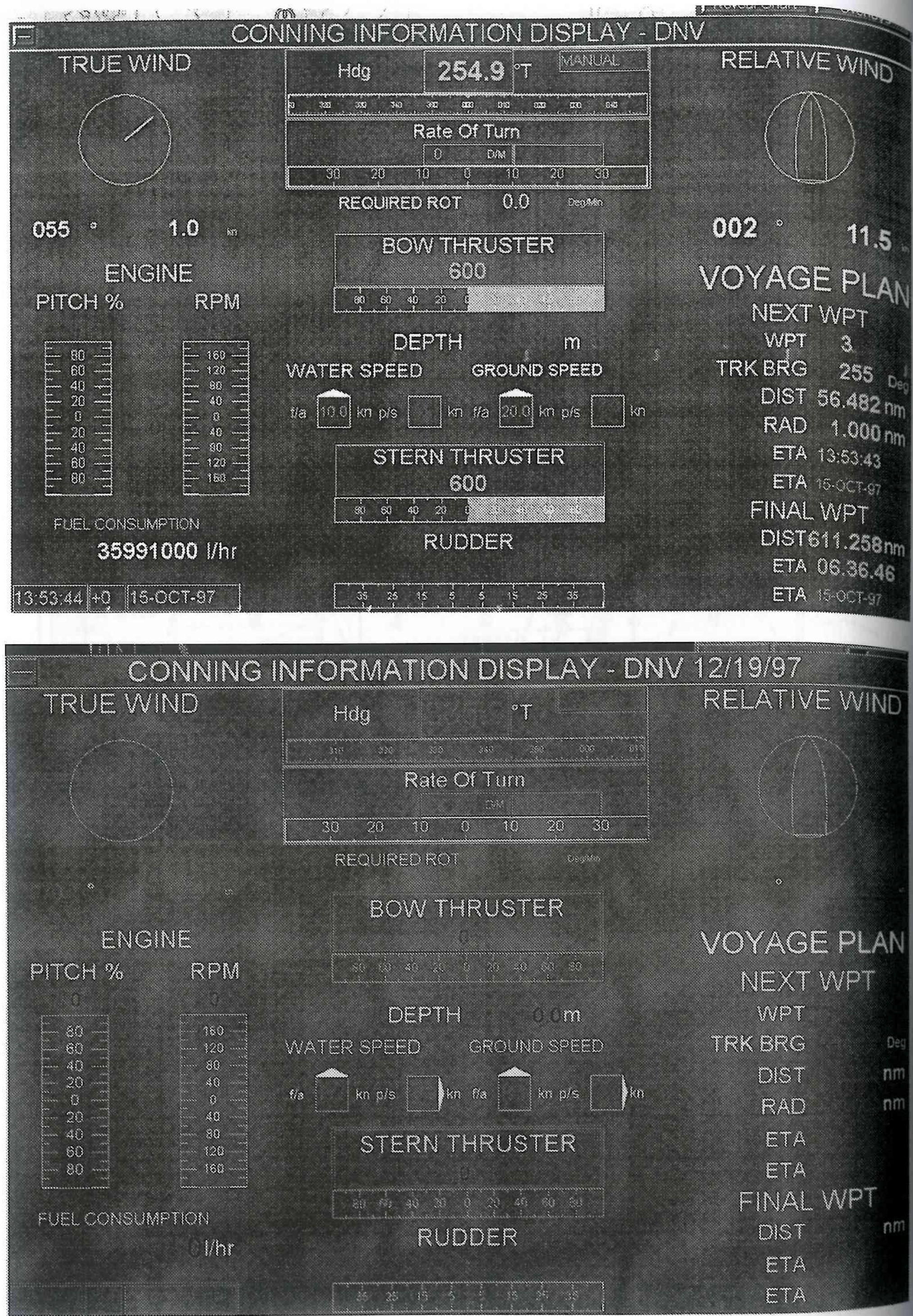


Figure 6.9 Examples of VMS-VT conning information display screens. (Reproduced courtesy of Litton Marine Systems.)

The conning station is usually configured to display a single page of specific navigation data as specified by regulatory group requirements. For this arrangement a pointing device is not provided since the display is non-interactive. At the conning station the screen is known as the conning information display (CID). Where possible the navigational and meteorological digital data is presented on the CID screen graphically to mimic analogue instruments in order to make it easier for an operator to assimilate and manage data quickly. The data presented is updated continuously and has a fixed layout pattern so that particular data is always available at the same location. A similar CID page is often available as a large display overlay screen at the VMS-VT navigation station and planning station (see Figure 6.9).

DNV on the screen displays of Figure 6.9 refers to the classification society Det Norske Veritas, Norway.

An engineering information display, as shown in Figure 6.10, can be provided as a display overlay screen at the VMS-VT navigation station and planning station or as a full-screen display at a dedicated monitor. The system can also be configured to display other pages such as a performance monitor window as shown in Figure 6.11.

As Figures 6.9–6.11 indicate, the main advantage of the VMS-VT system is its flexibility in presenting information that can be displayed in a manner that meets the customer's requirements.

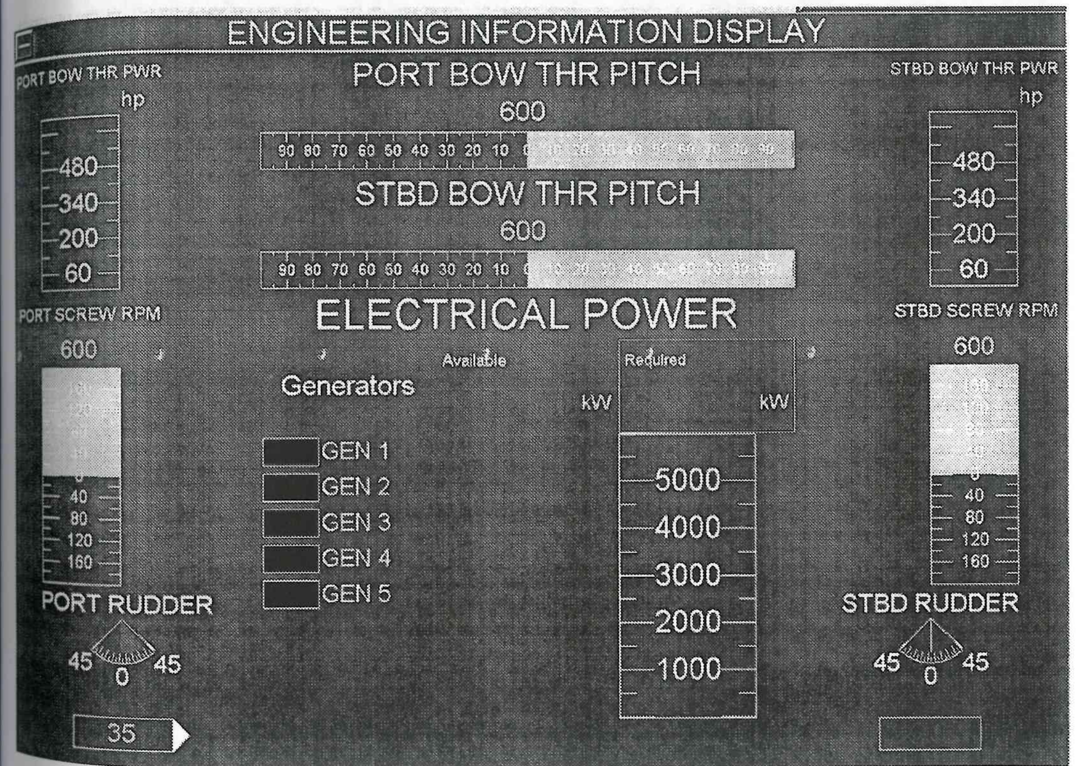


Figure 6.10 Example of VMS-VT engineering information display screen. (Reproduced Courtesy of Litton Marine Systems.)

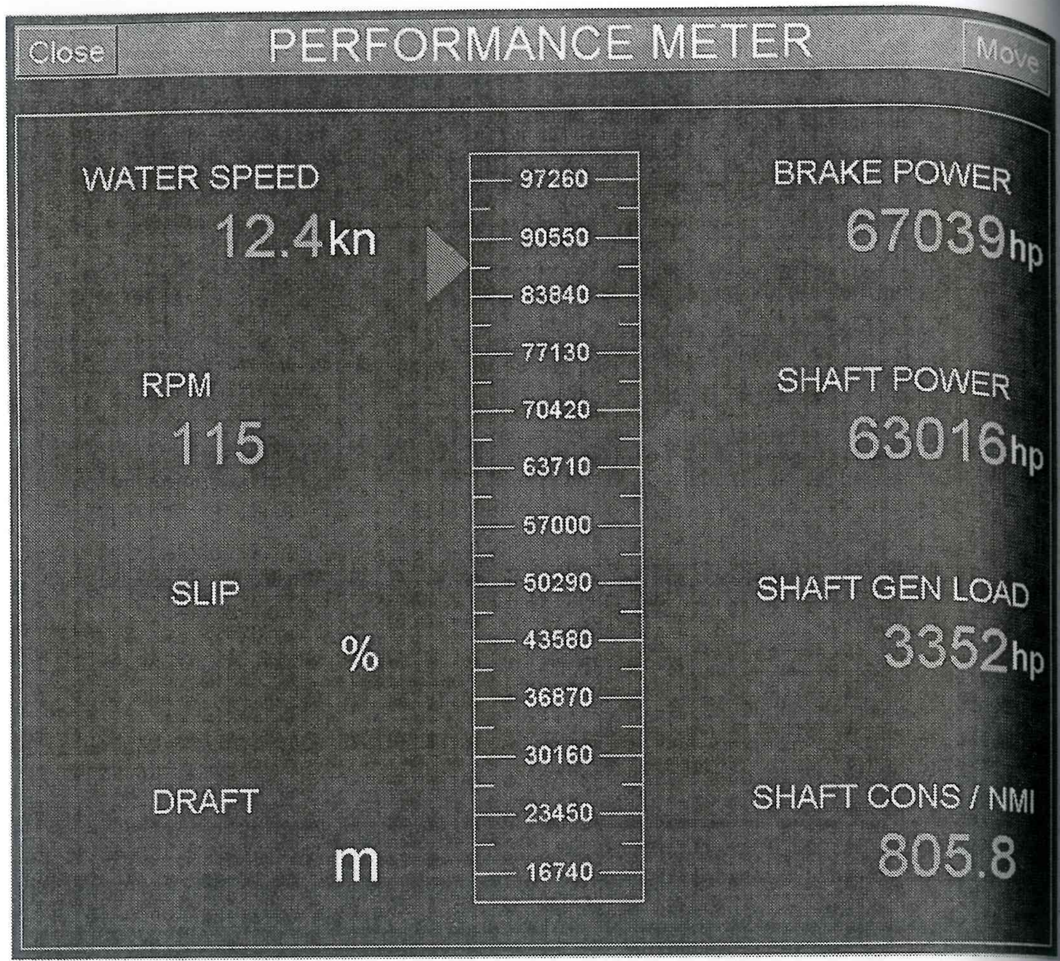


Figure 6.11 Example of VMS-VT performance monitor window. (Reproduced courtesy of Litton Marine Systems.)

Basic VMS-VT functions include:

- integration of data from various sensors
- data sharing on a local area network (LAN)
- display of real-time sensor information
- display of electronic charts with ownship position
- creation of a voyage plan
- execution of a voyage plan
- display of electronic bearing lines (EBLs)
- display of variable range markers (VRMs)
- comprehensive alarm and operator message system
- printing of ship's navigation data.

Optional VMS-VT functions include:

- autopilot control
- speed order control
- display of radar target information
- DNV certified track keeping
- ECDIS S-57 or digital navigational chart (DNC) display
- interface to voyage recorder
- creation and editing of charts using the digitizer or chart additions editor
- providing data to docking displays
- providing precision manoeuvring displays
- man overboard display
- providing data to a conning station
- display of engine room data
- display of meteorological data.

Computers required for essential and important functions are only to be used for purposes relevant to vessel operation and the VMS-VT is normally configured to prevent the operator from installing or running any other application.

A VMS-VT application that includes some of the optional functions mentioned above is shown in Figure 6.12.

Among the displays shown in Figure 6.12 is an ECDIS that uses digital chart data to produce a chart display (see Chapter 7 for more information on ECDIS). The VMS-VT system has the capability to catalogue and display many types of chart formats including commercially available scanned charts produced by official hydrographic offices and/or commercially produced vector charts. Chart formats differ but VMS-VT can be configured at the factory or on the ship to use the chart format specified

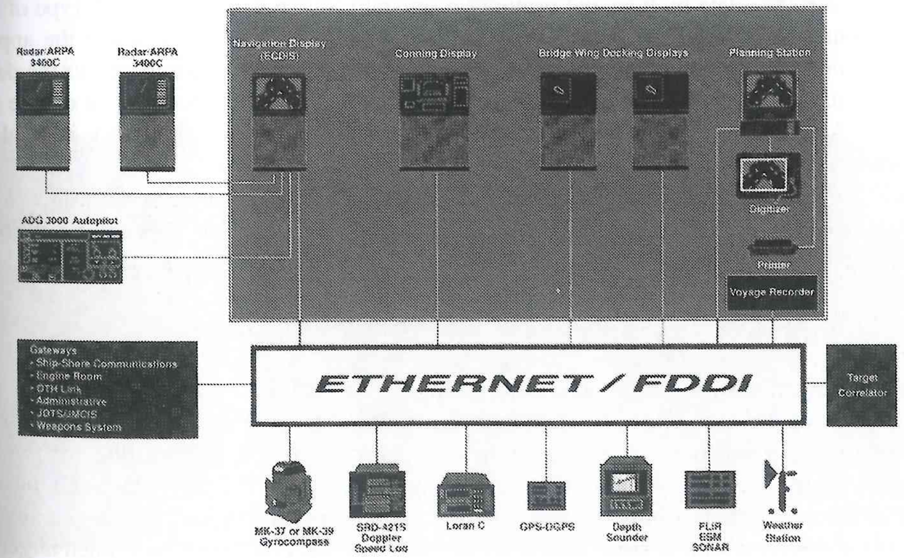


Figure 6.12 Block diagram of the VMS-VT system. (Reproduced courtesy of Litton Marine Systems.)

by the customer. Reference to Chapter 7 will show that an ECDIS must use an electronic navigational chart (ENC) which possesses a single universal data format and they must be 'official' charts in that they are issued on the authority of a government authorized hydrographic office.

Available chart formats include: S57 charts; NIMA (National Imagery and Mapping Agency) DNC charts; British Admiralty ARCS raster charts (BA charts); BSB format charts such as those issued by the National Oceanic and Atmospheric Administration (NOAA); and digitized charts. Electronic charts can be retrieved from CD-ROM disks or from the computer hard disk if the required chart has been stored there.

The VMS-VT Planning Station may include a digitizer pad so that staff can create electronic charts. The digitizer can also be used to edit these electronic charts when a published Notice to Mariners updates the corresponding paper chart. The charts are stored as individual files in the VMS-VT workstations. Those charts digitized at the planning station can be copied to floppy disks for back-up storage and for transfer between ships. A standard 1.44M byte floppy disk can hold about 20 detailed charts. The digitizer can also be used to create navlines with a latitude/longitude reference, which can be transferred and displayed on the RASCAR radars.

Sensor data integration and display

A major feature of the VMS-VT system is the ability to receive sensor data from the local area network and from direct hardware interfaces. The primary type of sensor data processed by the system is navigational information, which includes:

- heading
- speed over the ground
- speed through the water
- geographic position
- set and drift
- course over the ground.

The VMS-VT sorts the data by type and provides a separate source window for each type of data. To display the source window for a particular data type requires the operator to select the appropriate button on the main menu. Each source window lists a group of sensors appropriate to the data type. The present data from each sensor is included in the window so that the best source can be selected from the list. As an example the position source window, as shown in Figure 6.13, is displayed by selecting the POS button on the main menu.

The position source window provides a list of all the configured position sensors along with the present data from each sensor. The operator may select the desired source of position data from this list or may open source windows for other types of navigational data in a similar manner.

Radar target data

The VMS-VT system allows access and display of target information from multiple ARPA radars. The Litton Marine Systems RASCAR radar contains a target data logging switch for the target data logging option. If required, all the connecting RASCAR radars can send their target data allowing the operator to choose the source of ARPA target information. Radar data is automatically processed into a single target list so that if two radars have acquired the same target it will be displayed as one target at the VMS-VT. Symbols representing radar targets are displayed on the electronic chart. Each target symbol includes a speed vector, history dots and an identification number (ID).

A typical bridge layout with VMS-VT installed is shown in Figure 6.14.

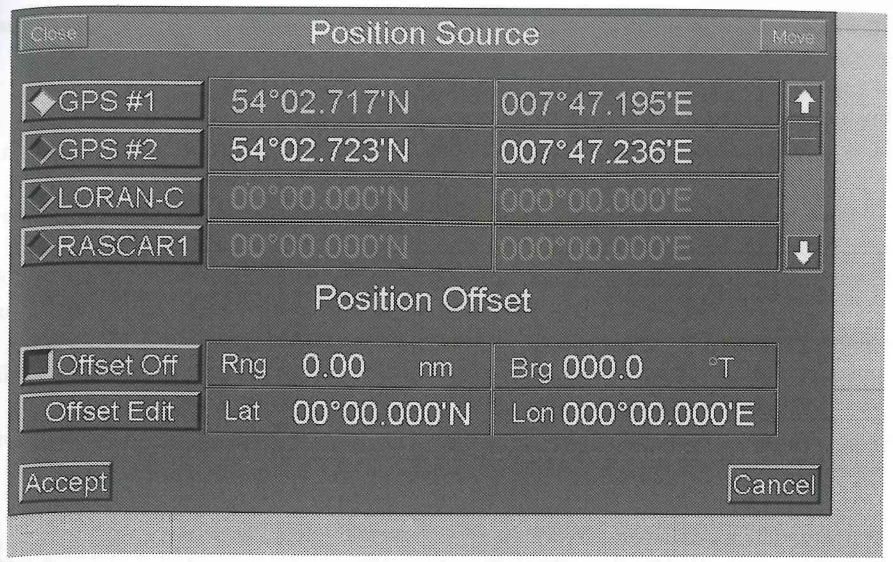


Figure 6.13 Example of VMS-VT position source window. (Reproduced courtesy of Litton Marine Systems.)

Figure 6.14 A typical integrated bridge VMS-VT installation. (Reproduced courtesy of Litton Marine Systems.)

6.11 Glossary

ABS American Bureau of Shipping.
AIS Automatic Identification System.
ANTS Automatic Navigation and Track-keeping System. A system which automatically keeps a ship along a safe pre-planned track.
ARCS Admiralty Raster Chart Service. The UKHO proprietary Raster Navigational Chart.
ARPA Automatic Radar Plotting Aid.
Bridge The area from which the navigation and control of the ship is managed.
Bridge system The total system required for the performance of bridge functions, including bridge personnel, technical systems, man/machine interface and procedures.
Bridge wing That part of the bridge on each side of the wheelhouse which extends to the ship's side.
CCTV Closed Circuit Television. A system that allows monitoring of positions remotely by using cameras and monitor screens.
Coastal waters Waters that encompass navigation along a coast at a distance less than the equivalence of 30 min of sailing with the relevant ship speed. The other side of the course line allows freedom of course setting in any direction for a distance equivalent to at least 30 min of sailing with the relevant speed.
Conning position A place on the bridge with a commanding view, which provides the necessary information and equipment for a conning officer (pilot) to carry out his functions.
Conning information display (CID) A display which clearly presents the state and/or value of all sensor inputs relevant to navigation and manoeuvring as well as all corresponding orders to steering and propulsion systems.
Display The means by which a device presents visual information to the navigator.
DGPS Differential Global Positioning System.
DNV Det Norske Veritas. A member of IACS.
Docking Manoeuvring the ship alongside a berth and controlling the mooring operations.
EBL Electronic bearing lines.
ECDIS Electronic Chart Display and Information System. The performance standard approved by the IMO and defined in publications from the IHO (Special Publications S-52 and S-57) and IEC document 1174.
ENC Electronic Navigational Chart. Those charts, manufactured for use with ECDIS, which meet the ECDIS performance standards and are issued by or on the authority of government-authorized hydrographic offices.
Ergonomics Application of the human factors implication in the analysis and design of the workplace and equipment.
ETA Estimated time of arrival.
GMDSS Global Maritime Distress and Safety System.
GNSS Global Navigation Satellite System. The use of GPS for civilian purposes.
GPS Global Positioning System. A satellite navigation system designed to provide continuous position and velocity data in three dimensions and accurate timing information globally.

Helmsman The person who steers the ship when it is under way.
IACS International Association of Classification Societies. Classification embodies the technical rules, regulations, standards, guidelines and associated surveys and inspections covering the design, construction and through-life compliance of a ship's structure and essential engineering and electrical systems.
IEC International Electrotechnical Commission. The organization which produces world standards in the area of electrical and electronic engineering.
IEC TC80 A technical committee of the IEC that covers the area of Marine Navigation and Radio Communication Equipment and Systems.
IHO International Hydrographic Organization. A grouping of national hydrographic offices responsible for promoting international standards in the fields of hydrographic surveying and chart production.
IMO International Maritime Organization. A specialized agency of the United Nations and responsible for promoting maritime safety and navigational efficiency.
ISO International Standards Organization. A non-governmental organization working to produce international agreements that are published as International Standards.
ITU International Telecommunications Union.
LAN Local area network.
LCD Liquid crystal display. A form of display where the display elements are typically dark coloured alphanumerics on a grey screen. The display is easily read even in bright light conditions.
MOB Man overboard.
Narrow waters Waters that do not allow the freedom of course setting to any side of the course line for a distance equivalent to 30 min of sailing with the relevant ship speed.
Navigation The determination of position and course of a ship and the execution of course alterations.
NMEA National Marine Electronics Association. An organization comprising manufacturers and distributors. Responsible for agreeing standards for interfacing between various electronic systems on ships. NMEA 0183 version 2.3 is the current standard.
Manoeuvring The operation of steering systems and propulsion machinery as required to move the ship into predetermined directions, positions or tracks.
Monitoring The act of constantly checking information from instrument displays and environment in order to detect any irregularities.
Ocean areas Waters that encompass navigation beyond the outer limits of coastal waters. Ocean areas do not restrict the freedom of course setting in any direction for a distance equivalent to 30 min of sailing with the relevant ship speed.
PPI Plan position indicator. A type of radar display.
Route planning Pre-determination of course and speed in relation to the waters to be navigated.
Route monitoring Continuous surveillance of the ship's position and course in relation to a pre-planned route and the waters.
RPM Revolutions per minute.

Screen A device used for presenting visual information based on one or more displays.

SOLAS Safety of Life at Sea. The International Convention for the Safety of Life at Sea, Chapter V Safety of Navigation, Regulation 20, Nautical Publications requires that 'All ships shall carry adequate and up-to-date charts, sailing directions, lists of lights, notices to mariners, tide tables and all other nautical publications necessary for the intended voyage.' SOLAS does not apply universally and some vessels, such as ships of war, cargo ships of less than 500 GRT, fishing vessels etc are exempt from the SOLAS requirements.

VRM Variable range markers.

Watchkeeping Duty undertaken by an officer of the watch. The officer of the watch is responsible for the safety of navigation and bridge operations until relieved by another qualified officer.

Waypoint A point entered into a computer and used as a reference point for navigational calculations. Planned voyages would have a series of waypoints indicating legs of the voyage. A modern computer is capable of storing multiple waypoints.

Wheelhouse Enclosed area of the bridge.

Workstation A position at which one or more tasks constituting a particular activity are carried out.

6.12 Summary

- Organizations such as the IMO, ISO and IEC have established international recognition of standards for ships involved in international trading.
- The integrated bridge system should be designed and installed as a physical combination of equipment or systems using interconnected controls and displays.
- Rules from classification societies, such as DNV, specify design criteria for bridge workstations, defining tasks to be performed and the siting of equipment to enable those tasks to be performed.
- The IEC Technical Committee (TC80) has produced a publication IEC 61209 covering operational and performance requirements, methods of testing and required test results for integrated bridge systems.
- To achieve optimum safety and efficiency in bridge operation, the classification society rules address the total bridge system that is considered to consist of four essential parts, namely the technical system, the human operator, the man/machine interface, and the procedures.
- The Rules for Nautical Safety are divided into three class notations: NAUT-C covers bridge design; W1-OC covers bridge design, instrumentation and bridge procedures; and W1 covers W1-OC and extensions within specified areas of W1-OC.
- Equipment carriage requirements are specified for ships according to the requested class notation.
- An operational safety manual is a requirement for class notation W1 and should obey the following guidelines: organization, daily routines, operation and maintenance of navigational equipment, departure/arrival procedures, navigational procedures, and system fall-back procedures.
- Ships requesting class notation W1-OC or W1 must comply with rules for bridge equipment tests. After installation of equipment on-board testing shall be performed in order to ascertain that the equipment, as installed, operates satisfactorily.

- A variety of manufacturers offer a range of integrated bridge systems that can be tailored to fit the requirements of the user.

6.13 Revision questions

1 Describe briefly the design criteria that define an integrated bridge system.
2 Describe briefly the equipment requirements for an automatic navigation and track-keeping system (ANTS).
3 Discuss the DNV rules for design criteria for bridge workstations and comment on the implications of such rules in terms of the tasks that have to be performed and the siting of relevant instruments/equipment required for those tasks.
4 What are the four essential parts that have to be considered to achieve optimum safety and efficiency in bridge operation.
5 Discuss the rule requirements set out in each section of the DNV Rules for Nautical Safety and comment on the different factors that affects the performance of the total bridge system.
6 What do you understand by class notations? Discuss the differences between the class notations NAUT-C, W1-OC and W1.
7 What do you understand by the term 'general bridge equipment requirements'. What are the specific requirements for different types of bridge equipment?
8 Comment briefly on the rules for manoeuvring information. What type of information should be included in the provision of manoeuvring information? What form should the presentation of manoeuvring information take?
9 Describe the requirement for bridge equipment testing. Mention the type of equipment to be tested and discuss the reasons for the requirement for testing.
10 Refer to one of the examples of an integrated bridge system discussed in Section 6.10 and discuss how the system is organized to meet the requirements for such a system as specified in Sections 6.2, 6.3 and 6.4.

Chapter 7

Electronic charts

7.1 Introduction

Ever since man first went to sea there has been a requirement for some form of recognition of the sea-going environment to assist in the safe passage to the required destination. Knowledge of the coastline, safe channels for navigation which avoid wrecks, sandbanks etc., and tidal information all play their part in assisting the navigator. Paper charts giving information about particular areas have been around for centuries and hydrographers from various countries have explored the world's oceans to produce up-to-date charts which are an invaluable aid to the seafarer whether they are aboard commercial vessels plying their trade around the world or leisure craft sailing for pleasure and recreation.

In 1683 an official survey of British waters was initiated by Royal Command, although the surveys that were published some 10 years later were produced at the surveyor's expense. In the 18th century much hydrographic work around the world was done by British hydrographers, although they still had to have their work published at their own expense, gaining recompense only by selling the results of their efforts privately. It was not until 1795 that the office of Hydrographer to the Board of Admiralty was established, the French having established their Hydrographic Office some 75 years earlier. The United Kingdom Hydrographic Office (UKHO), as it is now called, has an enviable reputation as a supplier of high quality charts and provides worldwide coverage with a folio of some 3300 charts. The UKHO is a member of the International Hydrographic Organization (IHO), a body set up to co-ordinate the activities of national hydrographic offices, promote reliable and efficient hydrographic surveys and ensure uniformity of chart documentation.

It was in 1807 that the Office of Coast Survey was set up in the United States for the purpose of surveying the US coast. Various name changes followed over the years, becoming the National Ocean Survey under the newly established National Oceanic and Atmospheric Administration (NOAA) in 1970. In 1982 a further name change produced the National Ocean Service (NOS) which contained an Office of Charting and Geodetic Services which was renamed as the Coast and Geodetic Survey (C&GS) in 1991. C&GS disappeared in a 1994 restructuring but the former subordinate division, the Nautical Charting Division, re-emerged as the present Office of Coast Survey (OCS), responsible for NOAA's mapping and charting programmes. Divisions within the OCS include the Marine Chart Division, which collects the data to enable the production of nautical charts, and the Hydrographic Surveys Division, which is responsible for all areas of hydrographic survey operations.

The OCS produces about 1000 nautical charts and is also a member of the IHO and, together with the National Imagery and Mapping Agency (NIMA) share responsibilities associated with IHO membership. The IHO presently consists of 67 member states. Most of these chart only their own waters but there are three nations that can supply chart folios of the world and two more that have coverage that extends outside their own waters. The IHO is a force for chart standardization

throughout the world and this is an important feature of the move towards digital production of chart data.

At the present time most hydrographic offices still operate with the paper chart as the basis of their operations. However, over the past few years electronics has moved into the sphere of charting and now digital chart data is becoming more popular and is likely to be the mainstay product of the hydrographic offices in the years to come. With this new technology the seafarer is provided with a means of viewing a chart using a monitor that can display, in colour, all the information present on a paper chart. The chart information is contained on a memory device such as a CD-ROM and can be stored on a computer hard disk. Suitable navigational software can enable the chart data to be viewed for the purpose of 'safe and efficient navigation'. The electronic chart is one where chart data is provided as a digital charting system and it is capable of displaying both geographical data and text to assist the navigator. An electronic chart may fall into one of two categories.

- Official, which describes those electronic charts which are issued by, or on the authority of, a national hydrographic office. The hydrographic offices are government agencies and are legally liable for the quality of their products regardless of whether those products are paper or digital. Such charts are updated at regular intervals in order to conform to the SOLAS (Safety of Life at Sea) requirement that charts should be 'adequate and up-to-date for the intended voyage'.
- Non-official, which describes those electronic charts which are issued by commercial organizations which may use data owned by a hydrographic authority but are not endorsed by that authority.

An electronic chart may be constructed using either of two types of data, raster or vector.

7.1.1 Raster data

Raster data is produced by scanning a paper chart. This process produces an image that is an exact replica of the paper chart and which comprises a number of lines that are composed of a large number of coloured dots, or pixels. This technique does not recognize individual objects, such as a sounding, which limits its ability to conform to certain international guidelines. However, the use of what is termed a vector overlay, which can display specified user data such as waypoints and system data such as radar overlays etc., can overcome this deficiency. The advantages of raster charts can be summarized as follows.

- User familiarity since they use the same symbols and colours as paper charts.
- They are exact copies of the paper charts with the same reliability and integrity.
- The user cannot inadvertently omit any navigational information from the display.
- Cost of production is less than their vector counterpart.
- Wide availability of official raster charts. ARCS charts, for example, have near worldwide coverage.
- By using vector overlays together with appropriate software, raster charts can be used for all standard navigational tasks normally undertaken using paper charts. They can also emulate some of the functions of an electronic display and information system (ECDIS).

Disadvantages of raster charts can be summarized as follows.

- The user cannot customize the display.
- When using vector overlays the display may appear cluttered.
- They cannot be interrogated without an additional database with a common reference system.

- They cannot, directly, provide indications or alarms to indicate a warning to the user.
- Unless data content is the same, more memory is required to store data compared to a vector chart.

7.1.2 Vector data

Apart from the electronic navigational chart (ENC), which is compiled using raw data, vector data may also be produced by scanning a paper chart. However, the raster image is then vectorized by digitally encoding individual charted objects and their attributes (structured encoding) and storing such data, together with the object's geographical location, in a database. The ENC is the designated chart for the ECDIS system and is discussed in the next section. Chart features may be grouped together and stored in thematic layers that individually categorize each group. For example, the coastline could form one layer while depth contours are found on another layer etc. The system operator can thus optimize the display to show only that data of interest and avoid the display becoming cluttered with unwanted data. The vector chart is intelligent in that it can provide information that allows a warning of impending dangers to be generated.

The process of producing vector charts is time consuming and expensive while verification of chart data is more complicated than its raster counterpart. The advantages of vector charts can be summarized as follows.

- Chart information is in layers which allows selective display of data.
- The display may be customized to suit the user.
- Chart data is seamless.
- It is possible to zoom-in without distorting the displayed data.
- Charted objects may be interrogated to give information to the user.
- Indications and alarms can be given when a hazardous situation, such as crossing a safety contour, occurs.
- Objects may be shown using different symbols to those used on paper or raster charts.
- Chart data may be shared with other equipment such as radar and ARPA.
- Unless data content is the same, less memory is required to store data compared to a raster chart.

Disadvantages of the vector chart can be summarized as follows.

- They are technically far more complex than raster charts.
- They are more costly and take longer to produce.
- Worldwide coverage is unlikely to be achieved for many years, if ever.
- It is more difficult to ensure the quality and integrity of the displayed vector data.
- Training in the use of vector charts is likely to be more time consuming and costly compared to that needed for raster charts.

The vehicle for the delivery of electronic chart data is the Electronic Chart Display and Information System (ECDIS) which is a navigation hardware/software information system using official vector charts. Such a system must conform to the internationally agreed standard adopted by the International Maritime Organization (IMO) as satisfying a vessel's chart-carrying requirements under SOLAS. The ECDIS hardware could be simply a computer with graphics capability or a graphics workstation provided as part of an integrated bridge system. The system has inputs from other sources, namely position sensors such as GPS or loran, course indication from the gyrocompass, speed from the ship's log etc.

The information is transmitted to the ECDIS using National Marine Electronics Association (NMEA) interfacing protocols. Radar information can also be superimposed using either raw data from a raster scan radar or as synthetic ARPA (automatic radar plotting aid) data. The ECDIS software must comprise a user interface and a component that allows charts to be displayed and data read. The chart data component of ECDIS is the electronic navigational chart (ENC) which must comply with ENC production specifications under the IHO's S-57 edition 3 data transfer standard. More details of this system can be found in Section 7.3.

7.2 Electronic chart types

There are many different types of electronic charts available that use different formats, different levels of content and attribution, and may, or may not, be official charts. As described above, all presently available electronic charts are either vector or raster. For the former, the chart may be based on the IHO S-57 format or some other format. Only if the level of content and attribution of the chart conforms to the IHO ENC product specification and is produced by, or on the authority of, a government authorized hydrographic office, can the chart be considered an ENC as defined by the IMO ECDIS performance standards.

Official vector charts issued by the relevant hydrographic offices should conform to the ENC product specification based on the IHO S-57 format. Privately produced vector charts (non-official) may, or may not, conform to the ENC product specification. However, the use of unofficial ENCs will render an ECDIS non-compliant. Finally, it is possible to obtain charts that do not use the IHO S-57 format and do not conform to the ENC product specification.

7.2.1 Privately produced vector charts

These are generally made from scanned hydrographic office paper charts. The image produced is then digitized by tracing lines and features on the chart. This vectorization process stores chart features in 'layers' which can be redrawn automatically at an appropriate size if the chart is zoomed into. Categories of data, such as spot depths, navigation marks etc., can be added/deleted as required. In some systems specific chart items can be interrogated to obtain more information.

The nature of the vector display is such that the chart data is not displayed electronically as it was compiled in its paper chart form. Most systems automatically decide on the information to be displayed, depending on the level of zoom, to avoid the image being cluttered. Thus a new operational regime has to be developed to take account of the implications of:

- adding/deleting layers of data
- zooming and seeing more/less data appear according to the level of zoom
- displaying the chart at a larger scale than the source paper chart.

One of the principal producers of digital format electronic charts is C-MAP of Norway with worldwide coverage of 7500 charts on a CD-ROM. Data is coded in a System Electronic Navigational Chart (SENC) format called CM-93/3 which is compliant with the IHO S-57 format. C-MAP 93/3 displays a -U- (for unofficial) on their privately produced S-57 compliant charts. Details of the use of a SENC in an ECDIS is discussed in Section 7.3.

7.2.2 Official raster chart

There are two official raster chart formats.

- BSB raster charts, which contain all the data found in NOAA paper charts, with updates published weekly. These updates are available via the Internet and are in-sync with the US Coast Guard (USCG), NIMA and Canadian notices. NOAA has 1000 official charts and all have been available in raster form since 1995. These raster charts are produced jointly by NOAA and Maptech Inc. under a co-operative research and development agreement. The growth of computer-based navigation systems, together with GPS and other positioning systems, has meant an increase in the sale of raster charts and today approximately twice as many raster charts are sold compared to paper charts. The raster charts are available in CD-ROM form with each CD-ROM containing about 55 charts together with other relevant navigational facilities.
- UKHO ARCS and Australian Hydrographic Office (AHO) Seafarer both produced in the UKHO's proprietary hydrographic chart raster format (HCRF). ARCS is updated weekly using a CD-ROM with the same information as the weekly Notice to Mariners used to correct paper charts. Seafarer is updated monthly on a similar basis. ARCS has near worldwide coverage with 2700 charts available on CD-ROM.

ARCS/Seafarer charts are produced from the same process used to print paper charts, i.e. a rasterized process is used either to print a paper chart or produce a raster chart. They are accurate representations of the original paper chart with every pixel referenced to a latitude and longitude. Where applicable, horizontal datum shifts are included with each chart to enable the chart, and any information overlaid on it, to be referenced back to WGS-84. Not all available charts have WGS-84 shift information and such charts must be used with caution when a GPS position fix is applied. Chart accuracy is discussed further in Section 7.4.

The UKHO ARCS production system involves the use of a raster base maintenance and on-line compilation system (ABRAHAM) which is used to update, manage and plot navigational chart bases. The ARCS production system is integrated with ABRAHAM as is shown in Figure 7.1.

In its simplest terms ABRAHAM is all processes that are necessary to create and maintain the high-resolution (25 μ/1016 dpi) monochrome raster bases from which paper charts are produced, and ARCS is all processes that turn the ABRAHAM bases into ARCS CD-ROMs including:

- processing bases into lower resolution (200 μ/127 dpi) colour images
- adding header and catalogue information
- quality assurance checks
- encrypting the data
- ending a CD-ROM master to a pressing plant
- checking the stock returned by the pressing plant.

The ARCS CD-ROM production can be subdivided into periodic processing cycles.

- Weekly. Updates for all charts affected by Notice to Mariners are generated, checked and placed on the weekly ARCS update CD-ROM. New charts and new editions published that week are also included on the update CD, as is the text of temporary and preliminary Notices to Mariners.
- Periodic. To prevent the update CD from filling up, accumulated updates are periodically moved onto reissues of the ARCS chart CD-ROMs. This results in the production of a reissued chart CD at the same time as the weekly update CD. Nominally, one chart CD requires to be reissued each

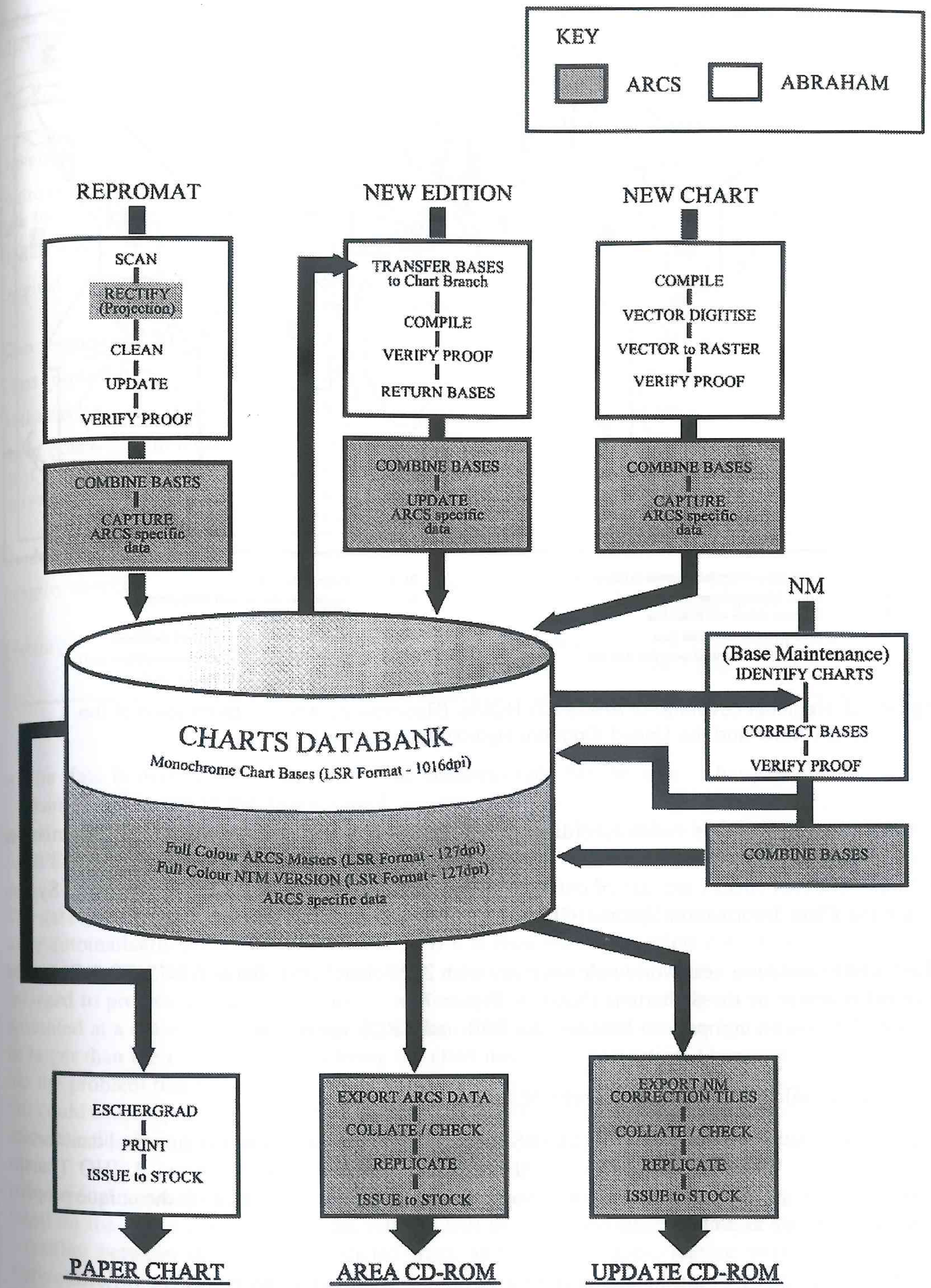
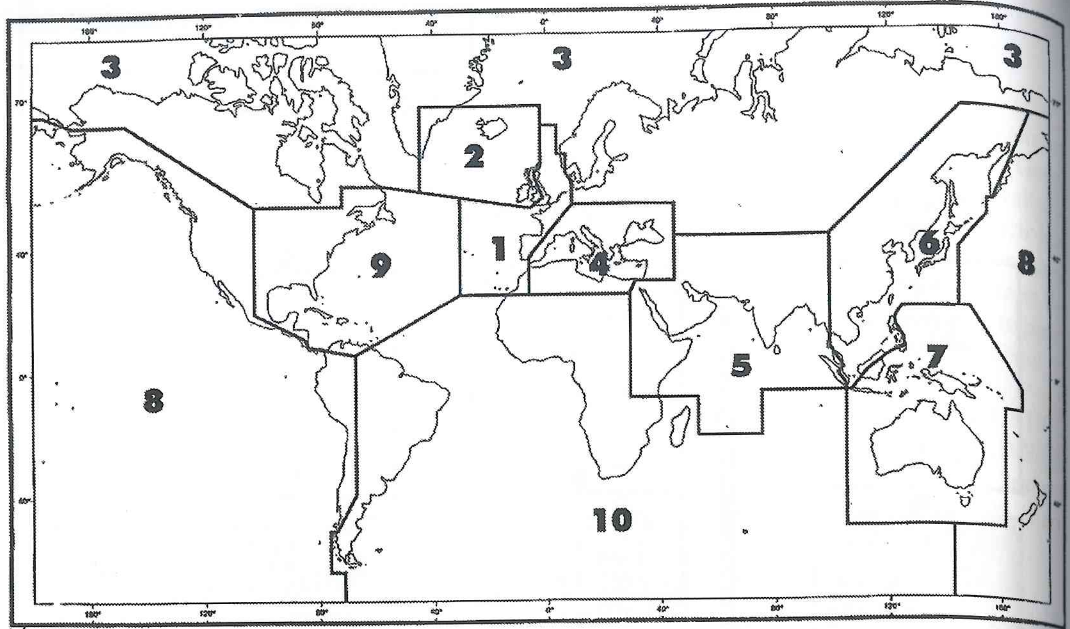


Figure 7.1 ARCS/ABRAHAM production system. (Reproduced with the permission of the Controller of HMSO and the United Kingdom Hydrographic Office.)



RC 1.	North Sea and English Channel to Gibraltar	RC 6.	Singapore to Japan
RC 2.	British Isles (west coast) and Iceland	RC 7.	Australasia, Borneo and Philippines
RC 3.	Northern waters and Baltic Sea	RC 8.	Pacific Ocean
RC 4.	Mediterranean and Black Seas	RC 9.	North America (east coast) and Caribbean
RC 5.	Indian Ocean (northern part) and Red Sea	RC 10.	South Atlantic and Indian Ocean (southern part)
		RC 11.	Ocean Charts (1:3,500,000 and smaller)

Figure 7.2 Regional coverage of ARCS CD-ROMs. (Reproduced with the permission of the Controller of HMSO and the United Kingdom Hydrographic Office.)

month, but the schedule varies according to the number of corrections outstanding and the number of chart CDs in stock.

- Monthly. Cross-checks are carried out against the data held on the Sales Order Processing System and the Chart Information System (CIS).

The UKHO provides a near worldwide coverage with 2700 charts available as ARCS CD-ROMs. The regional coverage of these charts is shown in Figure 7.2.

Table 7.1 gives a comparison between the BSB and ARCS raster types.

7.2.3 Electronic navigational charts (ENC)

These are the designated charts for the ECDIS system and they possess a single universal data format. Such charts use vector data based on the IHO Special Publication S-57, edition 3, IHO Transfer Standard for Digital Hydrographic Data. Some of the major points which identify the unique property of these charts are as follows.

- They are issued by or on the authority of a government-authorized hydrographic office.
- Items on the chart must be attribute-coded and must be able to be interrogated to provide information.

Table 7.1 Comparison between different raster chart types. (Reproduced courtesy of D. Edmonds of PC Maritime, UK)

Feature	*BSB*	*ARCS*
Government authorized	Yes	Yes
Entire catalogue always up to date to latest notice to mariner	Yes	Yes
Update service	Weekly	Weekly
Original scan from:	Stable mylar film originals used for printing paper charts	Stable colour separates used for printing paper charts
Scan resolution	762 dpi	1016 dpi
Chart resolution	256 dpi	127 dpi
Anti-aliasing	Yes	Yes
No of points used to relate the chart images to Lat/Long conversion	10–20, pixel to location conversions are also provided, accuracy depends on the printed chart	Pixel to position conversion is by calculation and is accurate to 1 pixel
Geodetic datum shifts	Yes	Yes
Integrity checks	Byte checksums are included in chart file	32-bit CRC check on original and updated image
Liability	US government accepts liability for errors on NOAA charts	UK government accepts liability on UKHO products

- The data is delivered in cells to provide seamless data for the task in hand. The cell structure changes according to the data set used.
- All chart data is referenced to a global geodetic datum, WGS-84, which is the datum used by GPS.

The data is fully scaleable and it only needs a view area to be defined for an appropriate level of data to be automatically presented to the operator. If it is required to add/delete data then information can be grouped into layers and turned on/off as required. Zooming can allow the chart image to be enlarged to provide greater ease of use. Zooming with a raster chart clearly shows when an image is presented at a scale greater than the compilation scale since the text and navigational symbols would be larger than their normal size rendering the chart unsafe for navigation. Over-scaling with an ENC has the problem that the navigational symbols remain the same size regardless of the scale used and this could cause a potential navigation hazard. The ECDIS is required to display an over-scale warning automatically if it has used zooming to produce an image beyond the compilation scale of the chart.

Individual contour lines can be defined as safety contours with anti-grounding warnings given based on the ship's closeness to them. Alarms will be generated automatically if the ECDIS detects a conflict between the vessel's predicted track and a hydrographic feature within the ENC that represents a potential hazard to the vessel.

The ECDIS can offer different chart information by displaying all ENC content, a subset of the ENC content (known as standard display) or a minimum permitted subset of ENC content (known as display base). The first two categories permit information to be added/deleted while the display base cannot have information deleted since it is stipulated as the minimum required for safe navigation. A System Electronic Navigational Chart (SENC) is that database obtained by the transformation of the ENC data, including any updates and data added by the user, by the ECDIS prior to display. It is the SENC that forms the basis for the display and the user decides what part of the SENC database is required for the display. It is a requirement that the ENC database must remain unaltered so that the SENC database could be reconstructed should it be debased in any way during operations.

The availability of ENCs will depend on key factors that affect the NHOs producing them. These factors include the following.

- Production experience. The rate of production should increase as staff gain more experience in the production of these charts.
- Data quality. Software tools necessary to underpin the quality assurance of the digital database have to be developed to ensure compliance with S57, edition 3 requirements. This will take time.
- Uniformity of data. There is a need for all hydrographic offices to ensure their ENCs are produced with consistency in the interpretation of the standard and to product specification. The use of regional co-ordinating centres is of use in facilitating this.
- Geographical cover. By concentrating on the geographical areas most used by shipping companies it should be possible to deliver the required charts ahead of others.

As an example of the development of ENCs, the UKHO awarded a contract to the Indian company, IIC Technologies, for data capture work in February 2000. This is the first step in the production of ENCs with the data sets produced by IIC to be quality assessed by the UKHO to ensure compliance with the required standards. The UKHO will also concentrate on stitching together the data set cells and matching the edges to produce a seamless ENC database. The contract is an enabling contract of up to four and a half years allowing the UKHO to request data sets in tranches with continuity of production.

The regional co-ordinating centres are an important means of distributing the ENCs to potential customers. The International Hydrographic Organization (IHO) proposed a system for supplying ENCs to be known as Worldwide ENC Database (WEND). Using this concept the world is divided into Regional ENC Co-ordinating Centres (RENCs). At present only one RENC has been set up.

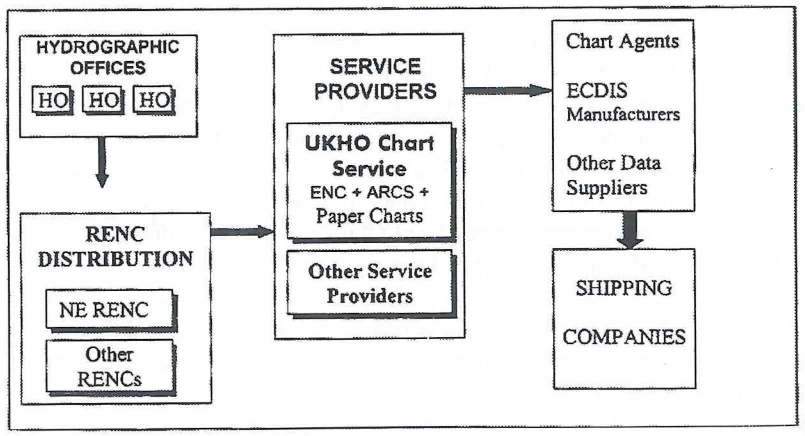


Figure 7.3 RENC distribution system. (Reproduced with the permission of the Controller of HMSO and the UK Hydrographic Office.)

Table 7.2 Equivalence to the paper chart. (Reproduced courtesy of D. Edmonds of PC Maritime, UK)

Privately produced vector charts	*Official raster (RNCs)*	*ENCs*
Generally a copy of the paper chart	An exact replica of paper chart	All data merged into cells
A different image to the original paper chart is presented at all levels of zoom and scale	The same image as the paper chart is always presented. The chart is more equivalent to the paper chart than any vector chart including ENCs	No resemblence to the paper chart
Symbols and colour vary with manufacturer	Symbols and colour are the same as the paper chart equivalent	The IHO publication S–52 defines new colours and symbols for ENCs
Accuracy, reliability and completeness vary with manufacturer	RNCs are as accurate, reliable and complete as the paper version	ENCs should eventually be more accurate and reliable than the paper version
A new operational regime is required	The same operational regime as paper charts is followed. There are some changes, if only because of screen size	A new operational regime is required

Table 7.3 Chart integrity. (Reproduced courtesy of D. Edmonds of PC Maritime, UK)

Privately produced vector charts	*Official raster (RNCs)*	*ENCs*
Produced by private companies	Produced by, or under the authority of government authorised hydrographic offices	Produced by, or under the authority of government authorised hydrographic offices
Unofficial	Official	Official
Generally no responsibility is accepted	Responsibility is accepted for chart data in terms of its completeness and accuracy in comparison with the equivalent paper chart	Responsibility is accepted for chart data in terms of its completeness and accuracy
Is unlikely to become legally equivalent to the paper chart	Is unlikely to become legally equivalent to the paper chart	Is legally equivalent to the paper chart
It may be possible to change original chart data	The chart data is tamper proof	The chart data is tamper proof
Charts can be zoomed (i.e., the display of a single chart is magnified or reduced without restriction. Chart detail varies depending on the level of zoom)	Chart zoom should be limited to a level that does not break up the image. Information displayed on the chart remains unaltered	Charts can be zoomed in or out without restriction. Chart detail varies depending on the level of zoom
Quality control varies with manufacturer	Quality control is government standard	Quality control is government standard

Table 7.4 Chart corrections. (Reproduced courtesy of D. Edmonds of PC Maritime, UK)

Privately produced vector charts	*Official raster (RNCs)*	*ENCs*
Up-to-dateness of charts varies with manufacturer	Charts are up-to-date at the point of sale	Charts will be up-to-date at the point of sale
It is difficult to determine the up-dating policy of manufacturers	Chart data is maintained up-to-date to clearly stated standards	Chart data is maintained to a clearly defined standard
Varies with manufacturer	On demand updates for leisure users	Not applicable
Varies with manufacturer	Subscription updates for commercial users	Subscription updates available
Varies with manufacturer	Automatic integration of chart updates	Automatic integration of chart updates

Table 7.5 Safety. (Reproduced courtesy of D. Edmonds of PC Maritime, UK)

Privately produced vector charts	*Official raster (RNCs)*	*ENCs*
Geodetic datum shift to WGS-84 may not be provided	Chart data includes geodetic datum shift to WGS-84, if known	All data is referenced to WGS-84
Chart data can be removed from the display. Significant navigation information may be inadvertently removed	Chart data cannot be removed from the display. The user cannot inadvertently remove significant navigation information	Chart data can be removed from the display. Significant navigation information may be inadvertently removed

namely the Northern Europe RENC known as PRIMAR. This is a co-operative arrangement between most of the national hydrographic offices in northern and western Europe. To date the hydrographic offices of Denmark, Finland, France, Germany, Netherlands, Norway, Portugal, Poland, Sweden and UK have signed the formal co-operation arrangement and other hydrographic offices have expressed an interest in joining. PRIMAR is operated by the UK Hydrographic Office and the Norwegian Mapping Authority's Electronic Chart Centre.

The ENCs will be sold through a network of distributors and should be able to provide worldwide cover by exchange of data with other RENCs once these are established in other parts of the world. A block diagram showing the RENC concept is shown in Figure 7.3.

Tables 7.2 to 7.5 summarize the features of each chart type in relation to each other.

7.3 Electronic chart systems

7.3.1 Electronic Chart Display and Information System (ECDIS)

There are several types of electronic chart systems available but only one performance standard has been approved by the International Maritime Organization (IMO) in November 1995. The IMO resolution A817(19) states that the ECDIS should 'assist the mariner in route planning and route monitoring and, if required, display additional navigation-related information'. The system approved is known as the Electronic Chart Display and Information System (ECDIS) and applies to vessels governed by Regulation V, Chapter 20 of the 1974 Safety of Life at Sea (SOLAS) convention. It complies with the carriage requirement for charts with an ECDIS system using Electronic Navigational Charts (ENCs). ECDIS is a navigational information system comprising hardware, display software and official vector charts and must conform to the ECDIS performance standards; amongst other aspects these performance standards govern chart data structure, minimum display requirements and minimum equipment specifications. Chart data used in an ECDIS must conform to the Electronic Navigational Chart (ENC) S-57, edition 3.0 specification and the performance standard for this was agreed by the International Hydrographic Organization (IHO) in February 1996. Any ENC must be issued on the authority of a government-authorized hydrographic office.

Back-up arrangements for ECDIS were agreed by the IMO in November 1996, becoming Appendix 6 to the Performance Standards and allowing ECDIS to be legally equivalent to the charts required under regulation V/20 of the 1974 SOLAS convention. It is an IMO requirement that the National Hydrographic Offices (NHOs) of Member Governments issue, or authorize the issue of, the ENCs, together with an updating service, and that ECDIS manufacturers should produce their systems in accordance with the Performance Standards. Other notable milestones leading to the ECDIS specification include the following.

- IHO Special Publication S-52 which specifies chart content and display of ECDIS. This includes appendices specifying the issue, updating and display of ENC, colour and symbol specification. The IHO Special Publication S-52 was produced in December 1996.
- IEC International Standard 61174. In this publication the International Electrotechnical Commission describes methods of testing, and the required test results, for an ECDIS to comply with IMO requirements. The standard was officially published in August 1998 and is to be used as the basic requirement for type approval and certification of an ECDIS which complies with the IMO requirements.

Some ECDIS definitions are summarized below.

- **Electronic Chart Display and Information System (ECDIS)** means a navigation system which, with adequate back-up arrangements, can be accepted as complying with the up-to-date chart required by regulation V/20 of the 1974 SOLAS Convention, by displaying selected information from a System Electronic Navigational Chart (SENC) with positional information from navigational sensors to assist the mariner in route planning, route monitoring and displaying additional navigational-related information if required.
- **Electronic Navigational Chart (ENC)** is the database, standardized as to content, structure and format, issued for use with ECDIS on the authority of government-authorized hydrographic offices.
- **System Electronic Navigational Chart (SENC)** is a database resulting from the transformation of the ENC by ECDIS for appropriate use, updates to the ENC by appropriate means, and other data added by the mariner.
- **Standard Display** means the SENC information that should be shown when a chart is first displayed on an ECDIS. The level of information provided for route planning and route monitoring may be modified by the mariner.
- **Display Base** means the level of SENC information which cannot be removed from the display, consisting of information which is required at all times in all geographical areas and all circumstances.

The basic ECDIS requirements can be summarized as follows.

- **ENC data.** This is to be supplied by government-authorized hydrographic offices and updated regularly in accordance with IHO standards.
- **Colours/Symbols.** These must conform to the specification outlined in IHO Special Publication S-52. Symbol size and appearance are specified and the mariner should be able to select colour schemes for displaying daylight, twilight and night-time conditions.
- **Own Ship's Position.** The ECDIS should show own ship's position on the display. Such a position is the result of positional input data received from suitable sensors and should be continuously updated on the display.
- **Change Scale.** The use of zoom-in and zoom-out should allow information to be displayed using different scales. ECDIS must display a warning if the information shown is at a scale larger than that contained in the ENC or if own ship's position is produced by an ENC at a larger scale than that shown by the display.
- **Display Mode.** The mariner should be able to select a 'north-up' or 'course-up' mode. Also the display should be able to provide true motion, where own ship symbol moves across the display, or relative motion where own ship remains stationary and the chart moves relative to the ship.
- **Safety Depth/Contour.** The mariner can select safety depth, whereby all soundings less than or equal to the safety depth are highlighted, or safety contour whereby the contour is highlighted over other depth contours.
- **Other Navigational Information.** Radar or ARPA data may be added to the display.

As emphasized earlier, one of the key requirements for ECDIS is to assist the user to plan a route and monitor the route while under way. This and other functions are listed below.

- **Route Planning.** The mariner should be able to undertake the planning of a suitable route, including the provision of waypoints which should be capable of being amended as required. It should be possible for the mariner to specify a limit of deviation from the planned route at which activation of an automatic off-track alarm occurs.
- **Route Monitoring.** ECDIS should show own ship's position when the display covers the area involved. The user should be able to 'look-ahead' while in this mode but be able to restore own ship's position using a 'single operator action'. The data displayed should include continuous indication of ship's position, course and speed and any other information, such as time-to-go, past track history etc., considered necessary by the user. Indication/alarms should feature using parameters set by the mariner.
- **Indication/Alarm.** ECDIS is required to give information about the condition of the system or a component of the system; an alarm should be provided when a condition requires urgent attention. An indication could be visual whereas an alarm could be visual but must also be audible. Indications should include, among others, information overscale, different reference system, route planned over a safety contour etc. Alarms should include, among others, system malfunction, deviation from route, crossing safety contour etc.
- **Record of Voyage.** ECDIS must be capable of recording the track of an entire voyage with timings not exceeding 4-hourly intervals. Also ECDIS should keep a record of the previous 12 h of a voyage; such a record should be recorded in such a way that the data cannot be altered in any way. Also during the previous 12 h of a voyage ECDIS must be capable of reproducing navigational data and verifying the database used. Information such as own ship's past track, time, position, speed and heading and a record of official ENC data used, to include source, edition, date, cell and update history, should be recorded at 1-min intervals.

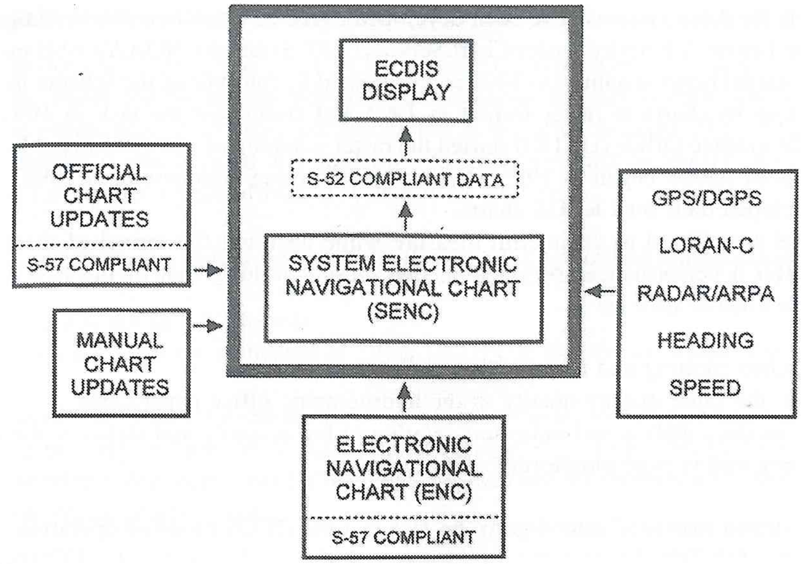


Figure 7.4 Block diagram of an ECDIS. (Reproduced courtesy of Warsash Maritime Centre.)

- **Back-up Arrangements.** This is required in case of an ECDIS failure. The back-up system should display in graphical (chart) form the relevant information of the hydrographic and geographic environment necessary for safe navigation. Such a system should provide for route planning and monitoring. If the back-up system is electronic in form it should be capable of displaying at least the information equivalent to the standard display as defined by the performance standard.

A block diagram of an ECDIS is shown in Figure 7.4.

The production of ENCs is proceeding but it is a lengthy and costly business and it is likely that widespread coverage will not be available for some time and certain regions may never be covered at all. Because of the delay likely in implementing ECDIS, hydrographic offices around the world have proposed an alternative official chart solution that uses the raster chart and is known as the Raster Chart Display System (RCDS).

7.3.2 Raster Chart Display System (RCDS)

This is a system capable of displaying official raster charts that meets the minimum standards required by an appendix to the ECDIS Performance Standard. The raster nautical chart (RNC) is a digital facsimile of the official paper chart and provides a geographically precise, distortion-free image of the paper chart.

The IHO proposed a raster chart standard that 'should form a part of the ECDIS performance standards where it would logically fit'. This was approved by the IMO's Maritime Safety Committee in December 1998 as a new appendix to the existing ECDIS Performance Standard, entitled 'RCDS Mode of Operation'. It is now permissible for ECDIS to operate in RCDS mode using official RNCs when ENCs are not available. The use of ECDIS in RCDS mode can only be considered providing there is a back-up folio of appropriate up-to-date paper charts as determined by national administrations.

Raster charts for these systems have been developed in recent years by major hydrographic offices and include the British Admiralty Raster Chart Service (ARCS) and the NOAA's BSB raster chart. The United States started raster scanning in 1991 and evaluated a prototype of the scheme in 1992. NOAA began converting its charts to raster format in 1993 and completed the task in 1994. The United Kingdom Hydrographic Office (UKHO) started the raster scanning of its Admiralty charts in 1994 and shipboard trials of ARCS began in 1995; the service becoming commercial in 1996. Other nations have also developed their own RCDS charts.

Raster charts are offered as an interim measure while awaiting the arrival of the ENCs and are designed to offer a performance specification that closely follows that of the ENCs and includes important requirements such as:

- continuous chart plotting and chart updating
- at minimum, the same display quality as the hydrographic office paper chart
- extensive checking, alarms and indicators relating to the integrity and status of the system
- route planning and voyage monitoring.

The IMO has drawn mariners' attention to the fact that the RCDS mode of operation lacks some of the functionality of ECDIS. Some of the limitations of RCDS mode compared to ECDIS mode include the following.

- The raster navigational chart (RNC) data will not itself trigger automatic alarms although some alarms can be generated by the RCDS from information inserted by the user.
- Chart features cannot be altered or removed to suit operational requirements. This could affect the superimposition of radar/ARPA.
- It may not be possible to interrogate RNC features to gain additional information about charted objects.
- An RNC should be displayed at the scale of the paper chart and RCDS capability could be degraded by excessive use of the zoom facility.
- In confined waters the accuracy of the chart data may be less than that of the position fixing system in use. ECDIS provides an indication in the ENC that permits determination of the quality of the data.

7.3.3 Dual fuel systems

Because of the adoption by the IMO of the amendments to the performance standards for ECDIS to include the use of RCDS, an ECDIS is now able to operate in two modes:

- ECDIS mode when ENC data is used
- RCDS mode when ENC data is unavailable.

Thus the dual fuel system is one that is either an ECDIS or RCDS depending on the type of chart data in use. At the present there are only few ENCs so the ability to use ECDIS is restricted. RNCs are plentiful and can provide two vital functions:

- provide official electronic chart coverage for areas not covered by ENCs
- provide link coverage between the ENCs that are available.

7.3.4 Electronic chart systems (ECS)

Where a system does not conform to either ECDIS or RCDS performance standards it is classified as an ECS system. There are no official performance standards for this system. The IMO had been considering the production of advisory guidelines but at the 1998 meeting of the IMO Navigation Safety Subcommittee it was decided that guidelines for ECS were not necessary and the matter will not be pursued further. As a general rule, a system is an ECS if:

- it uses data which is not issued under the authority of a government-authorized hydrographic office
- vector chart data is not in S-57 format
- the system does not meet the standards of either ECDIS or RCDS performance standards.

An ECS may not be used as a substitute for official paper charts, and ships fitted with an ECS are legally required to carry suitable up-to-date official paper charts. Examples of ECS include radar systems incorporating video maps, stand-alone video plotters and all systems while using commercial raster charts and vector charts systems.

7.4 Chart accuracy

Any chart is only as good as the original survey data allows and the accuracy with which that data is recorded on the chart by the cartographer. A navigational chart is referenced to two data: horizontal, for latitude and longitude; and vertical, for depth and height.

Since the beginning of mapmaking, local maps were based on the earth's shape in that area and, since the earth is not a perfect sphere, the shape does vary from location to location. Figure 7.5 shows a representation of a vertical slice through the earth. The diagram shows an uneven surface to the

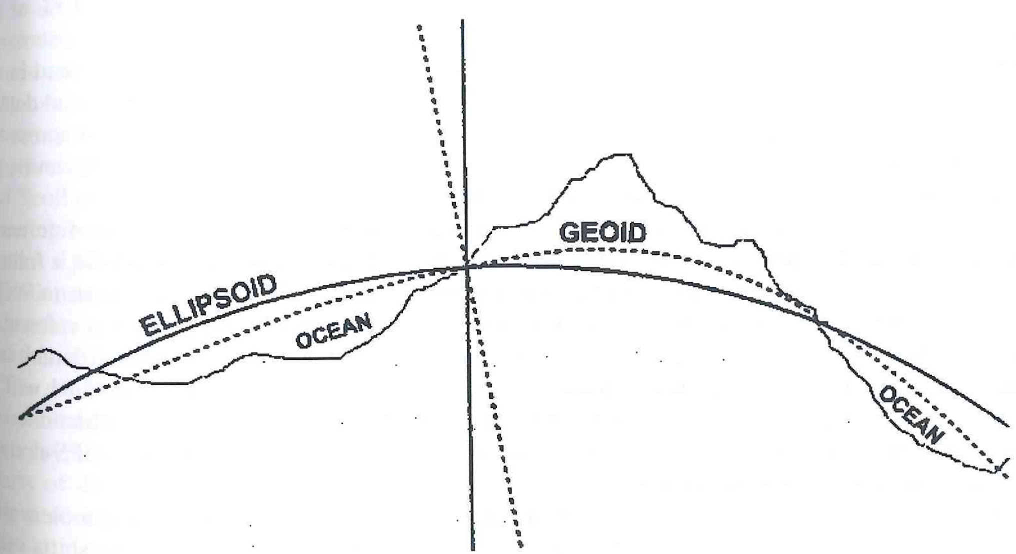


Figure 7.5 View of the earth's surface showing the geoid and ellipsoid. (Reproduced courtesy of Warsash Maritime Centre.)

earth, a dotted line representing a geoid and a solid line representing an ellipsoid. The geoid represents a surface with equal gravity values and where the direction of gravity is always perpendicular to the ground surface. For mapping purposes it is necessary to use a geodetic datum which is a specifically orientated reference ellipsoid. The surface of a geoid is irregular while that of an ellipsoid is regular.

Many different ellipsoids have been used to represent the best fit to the geoid in a particular area. The use of an ellipsoid for positional calculations must first be referenced to the geoid and that relationship defines what is known as a datum. The accuracy of a particular datum may be fine for the local area for which it was intended but the accuracy may suffer as the deviation from that area increases. There are scores of different data such as Ordnance Survey Great Britain 1936 (OSGB36), the European Datum 1950 (ED50), the Australian Geodetic System 1984, North American Datum 1983 (NAD83), etc. Charts drawn for a particular area therefore may contain datum information that is localized.

The use of satellite systems has involved the use of a global datum and GPS uses the World Geodetic System 1984 (WGS-84) which uses a model of the complete earth. The ellipsoid for this system is centred on the Earth's centre of mass and, over the earth as a whole, is a better fit to the geoid than other ellipsoids, although the local datum may give a better fit within their own small area. Ideally all charts should be referenced to WGS-84 but this is not expected to occur for many years to come. Reasons for the delay include:

- the time necessary to replace current charts with new versions using WGS-84
- lack of data necessary to calculate datum shifts and, in some cases, the datum used for the chart is either unknown or poorly defined.

As far as the UKHO is concerned, about 20% of its charts are referenced to the WGS-84 datum, a further 40% use datum when the shift is known, while some 40% use unknown datum. When the shift to WGS-84 is known the UKHO charts have a 'Satellite Derived Positions' note that provides shift values in minutes of latitude and longitude which allows GPS-determined positions, referenced to WGS-84, to be correctly adjusted before they are plotted on the chart. Currently about 40% of the UKHO charts contain shift values.

Electronic chart systems using raster chart displays can use the datum shift values indicated in the 'Satellite Derived Positions' note on the chart to convert the WGS-84 co-ordinates to the local datum. The shift values are mean values for the area covered by the chart but the shift variation across the chart is within manual plotting tolerance at the scale of the chart and can be ignored. However, the quoted shift values on an adjacent chart could well be different.

For electronic chart systems using vector charts it is a requirement that the charts are referenced directly to WGS-84. Since so few official paper charts are referenced directly to WGS-84 it follows that vector chart producers must use a mathematical model to shift the data on certain charts to WGS-84. Users of the system should always check to see whether the official paper chart is referenced directly to WGS-84. If the official chart has a 'Satellite Derived Positions' note giving datum shift values then it could safely be assumed that errors introduced by the conversion to WGS-84 will be small at the scale of the official chart. If WGS-84 shift values do not appear on the paper chart it would suggest that the existing data is insufficient to establish accurate datum shifts and GPS-derived positions cannot be used with confidence.

With ECDIS and the use of ENCs, all references are to WGS-84 so there should be no problem with datum shifts. However, as discussed earlier, there could be a problem of geodetic datum shifts using paper charts, RNCs and privately produced vector charts if positional information is received based on one datum and such data is plotted on a chart which is based on another datum. Figure 7.6

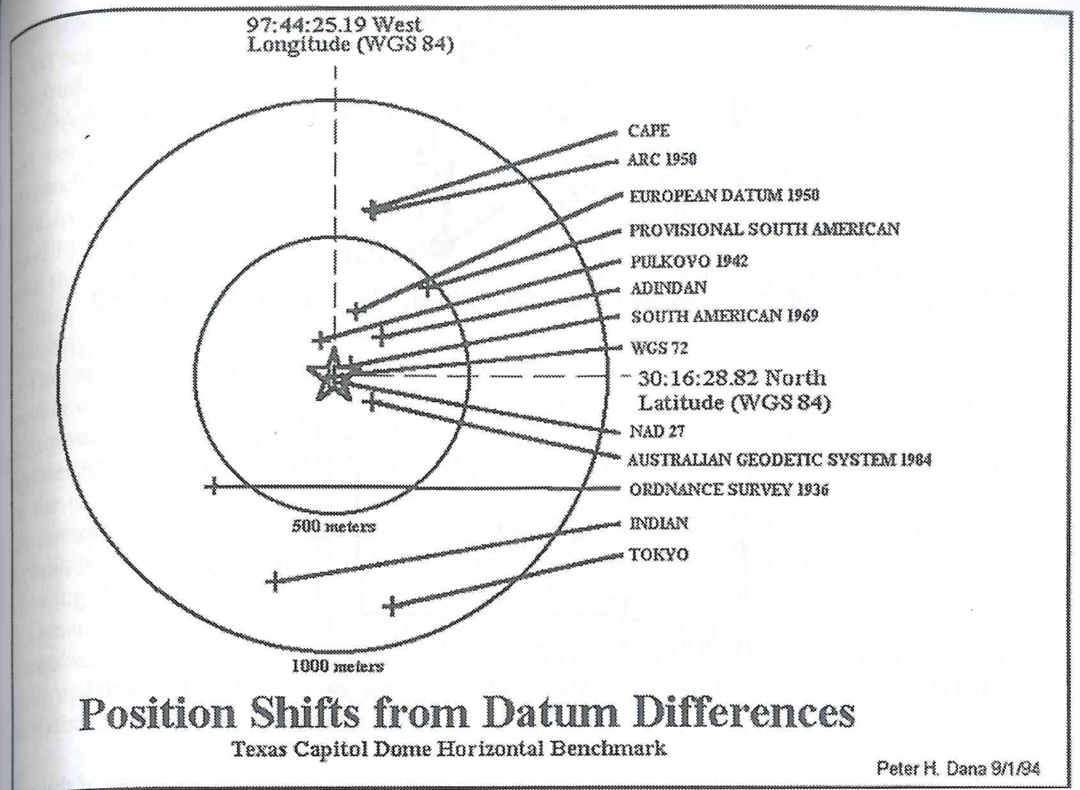


Figure 7.6 World geodetic datums. (Reproduced courtesy of PC Maritime.)

illustrates the variation in latitude and longitude positions that could be derived for the same real location depending on the datum used.

Consider another example of datum differences in the English Channel. The Admiralty charts covering the English coastline are in OSGB36 whereas the Admiralty charts covering the French coastline are in ED50. The OSGB36 datum is used for charts covering the coastline of England, Wales and Scotland while the ED50 was developed for military mapping in Central Europe. UKHO charts covering both sides of the channel tend to be in OSGB36. Thus if an operator working in the channel plotted a position on an OSGB36 chart and then moved to a European 1950 chart without allowing for a datum shift, there will be a positional error as indicated in Figure 7.7.

In some regions of the world the difference between WGS-84 and the local datum can be quite large and this is illustrated in Figure 7.8.

The solution to the problem is obviously to obtain positional information in WGS-84 and to apply the published shift every time a change of paper chart is made. It must be remembered that GPS accuracy has tolerance values and any inaccuracy derived from GPS may be exacerbated by plotting charts of different datum. Most GPSs have built-in datum transformations so that the system can output positions in a local datum but this has certain disadvantages.

- Because there are no standards applicable to the transformation formulae, two different GPSs may use different formulae and give different results. The solutions produced are averaged over a wide

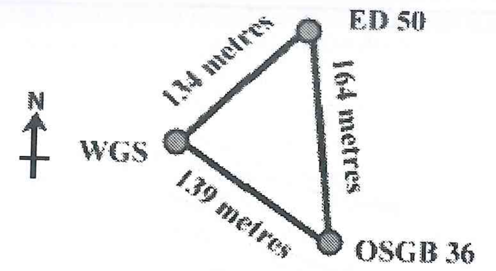


Figure 7.7 An example of datum shift in the English Channel. (Reproduced courtesy of PC Maritime.)

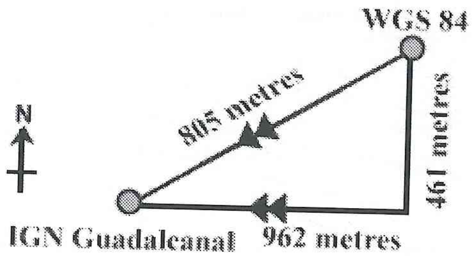


Figure 7.8 An example of datum shift in the Pacific. (Reproduced courtesy of PC Maritime.)

area and any transformation error may range from, say 25 m to much more at the fringes of the area covered by the datum.

- It is difficult to ensure the GPS is switched to the correct datum every time a chart is changed.
- GPS positions may be fed simultaneously to other equipment, such as ARPA, autopilot etc., which expect to receive data in WGS-84 co-ordinates.
- Some GPSs apply the data transformation to all waypoint positions held in memory when a datum other than WGS-84 is selected for the display of positions.

It may be better to maintain the output of GPS in WGS-84. As stated earlier, for the UKHO paper charts, a shift from WGS-84 to the local datum is printed on the chart. Any figure printed on the chart indicates that the original survey has been referenced to WGS-84 and the published shifts can be used with confidence. If the chart contains no shift data then no referencing to WGS-84 has been made and any plotted positions made must be treated with caution because of possible shift errors.

An advantage of modern charts and the use of software is that the management of datum shifts can be automated. A system such as ARCS has the shift data included and thus an RCDS can keep track of the data of positions of all types, including vessel position and track, waypoints and any other overlaid points on the chart, and adjust them all to the local geodetic datum as required.

7.5 Updating electronic charts

As mentioned on page 228 with reference to the UKHO's ARCS system, updates for all charts affected by Notice to Mariners (up to about 200 a week) are generated, checked and placed on a weekly ARCS Update CD-ROM which includes temporary and preliminary notices. This provides

error-free automatic corrections and provides cumulative updates with only the latest update CD-ROM required. The CD-ROMs are sent to chart agents who then send them to shipping companies as required.

NOAA provides continuous updating to all 1000 charts using information from the USCG, NIMA and the Canadian Hydrographic Service, and Maptech makes the necessary raster chart updates. Maptech uses modern technology to update only those parts of a chart identified as needing correction. This so-called 'patch' technique compares the existing chart file and its corrected counterpart on a pixel-by-pixel basis. A difference file is produced which can be manipulated so that it registers exactly with the existing raster file to which it applies. A raster chart can therefore be updated by displaying it, using the relevant CD-ROM, and using the patch file to alter the pixels on the old chart as necessary to incorporate the corrections.

The updating service became available on subscription in January 2000. Customers receive a weekly e-mail that contains a hot link to the update computer server. Clicking on the hot link begins the transmission of the update patches to the computer; the updates in the transmission are cumulative updates for all charts on a CD-ROM. Downloading takes from a few seconds to up to 5 min depending on the modem speed. Once the file reception is completed the charts may be corrected and stored on the computer's hard drive. It is anticipated that dynamic updating should soon be available. With this technique the charts and patches are kept separate and the patch is applied to the chart in real time allowing the user to see the changes produced by the patch.

Dynamic patching is the preferred method under the international standards for ECDIS where it is a requirement that mariners should not change the original data files. It is expected that in future single chart updates may be made available rather than a complete CD's worth and that the procedure will be extended to ENCs when they become available.

7.6 Automatic Identification System (AIS)

Automatic Identification System (AIS) is a shipborne transponder system capable of broadcasting continuously, using the VHF marine band, information about the ship. Such information could include:

- ship identification data, i.e. ship name, call sign, length, breadth, draught etc.
- type of cargo carried and whether it was hazardous in nature
- course and manoeuvring data
- position to GPS accuracy limits.

Such broadcast information would be capable of reception by other AIS-equipped ships and by shore sites such as Vessel Traffic System (VTS) stations within broadcast range. Data received by a ship or shore station could be relayed to an ECS and AIS targets could be displayed, with GPS or DGPS accuracy, with a velocity vector indicating speed and heading. By 'clicking' on a target, other information such as ship identification data etc. could be displayed. A typical AIS scenario is illustrated in Figure 7.9.

An AIS transponder system requires a GPS or DGPS receiver, a VHF transmitter, two VHF TDMA receivers, a VHF DSC receiver and a standard marine electronic communications connection to the ship's display system. Position and timing information is derived from the GNSS (GPS) receiver. Information, such as ship's heading, course and speed over ground, is normally broadcast using AIS but other information such as destination, ETA etc. could also be promulgated if available.

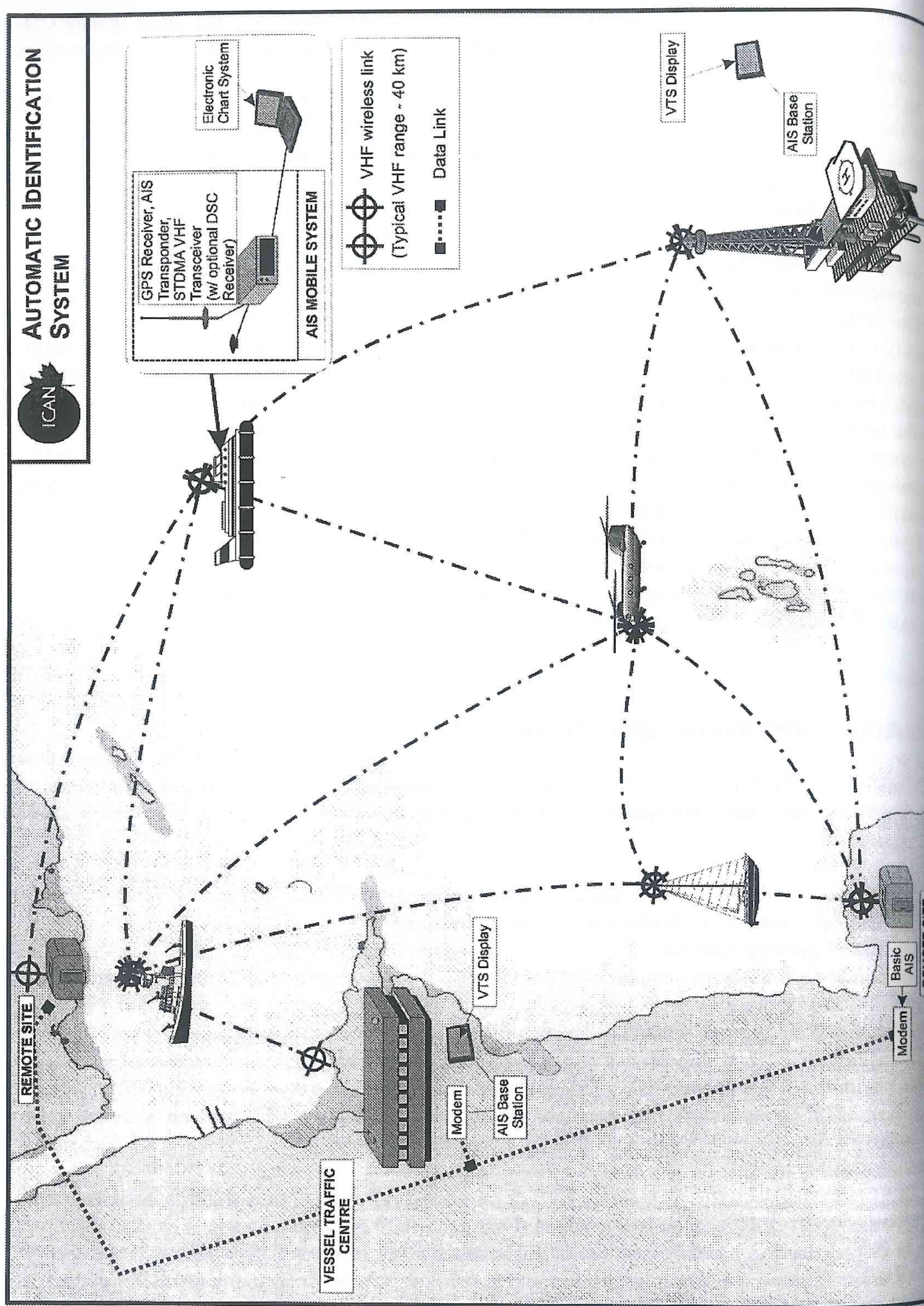


Figure 7.9 Automatic Identification System (AIS). (Reproduced courtesy of ICAN.)

The AIS transponder transmits using 9.6 kbyte GMSK (Gaussian minimum shift keying) FM modulation over 25 kHz or 12.5 kHz channels using HDLC packet protocols. The channel bandwidth of 25 kHz is for use on the high seas and the 12.5/25 kHz channel bandwidth used as defined by the appropriate authority in coastal waters. There are two radio channels available for transmission/reception that minimize RF interference, provide increased capacity and allow channels to be shifted without loss of communication from other ships. The ITU has allocated frequencies with AIS channel 1 using 161.975 MHz (ch87B) and AIS channel 2 using 161.025 MHz (ch88B).

Each transponder self-allocates time slots for its position reports and such reports occur at time intervals that correspond to the traffic situation. This method of communication is known as self-organizing time division multiple access (SOTDMA). The SOTDMA broadcast mode allows the system to be overloaded by up to 500% while still providing nearly 100% communication capacity for ships within 10 nautical miles of each other in ship-to-ship mode. If system overload tends to occur, then targets at the longer ranges will tend to drop out of the system leaving only closer range targets, which are the ones of greater interest to the navigator. There are 2250 time slots established every 60 s for each AIS channel; this gives a time slot duration of 26.67 ms and as each slot has 256 bits the data transmission rate is 9600 bit s^{-1}.

AIS stations continuously synchronize with other stations to obviate any slot transmission overlap. Slot selection by an AIS station is randomized within a defined interval and triggered with a random timeout of between 0 and 8 frames. When a station changes its slot assignment the new location and associated timeout is pre-announced, thus allowing new stations to be received.

Although the AIS concept has been around for many years and trials have taken place at many geographical locations, there is still much work to be done to produce an internationally-agreed standard. Some of the detail of what has been achieved to date is listed below.

IMO Resolution MSC.74(69). Annex 3, Recommendation on Performance Standards for a Universal Shipborne Automatic Identification System (AIS)

The 43rd session of the IMO Navigation Subcommittee, which met in July 1997, completed a draft performance standard on shipborne automatic identification systems (transponders). This performance standard describes the operational requirements for the device but does not define the telecommunications protocol the device must use. The 69th session of the IMO Maritime Safety Committee formally adopted the standard without change in May 1998.

A report from the Subcommittee on Safety of Navigation on its 45th session included the following items.

1 All ships of 300 gross tonnage and upwards (engaged on international voyages), cargo ships of 500 gross tonnage and upwards (not engaged on international voyages), and passenger ships, irrespective of size, shall be fitted with AIS, as follows:

1.1 ships constructed on or after 1 July 2002;

1.2 ships engaged on international voyages constructed before 1 July 2002;

1.2.1 in the case of passenger ships irrespective of size and tankers of all sizes, not later than 1 July 2003;

1.2.2 in the case of ships, other than passenger ships and tankers, of 50000 gross tonnage and upwards, not later than 1 July 2004;

1.2.3 in the case of ships, other than passenger ships and tankers, of 10000 gross tonnage and upwards but less than 50000 gross tonnage, not later than 1 July 2005;

1.2.4 in the case of ships, other than passenger ships and tankers, of 3000 gross tonnage and upwards but less than 10000 gross tonnage, not later than 1 July 2006;

1.2.5 in the case of ships, other than passenger ships and tankers, of 300 gross tonnage and upwards but less than 3000 gross tonnage, not later than 1 July 2007; and

1.3 ships not engaged on international voyages constructed before 1 July 2002, not later than 1 July 2008.

2 The Administration may exempt ships from the application of the requirements of this paragraph when such ships will be taken permanently out of service within two years after the implementation date specified in paragraph 1.

3 AIS shall:

3.1 provide automatically to appropriately equipped shore stations, other ships and aircraft information, including the ship's identity, type, position, course, speed, navigational status and other safety-related information;

3.2 receive automatically such information from similarly fitted ships;

3.3 monitor and track ships; and

3.4 exchange data with shore-based facilities, the requirements of this paragraph shall not be applied to cases where international agreements, rules or standards provide for the protection of navigational information. AIS shall be operated taking into account the guidelines adopted by the Organization.

ITU-R Recommendation M.1371, Technical Characteristics for a Universal Shipborne Automatic Identification System Using Time Division Multiple Access in the Maritime Mobile Band

The International Telecommunications Union Sector for Radiocommunication (ITU-R) met in March 1998 to define the technology and telecommunications protocol for this device. The draft recommendation completed by Working Party 8B was approved by Study Group 8, which met in July 1998. The recommendation was formally adopted in November 1998 and the publication is now available for a fee (see website www.itu.org). The International Association of Lighthouse Authorities (IALA) has been the main organization co-ordinating the development of the Universal AIS Transponder and a revision of this standard is being prepared by IALA for submission to the ITU-R Working Party 8B in October 2000. If adopted it will become ITU-R Recommendation M.1371–1.

IEC Standard 61993–2 on AIS

In July 1998, the International Electrotechnical Commission TC80/WG8-U.AIS started work on the performance, technical, operational and testing standard for the Universal AIS Transponder. The working group is expected to meet regularly and complete its work during the year 2000 with an expected publication date for the standard of December 2001. This standard will supersede IEC Standard 61993–1 on digital selective calling AIS transponders. This new standard will define testing and interfacing requirements for AIS systems. Commercially-produced systems should meet all the three standards described above.

ICAN have developed an AIS module which is an add-on to their 'Aldebaran' Electronic Charting System. The module has been developed for use with Saab TransponderTechs AIS hardware for which ICAN is the exclusive Canadian agent. The AIS module enables ICAN's ECS to display broadcast AIS information on screen in InfoPanels and as overlays. A typical screen display with this feature is shown in Figure 7.10.

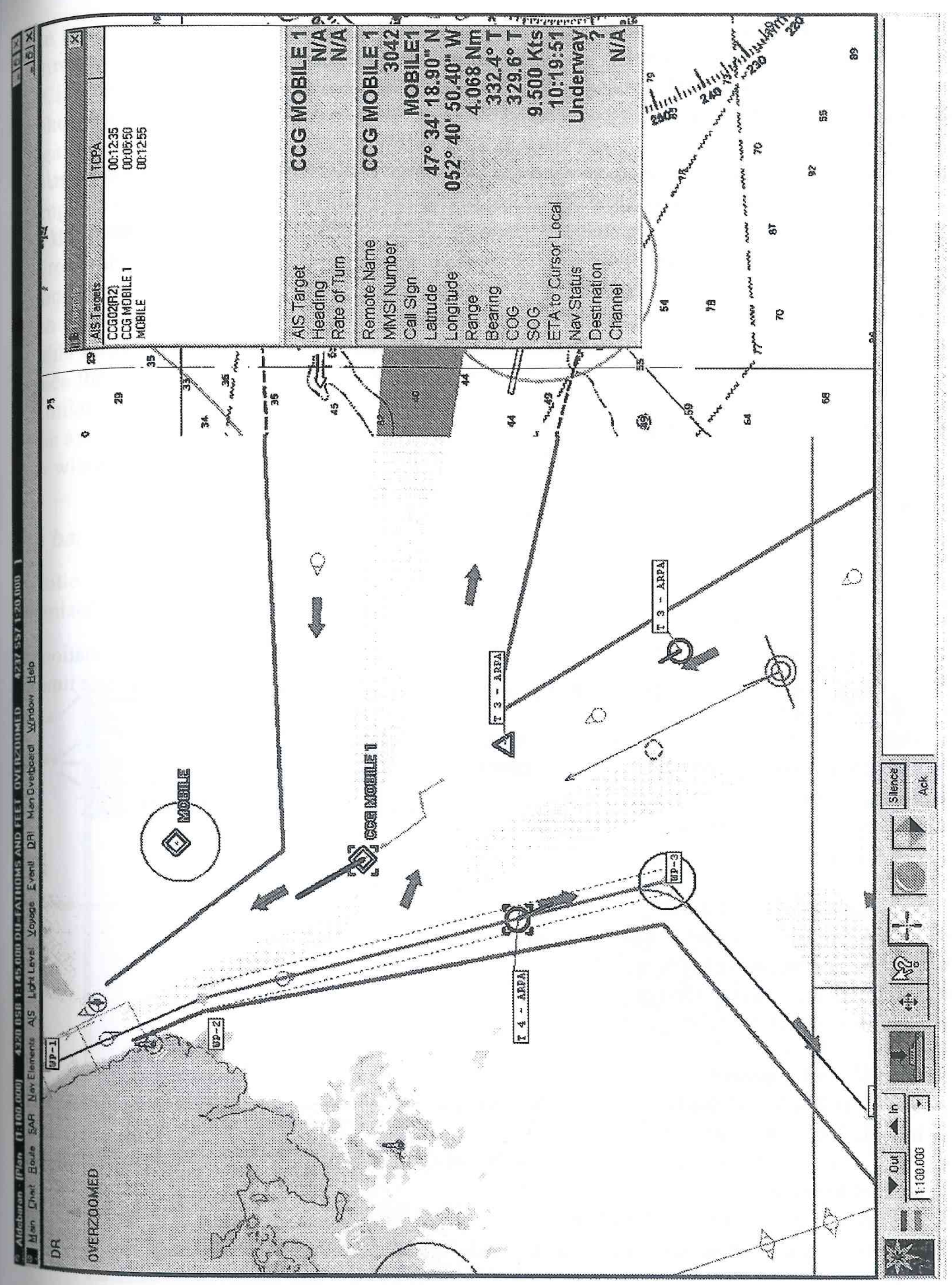


Figure 7.10 Display showing AIS target information. (Reproduced courtesy of ICAN.)

Features of the ICAN AIS module are as follows.

1 AIS Target Monitoring
- Unlimited on-screen AIS targets.
- AIS Tracking InfoBox sorted based on TCPA and RCPA.
- Targets can be individually centred on screen.
- Single target activation.
- Messages can be addressed or sent via broadcast as binary or ASCII data on specific channels.
- Automatic (scheduled) and manual data transmissions.
- Binary transmissions include: man overboard, ARPA, markers and points of interest (SAR, waypoints, routes and zones).
- Displayed AIS transponder channels.
- On screen CPA display.
- Alarms and indications based on configurable CPA properties.

2 Long Range AIS Monitoring
- Microsoft's MAPI (Mail Application Programming Interface) based mail set-up.
- Office and remote monitoring through Inmarsat terminal or service provider.
- Filtered sender information.
- Multiple e-mail address transmissions (single Inmarsat message).
- Configurable gateway formats.

3 AIS Module Configuration
- Remote target properties (shape, labels).
- Name, call sign, ship type, MMSI, IMO no., draught, trip, destination and ETA to destination.
- Own ship transponder transmission information (Nav sensor, antenna location, UTC date time and channel designation).
- Distinguishable transponder characteristics (R2 vs R3 labelling).
- ECS back-up positioning device (transponder GPS).
- Transponder GNSS status.
- Closest point of approach (time and range based).
- Channel polygons.

4 Data logging and Distribution
- Unfiltered logging of serial inputs, including AIS transponder information.
- File-based distribution of logged data.
- TCP/IP distribution of serial inputs.
- Playback of recorded data.

5 ICAN ECS Environment
- Seamless display of charts of S-57, NTX, BSB and MRE formats (other formats in development include ARCS and CM-93).
- Point-of-interest feature allows constant update of range/bearing to any point, marker or waypoint (station keeping).
- Ability to add other software modules including high resolution radar overlay, useful for coastline mapping (scanner up to 120 rpm, 8-bit radar image, raw radar data recording capable).

Information on this AIS module and other useful products offered by ICAN are available on their website www.ican.nf.net.

7.7 Navmaster Electronic Navigation System

There are a multitude of suppliers of software suitable for implementing an electronic navigation system, requiring only the hardware and suitable electronic charts to produce an ECDIS or an ECDIS in RCDS mode. The 'Navmaster Professional' from PC Maritime of Plymouth, UK is used as a basis for showing how the software can assist the navigator in passage planning, position logging and navigation management, providing as it does a continuous display of vessel positions received from GPS and plotted on official electronic charts. The minimum system requirements for Navmaster are: a computer operating with a Pentium 133, or better, processor; Windows 95/98/NT/2000; 10-Mbyte hard drive for minimum installation; CD-ROM and floppy-disk drives; 32-Mbyte RAM; and a monitor with 800 × 600 resolution with 256 colours or more. Input/output requirements are one serial and one parallel port. The software is supplied on a CD-ROM. The system uses electronic chart data, which is the copyright of various national hydrographic offices; chart data is protected by a security key that allows access to the charts only via a user PIN number.

Once the software has been loaded into the computer then starting with Navmaster the display will be similar to the one shown in Figure 7.11.

The toolbars and side panels can be moved around the screen, hidden and displayed as required. The main window contains the following.

Title bar

The title bar displays the program control icon, the activation or active image title and the standard minimize/maximize/restore/close buttons.

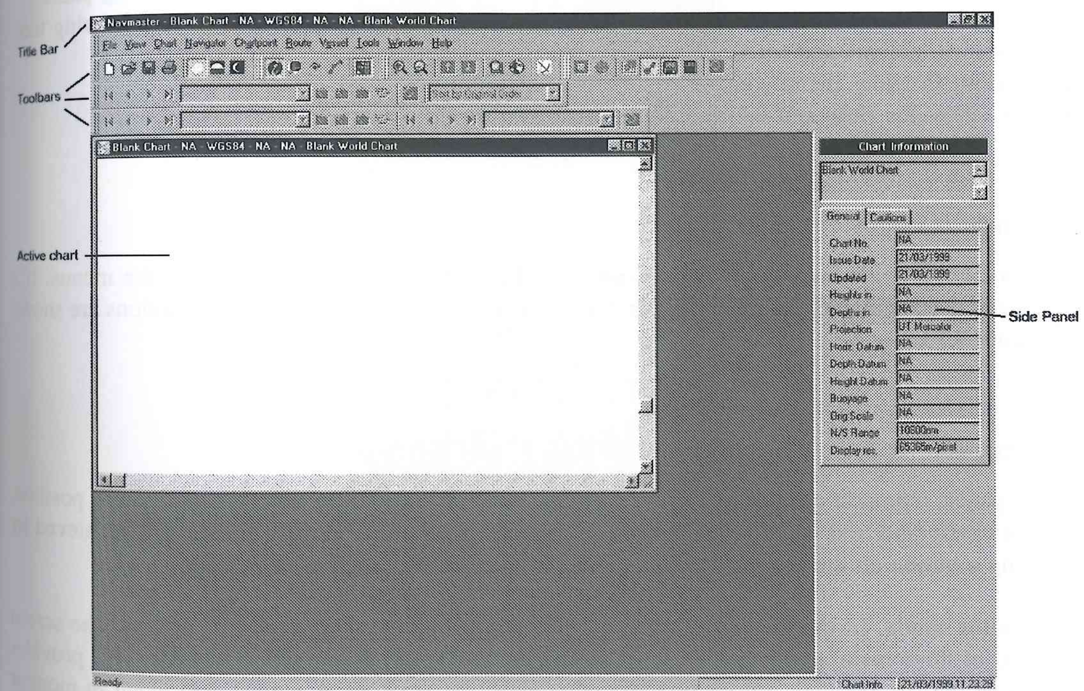


Figure 7.11 The Navmaster start-up window. (Reproduced courtesy of PC Maritime.)

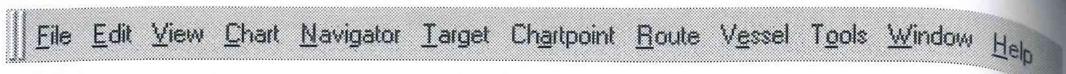


Figure 7.12 Navmaster menu bar headings. (Reproduced courtesy of PC Maritime.)

Menu bar

The menu bar displays the menu headings as shown in Figure 7.12. These are as follows.

- File. Contains standard menu commands for file management, printing and workspace, opening charts, and opening and saving chartpoint and route databases.
- Edit. Provides standard menu commands.
- View. Provides menu commands to select modes of operation, turn on or off the toolbars, side panel and status bar.
- Chart. Provides menu commands to change the chart display, install chart permits and updates, set the location of charts and updates and set chart-related options.
- Navigator. Provides menu commands to: turn position plotting on or off and set DR parameters; turn position logging on or off and make log entries; upload routes and waypoints to GPS; access diagnostic windows for equipment interfacing; open the Autoscroll monitor window; set position and navigation-related options.
- Target. Provides menu commands to Activate/Deactivate ARPA and Tender tracking and set related options.
- Chartpoint. Provides menu commands related to chartpoints.
- Route. Provides menu commands related to routes.
- Vessel. Provides menu commands to enter vessel information for use when calculating plans.
- Tools. Provides menu commands to display tidal atlas and activate the Range and Bearing tool, customize toolbars and set workspace and tidal atlas options.
- Window. Provides menu commands to manipulate windows.
- Help. Provides Help and information on obtaining technical support.

Toolbars

The toolbars provide buttons that access some of the frequently used commands in the menus. If a command is unavailable, its button appears greyed-out. Toolbars and their button functions are shown in Figure 7.13.

Side panels

These panels represent each of the main functions of the Navmaster system, i.e. monitoring position, storing chartpoints and creating and calculating routes. Switching between functions is achieved by pressing a button on the display toolbar or by selecting an item in the View menu.

1 Monitor mode. In this mode it is possible to monitor and plot the vessel's passage. The screen consists of three main areas: the chart area, the side panel and the toolbars. The chart area provides a view of the current chart, which may be manipulated as required. A typical side panel in monitor mode is shown in Figure 7.14.

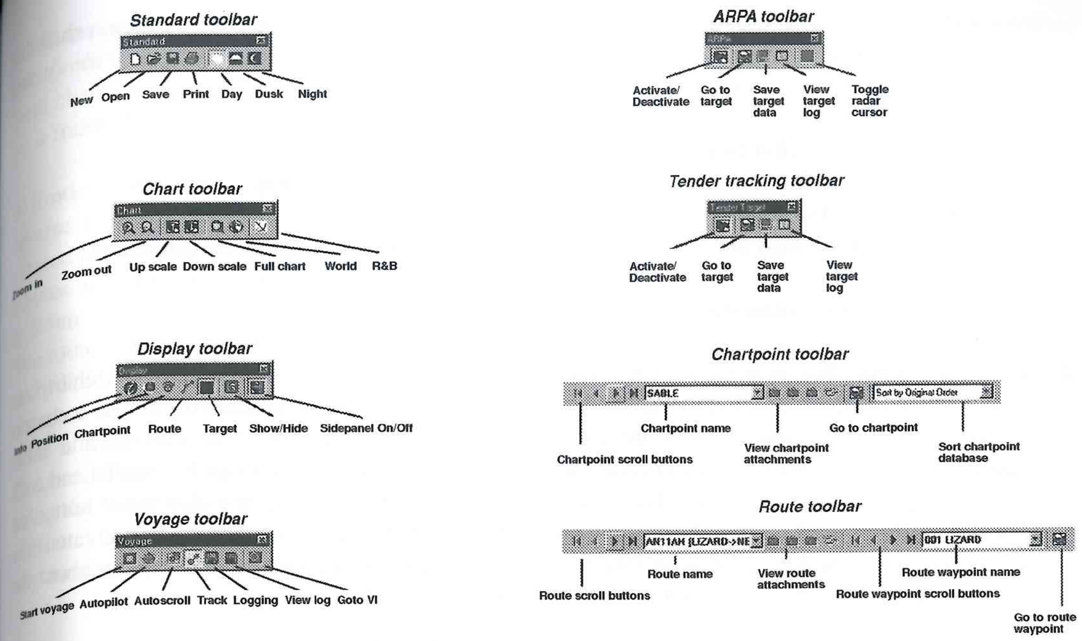


Figure 7.13 Toolbars used in the Navmaster display. (Reproduced courtesy of PC Maritime.)

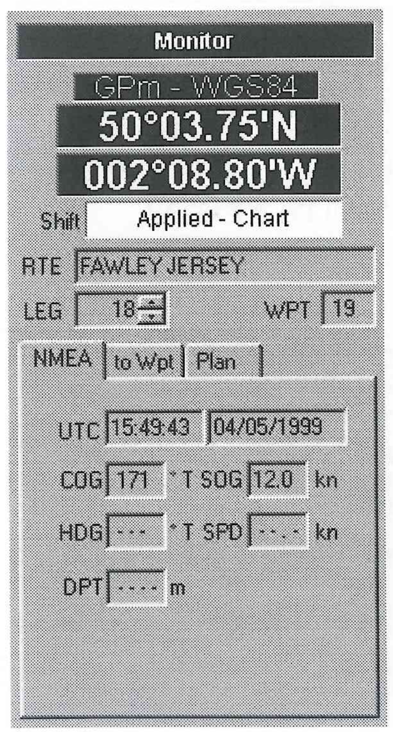


Figure 7.14 Navmaster monitor mode side panel. (Reproduced courtesy of PC Maritime.)

The panel repeats the position obtained from the GPS, provides information on any datum shift that has been applied, and displays the current route name and active leg. Three tabs provide further information:

NMEA — repeats information from electronic instruments;
to Wpt — provides calculated information from current position to the next waypoint in the route;
Plan — repeats information for the leg from the passage plan if one has been calculated.

The Autocheck box activates/deactivates automatic leg advance.

2 Chartpoint mode. In this mode it is possible to add, delete, edit or save chartpoints. A chartpoint is the latitude and longitude of a geographical position stored in a database; a chartpoint on a chart is shown as a blue circle. Each chartpoint has database fields which allow the user to add other information which may be of assistance. Any number of chartpoint databases can be created and each database can contain any number of chartpoints. To enter chartpoint mode, the chartpoint button on the display toolbar (see Figure 7.13) is pressed and, provided side panel display is activated, the chartpoint side panel will be displayed (see Figure 7.15). The panel provides information about the current chartpoint. Each field within the panel can be edited.

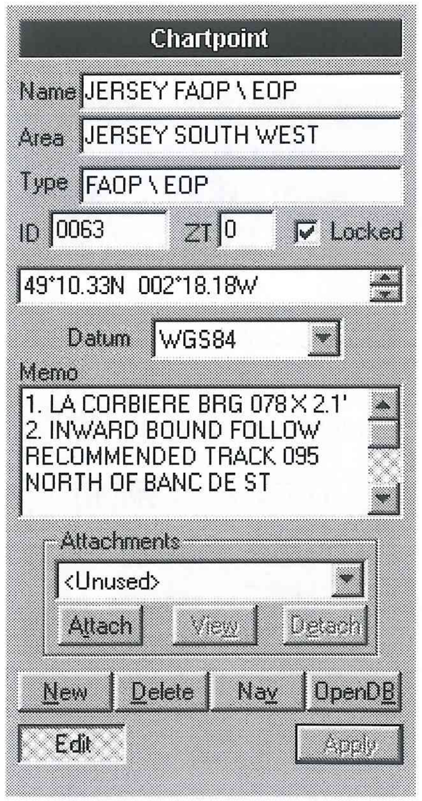


Figure 7.15 Navmaster chartpoint mode side panel. (Reproduced courtesy of PC Maritime.)

Navmaster stores chartpoints in WGS-84 co-ordinates where possible and, provided a selected chartpoint is on the currently selected chart, it is possible to view and edit the chartpoint to match the local chart datum. A chartpoint can simply be used as a marker on a chart or, if used to indicate points on a route, they are known as waypoints.

3 Route mode. This mode enables the user to create new routes, edit existing routes and copy or reverse routes. A route is a sequence of waypoints built up from previously stored chartpoints or created by clicking on a chart. The route is drawn on the chart for evaluation and possible amendment. Routes are stored in databases and there can be many routes stored.

Route mode can be accessed by pressing the route button on the display toolbar (see Figure 7.13). The route side panel will be displayed, provided the side panel is switched on. Routes may be created, and edited, using waypoints from a chartpoint database or by drawing the route directly on the screen chart, or by a combination of both methods. Whatever route method is used, each waypoint in the route is inserted into the box on the route side panel and a line will connect the route waypoints on the chart. This line can be adjusted depending on whether the user adds, deletes or moves waypoints using the route side panel.

Routes are stored in a route database and any number of route databases can be created, containing any number of routes. A typical side panel in route mode is shown in Figure 7.16.

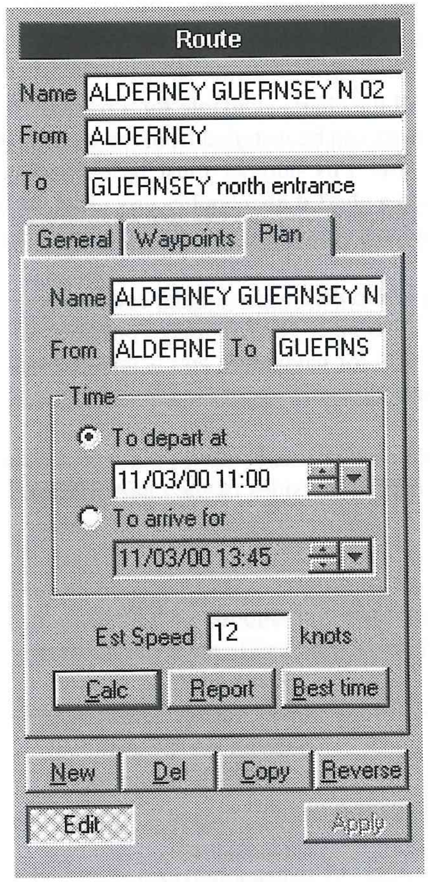


Figure 7.16 Navmaster route mode side panel. (Reproduced courtesy of PC Maritime.)

Three tabs provide further information:

General	enables the user to enter and display a textual note relating to the route;
Waypoints	lists the waypoints in the route and provides a means to select waypoints for amendment or deletion or to locate a new waypoint;
Plan	gives the ability to calculate a passage plan based on the route which the user can print or view on the screen.

Other side panels, which are available but not illustrated, are Target Tracking, which provides information on ARPA and Tender targets, and Information which gives information on the selected chart.

7.7.1 Installing charts

Navmaster supports the UKHO ARCS and the Australian Hydrographic Office Seafarer charts and will support ENC charts by the end of 2000. To install these charts the user needs:

- the floppy disk containing a licence file and chart permit file
- one (or more) chart CD-ROM
- one update CD-ROM with the latest chart corrections.

Each chart CD-ROM contains all the charts available for a particular region. A chart permit is a code that unlocks a specific chart. Charts can be installed from the chart permit disk or by entering the chart permit number manually. The user PIN number must be entered before a chart can be loaded or installed. When Navmaster loads a chart it also applies any chart updates at that time. A chart can be displayed without its update but a warning will be displayed indicating the fact that corrections are missing.

The ARCS or Seafarer chart is supplied as two, independent images namely a low-resolution (LR) image and a high-resolution (HR) image. The LR image provides an overview of the chart while the HR image is the one recommended for navigation and is updated with Notice to Mariner corrections. Navmaster provides further zooming in and out of the LR and HR images to give five levels of display for each chart.

The chart can be manipulated so that it is centred on a selected cursor position and the chart can be panned by using the scroll bars at the sides of the chart window.

Table 7.6 The five levels of display for each chart

Resolution	*Zoom level*	*Warning*
Low resolution	Zoom out (LR-out)	Underscale
	Normal (LR)	Underscale
High resolution	Zoom out (HR-out)	Underscale
	Normal (HR)	None
	Zoom in (HR-in)	Overscale

7.7.2 Using Navmaster

When using Navmaster the recommended sequence to follow is:

- create chartpoints
- create a route
- calculate a plan
- monitor by plotting track, viewing data in the Navigation Monitor panel and comparing progress with the plan.

Navmaster is a multi-window application. Charts, the log, waypoint lists etc. all have their own window and windows can be tiled, cascaded or kept in the background as required. Turning on Autoscroll opens a dedicated window which displays the vessel's position in the centre of a chart. For safety reasons the Autoscroll window cannot be minimized so that the user is fully aware of the vessel's position. However, the window can be resized to allow more room for other charts, or it can be covered by a maximized window.

If the Autoscroll window is closed then Autoscroll is turned off. The remaining windows give complete flexibility to organize the charts to suit the task in hand. For example, new chart windows could be opened to:

- look ahead by displaying the vessel's position on a smaller scale chart than the Autoscroll chart
- view charts for other segments of the route
- view the approaches or harbour charts for intended destination
- plan new routes or chartpoints.

While the above is going on it is still possible to view a continuously updating vessel position on the largest scale chart available.

The maximum number of chart windows that can be opened is limited to three plus the Autoscroll window. The number can be increased but the default value of three is chosen to prevent users inadvertently opening too many windows.

The Chart Information panel in Navmaster displays information on the selected chart and indicates the following.

- Chart Description. The Hydrographic Office description of the chart.
- Chart No. The Hydrographic Office chart number.
- Orig Scale. The scale of the paper version of the chart.
- Edition Date. The date the chart was first issued.
- Updated. The date of the last update.
- Heights In. The units of height used.
- Depths In. The units of depth used.
- Projection. The type of projection used in the production of the chart.
- Horiz Datum. The geodetic datum of the chart. EG OSGB36 – The Ordnance Survey of Great Britain (1936) datum.
- Depth Datum. The datum to which depths are referred.
- Height Datum. The datum to which heights are referred.
- Buoyage. The buoyage system in use on the chart.
- N/S Range. The vertical distance in nautical miles of the portion of the chart currently displayed in the chart window.
- Display Resolution. The number of metres represented by each pixel on the computer display, which will alter depending on the zoom level of the chart.

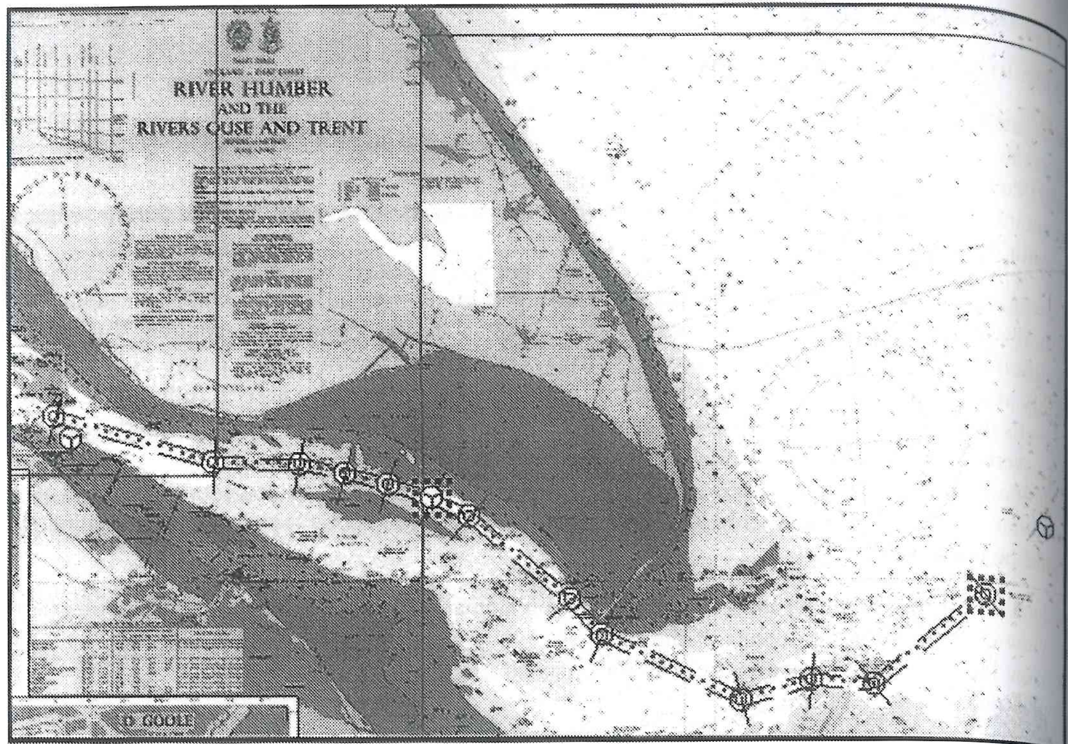


Figure 7.17 ARCS chart 109, River Humber and the Rivers Ouse and Trent OSGB36. (Reproduced courtesy of PC Maritime.)

Passage plans

Having created a route, the user can enter estimated speed, desired departure/arrival times and calculate for each leg of the route:

- course to steer, allowing for variation, deviation and tidal stream (if required)
- distance
- estimated time.

The user can view the plan on screen, change variables as required and then print a copy of the plan. As an example of a chart overlaid with a route Figure 7.17 shows ARCS chart 109, with a route approaching the Humber River, illustrating waypoints entered for the planned route.

Route monitoring options can be chosen so that it is possible to:

- automatically increment route legs as the vessel passes through waypoints so that Navmaster calculations on range and bearing to the next waypoint are relevant, and up-to-date information is sent to the Autopilot
- monitor the vessel's progress against the planned route.

Other options include the following.

- Automatic leg advance. Choosing this option allows the route legs to increment automatically as the vessel passes through the waypoint detection parameters set by the user.

- Waypoint detection. Choosing this option and setting a radius for the route leg to increment to the next leg when vessel position enters the circle. On entry a warning is given. The position and time of entry, and waypoint name are recorded in the log. See Figure 7.18.
- Passing perpendicular. Choosing this option allows the route leg to increment to the next leg when vessel position crosses a line drawn at right angles to the current leg. On passing, a warning is given. Position, time of entry and waypoint name are entered in a log. See Figure 7.18.
- Limits of deviation. Choosing this option allows a deviation limit to be set. If the vessel position exceeds this limit a warning message is displayed and remains until the vessel returns inside the

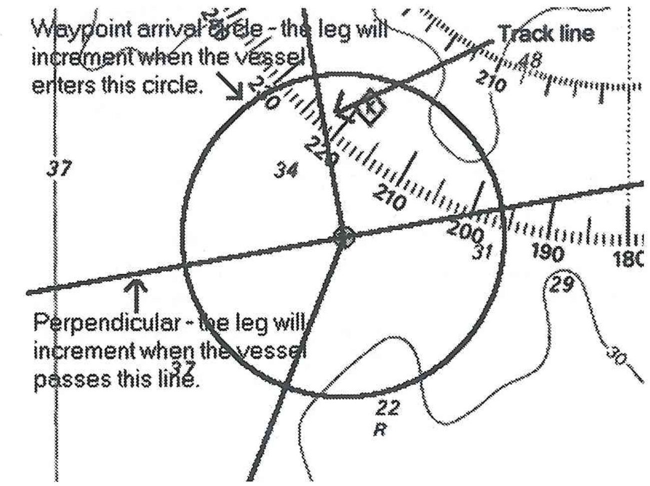


Figure 7.18 Use of waypoint arrival circle and passing perpendicular. (Reproduced courtesy of PC Maritime.)

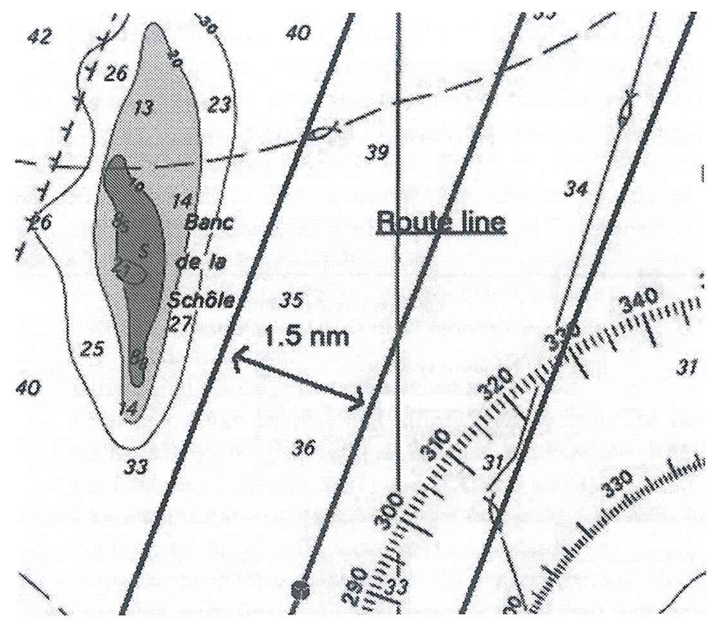


Figure 7.19 Use of limits of deviation. (Reproduced courtesy of PC Maritime.)

Your Company Name — Your company logo

Passage Plan Report

FROM : SPURN APPROACHES
TO : IMMINGHAM

Vessel	:	Options : Tides	[Off]
Estimated speed	: 5.0 knots	Variation	[Off]
Passage distance	: 18.0 nm	Deviation	[Off]
Passage time	: 000:03:35	Calculated	: 11:52:13 / 6/24/00
Route name	: HARBOUR ENTRY	Viewed	: 12:16:52P 24/06/2000

Rte Wpt No	Datum	Time	Elap Time (ddd:hh:mm)	Name	Position	Crse (°T)	Leg (nm)	Accum (nm)	To Go (nm)
1	WGS84	11:52:13 6/24/00	000:00:00	SPURN HEAD APPROACHES	53°34.80'N 000°17.70'E	231	2.51	0.00	18.0
2	WGS84	12:22:20 6/24/00	000:00:30	SPURN LIGHTSHIP	53°33.22'N 000°14.43'E	274	1.05	2.51	15.4
3	WGS84	12:34:57 6/24/00	000:00:43	SE CHEQUER	53°33.29'N 000°12.67'E	254	1.26	3.56	14.4
4	WGS84	12:50:02 6/24/00	000:00:58	NO 3 CHEQUER	53°32.95'N 000°10.64'E	295	2.64	4.82	13.1
5	WGS84	1:21:40 6/24/00	000:01:29	SUNK CHANNEL	53°34.06'N 000°06.63'E	319	0.83	7.46	10.5
6	WGS84	1:31:36 6/24/00	000:01:39	HAWKE	53°34.68'N 000°05.71'E	309	2.25	8.29	9.67
7	WGS84	1:58:38 6/24/00	000:02:06	HAWKE S4	53°36.11'N 000°02.79'E	296	0.74	10.5	7.42
8	WGS84	2:07:27 6/24/00	000:02:15	HAWKE S5	53°36.43'N 000°01.68'E	287	0.78	11.3	6.68
9	WGS84	2:16:48 6/24/00	000:02:25	SUNK S6	53°36.66'N 000°00.43'E	285	0.75	12.1	5.90
10	WGS84	2:25:50 6/24/00	000:02:34	SUNK S7	53°36.86'N 000°00.79'W	281	0.82	12.8	5.15
11	WGS84	2:35:38 6/24/00	000:02:43	SUNK S8	53°37.01'N 000°02.14'W	272	1.47	13.6	4.33
12	WGS84	2:53:17 6/24/00	000:03:01	SUNK SPIT	53°37.05'N 000°04.61'W	286	2.86	15.1	2.86
13	WGS84	3:27:35 6/24/00	000:03:35	IMMINGHAM OIL TERMINAL	53°37.85'N 000°09.22'W	000	0.00	18.0	0.00

Pre-departure check list
Navmaster Raster Chart Display System

1: Navmaster system on ☐
2: Correct chart displayed ☐
3: Folio mode and Autoscroll on ☐
4: This route displayed on chart ☐
5: Position logging on ☐
6: Logging on ☐

On completion of pre-departure checks this form is to be signed by the responsible officer and handed to the master.

Port.................................... Signed.................................... Date....................................

Figure 7.20 Passage plan for a route into Immingham on the River Humber. (Reproduced courtesy of PC Maritime.)

limit. When the vessel exceeds the limit a log entry is made, with time and position. A further log entry is made when the vessel returns inside the limit. See Figure 7.19.

Creating a passage plan

A passage plan can be created as follows.

1 Prepare the route.
2 Select the plan tab on the Route panel (a typical Route side panel is shown in Figure 7.16).
3 Enter departure/arrival time and estimated speed.
4 Set any options required.
5 Click on Calc.
6 Click on Report to see the plan.

A typical passage plan report for the route of Figure 7.17 is shown in Figure 7.20.

Because Navmaster calculates routes almost instantly it is a simple matter to change parameters such as vessel speed, date and options.

The above has been extracted, with permission, from the Navmaster User Guide and only gives a very limited overview of the facilities available with the system. More detail can be obtained from the manufacturers PC Maritime, Brunswick House, Brunswick Road, Plymouth PL4 0NP, UK. E-mail: marketing@pcmaritime.co.uk and website: www.pcmaritime.co.uk.

7.8 Glossary

AHO Australian Hydrographic Office.
AIS Automatic Identification System, see Transponder.
ARCS Admiralty Raster Chart Service. The UKHO proprietary RNC.
ARPA Automatic Radar Plotting Aid.
Chart cell The smallest unit for geographical data. Each cell has a unique address in memory and may possess different data volume and size characteristics.
Chart symbol A graphical representation of an object or characteristic.
CIS Chart Information System.
'Course-up' display A display where the heading of own ship is upwards on the screen and the chart moves relative to own ship.
CPA Closest Point of Approach.
Database A set of stored data used for a particular application which can be assessed as required.
Datum See Geodetic datum.
DGPS Differential Global Positioning System.
ECDIS Electronic Chart Display and Information System. The performance standard approved by the IMO and defined in publications from the IHO (Special Publications S-52 and S-57) and IEC document 1174.
ECS Electronic Chart System. A system that, unlike ECDIS, has no obligation to conform to the ECDIS performance standards.
Ellipsoid A regular geometric shape which closely approximates to the shape of a geoid, having a specific mathematical expression, and can be used for geodetic, mapping and charting purposes.

ENC Electronic Navigational Chart. Charts, manufactured for use with ECDIS, which meet the ECDIS performance standards and are issued by or on the authority of government-authorized hydrographic offices.

ETA Estimated time of arrival.

Geodetic datum A specifically orientated reference ellipsoid requiring typically eight parameters to define it. Two parameters relate to the dimensions of the ellipsoid, three parameters specify its centre with respect to the Earth's centre of mass while the remainder specify ellipsoid orientation with respect to the average spin axis of the Earth and Greenwich reference meridian. Provides a horizontal datum.

Geoid An undulating but smooth representation of equal values of the Earth's gravitational field coinciding most closely with mean sea level. The geoid is the primary reference surface for heights.

GMSK Gaussian Minimum Shift Keying.

GNSS Global Navigation Satellite System. The use of GPS for civilian purposes.

GPS Global Positioning System. A satellite navigation system designed to provide continuous position and velocity data in three dimensions and accurate timing information globally.

Hardware The physical part of a computer system that provides the processing capability; includes peripheral devices and cabling.

HCRF Hydrographic Chart Raster Format. Developed by the UKHO and used by them for the Admiralty Raster Chart Service (ARCS) and by the AHO for its Seafarer Chart Service. Other HOs are expected to adopt the format.

HDLC High-Level Data Link Control, specified by ISO/IEC 3309, 5th edition 1993.

IEC International Electrotechnical Commission. The organization which produces world standards in the area of electrical and electronic engineering.

IHO International Hydrographic Organization. A grouping of national hydrographic offices responsible for promoting international standards in the fields of hydrographic surveying and chart production.

IMO International Maritime Organization. A specialized agency of the United Nations and responsible for promoting maritime safety and navigational efficiency.

ITU-R International Telecommunications Union Sector for Radiocommunication.

MMSI Maritime Mobile Service Identities. An international system of automatic identification for all ships.

NHO National Hydrographic Office.

NIMA National Imagery and Mapping Agency.

NMEA National Marine Electronics Association. An organization comprising manufacturers and distributors. Responsible for agreeing standards for interfacing between various electronic systems on ships. NMEA 0183 version 2.3 is the current standard.

NOAA National Oceanic and Atmospheric Administration.

'North-up' display A display configuration where north is always in the up direction. This corresponds to the orientation of nautical charts and is the normal display for an ECDIS.

Notice to Mariners A notice issued by hydrographic offices, on a periodic or occasional basis, relating to matters that affect nautical charts, sailing directions, light lists and other nautical publications.

NOS National Ocean Service.

OCS Office of Coast Survey.

Own ship Used to define the vessel on which the electronic chart system is operating.

Performance standard Used to define the minimum performance requirements for a system to meet the requirements of the SOLAS Convention.

Pixel An abbreviation for picture element. It is the smallest element that can be resolved by electronic raster devices such as a scanner, display and plotter.

PRIMAR A series of regional distribution centres (RENCs) will be set up for the distribution of ENCs, and PRIMAR is the first of these centres.

RCDS Raster Chart Display System. A navigation system which can be accepted as complying with the paper version of the up-to-date chart requirements of regulation V/20 of the SOLAS Convention, by displaying RNCs with position information from navigation sensors to assist the mariner in route planning and route monitoring, and if required display additional navigation related material.

RCPA Range to closest point of approach.

RENC Regional ENC Co-ordinating Centre.

RNC Raster navigational chart. A facsimile of a paper chart. Both the paper chart and the RNC are originated by, or distributed on the authority of, a government authorized-hydrographic office.

Route monitoring A function required of an ECDIS whereby own ship present position can be displayed on the chart and viewed relative to the chart data.

Route planning A function required of an ECDIS whereby the mariner can study the intended route on a display and select an intended track, marking it with waypoints and other navigational data.

S-52 IHO Special Publication S-52. Specification for chart content and display aspects of ECDIS.

S-57 IHO Special Publication S-57. IHO transfer standard for digital hydrographic data, edition 3. It describes the data model and format to be used for ENCs.

Safety contour The contour selected by the mariner, using the SENC data, to determine soundings which, relative to own ship's draught, provide safe water channels. The ECDIS can use the information to generate anti-grounding alarms.

Safety depth The depth, selected by the mariner, which defines own ship's draught plus under-keel clearance which can be used by the ECDIS to indicate soundings on the display which may be equal or less than the defined value.

SENC System Electronic Navigational Chart. This is the database produced by chart suppliers which meets the requirements of the IHO Special Publication S-57.

Software This includes all the programs that can be used on a computer. Software can be subdivided into the operational software required for the computer to function and the application software developed for specific user applications.

SOLAS Safety of Life at Sea. The International Convention for the Safety of Life at Sea Chapter V Safety of Navigation, Regulation 20, Nautical Publications requires that 'All ships shall carry adequate and up-to-date charts, sailing directions, lists of lights, notices to mariners, tide tables and all other nautical publications necessary for the intended voyage'. SOLAS does not apply universally and some vessels, such as ships of war, cargo ships of less than 500 GRT, fishing vessels etc are exempt from the SOLAS requirements.

SOTDMA Self-organizing time division multiple access. Used by mobile stations operating in autonomous and continuous mode. The protocol offers an access algorithm that quickly resolves conflicts without intervention from controlling stations.

Standard display The SENC information that should be displayed when a chart is first accessed by the ECDIS. The level of data contained can be customized to suit the mariner.

TCPA Time to closest point of approach.

TDMA Time division multiple access.

Transponder (AIS) A shipborne transmit/receive system which broadcasts continuously, on VHF frequencies, details about ship's identity, ship characteristics, type of cargo, destination, course and speed. The ECDIS can be used to display AIS targets together with their speed and course vectors.

UKHO United Kingdom Hydrographic Office.

USCG US Coast Guard.

UTC Co-ordinated universal time. Developed to meet the requirements of scientists to provide a precise scale of time interval and navigators surveyors and others requiring a time scale directly related to the earth's rotation.

VTS Vessel Traffic System. A system for managing shipping traffic in congested areas such as ports and inland waterways.

Waypoint A point entered into a computer and used as a reference point for navigational calculations. Planned voyages would have a series of waypoints indicating legs of the voyage. A modern computer is capable of storing multiple waypoints.

WEND Worldwide ENC database. A model, developed by the IHO, to act as a distribution network to supply ENCs to ECDIS compliant ships.

WGS-84 World Geodetic System 1984. A global datum system for horizontal datum used as a standard in ECDIS.

Zoom A method of changing the scale of the displayed chart information on the screen. Zoom-in or zoom-out facilities are usually provided at the touch of a button.

7.9 Summary

- An electronic chart is one where chart data is provided as a digital charting system capable of displaying both geographical data and text.
- An electronic chart is 'official' if it is issued by or on the authority of a national hydrographic office. All other charts are 'non-official'.
- An electronic chart may use raster data or vector data.
- Delivery of electronic chart data is via an Electronic Chart Display and Information System (ECDIS) which is a navigational information system, comprising hardware, software and official vector charts and must conform to ECDIS Performance Standards.
- Chart types available include privately produced vector, official raster and Electronic Navigational Chart (ENC). The ENC is the designated chart system for ECDIS.
- A Raster Chart Display System (RCDS) is one that displays official raster navigational charts (RNCs).

- A dual fuel system is one that operates as an ECDIS or RCDS mode according to the type of chart data in use.
- Chart accuracy may depend on local datum that may differ from that used by satellite systems which use a global datum, e.g. WGS-84. Corrections may be necessary before a position is plotted on a chart.
- Electronic charts are updated regularly to ensure conformity with the SOLAS requirement that charts should be 'adequate and up-to-date for the intended voyage'.
- Automatic Identification System (AIS) is a shipborne transponder system that broadcasts information about a ship fitted with the system. The data generated may be used by other AIS-fitted ships and/or shore stations and such data may be passed to an electronic charting system where AIS-fitted ships could appear as 'targets' on the electronic chart. Such targets could be interrogated to generate information such as ship's speed, heading and other data.
- For any ECDIS system to operate, suitable software must be available to enable the function of an ECDIS system to meet performance standards as laid down by the regulatory bodies. A particular system examined is the Navmaster Electronic Navigation System of PC Maritime.

7.10 Revision questions

1 What do you understand by the term 'electronic chart'? What is the definition of an 'official' electronic chart?
2 Explain briefly the difference between a chart produced using raster data and one produced using vector data. Give advantages/disadvantages associated with each type of chart.
3 Explain briefly what defines an electronic navigational chart (ENC) used with ECDIS. What are the advantages of an ENC in terms of chart information that can be displayed?
4 Describe what you understand by the term Electronic Chart Display and Information System (ECDIS). What are the basic requirements of an ECDIS?
5 Describe what you understand by the term Raster Chart Display System (RCDS) and state briefly how a RCDS could be used in a dual fuel system.
6 Explain why there may be a difference between local datum used for a particular chart and the global datum used in ECDIS. How would a position, determined from a GPS or DGPS input, be affected if plotted on a chart based on a different datum?
7 Describe briefly the concept of an Automatic Identification System (AIS). Explain the advantages to be gained by fitting ships and specific shore stations with AIS.
8 The Navmaster Electronic Navigation System (Section 7.7) uses on-screen side panels that represent main functions of the system. Describe briefly the function of the following side panels:
(a) monitor mode
(b) chartpoint mode
(c) route mode.
9 Using the Navmaster Electronic Navigation System (Section 7.7) describe how charts may be installed in the system. What information is displayed in the chart information panel for a selected chart?
10 Using the Navmaster Electronic Navigation System (Section 7.7) as a basis, describe the recommended sequence to be followed for route planning and monitoring. Define what is meant by a chartpoint and describe how chartpoints could be used in route planning.

Chapter 8

The ship's master compass

8.1 Introduction

Of all the navigation instruments in use today, the master compass is the oldest and probably the one that most navigators feel happiest with. However, even the humble compass has not escaped the advance of microelectronics. Although modern gyrocompasses are computerized the principles upon which they work remain unchanged.

8.2 Gyroscopic principles

At the heart of a marine gyrocompass assembly is a modern gyroscope consisting of a perfectly balanced wheel arranged to spin symmetrically at high speed about an axis or axle. The wheel, or rotor, spins about its own axis and, by suspending the mass in a precisely designed gimbals assembly, the unit is free to move in two planes each at right angles to the plane of spin. There are therefore three axes in which the gyroscope is free to move as illustrated in Figure 8.1:

- the spin axis
- the horizontal axis
- the vertical axis.

In a free gyroscope none of the three freedoms is restricted in any way. Such a gyroscope is almost universally used in the construction of marine gyrocompass mechanisms. Two other types of gyroscope, the constrained and the spring-restrained are now rarely seen.

In order to understand the basic operation of a free gyroscope, reference must be made to some of the first principles of physics. A free gyroscope possesses certain inherent properties, one of which is inertia, a phenomenon that can be directly related to one of the basic laws of motion documented by Sir Isaac Newton. Newton's first law of motion states that 'a body will remain in its state of rest or uniform motion in a straight line unless a force is applied to change that state'. Therefore a spinning mass will remain in its plane of rotation unless acted upon by an external force. Consequently the spinning mass offers opposition to an external force. This is called 'gyroscopic inertia'. A gyroscope rotor maintains the direction of its plane of rotation unless an external force of sufficient amplitude to overcome inertia is applied to alter that direction. In addition a rapidly spinning free gyroscope will maintain its position in free space irrespective of any movement of its supporting gimbals (see Figure 8.2).

Also from the laws of physics it is known that the linear momentum of a body in motion is the product of its mass and velocity (mv). In the case of a freely spinning wheel (Figure 8.3), it is more

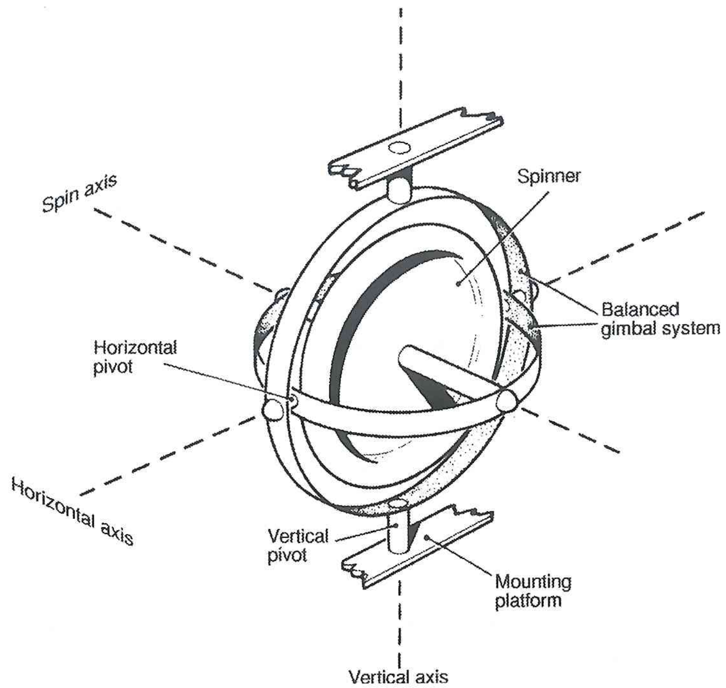


Figure 8.1 A free gyroscope. (Reproduced courtesy of S. G. Brown Ltd.)

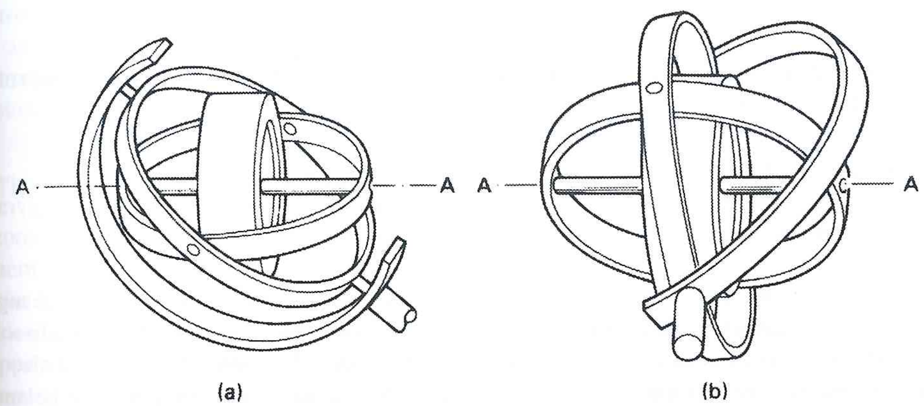


Figure 8.2 The gyrospin axis is stabilized irrespective of any movement of the supporting gimbals. (Reproduced courtesy of Sperry Ltd.)

convenient to think in terms of angular momentum. The angular momentum of a particle spinning about an axis is the product of its linear momentum and the perpendicular distance of the particle from the axle:

$$\text{angular momentum} = mv \times r$$

where r = rotor radius.

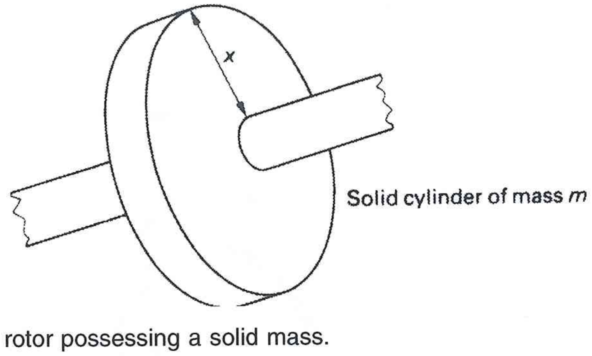


Figure 8.3 A spinning rotor possessing a solid mass.

The velocity of the spinning rotor must be converted to angular velocity (ω) by dividing the linear tangential velocity (v) by the radius (r). The angular momentum for any particle spinning about an axis is now:

$$m\omega r^2$$

For a spinning rotor of constant mass where all the rotating particles are the same and are concentrated at the outer edge of the rotor, the angular momentum is the product of the moment of inertia (I) and the angular velocity:

$$\text{angular momentum} = I\omega$$

where $I = 0.5\ mr^2$.

It can now be stated that gyroscopic inertia depends upon the momentum of the spinning rotor. The momentum of such a rotor depends upon three main factors:

- the total mass, M of the rotor (for all particles)
- the radius r summed as the constant K (for all the particles) where K is the radius of gyration
- the angular velocity ω.

The angular momentum is now proportional to ωMK^2. If one or more of these factors is changed, the rotor's gyroscopic inertia will be affected. In order to maintain momentum, a rotor is made to have a large mass, the majority of which is concentrated at its outer edge. Normally the rotor will also possess a large radius and will be spinning very fast. To spin freely the rotor must be perfectly balanced (its centre of gravity will be at the intersection of the three axes) and its mounting bearings must be as friction-free as possible. Once a rotor has been constructed, both its mass and radius will remain constant. To maintain gyroscopic inertia therefore it is necessary to control the speed of the rotor accurately. This is achieved by the use of a precisely controlled servo system.

8.2.1 Precession

Precession is the term used to describe the movement of the axle of a gyroscope under the influence of an external force. If a force is applied to the rotor by moving one end of its axle, the gyroscope will be displaced at an angle of 90° from the applied force. Assume that a force is applied to the rotor in Figure 8.4 by lifting one end of its axle so that point A on the rotor circumference is pushed

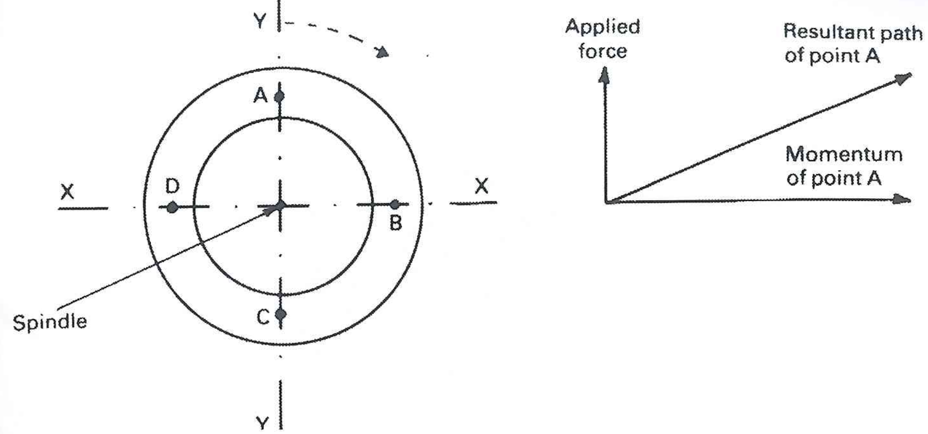


Figure 8.4 Gyro precession shown as a vector sum of the applied forces and the momentum.

downwards into the paper. The rotor is rapidly spinning clockwise, producing gyroscopic inertia restricting the effective force attempting to move the rotor into the paper. As the disturbing force is applied to the axle, point A continues its clockwise rotation but will also move towards the paper. Point A will therefore move along a path that is the vector sum of its original gyroscopic momentum and the applied disturbing force. As point A continues on its circular path and moves deeper into the paper, point C undergoes a reciprocal action and moves away from the paper. The plane of rotation of the rotor has therefore moved about the H axis although the applied force was to the V axis.

The angular rate of precession is directly proportional to the applied force and is inversely proportional to the angular momentum of the rotor. Figure 8.5 illustrates the rule of gyroscopic precession.

8.2.2 The free gyroscope in a terrestrial plane

Now consider the case of a free gyroscope perfectly mounted in gimbals to permit freedom of movement on the XX and YY axes. In this description, the effect of gravity is initially ignored. It should be noted that the earth rotates from west to east at a rate of 15°/h and completes one revolution in a 'sidereal day' which is equivalent to 23 h 56 min 4 s. The effect of the earth's rotation beneath the gyroscope causes an apparent movement of the mechanism. This is because the spin axis of the free gyroscope is fixed by inertia to a celestial reference (star point) and not to a terrestrial reference point. If the free gyro is sitting at the North Pole, with its spin axis horizontal to the earth's surface, an apparent clockwise movement of the gyro occurs. The spin axis remains constant but as the earth rotates in an anticlockwise direction (viewed from the North Pole) beneath it, the gyro appears to rotate clockwise at a rate of one revolution for each sidereal day (see Figure 8.6).

The reciprocal effect will occur at the South Pole. This phenomenon is known as gyro drift. Drift of the north end of the spin axis is to the east in the northern hemisphere and to the west in the southern hemisphere. There will be no vertical or tilting movement of the spin axis. Maximum gyro tilt occurs if the mechanism is placed with its spin axis horizontal to the equator. The spin axis will be stabilized in line with a star point because of inertia. As the earth rotates the eastern end of the spin axis appears to tilt upwards. Tilt of the north end of the spin axis is upwards if the north end is to the east of the meridian and downwards if it is to the west of the meridian. The gyro will appear to execute one

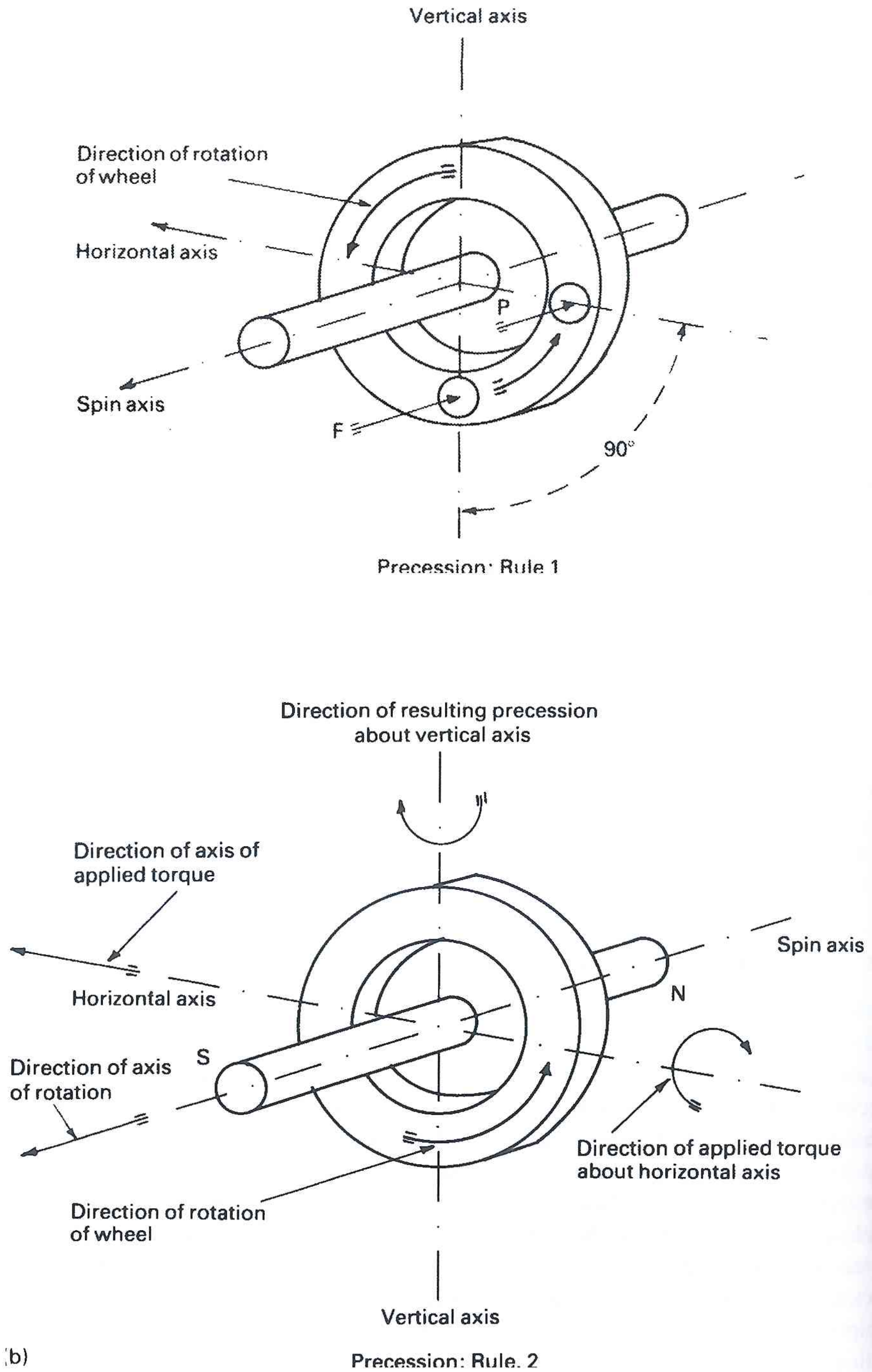


Figure 8.5 (a) Resulting precession P occurs at 90° in the direction of spin from the applied force F. This direction of precession is the same as that of the applied force. (Reproduced courtesy of Sperry Ltd.) (b) The direction of axis rotation will attempt to align itself with the direction of the axis of the applied torque. (Reproduced courtesy of Sperry Ltd.)

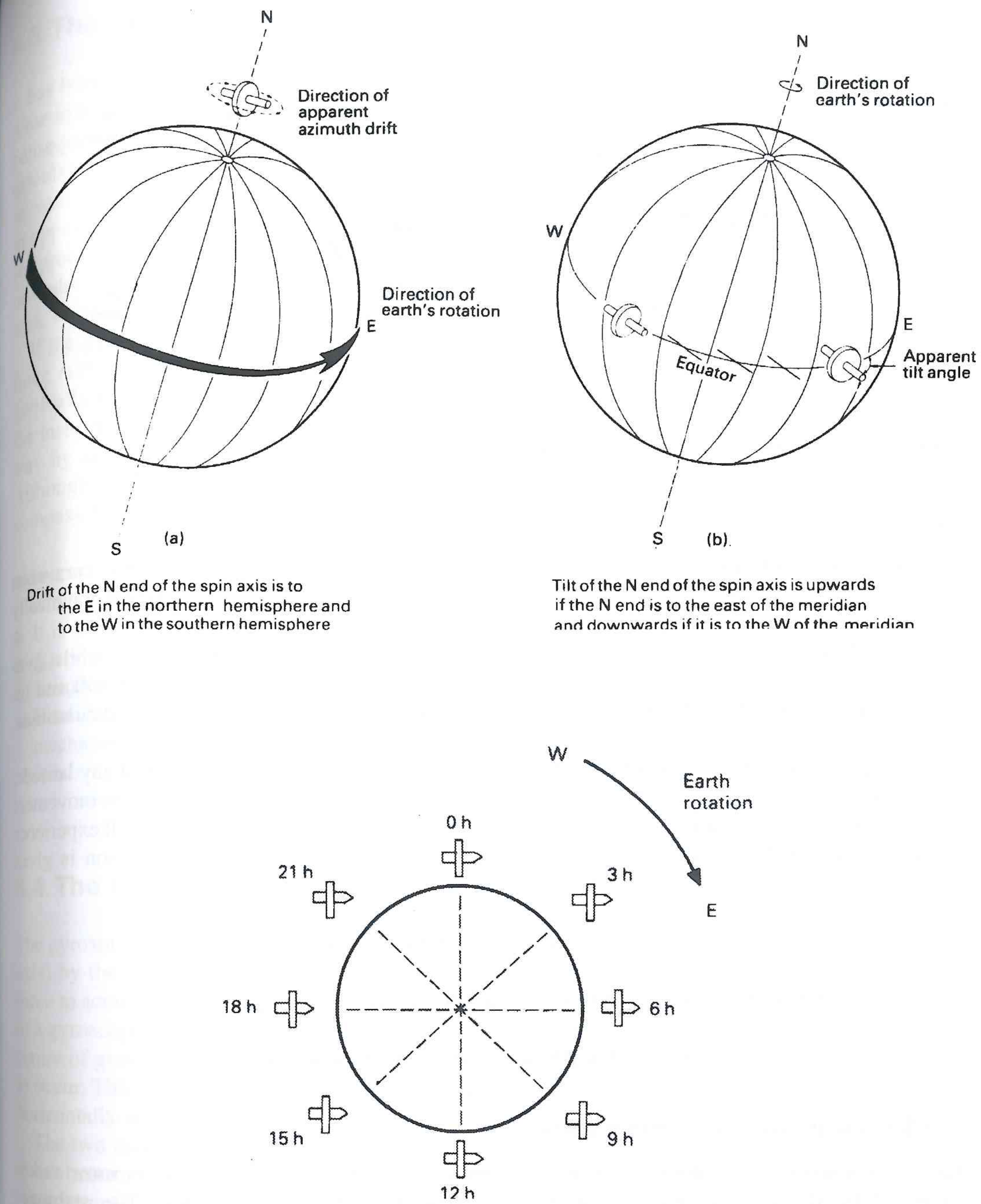


Figure 8.6 (a) Effect of earth rotation on the gyro. (Reproduced courtesy of Sperry Ltd.) (b)View from the South Pole. The earth rotates once every 24 h carrying the gyro with it. Gyroscopic inertia causes the gyro to maintain its plane of rotation with respect to the celestial reference point. However, in relation to the surface of the earth the gyro will tilt.

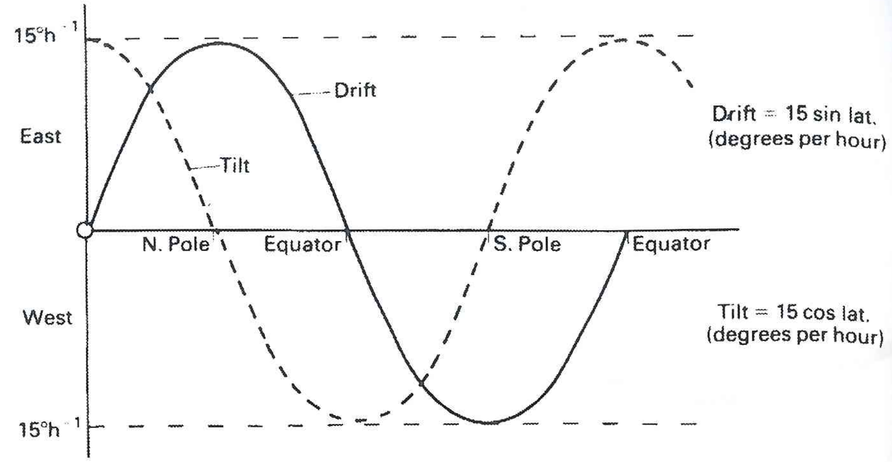


Figure 8.7 The graphical relationship between drift and tilt.

complete revolution about the horizontal axis for each sidereal day. No drift in azimuth occurs when the gyro is directly over the equator. The relationship between drift and tilt can be shown graphically (see Figure 8.7).

Figure 8.7 shows that gyro drift will be maximum at the poles and zero at the equator, whilst gyro tilt is the reciprocal of this. At any intermediate latitude the gyro will suffer from both drift and tilt with the magnitude of each error being proportional to the sine and cosine of the latitude, respectively.

When a gyro is placed exactly with its spin axis parallel to the spin axis of the earth at any latitude, the mechanism will maintain its direction relative to the earth. There is no tilt or azimuth movement and the gyro may be considered to be Meridian stabilized. As the earth rotates the gyro will experience a movement under the influence of both tilt and azimuth motion. The rate of tilt motion is given as:

$$\text{tilt} = 15° \cos \text{latitude (degrees per hour)}$$

where 15° is the hourly rate of the earth's rotation. The azimuth drift is:

$$\text{azimuth drift} = 15° \sin \text{latitude (degrees per hour)}$$

8.2.3 Movement over the earth's surface

The free gyroscope, as detailed so far, is of no practical use for navigation since its rotor axis is influenced by the earth's rotation and its movement over the earth's surface. The stabilized gyroscopic change in position of longitude along a parallel of latitude requires a correction for the earth's rotary motion. Movement in latitude along a meridian of longitude involves rotation about an axis through the centre of the earth at right angles to its spin axis. Movement of the mechanism in any direction is simply a combination of the latitudinal and longitudinal motions. The faster the gyroscope moves the greater the rate of angular movement of the rotor axle attributable to these factors.

8.3 The controlled gyroscope

It has been stated that a free gyroscope suffers an apparent movement in both azimuth and tilt of the rotor axis depending upon its latitudinal location. When fitted to a vessel the latitude is known and consequently the extent of movement in azimuth and tilt is also known. It is possible therefore to calculate the necessary force required to produce a reciprocal action to correct the effect of apparent movement. A force can be applied to the gyro that will cause both azimuth and tilt precession to occur in opposition to the unwanted force caused by the gyro's position on the earth. The amplitude of the reciprocal force must be exactly that of the force producing the unwanted movement, otherwise over or under correction will occur. If the negative feedback is correctly applied, the gyro will no longer seek a celestial point but will be terrestrially stabilized and will assume a fixed attitude.

If the gyro is drifting in azimuth at '*N*' degrees per hour in an anticlockwise direction, an upward force sufficient to cause clockwise precession at a rate of '–*N*' degrees per hour must be applied vertically to the appropriate end of the rotor axle. The result will be that the gyro drift is cancelled and the instrument points to a fixed point on earth. Gyro tilt movement can also be cancelled in a similar way by applying an equal and opposite force horizontally to the appropriate end of the rotor axle. Although the gyro is now stabilized to a terrestrial point it is not suitable for use as a navigating compass for the following reasons.

- It is not north-seeking. Since the recognized compass datum is north, this factor is the prime reason why such a gyro is not of use for navigation.
- It is liable to be unstable and will drift if the applied reciprocal forces are not precise.
- A complex system of different reciprocal forces needs to be applied due to continual changes in latitude.
- Because of precessional forces acting upon it through the friction of the gimbal bearings, the mechanism is liable to drift. This effect is not constant and is therefore difficult to compensate for.

8.4 The north-seeking gyro

The gyrospin axis can be made meridian-seeking (maintaining the spin axis parallel to the earth's spin axis) by the use of a pendulum acting under the influence of earth gravity. The pendulum causes a force to act upon the gyro assembly causing it to precess. Precession, the second fundamental property of a gyroscope, enables the instrument to become north-seeking. As the pendulum swings towards the centre of gravity, a downward force is applied to the wheel axle, which causes horizontal precession to occur. This gravitational force acting downward on the spinner axle causes the compass to precess horizontally and maintain the axle pointing towards true north.

The two main ways of achieving precessional action due to gravity are to make the gyro spin axis either bottom or top heavy. Bottom-heavy control and a clockwise rotating gyro spinner are used by some manufacturers, whereas others favour a top-heavy system with an anticlockwise rotating spinner. Figure 8.8(a) illustrates this phenomenon.

With bottom-heavy control, tilting upwards of the south end produces a downward force on the other end, which, for this direction of spinner rotation, produces a precession of the north end to the west. In a top-heavy control system, tilting upwards of the north end of the gyro produces a downward force on the south end to causes a westerly precession of the north end. The result, for each arrangement, will be the same.

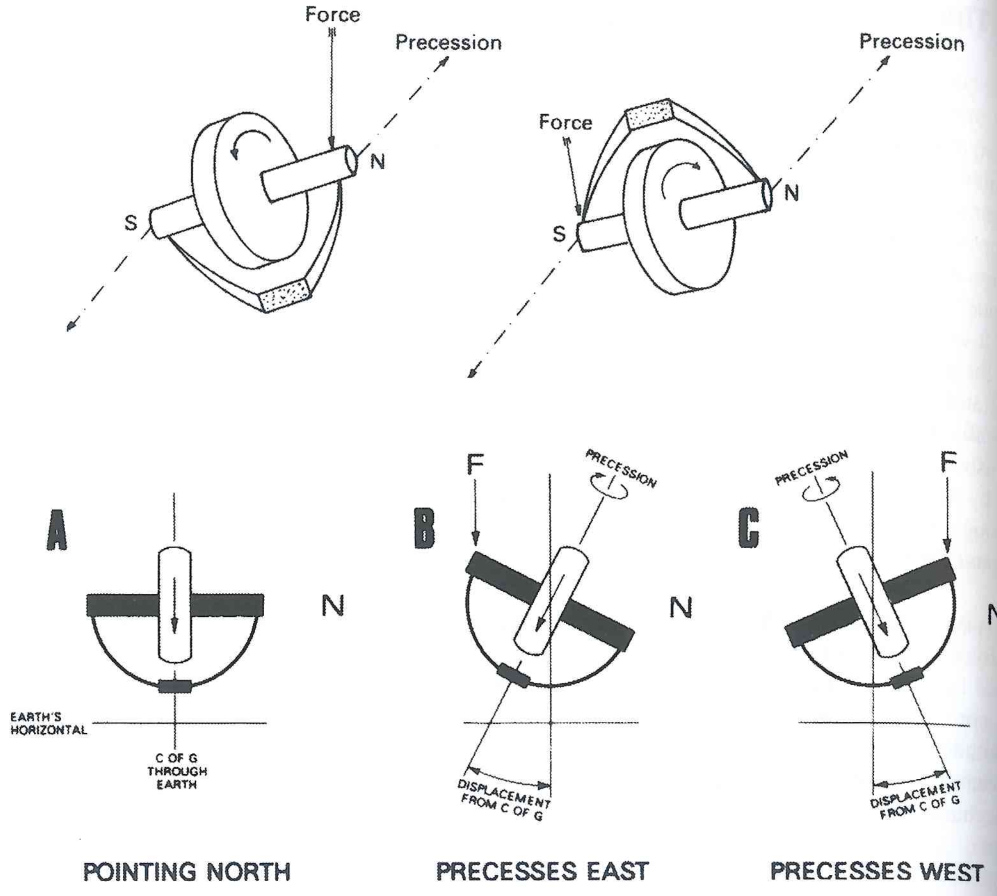


Figure 8.8 (a) Methods of gravity control: bottom-heavy principal and top-heavy control. (b) Principle of gravity control. (Reproduced courtesy of S. G. Brown Ltd.)

8.4.1 Bottom-heavy control

Figure 8.8(b) illustrates the principle of precession caused by gravity acting on the bottom-weighted spin axis of a gyroscope. The pendulous weight will always seek the centre of gravity and in so doing will exert a torque about the gyro horizontal axis. Because of the earth's rotation and gyro rigidity, the pendulum will cause the gravity control to move away from the centre of gravity. The spinner is rotating clockwise, when viewed from the south end, and therefore, precession, caused by the gravitational force exerted on the spin axis, will cause the northeast end of the spin axis to move to the east when it is below the horizontal. A reciprocal action will occur causing the northeast end of the spin axis to precess towards the west when above the horizontal. The spin axis will always appear to tilt with its north end away from the earth (up) when to the east of the meridian, and its north end towards the earth (down) when to the west of the meridian (see Figure 8.9).

This action causes the north end of the spin axis, of a gravity-controlled undamped gyro, to describe an ellipse about the meridian. Because it is undamped, the gyro will not settle on the meridian. Figure 8.9 shows this action for a gyro with a clockwise rotating spinner. The ellipse

produced will be anticlockwise due to the constant external influences acting upon the gyro. The extent of the ellipse will, however, vary depending upon the initial displacement of the gyro spin axis from the meridian and from the earth's horizontal. The term 'north-seeking' is given to the undamped gravity controlled gyro mechanism because the northeast end of the spin axis describes an ellipse around the North Pole but never settles. Obviously such a gyro is not suitable for use as a precise north reference compass aid.

8.4.2 The north-settling gyro

The ellipse described by the previous gyro mechanism possesses a constant ratio of the major and minor axes. Clearly, therefore, if the extent of one axis can be reduced, the length of the other axis will be reduced in proportion. Under these conditions the gyro spin axis will eventually settle both on the meridian and horizontally. If the gyro axis is influenced by a second force exerting a damping torque about the vertical axis, so as to cause the spin axis to move towards the horizontal, it is obvious from Figure 8.10 that the minor axis of the ellipse will be reduced.

As the north end of the spin axis moves to the west of the meridian, the earth's rotation will cause a downward tilt of the axis. This effect and the torque (Tv) will cause the gyro axis to meet the earth's horizontal at point H, which is a considerable reduction in the ellipse major axis. As Figure 8.10 clearly shows this action continues until the gyro settles in the meridian and to the surface of the earth, point N.

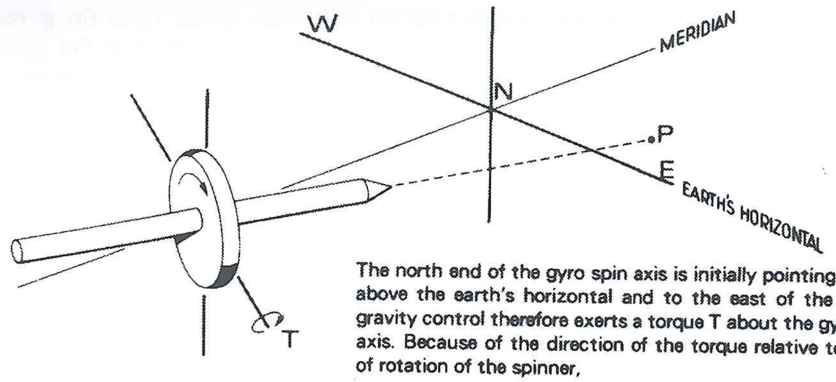
8.4.3 Top-heavy control

Whereas the previous compass relies on a bottom-weighted spin axis and a clockwise spinning rotor to produce a north-settling action, other manufacturers design their gyrocompasses to be effectively top-weighted and use an anticlockwise spinning rotor. But adding a weight to the top of the rotor casing produces a number of undesirable effects. These effects become pronounced when a ship is subjected to severe movement in heavy weather. To counteract unwanted effects, an 'apparent' top weighting of the compass is achieved by the use of a mercury fluid ballistic contained in two reservoirs or ballistic pots.

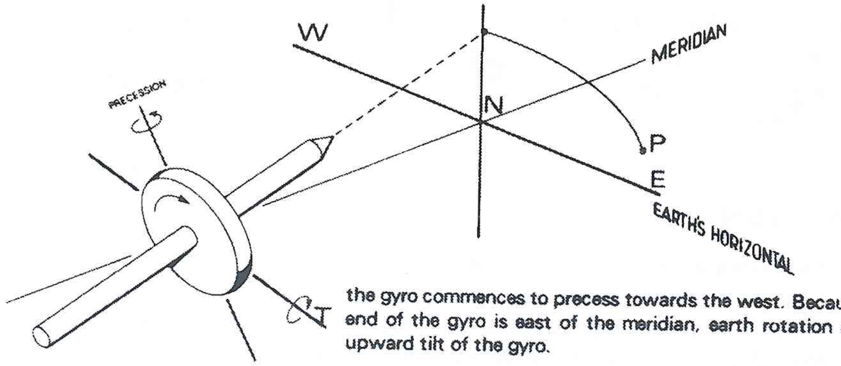
As shown in Figure 8.11, each ballistic pot, partly filled with mercury, is mounted at the north and south sides of the rotor on the spin axis. A small-bore tube connects the bases of each pot together providing a restricted path for the liquid to flow from one container to the other. The ballistic system is mounted in such a way that, when the gyro tilts, the fluid will also tilt and cause a displacement of mercury. This action produces a torque about the horizontal axis with a resulting precession in azimuth.

Consider a controlled gyroscope to be at the equator with its spin axis east west as shown in Figure 8.12. As the earth rotates from west to east the gyro will appear to tilt about its horizontal axis and the east end will rise forcing mercury to flow from pot A to pot B. The resulting imbalance of the ballistic will cause a torque about the horizontal axis. This in turn causes precession about the vertical axis and the spin axis will move in azimuth towards the meridian. The right-hand side of the gyro spin axis now moves towards the north and is referred to as the north end of the spin axis. Without the application of additional forces, this type of gyro is north-seeking only and will not settle in the meridian. The north end of the spin axis will therefore describe an ellipse as shown in Figure 8.9.

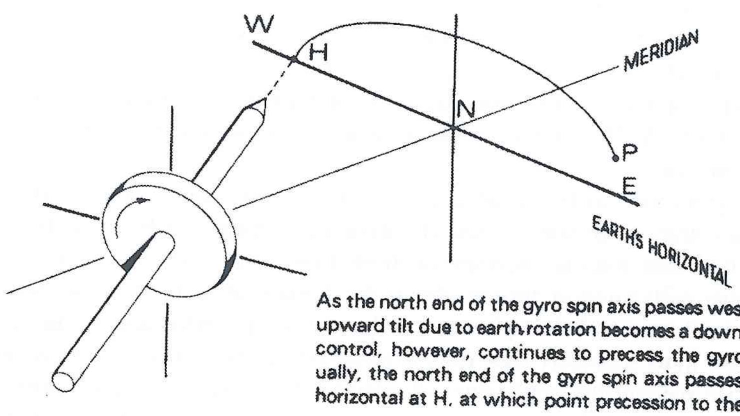
As the extent of the swings in azimuth and the degree of tilt are dependent upon each other, the gyro can be made to settle by the addition of an offset control force.



The north end of the gyro spin axis is initially pointing at P, which is above the earth's horizontal and to the east of the meridian. The gravity control therefore exerts a torque T about the gyro's horizontal axis. Because of the direction of the torque relative to the direction of rotation of the spinner,

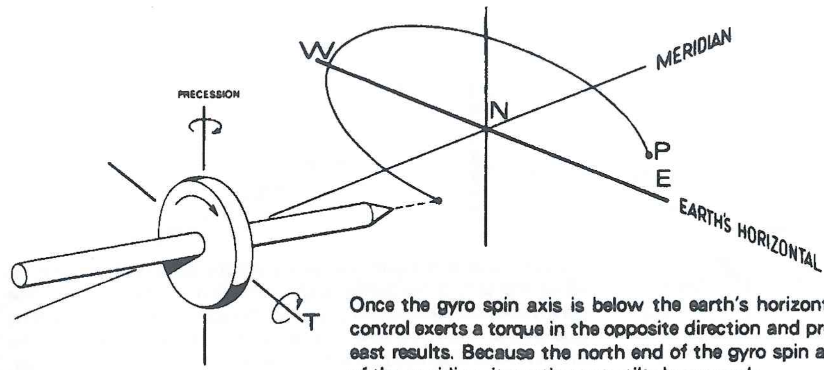


the gyro commences to precess towards the west. Because the north end of the gyro is east of the meridian, earth rotation results in an upward tilt of the gyro.

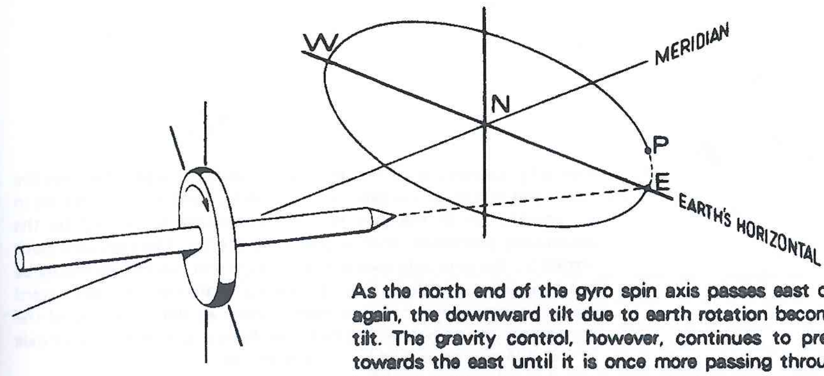


As the north end of the gyro spin axis passes west of the meridian, the upward tilt due to earth rotation becomes a downward tilt. The gravity control, however, continues to precess the gyro westwards. Eventually, the north end of the gyro spin axis passes through the earth's horizontal at H. at which point precession to the west ceases.

Figure 8.9 Behaviour of the gravity-controlled gyro (undamped). (Reproduced courtesy of S.G. Brown Ltd.)



Once the gyro spin axis is below the earth's horizontal, the gravity control exerts a torque in the opposite direction and precession to the east results. Because the north end of the gyro spin axis is still west of the meridian, it continues to tilt downwards.



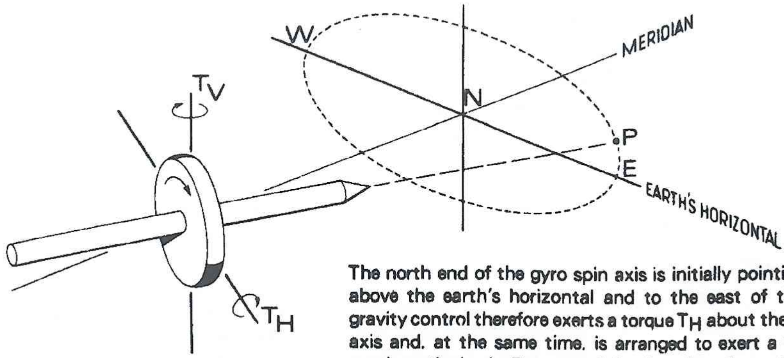
As the north end of the gyro spin axis passes east of the meridian again, the downward tilt due to earth rotation becomes an upward tilt. The gravity control, however, continues to precess the gyro towards the east until it is once more passing through the earth's horizontal. The gyro then commences to precess towards the west again (still tilting upwards) and will eventually pass through point P. The ellipse about North is thus completed and continues.

Figure 8.9 Continued

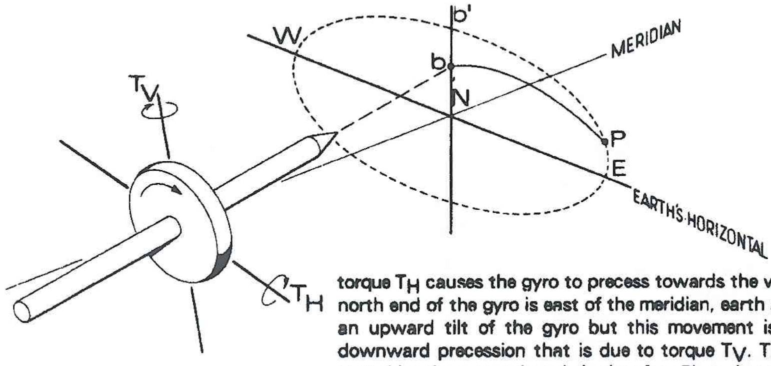
8.5 A practical gyrocompass

The apparent tilting of the gyroscope can be reduced by producing an offset controlling force, which in effect creates 'anti-tilt' precession allowing the unit to settle in the meridian. This is achieved by creating a force about the vertical axis to cause precession about the horizontal axis. This is achieved, in this gyro system, by offsetting the mercury ballistic controlling force slightly to the east of the vertical. The point of offset attachment must be precise so that damping action causes the gyro to settle exactly in the meridian. A comparatively small force is required to produce the necessary anti-tilt precession for the gyrocompass to be made suitable for use as a navigation instrument.

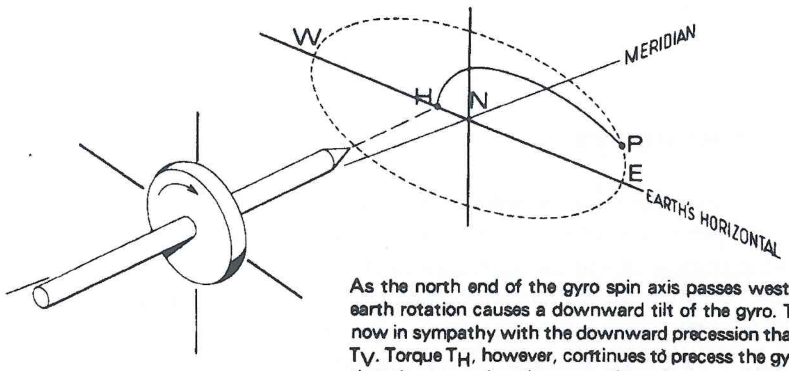
Figure 8.10 shows the curve now described by the north end of the damped gyrocompass which will settle in the meridian. An alternative and more commonly used method of applying anti-tilt damping is shown in Figure 8.13.



The north end of the gyro spin axis is initially pointing at P, which is above the earth's horizontal and to the east of the meridian. The gravity control therefore exerts a torque T_H about the gyro's horizontal axis and, at the same time, is arranged to exert a torque about the gyro's vertical axis. Because of the direction of rotation of the spinner,

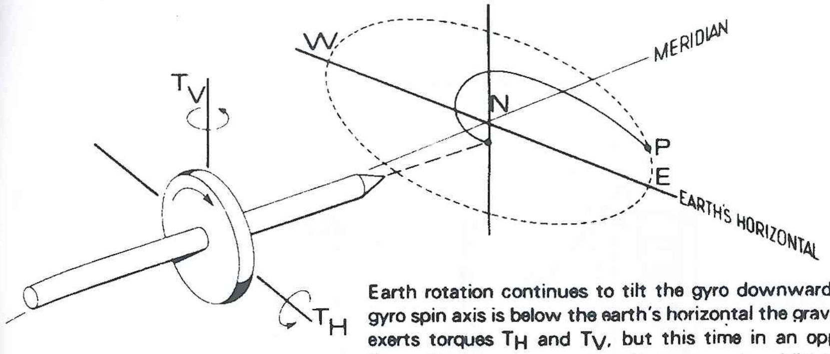


torque T_H causes the gyro to precess towards the west. Because the north end of the gyro is east of the meridian, earth rotation results in an upward tilt of the gyro but this movement is damped by the downward precession that is due to torque T_V. The resultant path traced by the gyro spin axis is therefore Pb and not Pb', as would be the case without the damping torque T_V. Note that the downward (damping) precession becomes more evident as the north end of the gyro spin axis approaches the meridian. Note also that the minor axis of the ellipse is decreased by the amount bb'

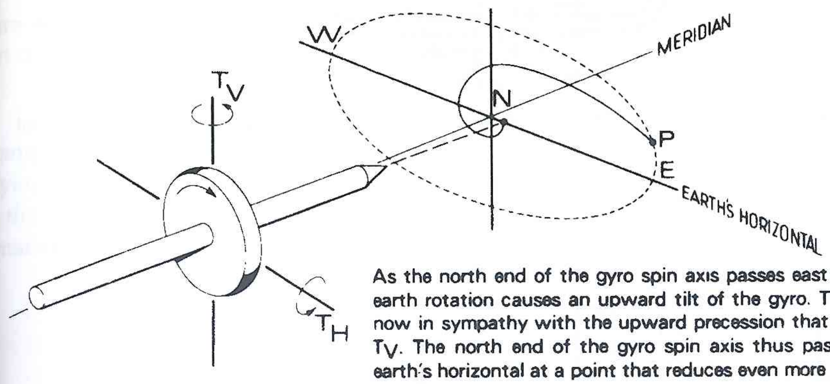


As the north end of the gyro spin axis passes west of the meridian, earth rotation causes a downward tilt of the gyro. This movement is now in sympathy with the downward precession that is due to torque T_V. Torque T_H, however, continues to precess the gyro westwards so that the gyro spin axis passes through the earth's horizontal at H, at which point torques T_H and T_V cease. Note that the major axis of the ellipse is considerably decreased.

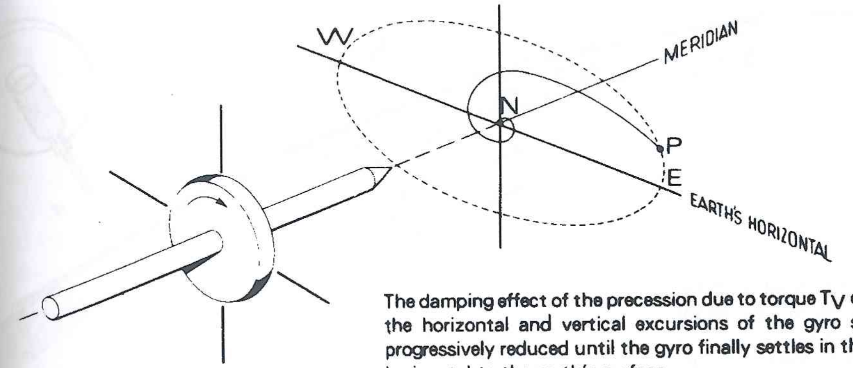
Figure 8.10 Behaviour of the gravity-controlled gyro (damped). (Reproduced courtesy of S.G. Brown Ltd.)



Earth rotation continues to tilt the gyro downwards, and once the gyro spin axis is below the earth's horizontal the gravity control again exerts torques T_H and T_V, but this time in an opposite direction. Torque T_H now causes precession eastwards, whilst torque T_V causes precession upwards and thus damps the downward tilt that is due to earth rotation. The resultant movement of the gyro causes the north end of the gyro spin axis to pass through the meridian at a point that reduces even more the minor axis of the ellipse.



As the north end of the gyro spin axis passes east of the meridian, earth rotation causes an upward tilt of the gyro. This movement is now in sympathy with the upward precession that is due to torque T_V. The north end of the gyro spin axis thus passes through the earth's horizontal at a point that reduces even more the major axis of the ellipse.



The damping effect of the precession due to torque T_V continues, with the horizontal and vertical excursions of the gyro spin axis being progressively reduced until the gyro finally settles in the meridian and horizontal to the earth's surface.

Figure 8.10 Continued

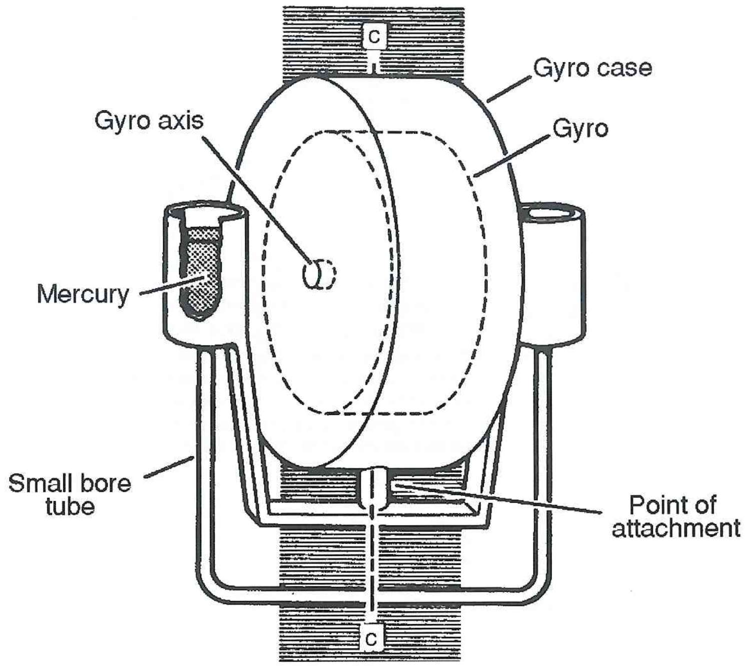


Figure 8.11 A method of applying 'offset damping' to the gyro wheel. (Reproduced courtesy of Sperry Ltd.)

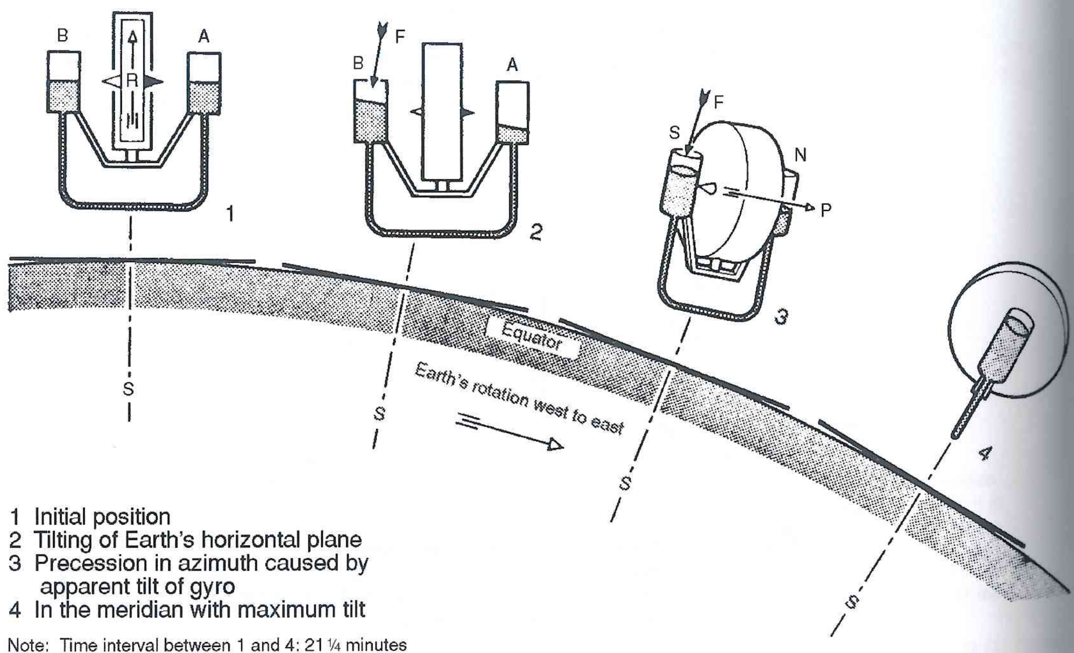


Figure 8.12 Precession of a controlled gyroscope at the equator.

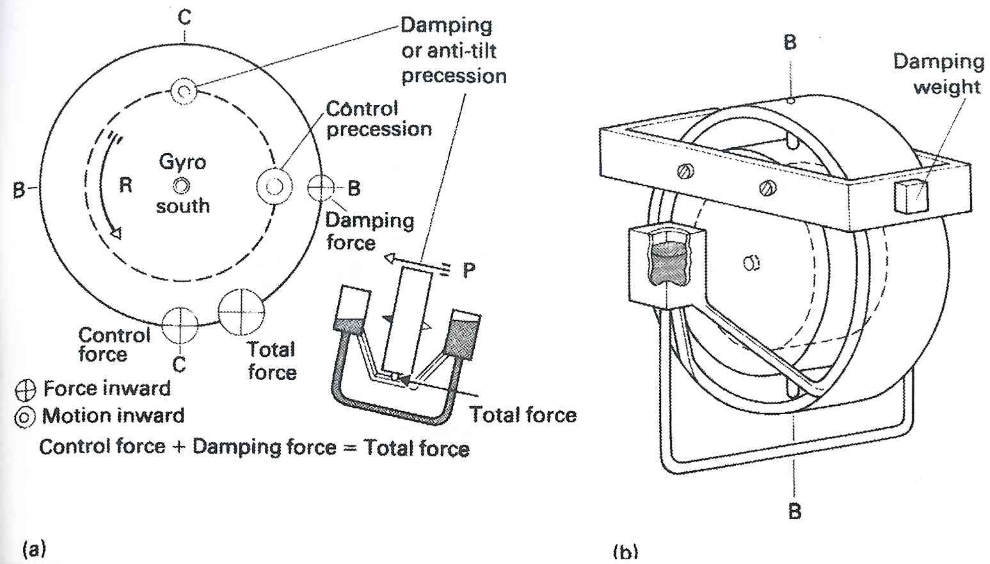


Figure 8.13 (a) Effect of control force plus damping force.(b) An alternative method of applying offset damping. (Reproduced courtesy of Sperry Ltd.)

Damping gyroscopic precession by the use of weights provides a readily adjustable system for applying damping. The period of gyro damping is directly related to the size of the damping force, and thus the weight. If the weight is increased, the damping percentage will be increased. The effect of alternative damping application is illustrated in Figure 8.14.

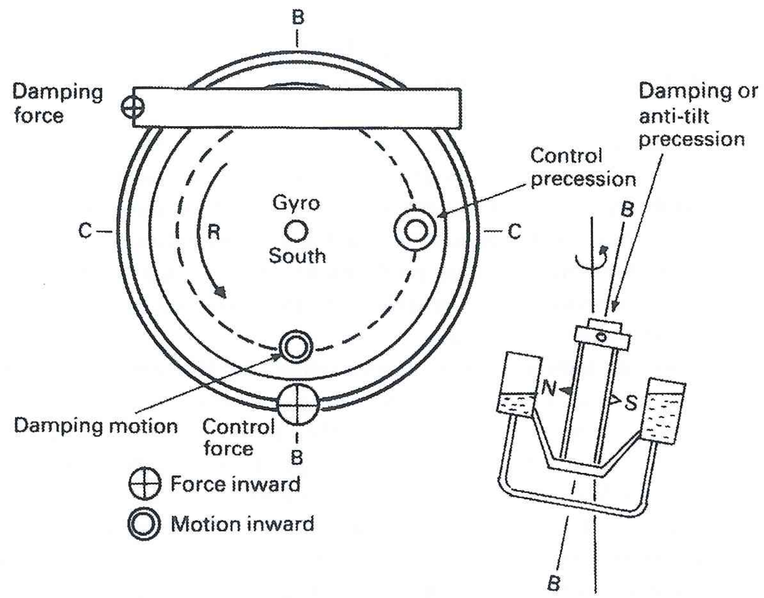


Figure 8.14 The effects of alternative damping application.

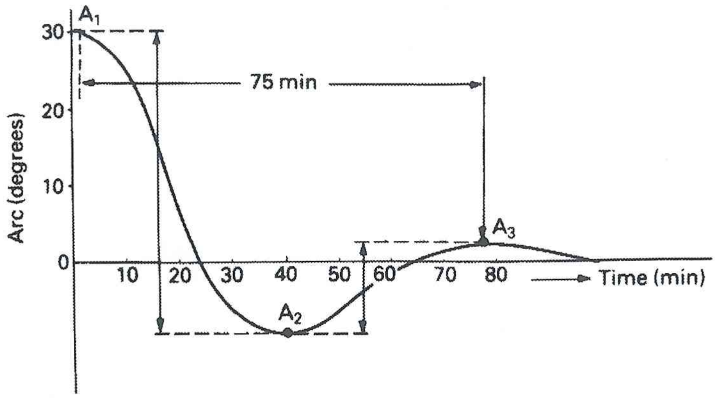


Figure 8.15 The settling curve of a typical gyro compass with a 75-min period.

The amount of damping required depends upon the rate of tilt of the gyro axle and as such will be affected by latitude. As has been shown previously, tilt is a maximum at the equator. It follows, therefore, that damping should also be a maximum at the equator. However, the damping period will always remain constant, at approximately 86 min for some gyros, despite the change of amplitude of successive swings to east and west of the gyro axle. All gyrocompasses therefore require time to settle. Figure 8.15 shows a typical settling curve for a gyro possessing a damping period of greater than 80 min. The time taken for one oscillation, from Al to A3 is termed the natural period of the compass.

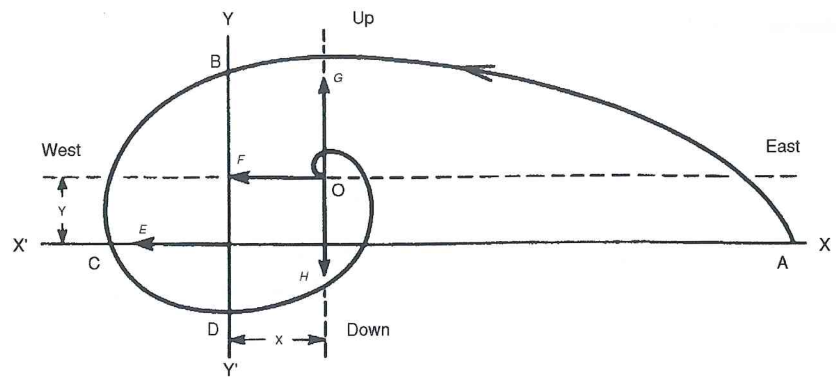
8.5.1 The amount of tilt remaining on a settled gyro

The settling curve traced by the north end of the gyrospin axis illustrated in Figure 8.10 assumes that the gyrocompass is situated at the equator and will, therefore, not be affected by gyro tilt. It is more likely that a vessel will be at some north/south latitude and consequently drift must be taken into account.

It has been stated that for a gyrocompass in northern latitudes, the gyrospin axis will drift to the east of the meridian and tilt upwards. For any fixed latitude the easterly drift is constant. Westerly precession, however, is directly proportional to the angle of tilt of the rotor axle from the horizontal, which itself is dependent upon the deviation between it and the meridian. At some point the easterly deviation of the north end of the spin axis produces an angle of tilt causing a rate of westerly precession that is equal and opposite to the easterly drift. The north end, although pointing to the east of the meridian, is now stabilized in azimuth.

As the north end moves easterly away from the meridian both the rate of change of the tilt angle and the angle itself are increasing. The increasing angle of tilt produces an increasing rate of downward damping tilt until a point is reached where the upward and downward rates of tilt cancel. The north end of the axle is above the horizontal although the rotor axle is stabilized. Figure 8.16 shows that the gyrocompass has settled, at point 0, to the east of the meridian and is tilted up.

The extent of the easterly and northerly (azimuth and tilt) error in the settled position is determined by latitude. An increase in latitude causes an increase in both the easterly deviation from the meridian and the angle of tilt above the horizontal. It is necessary therefore for latitude error, as the discrepancy is called, to be corrected in a gyrocompass.



E: Rate of westerly movement of meridian caused by turntable movement of the Earth's surface

F: Rate of westerly precession of the gyro caused by the north end having tilted upwards

G: Rate of upward tilt of north end of spin axis due to gyro setting to east of meridian

H: Rate of downward precession of north end of spin axis due to damping (anti-tilt) precession

Figure 8.16 A curve showing error to the east and tilt caused by latitude on a settled gyrocompass. X is the angle away from the meridian and Y is the angle with the horizon (tilt). (Reproduced courtesy of Sperry Ltd.)

As latitude increases, the effect of the earth's rotation becomes progressively less and consequently tilting of the rotor axle becomes less. It follows, therefore, that the rate of damping precession needed to cancel the rate of tilt, will also be less.

8.6 Follow-up systems

A stationary gravity-controlled gyrocompass will adequately settle close to the horizontal and near to the meridian, provided that it has freedom to move about the horizontal and vertical axes. However, if the gyrocompass is to be mounted on a ship, the base (phantom) ring needs to be capable of rotating through 360° without introducing torque about the vertical axis.

Freedom about the vertical axis is particularly difficult to achieve without introducing torque to the system. The most common way of permitting vertical-axis freedom is to mount the gyro in a vertical ring with ball bearings on the top and base plates. Obviously the weight of the unit must be borne on the lower bearing, which can create considerable friction and introduce torque. A number of methods have been developed to eliminate torque about the vertical axis. These include the use of high tensile torsion wires and buoyancy chambers, as described for each compass later in this chapter.

8.7 Compass errors

The accuracy of a gyrocompass is of paramount importance, particularly under manoeuvring situations where the compass is interfaced with collision-avoidance radar. An error, either existing or produced, between the actual compass reading and that presented to the radar could produce potentially catastrophic results. Assuming that the compass has been correctly installed and aligned, the static compass errors briefly listed below, should have been eliminated. They are, however, worthy of a brief mention.

8.7.1 Static errors

An alignment error can be:

- an error existing between the indicated heading and the vessel's lubber line
- an error existing between the indicated lubber line and the fore and aft line of the vessel.

Both of these errors can be accurately eliminated by critically aligning the compass with the ship's lubber line at installation.

Transmission error

An error existing between the indicated heading on the master compass and the heading produced by any remote repeater is a transmission error. Transmission errors are kept to a minimum by the use of multispeed pulse transmission.

Variable errors

Variable compass errors can effectively be classified into two groups.

- Dynamic errors that are caused by the angular motion of the vessel during heavy weather and manoeuvring.
- Speed/latitude errors that are caused by movement of the vessel across the earth's surface.

The magnitude of each error can be reduced to some extent as shown in the following text.

8.7.2 Dynamic errors

Rolling error

The gyrocompass is made to settle on the meridian under the influence of weights. Thus it will also be caused to shift due to other forces acting upon those weights. When a vessel rolls, the compass is swung like a pendulum causing a twisting motion that tends to move the plane of the sensitive element towards the plane of the swing. For a simple explanation of the error consider the surge of mercury caused in both the north and south reservoirs by a vessel rolling. If the ship is steaming due north or south, no redistribution of mercury occurs due to roll and there will be no error (see Figure 8.17).

But with a ship steaming due east or west, maximum lateral acceleration occurs in the north/south direction causing precession of the compass. However, rolls to port and starboard are equal, producing equivalent easterly and westerly precession. The resulting mean-error is therefore zero, as illustrated in Figure 8.18.

If the ship is on an intercardinal course the force exerted by the mercury (or pendulum) must be resolved into north/south and east/west components (see Figure 8.19).

The result of the combined forces is that precession of the compass occurs under the influence of an effective anticlockwise torque. Damping the pendulum system can dramatically reduce rolling error. In a top-heavy gyrocompass, this is achieved by restricting the flow of mercury between the

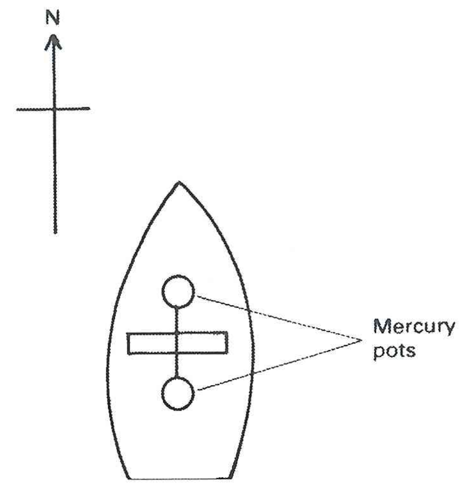


Figure 8.17 A ship steaming due north or south produces no roll error.

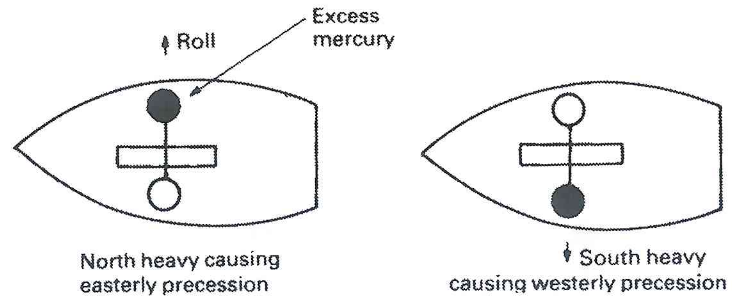


Figure 8.18 Precession rates created by a rolling vessel on an east/west course are equal and will cancel.

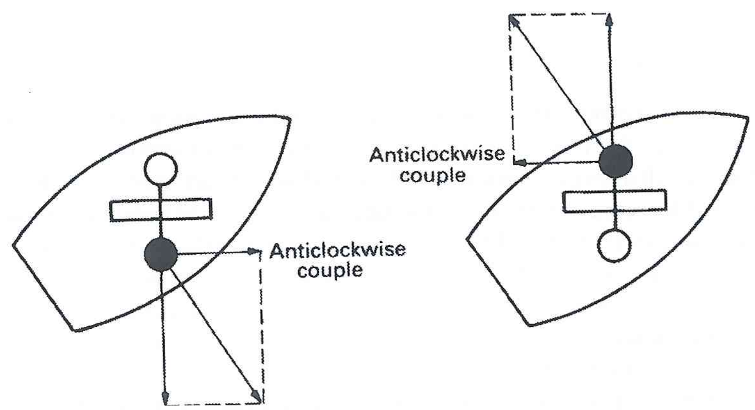


Figure 8.19 For a vessel on an intercardinal course, rolling produces an anticlockwise torque.

two pots. The damping delay introduced needs to be shorter than the damping period of the compass and much greater than the period of roll of the vessel. Both of these conditions are easily achieved.

Electrically-controlled compasses are roll-damped by the use of a viscous fluid damping the gravity pendulum. Such a fluid is identified by a manufacturer's code and a viscosity number. For example, in the code number 200/20, 200 refers to the manufacturer and 20 the viscosity. A higher second number indicates a more viscous silicon fluid. One viscous fluid should never be substituted for another bearing a different code number. Additionally since roll error is caused by lateral acceleration, mounting the gyrocompass low in the vessel and as close as possible to the centre of roll will reduce this error still further.

Manoeuvring (ballistic) error

This error occurs whenever the ship is subject to rapid changes of speed or heading. Because of its pendulous nature, the compass gravity control moves away from the centre of gravity whenever the vessel changes speed or alters course. Torque's produced about the horizontal and vertical axis by manoeuvring cause the gyro mechanism to precess in both azimuth and tilt. If the ship is steaming due north and rapidly reducing speed, mercury will continue to flow into the north pot, or the gravity pendulum continues to swing, making the gyro spin axis north heavy and thus causing a precession in azimuth.

In Figure 8.20 the decelerating vessel causes easterly precession of the compass. Alternatively if the ship increases speed the compass precesses to the west.

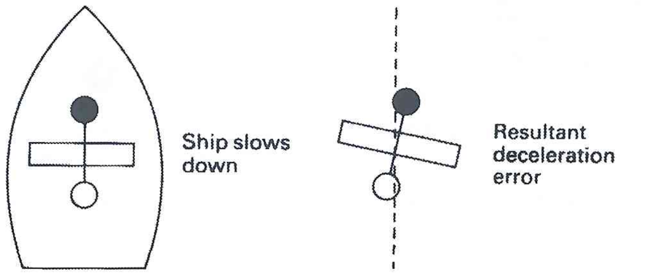


Figure 8.20 Resultant easterly error caused by the vessel slowing down.

Latitude (damping) error

Latitude error is a constant error, the magnitude of which is directly proportional to the earth's rotation at any given latitude. It is, therefore, present even when the ship is stationary. As has previously been stated, a gyrocompass will always settle close to the meridian with an error in tilt. To maintain the gyro pointing north it must be precessed at an angular rate varying with latitude. At the equator the earth's linear speed of rotation is about 900 knots and rotation from west to east causes a fixed point to effectively move at 900 × cos (latitude) knots in an easterly direction. For any latitude (λ) the rate of earth spin is $\omega = 15° h^{-1}$. This may be resolved into two components, one about the true vertical at a given latitude ($\omega \sin \lambda$) and the other about the north/south earth surface horizontal at a given latitude ($\omega \cos \lambda$) as illustrated in Figure 8.21.

The component of the earth's rotation about the north/south horizontal may be resolved further into two components mutually at right angles to each other. The first component is displaced $a°$ to the east

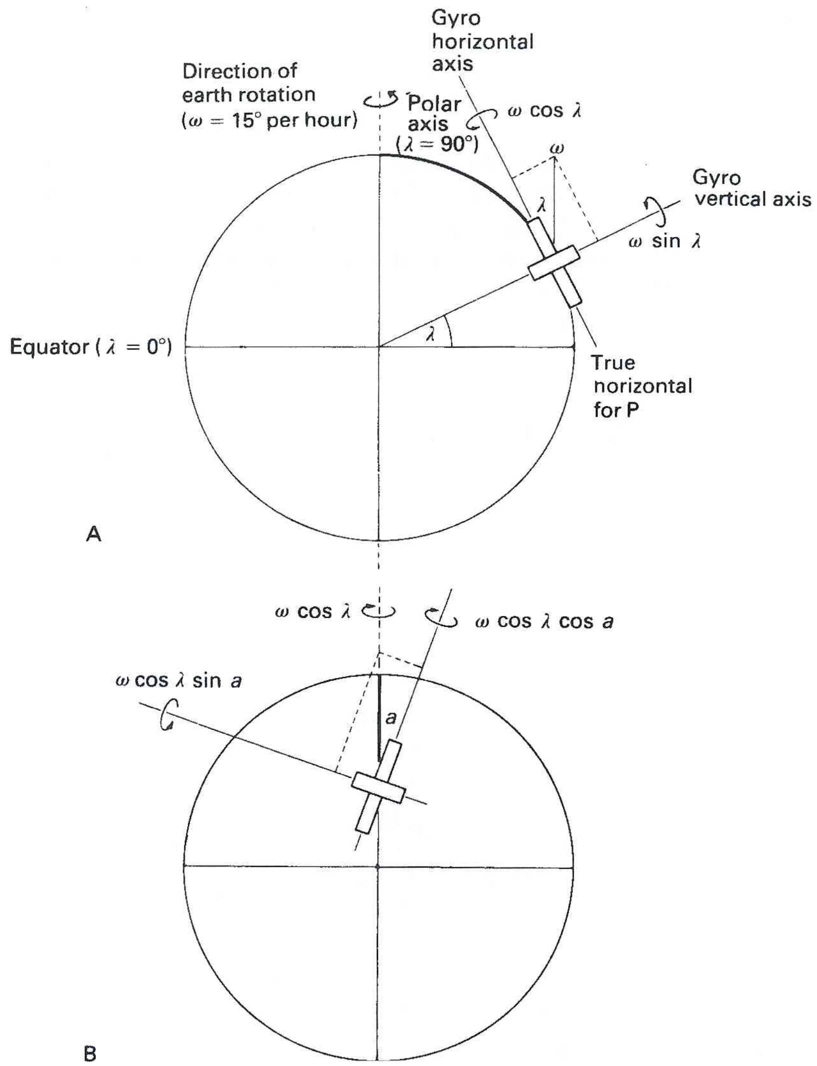


Figure 8.21 Apparent movement of a gyro. (Reproduced courtesy S. G. Brown Ltd.)

of the meridian producing a rate of spin $\omega \cos \lambda \sin a°$, whilst the other is $90 - a°$ to the west of north to produce a rate of spin $\omega \cos \lambda \cos a°$.

Correction for latitude error requires that a torque be applied to precess the gyro at an angular rate, varying with latitude, to cancel the error. This will be an external correction that can be either mechanical or electronic. For mechanical correction, a weight on the gyro case provides the necessary torque. The weight, or 'mechanical latitude rider', is adjustable thus enabling corrections to be made for varying latitudes. Another method of mechanical correction is to move the lubber line by an amount equal to the error. Latitude correction in a bottom-weighted compass is achieved by the introduction of a signal proportional to the sine of the vessel's latitude, causing the gyro ball to precess in azimuth at a rate equal and opposite to the apparent drift caused by earth rotation.

Speed and course error

If a vessel makes good a northerly or southerly course, the north end of the gyro spin axis will apparently tilt up or down since the curvature of the earth causes the ship to effectively tilt bows up or down with respect to space. Consider a ship steaming due north. The north end of the spin axis tilts upwards causing a westerly precession of the compass, which will finally settle on the meridian with some error in the angle, the magnitude of which is determined by the speed of the ship. On a cardinal course due east or west, the ship will display a tilt in the east/west plane of the gyro and no tilting of the gyro axle occurs – hence no speed error is produced. The error varies, therefore, with the cosine of the ship's course. Speed/course gyrocompass error magnitude must also be affected by latitude and will produce an angle of tilt in the settled gyro. Hence latitude/course /speed error is sometimes referred to as LCS error.

8.7.3 Use of vectors in calculating errors

With reference to Figure 8.22,

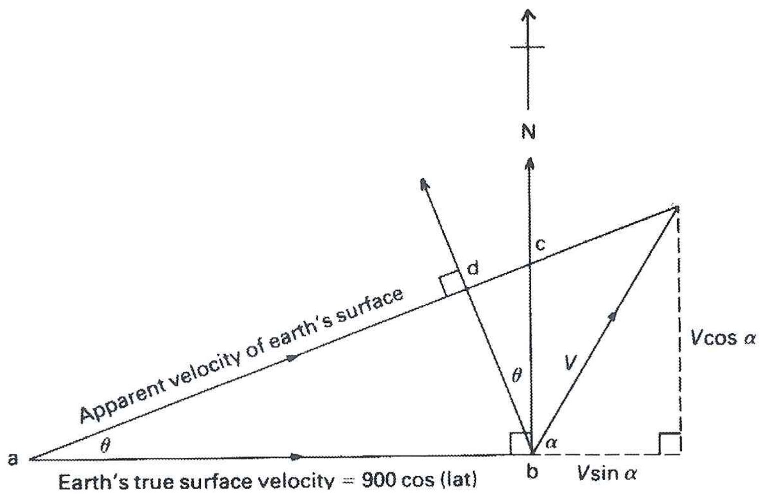


Figure 8.22 Use of vectors in calculating errors

$$V = \text{ships speed in knots}$$
$$V \sin \alpha = \text{easterly component of speed}$$
$$\alpha = \text{ships course}$$
$$V \cos \alpha = \text{northerly component of speed}$$
$$\text{angle acb} = \text{angle dcb}$$
$$\text{angle abc} = \text{angle bdc} = 90°$$
$$\text{angle bac} = \text{angle cbd} = \theta = \text{error}$$

In triangle abc:

$$\text{Error in degrees} = \text{angle bac} = \theta = \tan^{-1} \frac{V \cos (\text{course})}{900 \cos (\text{latitude}) + V \sin (\text{course})}$$

Obviously the ship's speed is very much less than the earth's surface velocity therefore:

$$\tan \theta \simeq \frac{V \cos (\text{course})}{900 \cos (\text{latitude})}$$

The angle θ may be approximately expressed in degrees by multiplying both side of the equation by a factor of 60. Now:

$$\text{approximate error in degrees} = \frac{V \cos (\text{course})}{15 \cos (\text{latitude})}$$

8.8 Top-heavy control master compass

Produced before the move towards fully sealed gyro elements, the Sperry SR120 gyrocompass (Figure 8.23) is a good example of an early top-heavy controlled system. The master compass consists of two main assemblies, the stationary element and the movable element.

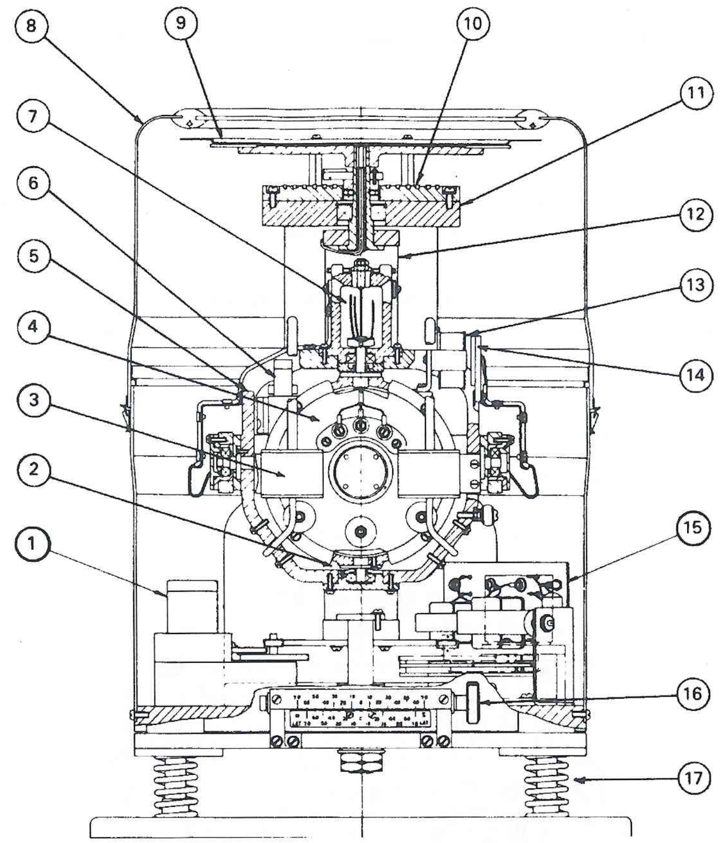


Figure 8.23 A south elevation sectional view of a Sperry master compass . Key:1. Stepper transmitter; 2. Support ball bearings; 3. Ballistic pots; 4.Rotor (encased); 5.Rotor case; 6. Damping weight; 7. Suspension wire; 8. Cover; 9.Compass card; 10.Slip rings; 11. Main support frame; 12. Phantom ring support assembly (cutaway); 13. Follow-up primary transformer; 14. Follow-up secondary transformer; 15. Follow-up amplifier; 16. Latitude corrector; 17. Spring/shock absorber assembly.