be unreasonable to reduce services and perhaps it would even become attractive to expand them.

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KEY WORDS

1. Lights and buoyage. 2. Safety.

Navigation with km and gon

Sven Stubert

1. INTRODUCTION. Shipping and aviation have gone metric like society in general and charting is moving the same way except for the use of the nautical mile and the knot. In 1969 the Comité International des Poids et Mesures (CIPM) classified them for temporary use and only for purposes already common.

In 1974 it was recommended by IMCO, the predecessor of the International Maritime Organization (IMO), that the nautical mile and knot should be used in navigation until further notice. The International Civil Aviation Organization (ICAO) has also recommended its members to use the nautical mile and knot throughout – which was not always the case – for some time to come. A change of the present practice is now under consideration, especially by the following organizations:

– Subcommittee on Safety of Navigation, formed by the Maritime Safety Committee (MSC) under IMO in London,

– Replacement of the Nautical Mile Panel (RNMP), formed by the Air Navigation Commission under ICAO in Montreal.

IMO and ICAO are 'specialized agencies' within their parent organization, the United Nations.

As units for distance, speed, direction and position are closely connected in navigation, they will all be dealt with below. It will then be found that there are mainly the following two systems or combinations of units to choose between. (See also appendix 1.)

Mode A: nautical mile, knot, degree, minute (of arc).

Mode B: km, km/h, gon (grade), cgon (centigon).

2. REASONS FOR A CHANGE. Formerly, sailing and sea navigation were a very specialized business, separate from life on land. In those days, sailors could very well have their own units for ships, cargoes and navigation, but today life is different. There are no longer such barriers between sea, submarine, offshore, land, road and air activities. Now there are many more common interests and cooperation in transportation, because transport by sea, on land and in the air are only parts of overall transport systems, and the shipper who sends his goods desires only one business contract,

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one document, one price and one currency for the whole transport package from door to door.

Much can be gained by cooperation in the surveying of land, archipelagos, continental shelfs and the open sea, as well as in the computer-aided production of charts and maps. For the future, it is also important that expensive worldwide positioning and communication systems can be generally utilized.

Though the charts were originally produced for the navy and the merchant marine, they are now increasingly used for such non-naval purposes as the building and operating of canals, bridges, tunnels, pipelines, cables and offshore constructions by people who are thinking, calculating and designing in metric units. The fastest-growing class of chart users are amateur yachtsmen, who are likely to be more familiar with km and km/h than with the nautical mile and knot.

For these and other reasons, it is now urgent that all kinds of producers and users of charts, publications and instruments use the same units. The aim of this paper is to show how the units used for navigation, aviation and positioning can be changed safely and advantageously from mode A to mode B. The examples will mainly concern simple basic elements in the navigation of ships.

3. BACKGROUND. The first navigators had no need for measuring at all, while they were punting, paddling, rowing and sailing in their home waters. When they extended their voyages, they located themselves by the aid of weather, winds, waves, clouds, birds and an astronomy based on their own experiences, until they approached a coast. Instead of measuring distances they measured durations of voyages in days and rowing turns. They had no need for other units. When the sailors got maps and could measure distances, angles, speeds and times, and could also calculate with them, they adopted units invented by astronomers and geographers.

Systems of figures. Four thousand years ago, astrologers and astronomers in Babylon (Baghdad in today's Iraq) used the Babylonian or Sumerian sexagesimal system of figures based on the numerals 1, 6, 10, 60. All fractions were sixtieths, so the denominator was always 60. They learned about the new decimal (or decadic) system of figures with the base 10 and the fundamental numerals 1, 10, 100, etc., but they never adopted it, probably because of the huge number of observations recorded sexagesimally.

There have also been systems with other bases, for example, 2, 5, 8, 12, 20. The first one is the binary (or dyadic) system, which only uses the digits 0 and 1 – for nothing and something – in computing. These other bases have all been used for old, now vanishing units of measurement. Some thousand years ago the 20-system was used both in the Western and Eastern Hemispheres, and it still remains in some languages.

Arithmetic exists basically in terms of the addition and the position systems of numbers. Such systems have been developed and used in different parts of the world. The following two are well known.

Roman numerals are the letters used in the Roman Empire for writing numbers, for example, MDCLXVI = 1666, according to the quintal addition (and subtraction) system, which, however, can also be used for multiplication and division.

The position system, or the place-value notation system, is that used by us today, where the value depends both on the figure itself and its place in a sequence of digits. During the last 400 years, this system has been improved by the development of decimals, roots, powers, logarithms, etc., and is now a comprehensive, logical and universal arithmetic. Examples of its use are shown in table 1.

4. CIRCLE DIVISION. The Babylonian astronomers divided the circle into $6 \times 60 = 360$ degrees. This is about the same as the number of days in a year. The apparent day-by-day movement of the Sun in the zodiac is thus about 1°.

TABLE 1. PLACE-VALUE NOTATION, POWERS AND PREFIXES

Number	Power			Example
1 000 000	10^6	M	mega	MW
1 000	10^3	k	kilo	km
0·01	10^{-2}	c	centi	cgon
0·001	10^{-3}	m	milli	mgon

The instruments available to the astronomers did not make accurate measurement possible, but small fractions were used in calculations. Such fractions were adopted as below, but when they spread to Europe, the Babylonian divisions were described in Latin, and finally shortened to the units minute, second and ters.

$1 \times \frac{1}{60}$	pars minutum	= reduced part	= minute
$1 \times \frac{1}{60} \times \frac{1}{60}$	minuta secunda	= second partition	= second
$1 \times \frac{1}{60} \times \frac{1}{60} \times \frac{1}{60}$	minuta tertio	= third partition	= ters

Three thousand years ago, good water clocks were available for the accurate measurement of time. The astronomers then partitioned the hour in the same fractions as above. That is the reason why we also subdivide the degree and the hour in the same way and use the same words for units of angle and time. That was favourable for the Babylonians but not for us.

5. THE COMPASS. Directions in nature can be described in different ways, for example, with or against the current, to or from the shore, and sailors have given names to winds from different directions. It was then reasonable to use the names of winds for the directions (points) of the compasses, and such names have been used on compasses right up to this century.

People in the north have always appreciated the sunshine from the south. Other people have been fascinated by the rising Sun in the east, and yet others have searched for the shade. All of them have had feelings for the directions in nature – in the environment. Therefore, it was natural to give names to the four cardinal points on the compass card. Later on were added intercardinal points, increased to 32 points, then half points, and finally quarter points; 128 in all.

As navigation developed into a science, degrees were used in calculations, and were desired on charts and compasses. The introduction of the liquid compass, better magnets and improved materials made it possible to increase the diameter of the compass card. When it reached 25 cm, it was big enough to provide room for easily readable degrees at the circumference. The 360° did not, however, fit very well together with the cardinal points, as can be seen in in Fig. 1.

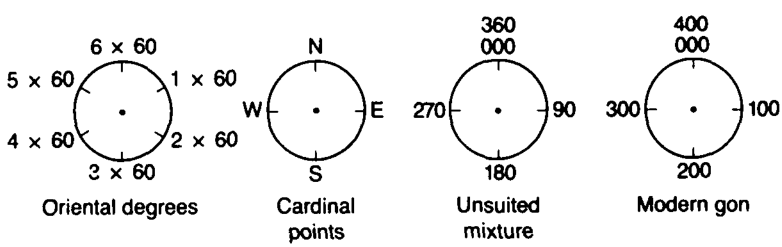

Fig. 1. Graduation of compass cards

The cardinal points were easy to find on the compass, the chart and in the environment, but the 360 degrees were strange to shipmasters. To ease the use of degrees, the manufacturers of compass cards printed degree scales with the different graduations shown in Figure 2, often in combination with all the points and with some decorations in addition.

Degrees grouped in quadrants as in Figure 2(A) are easy to read and to put into practice, but the calculations are complicated. By and by, navigators accepted Figure 2(B) with degrees from 0° to 180° east and west, because the calculations became easier. For making the calculations still easier and consistent, graduation as in Figure 3(C) was introduced at the beginning of this century, but many masters were doubtful of this, so combinations of (A) and (C) were frequent.

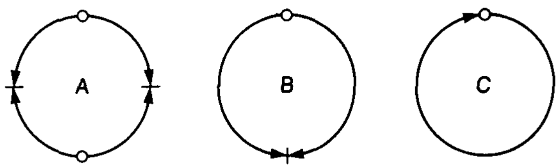

Fig. 2. Quadrantal, semicircular and circular degree scales

In the middle of this century, a British manufacturer of magnet compasses stated that graduation as in Fig. 2(A) was rare, that graduation as in Fig. 2(B) was often asked for, and that (C) was the most common. Simultaneously with the introduction of graduation Fig. 2(C), it was decided that clockwise should be the positive direction for course, bearing, azimuth, variation, deviation, leeway, etc. This facilitates the calculations.

A 400 gon grading would fill all the requirements mentioned above. An advantage with gon is that we are more used to multiples of 100 than of 90, and we are more used to calculate with, and to estimate, parts of 100ths than of 90ths and 60ths. It is also easier to comprehend and visualize the cardinal points 000, 100, 200, 300, 400 gon than 000, 090, 180, 270, 360 degrees. When changing from 360° to 400 gon, it would be wise to see on the charts the two graduations shown in Figure 3.

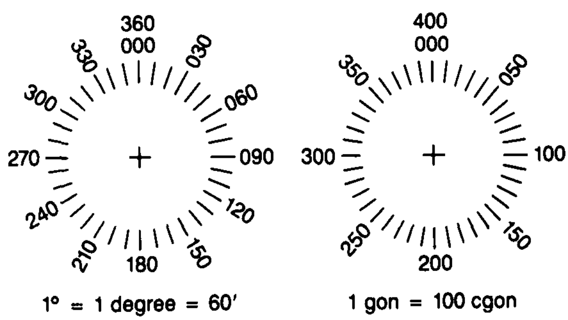

Fig. 3. Graduations in degrees and gon

6. POSITIONS. These were introduced in maps and lists of names by geographers in the eastern Mediterranean. Some 2000 years ago they graduated the latitude from the Equator to the North Pole from 0° to 90°, though they considered it to be too hot for human beings in the south and too cold in the north. Longitude was also measured in degrees, but there were many different initial or zero meridians.

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Latitude has been fixed by astronomic observations since antiquity, but the accuracy was poor until the Danish astronomer Tycho Brahe designed, manufactured and used better instruments by the end of the sixteenth century. Thereby he improved the accuracy from 10′ to 1′, but this was on land. At sea, the accuracy was improved from 1° to 1′ in the eighteenth century, when Sir Isaac Newton invented the principle of the sextant, and John Hadley in London manufactured one and published the first description of it.

Longitude was much more difficult to fix even on land, and only approximate methods were available at sea until the eighteenth century, when the clockmaker John Harrison invented and manufactured the first watch that functioned well at sea. Others improved the design, introduced the name chronometer and made them common. Then it became possible to find the longitude within 1′ (at least, when the conditions were good).

In 1788 HMS *Bounty*, which carried the second copy of the Harrison watch, arrived at the position where they expected to find Pitcairn Island in the Pacific. They realized, however, that the discoverer, who had been there a few years earlier without a chronometer, had made an error of 3° 24′ (= 204′ or 342 km) in the longitude but only 2′ on the latitude.

In 1884 the meridian through the Airy Transit Instrument of the Greenwich Observatory (now museum) was adopted as the zero meridian; because 72 percent of the world merchant marine used that meridian, the Nautical Almanac of Greenwich had an edition four times as large as the second largest, and Greenwich Mean Time (GMT) was adopted as railway time in the USA as it had been earlier in the UK. The Greenwich meridian is still the guide, but the movements of the Earth are now observed with the help of the Carlsberg Automatic Transit Circle on the Canary Islands. These improvements, together with better types of logs, leads, compasses, charts and other aids formed the basis for navigation at sea in the twentieth century.

7. LATITUDE SCALES can be determined as shown in Fig. 4.

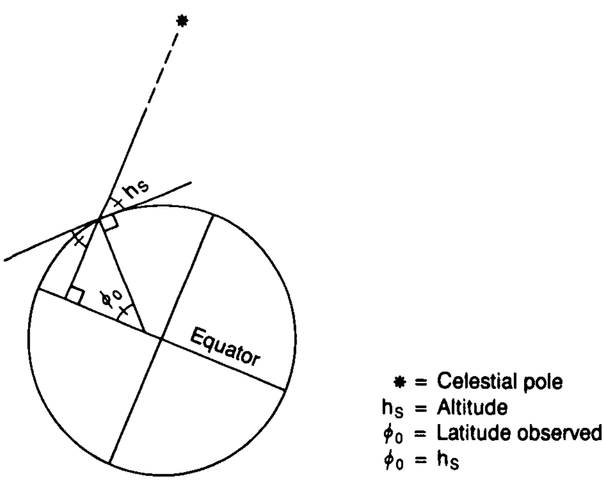

Fig. 4. Latitude equal to elevation of the Pole

Newton developed the idea that the Earth was not exactly spherical but flattened at the poles like an orange. Others thought it was elevated there, like a lemon. To solve the dispute, astronomers and surveyers made measurements in Scandinavia, France and South America. In 1740 they showed that the Earth's surface could be described as an

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ellipse, rotating – as the Earth itself – around the minor axis. They also estimated the lengths of the axes.

Once a meridian could be described as an ellipse, with known major and minor axes, its equation was also known. Then the tangent at any point could be found by differentiation, the curvature by a second differentiation, and thus the radius calculated. That radius is shortest at the equator and longest at the poles.

Two radii at 1′ angle cut a section of a meridian called a minute of arc when used for positions, and a nautical mile when used for distances. When measuring distances on the latitude scale, which is customary in navigation, the nautical mile will be about 0·5 percent shorter at the equator, and about 0·5 percent longer near the poles than at 45° latitude. This is an astronomic, geodetic, or geographic latitude scale. (If the radii are taken from the Earth's centre, the scale is geocentric.)

Others than navigators had need for an invariable unit like the 'telegraph nautical mile'. In 1929 the nautical mile was fixed as 1852 m by the International Hydrographic Bureau (IHB, now IHO), which has now become an international standard. The nautical mile can be written as the abbreviation n.m. with full stops, or possibly n m without full stops, and similarly in other languages, but not nm, which is a symbol for nanometer (1 nm = 0·000 000 001 m).

8. NEW UNITS. In the seventeenth century, decimal subdivision of units of measurement was suggested and discussed in some European countries, but did not make progress until the 1790s, during the French revolution, when many changes were made. One of these was the development and introduction of the metric system for units.

The French parliament set up a committee, headed by Count Louis Lagrange, who was the greatest mathematician of the eighteenth century. The famous chemist Antoine Laurent de Lavoisier was instrumental in drawing up the lines for the new system of units, which were, among others:

(i) to link the units of length, surface, volume, angle and weight;

(ii) to make the unit of length (metre) equal to 1/10 000 000 of the distance along the meridian ellipse from the equator to the North Pole;

(iii) to divide the right angle into 100 parts instead of 90;

(iv) to use the decimal system for all partitions.

For finding the most exact length of the metre, they measured along a meridian from Dunkirk via Paris to Barcelona by astronomic observations, triangulations and calculations until they derived an estimated length for the metre, and made a prototype of it. The measuring of the Earth has continued, and more exact standards for the shape and dimensions have been found. A comparison shows that the length of the metre came out almost as intended, but since then the definition has been changed three times and is now connected to light and time. Using today's language, the right angle is divided in 100 gon, each of 100 cgon (centigon), and the meridian quadrant is 100 × 100 = 10 000 cgon, which equals about 10 000 km.

The word gon, from the Greek word *gonia*, meaning angle, is also used as a standardized symbol. The plural form ought to be written without an s, as gons can signify gonsecond. At least seven different signs for gon have been tried, but no abbreviation or symbol has been standardized. Though gon could have been used for 200 years, degrees are still more common. International standardization has given preference to degrees, but it is now under consideration by a technical committee of the International Organization for Standardization (ISO) in Geneva named 'ISO/TC 12, quantities, units, symbols, conversion factors, and conversion tables':

(i) to suppress the nautical mile and the knot;

(ii) to suppress minutes of arc (′) and seconds (″) for plane angles;

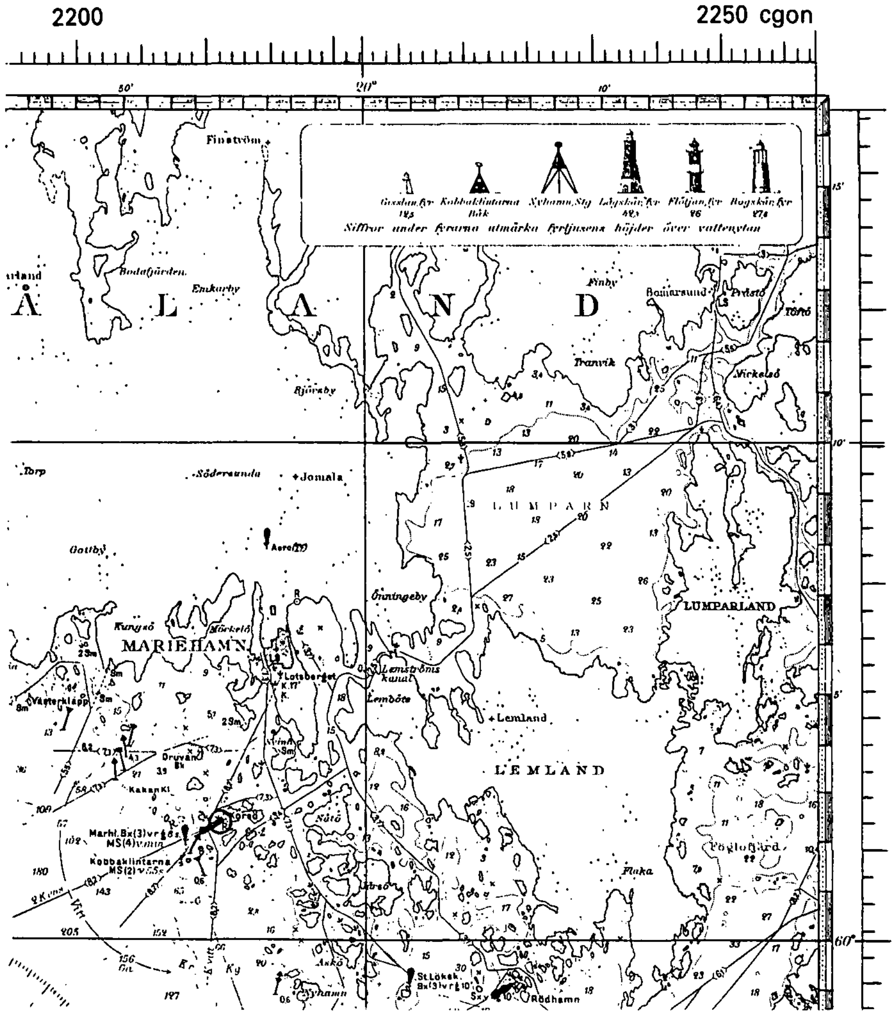

Fig. 5. Example of new chart graduation

(iii) to write degrees with decimals throughout;

(iv) to give equal preference to the degree and the gon.

In the distant future, preference will probably be given to using 400 gon for a complete circle, and the 360 degrees notation will be finally suppressed after 4000 years of intensive use.

9. CHART SCALES. Because of the shape of the Earth, the methods of projecting the curved surface onto plane charts, and the adaptation of the angular division of the meridian to suit celestial navigation, chart latitude scales are not usually uniform. Therefore it is common to use compasses (dividers) for taking off and measuring distances on the latitude scale, which at present is graduated in degrees, minutes and tenths of minutes, where 1 minute is approximately equivalent to 1852 m.

It is now suggested that additional latitude scales be printed with cgon, where 1 cgon is approximately equivalent to 1 km. It is also suggested that additional longitude scales be printed with cgon, so that both latitude and longitude can be measured with the same units. There are maps with km-scales in all four margins for the convenience of those

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who are used to measuring road lengths in km, but those scales cannot be used for determining position.

Many charts are based on old surveys, which were not very accurate and may also have different geodetic bases. Such shortcomings have, however, nothing to do with measuring in nautical miles or km. Without making changes other than the insertion of new scales conforming with the old ones, positions, distances and angles can be determined without conversion calculations, and are no better and no worse than before.

In spite of the increasing use of electronics in many ships, conventional terrestrial and astronomical navigation cannot be dispensed with for a long time, therefore conventional charts will continue to form the basis for navigation and will be needed when other techniques fail. As it is also clear that all charts cannot be replaced simultaneously, they must for some years be produced with both the old and the new measurement units on each chart, which can be done as follows:

(i) Nothing shall be deleted until the new units have come into common use.

(ii) New scales for latitude and longitude are to be added in addition to the old ones.

(iii) The new scales shall be divided into cgon.

(iv) The latitude scales shall be numbered from the equator to the poles and the longitude scales east and west from Greenwich in such a way that the positions and distances will be the same whether they are measured on the old or the new scales.

(v) The existing meridians, parallels and frame lines shall be lengthened sufficiently so that they can be used when measuring distances with compasses both on the old and new scales. No new meridians or parallels, that would confuse the picture, shall be added.

(vi) Where information on distance, speed, etc., is given in nautical miles, knots, degrees and minutes, their equivalents in km, km/h, gon and cgon shall be added.

(vii) The new scales shall be so designed that they facilitate fast, accurate and safe readings – which is not always the case with old scales.

(viii) Both the new cgon scales and the other new units should be printed in colour. A corner of a chart would then appear as in Fig. 5, except for the absence of colours.

As the shape of the Earth's surface deviates from that of a sphere, and as the latitude scales are adapted to astronomical navigation, the distances measured in cgon on the scale differ a little from the true distances in km. Such differences do not mean much for normal navigation, but charts can also be used for many other purposes. If desired, corrections can then be made as in Table 2, where 1 per mille corresponds to 1 m/km.

TABLE 2. CONVERSION OF CGON TO KILOMETRES

Latitude (gon)	00	10	20	30	40	50	60	70	80	90	100
Correction (‰)	+5	+4	+3	+2	+1	0	−1	−2	−3	−4	−5

When the irregularly curved surface of the Earth is projected by various methods on to the flat surface of a chart, several corrections can be made to measured distances if desired. This is difficult for users in general to do, but is easily done by the cartographer. The result can be presented in the format of Table 3.

It is also possible to give other corrections, for example, for lack of accuracy in previous geodetic bases. Finally, the paper may shrink or expand differently along and across the direction of the fibres (grain), for which corrections can be made by the information often found on charts. Electronic charts and maps can be produced in many different ways. Often, only parts of them are shown, which require special techniques

TABLE 3. FORMAT FOR PRESENTING CORRECTIONS TO DISTANCES MEASURED ON A CHART

Type of projection	Correction of a distance measured on the latitude
Mercator or conical	Upper part ‰ In the middle ‰ Lower part ‰
Gauss or transverse mercator	Left side ‰ In the middle ‰ Right side ‰

for showing positions and scales of distance when desired. Metric units should not be forgotten.

10. TERRESTRIAL NAVIGATION.

Distance and speed. At sea and in the air, it is common to use the nautical mile (n.m.) for distance and the knot (kn) for speed, but km and km/h are often used for canals, ferry routes, harbour entrances, high-speed boats and by the media. A consistent use of km and km/h would thus be advantageous. Conversions can be made simply by applying a factor of 1·852 (see appendix 1).

Diagrams on charts are often independent of units. Other constructions can be as easily made using either old or new units; for example, the two shown in Fig. 6 for finding a position. The distance (a km) to the shore or to a navigation mark is the same as the distance measured on the track, which is found by measuring the relative bearings of the mark.

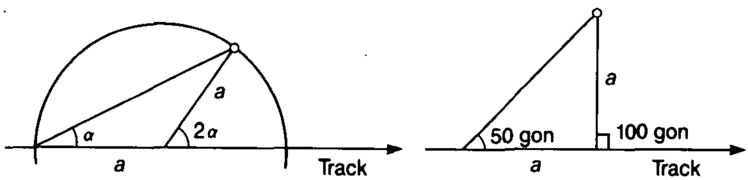

Fig. 6. Chart constructions independent of units

Range-finding. Today it is convenient to find the range of an object from one's own ship on the radar, but sometimes it can still be useful to use the sextant.

When the height (h m) of a vertical object is known and the vertical angle (α cgon) is measured, the distance (a km) to that object can be calculated (see Fig. 7).

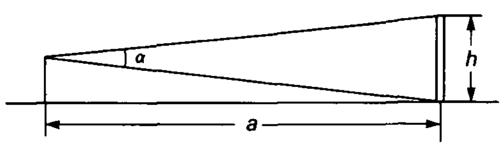

Fig. 7. Distance of vertical sextant angle

We know that

$$\frac{2\pi a\alpha}{400\times 100}=\frac{h}{1000}.$$

Then

$$a=\frac{20}{\pi}\times\frac{h}{\alpha}.$$

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The distance

$$a \approx 6{\cdot}4\,\frac{h}{\alpha}.$$

It is often difficult to identify the upper and lower ends of the object to be observed, and that will adversely affect the result; therefore the constant has been rounded off by 0·5 percent from 6·366 to 6·4.

The range of sight (s_1 n.m. or s_2 km) from an observer's eye at a known height (h m) above sea level to the horizon, where the visual line (the tangent) touches the water surface (Fig. 8), can be calculated trigonometrically and corrected for normal

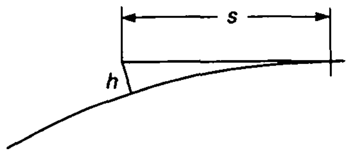

Fig. 8. Distance to sea horizon

(8 percent) refraction. (A) is a well-known formula for the range in n.m.; (B) is the same range in km but the constant is rounded off to 3·8 because the radius of the Earth varies, and other conditions are approximate.

$$s_1 = 2{\cdot}08\sqrt{h}\ \text{n.m.} \tag{A}$$
$$s_2 = 3{\cdot}8\sqrt{h}\ \text{km.} \tag{B}$$

An observer's eye at a known height (h_1 m) above the water can see the light from a beacon of another known height (h_2 m) above sea level at an extreme range (s_3 km), as shown in Fig. 9 and formula (C).

$$s_3 = 3{\cdot}8(\sqrt{h_1} + \sqrt{h_2})\ \text{km.} \tag{C}$$

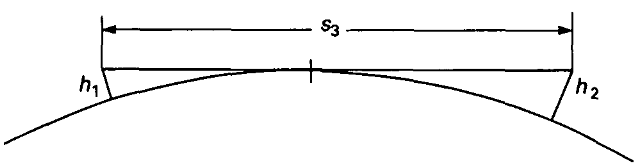

Fig. 9. Extreme range of light

Light ranges for beacons, navigation lights, searchlights, etc., are often given in n.m. but sometimes in km. The latter could be made the rule in the future.

Visibility can be reduced by fog, rain, snow, hail, dust, smoke, etc. Weather forecasts for navigation generally report on reduced visibility in m and n.m., but some countries do it in m and km. It would be better to use m and km throughout, as the length of a km is more suitable than the n.m. for the most important short distances.

According to ICAO, all vertical heights are given in feet, which also applies to reduced visibility, though horizontal visibility is reported in m. Information to the passengers on height is, however, often given in feet and m or sometimes only in m. In ship navigation, all vertical measures such as depth, waves, swell, tide and heights are given in m. A unification would use m for all vertical measurements.

Sounds from whistles, bells, gongs, etc., can be sent from ships or shore as navigational warnings. The ranges for audible apprehension of these varies much with the circumstances, but they are often given for 'normal' conditions in n.m. For purposes other than navigation, the range of sound is measured in km, which could be a rule also at sea.

Winds are given names from where they come, from land, places or points of the compass. As winds are continuously changing direction and speed horizontally and vertically, meteorologists measure the horizontal component at a certain height during a 10 min period. The direction is then given in dekadegrees; for example, 36 dekadegrees for a north wind means that the wind could have been oscillating between 355° and 005°. This is suitable for an aircraft approaching a landing strip with its direction marked in dekadegrees. Dekagon (dagon) could be used equally well for both winds and landing strips.

The wind speed can be given in different units. Most meteorologists use knots, when reporting to one another, but km/h is used in some metric countries. Knots are practical for ships, whose speed is measured in knots. In Scandinavia, m/s is mostly used for winds, as both m and s are base units of the International System of Units (SI). For military purposes, km/h is used for wind speed, when km/h is used for the aircraft speed.

The Beaufort notation is still used in some parts of the world. The Beaufort scale does not however, indicate the wind speed but the force of the wind, and that force is proportional to the speed squared.

Since meteorologists are now using computers, they say that they can easily use dagon and km/h in weather forecasts when requested.

Current and tidal streams can be described by direction (set) and speed (rate). The usage of language varies, but the International Maritime Organization (IMO) recommends 'Tide is setting in direction...' north or south in a sound, or by points of the compass, or by degrees of the compass – stating *to where* it goes. The unit for speed is mostly the knot, but some countries use km/h, and for rivers m/s is common. It is possible to use gon, dagon (dekagon), and km/h. Direction in gon or dagon and speed in km/h can be used also for ice-drift, drifting ships, oil discharges, etc.

The navigator of a ship can construct on a chart a vector for the course and speed of the ship over the ground, as the sum of the vector for the course and speed of the ship through the water, and the vector for the set and rate of the current. The lengths of the vectors are proportional to the speeds.

Weather-routeing with information on current, wind and waves from meteorologists on shore to ships is becoming common. It would be an advantage if all parties could use the same units.

Athwartship deviation from track in the case of Vessel Traffic Services (VTS) seems always to be given in m. The free horizontal clearances for passages under bridges are also given in m.

Acceleration is normally measured in m/s^2 or the number of g (about 9·8 m/s^2). They are both international standards.

Alteration of course to port or starboard can be given in degrees or gon. The rate of turn, or angular velocity, is the alteration of course per unit of time. It can be measured in °/min (degrees per minute) or gon/min. That will normally give numbers of one or two digits for merchant vessels. Some manufacturers graduate, however, from 0·0 to 1·0 °/s. Angular acceleration can be given in $°/s^2$ or gon/s^2. The turning radius or the radius of the track (path) is now measured in nautical miles, cables (of 185 m), m or km. For the future, m and km would be preferred.

Anchoring. When anchor-chains replaced hemp hawsers in the middle of the nineteenth century, they were manufactured in sections of 15 fathoms = 90 feet = about

27 m, joined by shackles. Thus we got the unit 'shackle' of about 27 m (first varying between 25 and 30 m) used by pilots when directing how much anchor-chain should be paid out. Since the middle of the twentieth century a chain need no longer be made in sections but may be manufactured and transported in any length. Instruments indicating the length of chain paid out are available. They are measured in m. This is practical, as the depth of water is mostly given in m on the charts. When anchoring offshore platforms, the anchor may be placed hundreds of metres from the platform. Thus it is best to use m throughout.

11. INSTRUMENTS. These were formerly so simple that everybody knew how they functioned, what they showed, and which the units were. Today, the readings are often given together with other information on monitors far away from water and wind. It is then important that it be clearly stated what the instruments are measuring; for example, speed over the ground, speed through the water, relative wind speed, etc., as well as the units. It may be possible to find out that N045269 means 045° 26·9′ N, but it would be better to write it so. The difficulty is that the Babylonian arithmetic does not fit today's techniques.

Nowadays navigation methods are changing from the use of the traditional separate instruments onboard to integrated, electronic, worldwide, satellite-supported radio navigation and location systems. The aim is to find the position (latitude, longitude, height), course, speed and other parameters for the navigator's own purposes and for simultaneous automatic and continuous transmission to land-based stations for their information, for monitoring and assisting ships, aircraft, trucks and other moving objects, and sometimes particular cargoes. These and similar developments seem to require the use of the same units by all parties involved in navigation and transportation – most likely metric units.

12. CHANGING. The changing of units, as described in this article, has already met with a positive response from people who are active in navigation, aviation and positioning in Scandinavia. The only objections heard are the traditional two, namely the cost of change and the risk of mistakes.

The units for distance, speed, angle and position can thus be changed from *mode A*, with nautical mile, knot, degree and minute, to *mode B* with km, km/h, gon and cgon. As all these units are closely connected, they must be changed at the same time. Any mixing of the two modes or changing step by step would be ill-advised. A change of the units can, however, not be universal unless so decided by IMO and ICAO, who are now studying the possibilities.

It is assumed that all messages sent from ship to ship, from ship to shore, between civil flights, and from flights to the ground shall be sent with metric units from a certain moment onwards. It could be at noon in Greenwich, and may be different times for IMO and ICAO. The routines on board of each ship or plane can, however, be changed at a more suitable time, decided by the captain, who will probably choose the time between two voyages or flights. Such changes will include the routines onboard and instrument scales. It would be possible to do all this before the year 2000.

APPENDIX I.

SOME OLD AND NEW UNITS WITH THEIR CONVERSION FACTORS.

1 n.m.	= 1 nautical mile	=	1·852 km
1 kn	= 1 knot	=	1·852 km/h
1 m/s		=	3·6 km/h
1°	= 60′	=	60 minutes of arc
1′ on the latitude		≙	1 n.m. (approx)

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1° on the longitude		≙	4 minutes of time
400 gon	= 360°		
100 gon	= 90°	= 5400′	
1 gon	= 0·9°	=	54′
1 gon	= 100 cgon	= 1000 mgon	
1 cgon	= 1 centigon	=	0·01 gon = 0·54′
1 mgon	= 1 milligon	=	0·001 gon = 0·054′
1 dagon	= 1 dekagon	=	10 gon
1 cgon on the latitude		≙	1 km (approx)
1 gon on the longitude		≙	3·6 minutes of time

The abbreviation 'n.m.', which stands for nautical mile, should not be confused with the designation 'nm' that stands for nanometre (0·000 000 001 m).

The designation 'dagon' stands for dekagon (10 gon) and it should not be confused with 'dgon' for decigon (0·1 gon). It can be used in two ways, namely (A) 23 dagon = 230 gon and (B) 23 dagon = 225–235 gon.

The designation 'gon' is increasingly used in many languages, but the traditional words are as follows:

	English	French	German
°	degree	un degré	ein Grad
gon	grade	un grade	ein Gon

It is important to find out, at an early stage, which units and prefixes are to be preferred for different purposes in order to avoid a great variety followed by changes and confusions. The following units and examples of their uses are recommended.

km	km/h	gon		cgon
length	speed	compass	angle	position
distance	current	variation	direction	latitude
range	tide	deviation	bearing	longitude
sight	ice drift	course	fairway	altitude
visibility	wind speed	leeway	azimuth	sextant

KEY WORDS

1. Terminology 2. Display of information. 3. Units

Fixed and Floating Structures – Maritime Risk Assessment and Desiderata for Safe Navigation

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This paper is based on a contribution to *Diagnostic Engineering*, No. 55, by permission of the Institution of Diagnostic Engineers.

This paper considers an involuntary collision between a vessel of significant displacement and a captive major offshore installation where the energy at impact will be massive,