Sergio has written this book with the same care, attention and enthusiasm he gives to his navigation on Mediterranean routes or in the ocean.
The principles, concepts and insights come together with advice and recommendations.
Navigation techniques, the boat, the crew and the captain's responsibilities are just some of the topics covered methodically and simply in these pages.
Anybody starting out at sea would love to have alongside them a navigator like Sergio; expert and generous, able to imbue confidence and explain the organization of life on board, the manoeuvres, how to test the equipment, the safety fittings, etc.
Sergio is a teacher who allows you to gain experience, for miles and miles, without taking unnecessary or excessive risks, but at the same time explaining how to deal safely and determinedly with any difficult spots in the navigation. Reading the different chapters of this book will help to build up knowledge and be better prepared to face unexpected events and reduce the possibility of mistakes, including simple errors, which in navigation can generate very difficult situations.
The book explains that the art of seafaring primarily consists of predicting, organizing and enhancing the quality of the boat and the crew. Respect for the sea is a principle that must always apply for anyone who sails a yacht, steers a motorboat or navigates on any craft.
I know that writing this book was a great challenge for Sergio, much more demanding than sailing in the North Sea, round Cap Finisterre or through the Strait of Gibraltar ...
A long route propelled by the wind of his experience and enthusiasm. I am convinced that Seafaring Theory and Practice deserves its own place in the library of each yacht, near the pilot's book, as a necessary and useful piece of on-board equipment.
Happy sailing!

Gianfranco Meggiorin
Head of Navimeteo

1 PILOTING AND DEAD RECKONING

Since the very beginning, navigation has always required skill and experience, and the problem of steering a craft along a fixed route is one of the most difficult that any sailor has ever faced. But it has also been a great challenge that over the centuries has stimulated man's intelligence, spirit of observation and creativity. This problem remained unsolved for centuries, with its uncertainties and difficulties, despite the enormous development of human knowledge and science in general.

Early navigation was mainly coastal and sailors could only rely on the observation of visible points to estimate their position and the distances covered. The most skilled and intelligent sailors marked down these observations in the "rough log", generating the embryo of what would later become the navigation charts and the ship's journal, the "smooth" or official log.

Over time, navigators learned how to fix their position by observing the stars and the Sun and, most importantly, established a reference point (at night the North Star) from which they could draw routes with different angles according to the destination to be reached.

By day, this point was given by the Sun completing its trajectory from east to west.

Then the early systems for measuring time started to be invented; in the beginning, it was the water hourglass and then the powder one, and it was possible to calculate, even if only approximately, the speed of the ship.

The use of the compass began around the beginning of the 14th century and enabled the most daring sailors to engage in longer and more demanding voyages; however, pinpointing the ship's position in the open sea remained very difficult.

The ability to determine the values of the Earth's magnetism (already known but not understood in ancient times) and therefore to correct the route as indicated by the compass, brought an additional element of safety and precision in support of our poor captains.

But it was only with the invention of the modern nautical chart, created in 1500 by the Flemish cartographer Gerhard Kremer (Italianized as Mercator), and of the chronometer (in the late 1700s) that navigation could finally be conducted with confidence and precision.

What navigation means

Navigation means directing a means of transport along unplotted routes (in the sky and at sea) i.e. through places where there are no natural or artificial paths to follow.

Maritime navigation is the science that gives sailors the technical knowledge and the practical ability to conduct a craft along a safe path, from one end of the "Great Sea" surrounding the Earth to the other.

This goal can be achieved by solving three main problems:

1. Choosing and finding a route

This must be done before setting sail by preparing for navigation using charts and other tools that we will look at in the following chapters. The problem will be solved geometrically with the use of lines passing through two or more points on the earth's surface.

2. Steering the boat on the chosen route

This problem will be solved by instruments measuring three basic elements: the direction (compass), the duration of the navigation (clock) and the speed (log).

3. Knowledge of our position

During navigation the craft is subject not only to the action of the propulsion and steering system (sail, engine, rudder) but also to winds, currents and wave action that make it difficult to steer accurately along the chosen route. This gives rise to the need to determine, at any time, the ship's position.

There are different systems for telling the position of the ship:

Dead reckoning

The ship's position is calculated from the direction followed (compass) and the distance covered from the last known position (speed x time).

Coastal navigation (Piloting)

The ship's position is determined by referring to known points (landmarks), visible on the coast and reported on charts.

Electronic navigation and radio navigation

The ship's position is determined by direction finder, Loran or GPS (Global Positioning System), the most recent and accurate satellite system.

Celestial navigation

The ship's position is determined using the sextant in relation to the position of the stars.

The combination of dead reckoning and coastal navigation is also known as Plain Navigation, which is the basis for understanding the problems of navigation and being able to manage a boat safely.

In Plain Navigation, the Earth is considered as a flat surface, and any problem is solved by applying the rules of elementary geometry (plane, not spherical). Hence the need to represent large areas of the Earth as a flat surface on specific nautical charts.

Recreational boating navigation

Navigation in maritime and inland waters for sporting and recreational purposes, not for profit.

Earth shape and size

To give the Earth a shape similar to the true one, it was agreed to consider the Earth as enclosed by a hypothetical surface at the average level of the sea extended across the continents. This sphere is called the Geoid and corresponds to an ellipsoid of rotation, slightly flattened at the poles, with a major axis and a minor axis that differ by approximately 3 km on a diameter of about 13,000 km.

For practical purposes, the Earth is regarded as a sphere and navigation theory is based on this assumption.

Earth or Polar Axis

This is the virtual axis around which the Earth rotates, in 24 hours, making a complete rotation. For an observer in the northern hemisphere, the Earth rotates counterclockwise. An observer in the southern hemisphere will instead see a clockwise rotation (*Figure 1.1*).

Earth's poles

These are the two points through which the Earth's axis passes. The North Pole points up towards the North Star, the first star of the Little Dipper (Ursa Minor), located on the extension (5 times) of the line joining the two stars on the outer edge of the Plough/Big Dipper (Ursa Major); the South Pole opposite the North Pole.

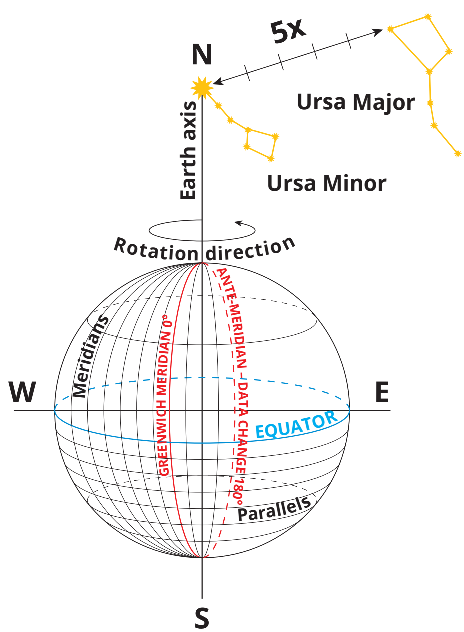

Fig. 1.1 - **Meridians and Parallels**

Due to the Earth's rotation, the North Star, which is on an extension of the Earth's axis, is a fixed point in the sky, while we will see all the other stars and constellations (Ursa Major included) rotating around it. Just a curiosity: due to the combined attraction of the Moon and Sun on the Earth, the Earth's axis changes its angle with respect to the ecliptic plane and rotates, returning to its original inclination in about 26,000 years. Due to this movement, known as precession, the celestial poles change. The star to which the Earth's axis is currently oriented is the one that we call the North Star, which deviates from the north celestial pole by about 001°.

In a few thousand years, the North Star will not be the same one that we see now, but by that time, we will be no doubt be very different too! (*Figure 1.1*). If we are navigating in the Southern Hemisphere, the North Star cannot be seen. We have to look at the Southern Cross to get an idea of where the South is.

Equator

This is the great circle obtained by the intersection of the Earth's surface with a plane perpendicular to the polar axis passing through the centre of the Earth and defines the directions east (E) and west (W) (*Figure 1.1*).

Meridians

These are the circumferences converging at the poles. They are all great circles like the equator. We consider the semicircles and, for reference purposes, while the number of these is infinite, we count 360 (one for each degree), 180 to the east and 180 to the west. A reference meridian, called the Prime Meridian, located by international convention at the town of Greenwich in England, is given the value zero. The letter "Z" (phonetically "Zulu") is used to refer to the time at the prime meridian. The Greenwich meridian divides the Earth into two hemispheres: eastern and western. The eastern hemisphere is located on the right of an observer from Greenwich looking towards the North Pole, the other side is the western hemisphere.

The meridian is divided into two parts at the poles: the meridian (the part where the observer is located) and the ante-meridian.

The Greenwich meridian determines the reference time, while its ante-meridian determines the date change line (*Figure 1.1*).

Parallels

These are all small circles parallel to the equator; there are 90 to the north and 90 to the south (the same as the number of degrees in a right angle). In fact, like the meridians, they can be divided into 60 minutes of arc and each minute into 60 seconds of arc or one tenth of a minute of arc (*Figure 1.1*).

Circumference and its subdivision

The circumference is a flat geometric figure and can be divided in various ways; we are interested in the division into arc and hour.

The Earth takes 24 hours to complete a full rotation around its axis, making a round angle of 360° corresponding to the great circle we call the equator. (The projection of the equator onto the celestial sphere is the celestial equator).

The clock dial is divided into 24 hours (2x12), and represents the celestial equator. The clock hand rotates at a constant speed equal to the angular velocity of rotation of the Earth, and tracks a reference star. The angle formed is called the hour angle.

The star to which we refer for the measurement of time is the Sun and therefore, if we are located on a specific meridian, after 24 hours (on average) we shall return to the same position, after a 360° rotation. During these 24 hours, the angle of the meridian we are on compared to the Sun, will change every second and will be recorded by our clock.

The Sun, in its apparent motion around the Earth, from east to west, makes a 360° longitude revolution every 24 hours on average: its speed is therefore 015° for each hour of average time (360°/24 = 015°). We will in fact have two measurements (hour angle in degrees and time in hours) expressing the same concept but in different units. In fact, as we shall see, and most importantly, the hour angle can be converted into a unit of length (the nautical mile).

Division into arcs

The circumference is divided into 360 parts, each called a degree (°); each degree is divided into 60 minutes of arc (‘ or arc minutes) and each minute of arc into 60 seconds of arc (“ or arc seconds).

Division into hours

In this case, the circumference is divided into 24 parts, each with an amplitude of 015° (see **Time Zone**); each part, called an hour (h), is one twenty-fourth of the circumference. The hour is divided into 60 parts, each called a minute (m). The minute is divided into 60 seconds (**s**).

Time indication

To indicate a certain time interval, the number of hours, minutes and seconds is given, indicating the corresponding symbols on the right (e.g. $\mathbf{8^h\ 17^m\ 24^s}$).

To indicate the current time or the time at which a certain action happens, we enter a series of four numbers - two for the hour and two for the minutes (e.g. **07:25** or simply **0725**). Except in special cases, the seconds are neglected.

Recalling the description of the hour angle and the time in hours we will have:

Hour angle (degrees, arc minutes, arc seconds)	Time in hours (hours, minutes, seconds)
360°	24^h
015°	1^h
001°	4^m
15'	1^m
1'	4^s
15"	1^s

The Nautical Mile (NM)

To understand how to get to the nautical mile, we introduce the concept of the radian.

We draw a circumference and on it we measure an arc **AB** equal to the radius **R**; the angle at the centre α, subtended by this arc, is called the radian.

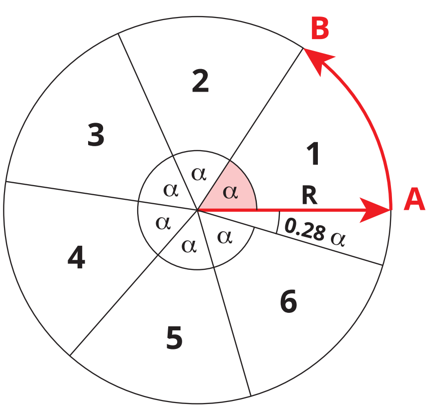

Fig. 1.2 - **Nautical Mile**

In a circumference, there are **6.28** radians and therefore 6.28 arcs AB, i.e. 6.28 times radius R.

Once the radius is known, the circumference is obtained by multiplying the radius by 6.28. The radius of the Earth is 6,371,000 metres:

6,371,000 x 6.28 = 40,009,880 m

This is simply the measure of the circumference of the Earth. Each circumference is composed of 360° and each degree of 60', therefore the number of arc minutes in a circumference is: **360° x 60' = 21,600'**

Dividing the length of the circumference by the number of arc minutes contained in it, we obtain the measurement of a minute of arc expressed in metres:
40,009,880 m: 21,600' = 1852.30 m

The nautical mile is the length of 1 arc minute of a great circle and is equal by convention to 1852 metres

The importance of this simple geometric theorem is that it transforms an angular measurement (degrees, minutes and seconds of arc) into a linear measurement (miles and metres) (*Figure 1.2*).

Speed at sea

The unit of measurement of speed at sea is the knot.
1 knot corresponds to 1 mile/hour

Since the unit of time, the hour, is already contained in the term knot, to indicate any speed it is sufficient to show the number of miles covered in one hour, followed by the word knot.
12 knots = 12 miles/hour (12 knots per hour is incorrect)

Knots - km/h - m/s
To convert a measurement expressed in kilometres to miles and vice versa, or to convert a speed expressed in knots to metres per second, or vice versa, we can use specific tables already calculated and published in the Nautical Tables, showing exactly the values searched for.

Without the tables, it is still possible to determine the values with sufficient accuracy by means of some very simple calculations.

To convert:
- from miles to kilometres we multiply by 2 and deduct 10%.
- from kilometres to miles we divide by 2 and add 10%.

Sometimes the wind speed is measured in metres per second instead of knots (windsurfers or dinghy sailors are used to this); here's how to get the conversion factor:

1 knot = 1 mile/hour
1852m/3600s = 0.51 m/s

To approximately convert knots into metres per second, we can simply multiply by 0.51 or for a rough approximation divide by 2.

Chip log
The problem of boat speed, in the absence of appropriate instruments (chronometer, log), was solved by calculating the distance covered from a fixed point on the sea surface in a short elapsed time and then re-calculating this value for a one-hour span.

With the chip log method, the fixed point was obtained by launching into the sea, from the stern, a small wooden board, with a lead insert as ballast.

This wooden board was roped to a long furling lanyard, with regularly spaced knots, generally every 15.4m (120th of the nautical mile which, as explained above, measures 1852 metres).

The wooden board was left to reach calm waters and the hourglass, set at 30" (120th of 1h), was turned over, simultaneously spinning the lanyard and counting the knots sliding between the fingers until the fall of the last grain. The number of knots that slid through the fingers indicated the miles covered in an hour. This is the origin of the word "knot" to indicate the speed in miles per hour.

In practice, a "correction factor", determined on the basis of experience, was also taken into account to allow for the drag that the board was subjected to by the boat (approx. 1/19 of 15.4m).

This system, despite its limitations, was used throughout most of the nineteenth century.

Calculations: distance, time, speed

In the planning phase of a trip and throughout the voyage, it is necessary to perform arithmetic operations between distance, time and speed. These operations are essential, and are the bread and butter for any sailor.

The formulae relating these three variables are as follows:

Time = Distance/Speed	**T = D/S**
Distance = Speed x Time	**D = SxT**
Speed = Distance/Time	**S = D/T**

At sea, the measurement units used to express such quantities are:

The hour for the time
The nautical mile for the distance
The knot for the speed

These units do not follow the same system, in fact:

The hour follows the Sexagesimal system
The nautical mile and the knot follow the Decimal system

Examples:

A time of 4^h and 23^m
(means 4 hours and 23 sixtieths of an hour)
A distance of 9.7 miles
(means 9 miles and 7 tenths of a mile)
A speed of 7.5 knots
(means 7 knots and 5 tenths of a knot)

Therefore, whenever we have to make calculations involving time, since it does not follow the decimal system but the sexagesimal one, we must be very careful not to confuse minutes with tenths and hundredths of hours and, vice versa, tenths and hundredths of hours with minutes.
It must be remembered that the hours and degrees are divided into 60 parts (sexagesimal scale), while the miles and the knots are divided into tenths (decimal scale).
Since it is not possible to carry out calculations mixing different systems, to avoid mistakes, the sexagesimal scale must be converted into decimals or vice versa.

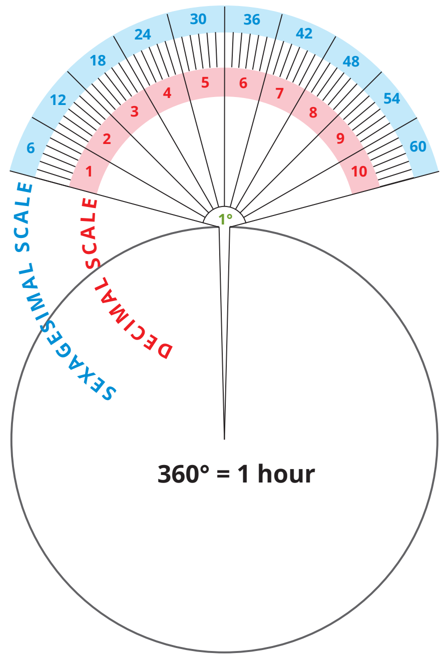

Fig. 1.3 - **Decimal - Sexagesimal**

In the illustration (*Figure 1.3*) the relationship between the two scales is very clear, i.e.:

1 tenth of an hour	**6 minutes**
1 tenth of a degree	**6 arc minutes**
1 tenth of a minute	**6 seconds**
1 tenth of an arc minute	**6 arc seconds**

Some examples for clarification

Example 1
A time of 4^h 24^m does not correspond to 4.24^h, but to 4^h and 4 tenths of an hour, i.e. 4.4^h.

Example 2
A time of 4.24^h does not correspond to 4^h 24^m, but to 4^h 14^m 24^s, in fact:
4.24^h equates to 4^h and 24 hundredths of an hour

→