ACADEMIA DE MARINHA

THE STELLAR COMPASS AND THE KAMAL

AN INTERPRETATION OF ITS PRACTICAL USE

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The Stellar Compass and the Kamal

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Introduction

Dear Flag Officers dear members of the table, dear comrades of the Indian Navy, ladies and gentlemen.

It is not only an honour to be here in Delhi again, participating in such an important event, but it is also a special opportunity for my wife and me to see again the friends we made before. Besides that, this time we are meeting new friends in two different areas, the archaeology and the navy, to whom I give my warmest salute, not only in my name but also in the name of Admiral Rogério de Oliveira the President of *Academia de Marinha*, the cultural organization of the Portuguese Navy from which I belong.

I think that the scholars of the *Archaeological Survey of India* will understand if I convey also my special regards to my comrades of the Indian Navy, with whom I share the same marvellous profession.

And I can tell all of you, ladies and gentlemen, that I came here mainly as a practical sailor, being the subject of my paper practical ideas of the use at sea of the stellar compass and the Kamal. The reason of this is because, although many scholars extensively studied these two important instruments of Indian Ocean navigation, the way they are utilized aboard ships is not so clearly explained by them.

Besides that, at the end of the 15th century there has been a meeting between European and Indian Ocean techniques, and at least two Portuguese Pilot Books of the beginning of the sixteenth century dealed with the use of the kamal.

So I hope that some of my experience aboard sailing and motor ships can be useful to help historians to better interpret the techniques of navigation of this area of the globe.

I am going to read only an abridged version of my paper trying of course to be brief and clear.

Environmental conditions of the Indo-Pacific regions of navigation and its consequence to navigation techniques

Before any other consideration about this subject, I would like to quote the words of a Portuguese sailor and also a religious man of the sixteenth century, that sailed extensively in the Atlantic. I am referring to Father Fernando Oliveira who also wrote important manuscripts of navigation and shipbuilding(1).

In his *O Livro da Fabrica das Naus*, recently published by Academia de Marinha(2), Father Oliveira wrote, commenting the Portuguese navigations of the period, and comparing them with those of the Greeks and Latins, who previously said that they were the inventors of the art of navigation:

> Ours [the Portuguese navigators] deserve greater praise for this [the explorations of the high seas], than the Greeks or the Latins: because they [the Portuguese] have done more for navigation in 80 years than the others did in the 2000 during which they reigned. And more improvements have been brought to this art than they ever achieved.

After these apparently Euro centric words he added:

> However, not even this allows us to say that we are {the Portuguese] the first inventors of the art, as they have so arrogantly declared. And it is not just because they have claimed it, that we must consent to the assertion: for, in many parts of the world where they have never gone and which were not reached by any doctrine of theirs, [we have seen that] there are ships and the art of navigation: in some places better than in others, according to the maturity of backwardness of the people who live there. We find, in China and Japan, reasonably fine ships where the existence of the doctrines of the Greeks, or their Neptune, has never been heard of. In Guinea and Brazil, Greeks were never mentioned either and, without them, navigation exists, in its own style, anyhow as taught by nature.

(1) The biography o Father Fernando Oliveira has been deeply studied in the XIXth century by Henrique Lopes de Mendonça (*O Padre Fernando Oliveira e a Sua Obra Nautica. Memoria, comprehendendo um estudo bigraphico sobre o afamado gramtico e nautographo, e a primeira reprodução typographica do seu tratado inedito Livro da Fabrica das Naus*, Lisboa, Academia Real das Sciencias, 1898).

(2) Fernando Oliveira, *O Livro da Fabrica das Naus*, Lisboa, Academia de Marinha, 1992, pp. 139, 140. This is the second edition of this important work, being the first by Lopes de Mendonça in his work referred in note 1. The manuscript is published in fac

It is my deep conviction that all the peoples of any area of the world adapt their techniques of any kind, to his environment. The same happens with the techniques of navigation and I am going to explain briefly what are the physical conditions of the navigation in the Indian and Pacific([3]) Oceans, compared to other areas.

The first important fact is that the Arab, Persian, Indian, Malayan, Chinese and Polynesian navigation is performed mainly in inter-tropical areas.

Let us take a look of fig. 1, where the inter-tropical areas of the seas of the world are shaded and the routes of navigation schematically represented. It is immediately apparent that Asian routes are mainly inter-tropical, with the only exception of routes of northern parts of China. The Portuguese, Spanish, Dutch, French and English routes have big proportions out of the tropics.

It is also evident from the map, that:

– European routes are long distance ones with many months at sea and out of sight of land.
– Arabian, Persian and Indian routes have some medium distance ocean routes, but more coastal navigation.
– Malayan and Chinese routes are mainly coastal or short distance high seas navigation, with the exception of the probable but not very frequent direct routes to Africa.
– Western Pacific routes are mainly short inter-island routes, which never exceed the 350 miles distance, with the exception of the voyages to Hawaii and New Zealand.

So all sailors find the necessary techniques and instrumentation for their areas of operation. And sailors are very practical and only use or develop what is needed for the purpose of the navigation.

Taking into consideration what has been said above, let us imagine what does a sailor needs to know to return to a previously discovered island or harbour in a continent, far away from his home place and out of sight of land which means that ocean navigation methods are needed, instead of coastal navigation methods.

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simile and there is a complete translation in English of the text and of the introduction of Rogério de Oliveira and initial commentaries by Fernando Contente Domingues and Richard Barker.

([3]) There is similarity of conditions between these two oceans; it is why I connect one to each other. Besides that the sailors of both areas should have been in contact, and developed similar techniques, although with slight differences, in consequence of some differences in their respective environments. It is this also for example the opinion of Tib

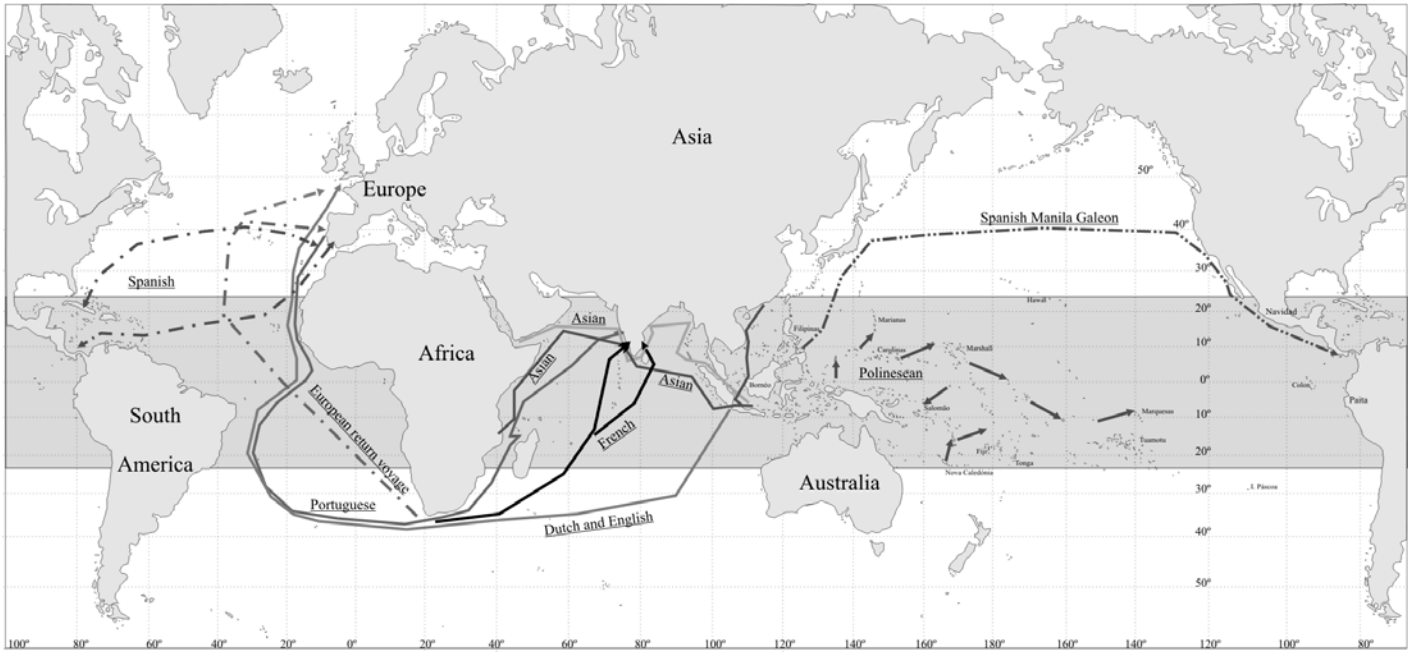


Fig. 1 – Intertropical areas at sea. European and Asian routes of navigation (only for showing areas of operation and consequently not with historical or sailing accuracy)

The first thing is to find a way of recognizing the direction he has to take to return there, admitting that the same system has been used to return to his point of departure. But for finding a direction it is necessary any reference to measure that direction.

Fig. 2 shows two islands A and B sketched on the sand of a beach. The arrow is the path that any ship has to sail on, to go from A to B or vice-versa. For attaining this objective, it is necessary to materialize any means of finding the direction, for example from A to B([4]).

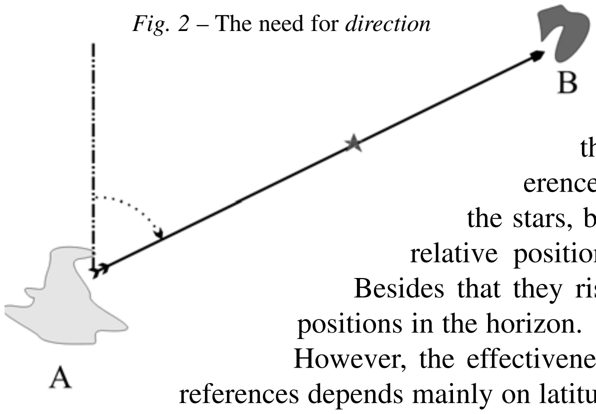
One of the ways is having a reference related to the direction of the swell, if it is constant during the period of navigation.

Another can be the direction of the wind, again if it is constant in direction.

Another can be the flight of birds, if they go always to the same place B.

We see that those means have too many *ifs*, and people soon recognized that the heavens, with its stars and planets during the night, and sun and moon during the day, could be a good reference. From those, the best are the stars, because they maintain their relative positions for very long periods. Besides that they rise and set in well-defined positions in the horizon.

Fig. 2 – The need for *direction*



However, the effectiveness of stars to be direction references depends mainly on latitude as we are going to see.

betts, expressed in a paper in 1979 (See G. R. Tibbets, *A Comparison of Medieval Arab Methods of Navigation With Those of the Pacific Islands*, Lisboa, sep. CXXI, Centro de Estudos de Cartografia Antiga, Junta de Investigações do Ultramar, 1979), performed some years after the publication of his very important work, *Arab Navigation in the Indian Ocean Before the Coming of the Portuguese* (London, The Royal Asiatic Society of Great Britain and Ireland, 1971. He says that: «My own opinion is that in both areas [Indian and Pacific oceans], there must have been a general mutual awareness of the way that navigational problems were solved. In the days when the Malaysian peoples travelled to Madagascar, the Pacific peoples may have been in contact with southeast Asia and similar navigational systems may have operated on both Malayan archipelago». See *op. cit*., p. 13.

([4]) We can also consider A as a continent. We can for example imagine a route from the African eastern coast to the island of Socotora.

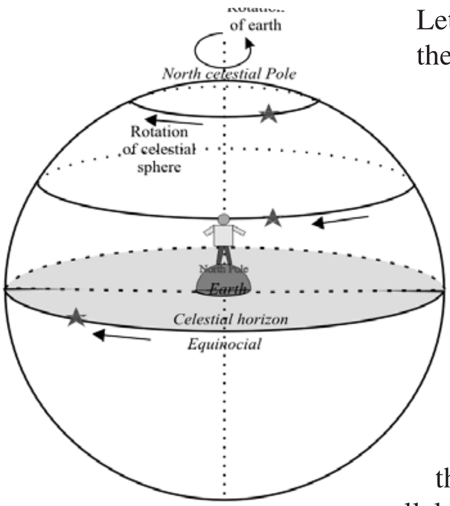


Fig. 3 – Observer at the Pole. Parallel sphere. Stars never rise and never set. Only half of the celestial sphere visible throughout the year.

Let us imagine that we are standing on the North Pole (fig. 3). On account of the rotation of the earth around its axis the celestial sphere moves apparently in the opposite direction. As we have the axis of the earth in our head, during 24 hours, the celestial hemisphere revolve around us, and celestial bodies never rise and never set. The astronomers and navigators call it parallel sphere, because the heavenly bodies have their movements along celestial parallels.

As there is no rising and setting, and they are always moving horizontally, celestial bodies are not good references for direction.

Let us now consider the observer at the Equator (fig. 4).

Heavenly bodies trace perpendicular circles around the observer, and their rising and setting bearings are maintained during long periods, specially the equatorial ones. See for example that a star at the equator (or the sun during the equinox), rises in the east, maintains its east bearing till meridian passage and maintains its west bearing till it sets.

If the observer is at high latitude (see fig. 5, observer at 45°N), heavenly bodies trace oblique circles relative to the horizon, and their rising and setting bearings vary rapidly.

Nevertheless, any observer at the same latitude has throughout the year always the same

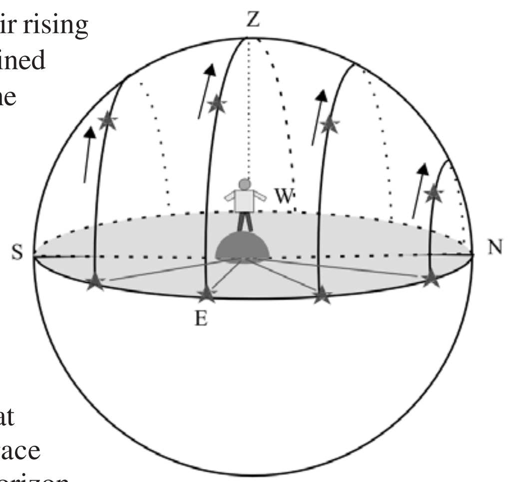


Fig. 4 – Observer at the Equator. Right sphere. Stars trace circles perpendicular to the horizon. Equatorial stars defining, during rising an setting, long periods of accurate bearings.

bearing of a given star during rising or setting. But if he changes latitude, the bearing will change appreciably if he is in high latitudes, but change a small amount in places near the equator.

For clarifying the situation, let us see the table shown after fig. 5, where the bearings (Z) of the rising of four stars of northern declination (δ) and the settings of four stars of southern declination, are shown for the latitudes 0° to 60° north, in intervals of five degrees of latitude.

The 8 stars selected are part of the 16 that Tibbets identified in the Arab stellar compass, and cover almost the entire horizon(5).

I am going to admit that we are looking to the sky in January 2002, which is sufficient for the purpose of my study. The declinations and bearings are to the accuracy of the degree and the bearings are from 0° to 360°, clockwise, which is the normal way used by navigators.

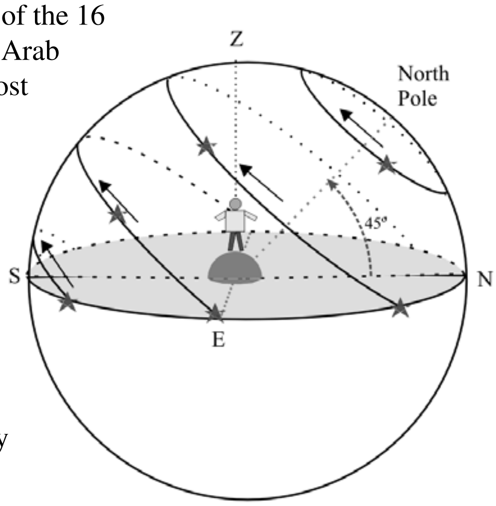


Fig. 5 – Observer at 45° of latitude. Oblique sphere. Stars trace circles oblique to horizon, defining, during rising an setting, very short periods of accurate bearings.

(5) See *Arab Navigation in the Indian Ocean…*, *op. cit*., pp. 294-299. Tibbetts follows Léopold Saussure, in the work of Gabriel Ferrand, (*Instruction Nautiques et Routiers Arabes et Portugais des XV ème et XVI ème Siècles*, Tome III, Paris, Librairie Orientaliste Paul Geuthner, 1928), pp. 92-124.

Observer in the northern hemisphere																
	Stars with northern declination. Bearings of rising.								Stars with southern declination. Bearings of setting.							
Latit.	Kochab		Schedar		Capella		Altair		Sirius		Antares		Canopus		Achernar	
	δ	Z	δ	Z	δ	Z	δ	Z	δ	Z	δ	Z	δ	Z	δ	Z
0º	74°N	016°	56°N	034°	46°N	044°	9° N	081°	17°S	253°	26°S	243°	53°S	217°	57°S	213°
5°N	“	015°	“	033°	“	044°	“	081°	“	253°	“	243°	“	217°	“	212°
10°N	“	012°	“	032°	“	043°	“	081°	“	253°	“	243°	“	216°	“	211°
15°N	“	004°	“	030°	“	042°	“	081°	“	253°	“	242°	“	215°	“	210°
20°N	“	—	“	027ª		040°	“	081°	“	252°	“	242°	“	213°	“	207°
25°N	“	—	“	023°	“	037°	“	080°	“	252°	“	241°	“	209°	“	203°
30°N	“	—	“	015°	“	034°	“	079°	“	251°	“	239°	“	203°	“	194°
35°N	“	—	“	—	“	028°	“	079°	“	250°	“	237°	“	194°	“	—
40°N	“	—	“	—	“	019°	“	078°	“	248°	“	234°	“	—	“	—
45°N	“	—	“	—	“	—	“	077°	“	246°	“	231°	“	—	“	—
50°N	“	—	“	—	“	—	“	076°	“	244°	“	226°	“	—	“	—
55°N	“	—	“	—	“	—	“	074°	“	240°	“	220°	“	—	“	—
60°N	“	—	“	—	“	—	“	072°	“	235°	“	209°	“	—	“	—

We can see that the bearings of the stars on rising (the setting is symmetrical), have a small variation with latitude, around latitudes 0 to 20 or 25 degrees. I enhanced the maximum variation in bearing of two degrees in light gray and of 4 degrees in dark gray.

By a similar operation (see table bellow), I will also find that for the same stars but to south latitudes of the same amount, which I only extended to 30°S, the bearings are the same.

Latit.	Kochab		Schedar		Capella		Altair		Sirius		Antares		Canopus		Achernar	
	δ	Z	δ	Z	δ	Z	δ	Z	δ	Z	δ	Z	δ	Z	δ	Z
0°	74°N	016°	56°N	034°	46°N	044°	9°N	081°	17°S	253°	26°S	243°	53°S	217°	57°S	213°
5°S	“	015°	“	033°	“	044°	“	081°	“	253°	“	243°	“	217°	“	212°
10°S	“	012°	“	032°	“	043°	“	081°	“	253°	“	243°	“	216°	“	211°
15°S	“	004°	“	030°	“	042°	“	081°	“	253°	“	242°	“	215°	“	210°
20°S	“	—	“	027°	“	040°	“	081°	“	252°	“	242°	“	213°	“	207°
25°S	“	—	“	023°	“	037°	“	080°	“	252°	“	241°	“	209	“	203°
30°S	“	—	“	016°	“	034°	“	079°	“	251°	“	239°	“	203°	“	194°

This is a very interesting fact that sometimes is not recognized, even by experienced navigators([6]). It gives an added advantage of using rising and setting stars for direction between the tropics because their bearings are equal if we are at the same latitude, even if we are in different hemi-

([6]) The formula for finding the bearing Z of any celestial body at rising or setting is: *cos Z = sen* δ *x sec* φ. As the latitude is always less than 90° its secant is always positive, spheres. This means that the entire area of the tropics is suitable for this purpose and not only half of it.

It also shows clearly, that for observers between the tropics, the rising and setting of stars are an accurate way for direction, and that out of the tropics, they are not suitable for that purpose.

In consequence of what has been said above, it can be understood that inter-tropical navigators soon recognized that the bearings of rising and setting of stars were almost constant when they made their inter-island voyages, although they did not had the notion of latitude as we have today.

So they began to recognize that the island B (fig. 2), was, as seen from island A or the continent, in the direction of the rising of some star. And this after repeated voyages.

As other islands or harbours in continents were in other directions, they soon memorized other different stars that were suitable to maintain the direction required.

As stars are only near the horizon for a short period, other stars were used on the same direction or bearing (this is nowadays the appropriate technical word).

As in the same bearing the amount of stars was not sufficient to cover all the horizon, soon practical navigators recognized that other stars would be associated with the others, if they made an image of them, altogether, on a piece of circular or square wood, where they marked all the stars useful for the purpose of finding different places.

From this stage, and taking into account that their voyages were in directions that covered the entire horizon, it is easy to understand the development of a compass rose that showed to the navigator the different directions which in the future could be the reference for future voyages. In consequence of this the *stellar compass* was introduced.

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so cos Z will always be of the same sign of sen δ. So the bearing Z will always be of the same name as the declination. This is also very clearly shown on the excellent work of David Lewis (*We the Navigators. The Ancient Art of Land finding in the Pacific*, second edition, Honolulu, University of Hawaii Press, 1994. In its Appendix I is a clear study about this subject. To the same conclusion arrived Pedro Nunes, the well-known Portuguese mathematician of the sixteenth century and cosmographer major of the Portuguese crown, when answering to the many questions of Martim Afonso de Sousa, a captain of an Armada recently returned from Brazil. To the question of finding in 35° S during sunrise and sunset the bearing of the sun SE1/4E and SW1/4W, respectively, when the sun had its most southern declination (in the Tropic of Capricorn), the same bearing that he had already experienced in the same latitude in 35°N, Nunes explained it clearly, not only with text and images but also mathematically. See, *Pedro Nunes, Obras*, 4 vols., Lisboa, Academia das Ciências, Imprensa Nacional, 1940, vol. I, pp. 165-174.

Stellar compass of the Indian Ocean

Let us imagine now specifically, the navigators of the Northern Indian Ocean (Persians, Indians, Arabs, Malays, Chinese), who sailed in northern latitudes between the 7th and 23rd parallel mainly in an east-west direction.

They soon recognized (like the Portuguese after recognized in the Atlantic), that the Pole Star which was always above their horizon and near the North Celestial Pole, was a good way to find direction and very appropriate to maintain an east-west course.

But as the Pole Star or the other stars of the Little Bear could be covered by clouds, other stars were chosen and drawn in a piece of wood, separated each other by the angles that separated them in the horizon. So, a star compass of the Indian Ocean was idealized being its details explained later. See fig. 7([7]).

All of this has been deeply studied by many scholars like Gabriel Ferrand([8]), G. R. Tibbetts([9]), Laguardia Trias([10]), Custódio de Morais([11]), Vitorino Magalhães Godinho([12]), Moura Braz([13]), David Lewis([14]), William Kelsalka([15]), Teixeira da Mota([16]), among many others. Lewis and Kelsalka made interesting sailing experiences, with extremely important results.

([7]) Adapted from Gabriel Ferrand, *Instructions Nautiques et Routiers …,* p. 91.

([8]) *Op. cit.*

([9]) G. R. Tibbetts, *Arab Navigation in the Indian Ocean Before the Coming of the Portuguese*, London, The Royal Asiatic Society of Great Britain and Ireland, 1971. Also, from the same author, *A Comparison of Medieval Arab Methods of Navigation With Those of the Pacific Islands*, Lisboa, Junta de Investigações Científicas do Ultramar, Centro de Estudos de Cartografia Antiga, 979.

([10]) Rolando A. Laguardia Trias, *Las Mas Antiguas Determinaciones de Latitude en el Atlantico y el Indico,* Madrid, Instituto Historico de Marina, 1963.

([11]) J. Custódio de Morais, *Determinação das coordenadas geográficas no Oceano Índico pelo pilotos portugueses e pilotos árabes no princípio do século XVI*, Coimbra, Universidade de Coimbra, 1960.

([12]) Vitorino Magalhães Godinho, «Navegação oceânica e origens da náutica astronómica», in *Ensaios (I, Sobre História Universal),* Lisboa, Sá da Costa, pp. 177-227.

([13]) C. A. Moura Braz, *O Encontro das Marinhas Oriental e Ocidental na Era dos Descobrimentos*, Lisboa, Sociedade de Geografia, 1962.

([14]) *Op. cit.*

([15]) Will Kelsalka, *An Ocean in Mind*, Honolulu, University of Hawaii Press, 1987.

([16]) A. Teixeira da Mota, «Méthodes de Navigation …», *op. cit*.

Léopold Sassure has deeply studied this subject and his considerations were extensively explained and justified in an article published in 1923 in Génève that Gabriel Ferrand included in his *Instructions Nautiques et Routiers Arabes et Portugais*([17]).

Tibbetts refers also this subject, mainly following de Sassure's ideas([18]).

The stellar compass rose, as previously explained, came into use on account of the specific conditions of the seas navigated. In consequence of the need of a multiple of 4 directions (the result of the previous definition of the 4 cardinal points), 32 directions were found which were related to the directions of the rising and setting of 15 conspicuous asterisms([19]). The remaining directions needed were the North Pole (defined by Polaris), and the South Pole.

The stars were primitively chosen mainly according to its bearing of rising and setting, the times of this phenomenon, and magnitude. It was necessary that after a star sets, becoming invisible, another be already above the horizon but sufficiently low to be a good direction indicator. This last star will be useful during a short period, after which another star will rise or is setting in a convenient position for direction reference.

So the idea was to have at any time of the night at least one star sufficiently low. All the others should follow in the same condition, in different positions of the horizon and obviously in different times of the night.

With this array of asterisms, there will be always the possibility of orientation of the compass in relation to the north south line, because the different stars make known angles with the north south line that is mainly represented by Polaris and the stars around the North Pole.

Scholars studied deeply this subject, trying to interpret its origin and date of implementation, the different stars or groups of stars used, etc. The names of the stars and the compass itself are shown in figures 6 and 7, based in de Saussure's work([20]).

([17]) *Op. cit.*, pp. 31-127.

([18]) See *Arab Navigation in the Indian …*, pp. 295-312.

([19]) Ibn Majid also says, when explaining the compass in his *First Fahida*, that «The rhums are 32 in number as they are divided on the ship and they make even numbers of them without using odd numbers.». Idem, *ibid.*, p. 76.

([20]) See *op. cit.*, pp. 93-124. Saussure has made the identification of the stars with the help of a mobile globe of the Observatory of Génève, which had sufficient accuracy for the purpose. This was made around 1920, but nowadays we have the enormous help of astronomic computer programs, which have great accuracy and flexibility. They allow

The table in fig. 6 shows, for 15 of January 1300 a. d., in a place of latitude 10°N and longitude 80°E (just north of Sri Lanka), the stars or constellations indicated by de Saussure([21]) with their magnitudes, declinations, bearings, altitudes and times of rising and setting and also times of meridian passage.

Star/Const.	Magnit.	Declinat.	Rising	Bear.	Setting	Bear.	Timem.p.
Polaris	2.1	85° 28'.1 N	—	—	—	—	1536
β Ursamenor / *Kochab*	2.2	76° 59'.9 N	**2053 *(3)***	008°.5	1605	351°.4	0637
γ Ursa Menor / *Pherkad*	3.1	74° 18'.9 N	**2210 *(6)***	011°.6	1544	348°.3	0659
α Ursa Maior / *Dubhe*	2.0	65° 25'.1 N	**1813 *(1)***	022°.3	0928	337°.6	0153
χ Ursa Maior / *Alioth*	1.7	59° 48'.3 N	**2039 *(2)***	028°.4	1112	331°.6	0357
α Cassiopeia / *Schedar*	2.5	52° 39'.3 N	0840	036°.0	**2232 *(7)***	324°.0	1536
β Cassiopeia / *Caph*	2.4	55° 15'.2 N	0805	033°.2	**2209 *(5)***	326°.7	1507
Capella	0.2	44° 50'.6 N	1316	044°.1	**0245 *(15)***	315°.9	1958
Vega	0.1	38° 21'.3 N	**0314*(17)***	050°.8	1622	309°.3	0948
Arcturus	0.2	22° 33'.9 N	**2255 *(8)***	066°.9	1136	293°.1	0518
Pleiades		24° 07'.0 N	1300	065°.0	**0141*(13)***	295°.0	
Altair	0.9	7° 18'.9 N	**0444 *(19)***	082°.5	1657	277°.5	1051
Cint. Orion – *Alnilan*	1.8	1° 54'.3 S	1433	091°.8	**0237*(14)***	268°.2	2033
Sirius	-1.6	16° 12'.9 S	1556	106°.4	**0340*(18)***	253°.6	2146
β, δ, π, Escorpião-δ	2.5	20° 22.9 S	**0108 *(11)***	110°.6	1240	249°.4	0654
Antares	1.1	24° 36'.2 S	**0138 *(12)***	114°.9	1305	245°.1	0721
α Centaurus	0.1	57° 35'.2 S	**0025 *(10)***	148°.8	1023	211°.2	0524
β Centaurus / *Hadar*	0.9	56° 50'.5 S	**2347 *(9)***	148°.0	0953	212°.0	0452
Canopus	-0.9	52° 25'.2 S	1631	143°.4	**0255 *(16)***	216°.6	2141
Achernar	0.6	60° 52'. 5 S	1154	152°.3	**2135 *(4)***	207°.7	1644

Fig. 6. Table showing the bearings of the stars of the stellar compass in 15 January 1300 a.d., in 10° N, 70° E.

On the columns of rising and setting times I highlighted the times that are in good condition for usefulness of direction indication and numbered them in sequence of observation during all the night. The ones not highlighted are not useful during that time of the year, because they rise or set during the day. But we have to understand that the stars not useful in January will be useful in other times of the year on account of the annual movement of the earth around the sun([22]).

us to materialize the heavens and its celestial bodies in any year and date we want, having easily not only the possibility of seeing the movement of the bodies in any place on earth, but also to have, among many other useful information, their coordinates. One of the programs I have used for the calculations of figures 6 and 8 is *Cyber Sky*.

([21]) *Op. cit*., pp. 108-109. De Saussure bases his identification on the work of Antoine d'Abadie, a French scientist that published his work in the *Journal Asiatique* de 1841 and from which he makes a long quotation.

([22]) On account of the translation of the earth around the sun, this celestial body moves apparently around the earth as seen from the earth. So, the stars seem to move relatively to the

So, taking in consideration that a star near the horizon can be utilized during a long period for direction indication([23]), the intervals of time shown are an indication that at the same time there was always one star available.

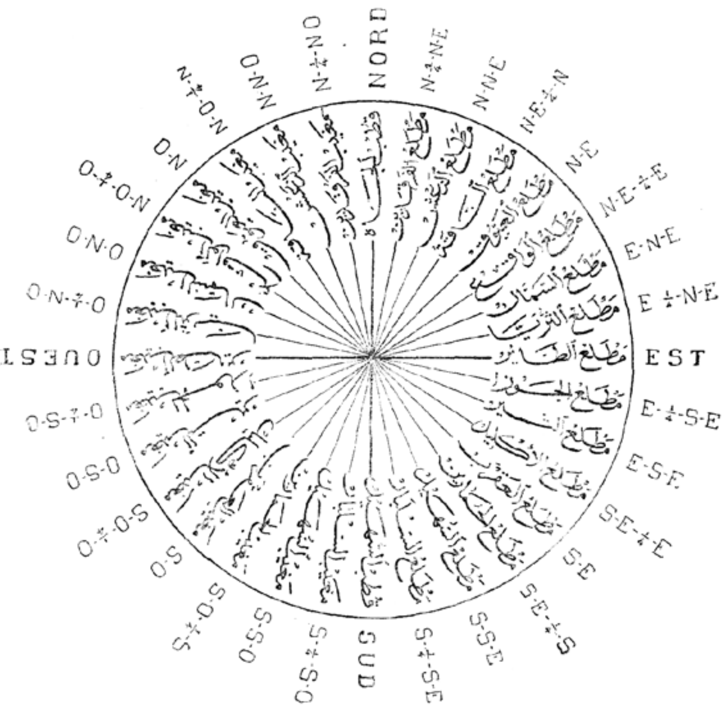

Fig. 7 – Stellar compass of the Indian Ocean.

sun (the projection of the apparent movement of the sun around the earth is called the *ecliptic*). One complete revolution of the earth around its axis and having as reference a star (sidereal day), is completed before the earth completes its rotation around the sun (solar day), because it is moving in space. As 360° translation takes a little more than 365 solar days the *retardation* of the solar day in relation of the duration of the sidereal day is a little less than one degree of arc (360°/365) or about 4 minutes of time. So we can say that the stars rise every day 4 minutes earlier. This will also means that in a certain place on earth and at the same day of the year we never have the same star in the same position on the visible celestial sphere.

([23]) David Lewis gives an indication of optimum altitudes of steering stars, as per his observations at sea and changing information with the local seamen. One of the indications says that a star can be used from near the horizon till around 15° altitudes. A sailor from the Pacific says that in Tonga they suggest to «steer by a star until it has reached a height the same as the sun has at 10 A. M.». This means in tropical areas an altitude of around 50°, which is too high (see, *We the Navigators*, pp. 97-98). My personnel experience, navigating in the Atlantic in inter-tropical areas in the square-rigger *Sagres* of the

Figure 7 shows a copy of the compass included in the work of Léopold de Saussure, as referred above.

The compass, with its 32 divisions, is divided in two halves by the north south line, materialized by the Pole Star, and has inscribed the names of the stars or star groups in one side, which are repeated on the other side, all the designations being preceded by the Arabic word meaning setting in the western part and rising in the eastern part.

We can understand that the separation of the useful stars by a regular angular interval will be impossible to achieve in nature. We can see in figure 8 (which is a representation of the «real» compass for the year 1300 a.d.), that the bearings of the stars that correspond to the table above are not distributed regularly.

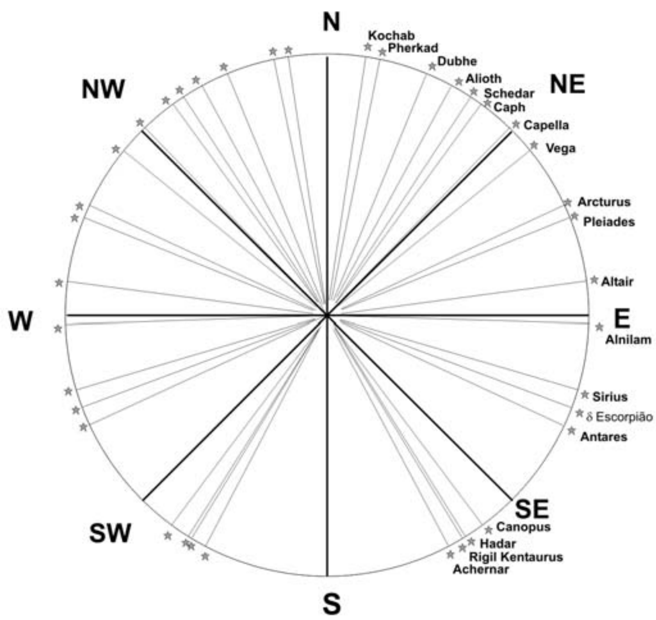

Fig. 8 – A grafical representation of the bearings of the stars included in the table of fig 6.

Portuguese Navy, shows that a star of the magnitude used in the stellar compass can be seen above the horizon with an altitude above around 6°. Its usefulness for direction can go to 20° of altitude. It is useful to recognize that my information and the one of David Lewis are related to the Pacific and the Atlantic, where atmospheric conditions are not as good as the ones in the Indian Ocean.

This apparent problem has intrigued scholars who tried to find the epoch when the compass was introduced through the calculation of different arrangements of the same stars that, on account of precession, change slightly their positions in the sky([24]).

But even de Saussure arrived to the conclusion that «…: l'usage de la boussole a rendu les noms de rumbs purement conventionnels (comme, par exemple, le nom de notre mois de septembre qui n'indique plus le septième mois)».

Tibbets also found that Ibn Majid himself commented the inaccuracy of the bearings for direction finding([25]). It is very useful to quote the two passages of the *Kitab al-Fawaid* referred by Tibbets and by him translated in his work. The first one is as follows:

> These stars or rhumbs [of the compass] are all of them approximate as we have shown in the Hawiya([26]):
>
> These stars and rhumbs with the Arabs
> Are only approximate, Oh my captain.
> If you set course exactly on them
> In a narrow place, then you will have difficulty. [here ends the quotation of the *Hawiya*]
>
> For they are only used for their names and not for their actual position in the heavens. Their positions are used for the compass rose which is divided into divisions and we have spoken and commented on this. Then we said on the Hawiya:
>
> The rest of the rhumbs of the compass are alike:
> It is a numerical division which can not be misleaded.

The other quotation referred to another chapter of the *Fawaid* that dealed with compass rhumbs([27]). It is as follows: «Aiyuk [Capella], is used to divide the heavens exactly in quarters for it is 45° from the east

([24]) Not only the above-mentioned scholars who studied Arab navigation tried to find the date when the bearings agreed with the equidistant rhumbs. An excellent work of Marina Tolmacheva tried to interpret this problem with an extensive use of different calculations for different epochs. Tolamcheva gave finally her stellar compass composition for the year 310 B.C., «… resolved in retrospect by a selective process bringing together a star and a rhumb showing best agreement of the present and projected azimuth».
See, Marina Tolmacheva, *An Analysis of the Arab Wind Rose*, University of Toledo, paper to be presented to the 1977 Convention of the Middle East Studies Association.

([25]) See *Arab Navigation…,* pp. 297-298.

([26]) Ibn Majid was quoting the passage in one of his previous works also referred by Tibbets who mentioned and listed 40 of those works. See *Arab Navigation…,* pp. 74-75.

([27]) See *op. cit.*, p. 139.

point and 45° from the North Pole. It is the only star used as rhumbs which is accurately in position.».

It is very interesting to note in figure 8 that Capella in fact, has the bearing of 45° NE, which fits exactly with the words of Ibn Majid. If there were any doubts about this subject, this only statement from this most famous Arab pilot would be sufficient.

Ibrahim Khoury calls also the attention to this problem in his work *As-Sufaliyya. «The Poem of Sofala» by Ahmad Ibn Majid*. When commenting al-Hawiya, the poem of Ibn Majid where this pilot referred «The Circle of Ship» (which is the stellar compass), says:

> The basis of this choice [the division of the compass in equal parts] would be, theoretically, the apparent rising and setting of these stars in the sectors. In fact, this is not always true, because the distance between two consecutive stars or groups of stars, is never 7 fingers as it should be (11° 15'), and that α β Cen (al-himaran) sector comes before Canopus and Achernar sectors, although its declination is superior to theirs, and this fact is well known among the arab seamen. In this conjecture, it seems that the Point-Polaris is of the utmost importance for drawing the sectors, which lead to the guiding stars. Thus the sectors are believed to be a kind of frame reference to show the beginners how to find and learn the positions of the stars of navigation that give sailing directions([28]).

So I think that the way to use the compass was not so complicated as sometimes is suggested. My final interpretation will be given latter at the end of this work.

Navigation in the Indian Ocean and the adequate techniques

Before analysing the practical way in which the sailors of the Indian Ocean used these instruments let us complement the environmental conditions that were explained in the beginning of this work.

The north Indian Ocean, except during the height of the southwest monsoon which corresponds roughly to the months of June, July and

([28]) Ibrahim Khoury, *As-Sufaliyya. «The Poem of Sofala» by Ahmad Ibn Majid*, Coimbra, Junta de Investigações Científicas do Ultramar, 1983. In this work, the author tries to demonstrate that Ibn Majid was not the pilot of Vasco da Gama. One of the reasons is the inclusion of false verses in this known work of Ibn Majid.

August([29]), has light to moderate winds and waves. There are generally clear skies and especially clear nights, very appropriate to the observation of heavenly bodies.

The voyages from west to east were performed from the beginning or the middle of April till the middle of May. This was the first period, taking in advantage the southwest wind of the beginning of the southwest monsoon. The second period was the crossing of the sea at the end of the southwest monsoon, to arrive at the coasts of India in mid September.

The return voyage, with the northeast wind was performed after the middle of October till the beginning of April.

Figure 9 shows schematically the north Indian Ocean and its main islands and coasts. It is clear that the voyage was mainly along a parallel of latitude and sometimes it was necessary to cross narrow passages like the Lachadweep Islands that were also spread in a north-south direction. The coasts of the Indian subcontinent have also more or less the same orientation.

It is also interesting to note that the navigation area was mainly between the equator and around the 23rd parallel of north latitude.

So, the safer and more adequate technique was to find the parallel of the destination, which was previously known, and stay on it until arriving near the coast. The image shows an example of voyage from Kalicut to Socotora.

This was the kind of technique used by all the modern navigators till the better knowledge of longitude in the end of the XVIII th century.

To find the parallel of destination a course had to be maintained, the stellar compass being used. To find ashore the «latitudes» of the harbours and to maintain the ship on the same parallel for long periods the stars were also utilized.

For this last purpose the pole star was the most useful and accurate star to be used, because it was recognized by the experience of observation that all the heavens circled around a point very near this heavenly body. The height of this star over the horizon was the main reference in the area, as for example is clearly explained by Ibn Majid in the *Faawid*.

([29]) Ibn Majid explains all of the strategies employed by the pilots to choose the best season for crossing the Indian Ocean from all the harbours and directions. See *Arab Navigation* …, pp. 225-242, which includes Tibbet's translation of the Eleventh Faida, *Monsoons and Connected Matters.* Commenting the anchorage in harbours after the crossing Majid says: «Because of this [the strength of the Dabur wind], intelligent men never make this journey during the 3 months or 90 days for then it is a gamble». (*Op. cit*., p. 227). The 90 days corresponded to the months of June, July and August.

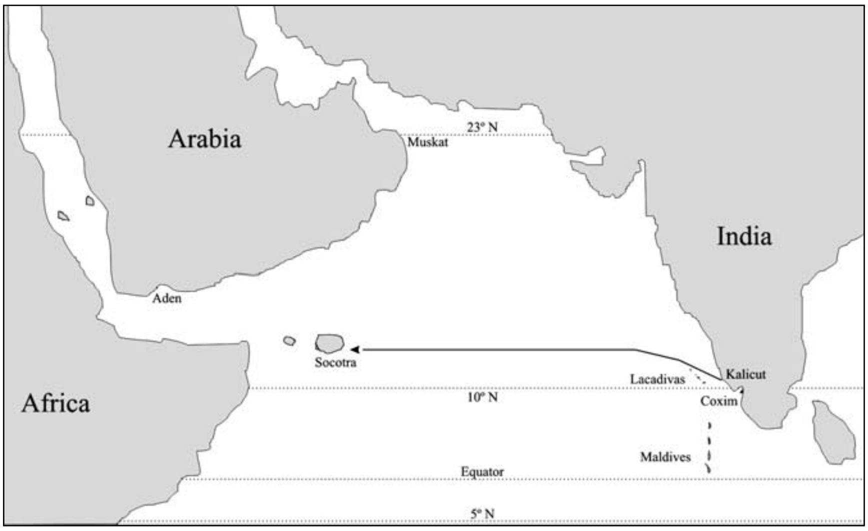

Fig. 9 – The North Indian Ocean area of navigation.

Besides that the Pole Star was visible from around 6° N(30), covering all the area navigated from this latitude to the north.

But as sometimes the heavens was obscured by clouds, the positions of other stars relative to the Pole Star were used for the same purpose, being the main reference for *parallel navigation* the height of the Pole Star on its inferior meridian passage(31).

This last situation is represented in figure 11 where the Little Bear is represented with the Pole Star in its tail, the movement of the heavens counter clockwise for an observer looking north, the celestial pole and the polar distance of Pole Star during the beginning of the 16th century.

So, having already seen the way to find direction, the remaining operation would be to measure with an acceptable accuracy the height of a star above the horizon.

(30) At least, because the Indian Ocean atmosphere is much more pure than the Atlantic one. See note 22 above.

(31) In all the texts of the pilots (Ibn Majid or Suleiman al Mahri, for example), it is clearly referred that this position of the Pole Sitar was the main reference. All the other star altitudes were reduced to this same reference. All the scholars referred recognize also this principle.

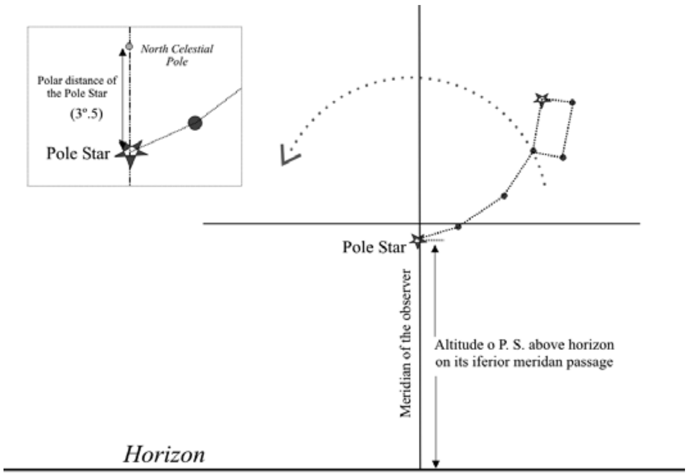

Fig. 10 – The Little Bear, the Pole Star and the main operation needeed for navigating along a parallel.

The Kamal

It seems that the first approach to this problem has been the measurement of this angle with something that could be practical and relatively uniform. The more intuitive instrument has been the human body. So soon sailors found that a stretched arm with the four fingers of the hand perpendicular to the line of sight could be a reference for measurement of an angle.

With the little finger in coincidence with the horizon and one, two or three fingers more superimposed to it, as the altitudes to be measured were very small, an altitude of a star could be measured. If the altitude exceeded four fingers it was possible to estimate how many fingers more were necessary to measure the altitude of the star.

As the angle subtended by the fingers of a human body are more or less constant because there is a proportion between the thickness of the fingers and the length of the stretched arm, this simple instrument was probably the first instrument in the history of navigation, after the lead line.

I had the opportunity to take measurements with the stretched arm, of the height of the forefinger and the height of four fingers (with the exception of the thumb), of nine persons, which are shown in the following table([32]).

([32]) The angles were found by simple trigonometry.

Length of arm (m/m)	Forefinger height (m/m)	Forefinger's angle (°)	4 finger's height (m/m)	Average of 4 finger's angle (°)
730	21	1° 37'	78	1° 31'
650	23	2° 00'	82	1° 48'
645	19	1° 41'	72	1° 36'
630	18	1° 37'	72	1° 37'
660	21	1° 48'	73	1° 36'
600	21	2° 00'	79	1° 52'
660	23	2° 00'	76	1° 38'
700	22	1° 48'	80	1° 38'
640	20	1° 47'	74	1° 39'
	Total aver.	1° 48'	Total aver.	1° 39'

It is very interesting to verify that the results have not a great discrepancy, although I did not take great care with the measurements. The last column is the angle subtended by 4 fingers divided by 4, which corresponds to the angle subtended by a finger with the average height of the 4 fingers([33]). The total average is 1° 39', value that will be very interesting to analyse later. Some photographs of my son in the attitude of measuring with the fingers and the arm stretched are shown in Plate 1.

This system originated the Arab or Indian Ocean unit of measurement of angles, which is the finger or *isba* in Arabic. In the beginning sailors probably were not preoccupied in having a uniform unit, or at least did not converted it to any constant unit. As soon as navigations were increased, it was found useful to standardize the finger measurement and the value agreed by scholars now gave to the *isba* the value of 1° 36' which is very approximate to the anatomical value of 1° 39'.

Ibn Majid, who says in his First Faida that «… the distance between two rhumbs is 7 *isba* and between each two mansions 8 *isba* making a total of 224 *isba*.»([34]), admits a constant value for the *isba*, which will be 360°/224 = 1° 36'([35]).

([33]) This anatomic measure was called by the pilots a *dhubban* and Ibn Majid explains this, saying that «Four *isba* is one *dhubban*, the *dhubban* being the place occu pied by the sword handle in the palm of the left handle as far half the nail of the little finger of the left palm». See *Arab Navigation* …, p. 76. This explanation is not very clear to me. De Saussure also gives an interpretation for this that is also not very clear to me. I think that Ibn Majid tried to explain what was the horizontal reference to measure vertically an angle with the 4 fingers, because their height decreases to the extremity of the fingers. I think that the reference was the vertical aperture of the 4 fingers passing through the middle of the little finger, which is more or less between the root of the little finger and the middle of the nail of this same finger.. See *Instruction Nautiques …,* p. 162.

([34]) See *op. cit.,* p. 76. Tibbets gives complete information about this subject later in his work (pp. 314-315) when dealing with the Navigational Theory.

([35]) The value of the *isba* is also clearly explained in the *Livro de Marinahria de André Pires*, where this portuguese Pilot refers in his manuscript (written between 1517-

Plate 1

The attitude of the observer when using his fingers.

James Prinsep gave very interesting information about the evolution of the simple instrument that followed this anatomic way of measuring angular altitudes. His article published in 1836 in the Journal of the Asiatic Society is very important to clarify the situation([36]).

In accordance with Prinsep, this anatomic way was first followed by the use of nine tablets of wood, the first and smaller one with four horizontal equidistant divisions, each one of one *isba*. The other 8 tablets, of increasing size, represented 5 to 12 *isba*([37]).

These 12 tablets were all connected by one string, which in my opinion had the main purpose of maintaining all the tablets together. In fact, the principal of the measurement was that the tablets, which had a uniform height, could substitute the fingers for measuring an angle with the arm completely stretched, without the need to superimpose fingers. So the navigator had always with him the possibility of measuring an angle from 1 to 12 fingers more accurately than with his fingers([38]).

Prinsep found also the *modern* instrument, brought to him, by a sailor of the Maldive islands which was:

> … a small parallelogram of horn (about two inches by one) with a string (or a couple of strings, in some instances), inserted in the centre. On the string are nine knots. To use the instrument for taking the height of Polaris, the string is held between the teeth, with horn at such distance from

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-1540), that «Se caso for que achares alguma carta de mouros e a quiseres graduar à nossa usança, tomarás 5 polegadas e reparti-las-ás em 8 partes, que são 8 graus …». This means that one *isba* is 8/5º or 1º 36'. See Luís Mendonça de Albuquerque, O Livro de Marinharia de André Pires, Lisboa, Junta de Investigações do Ultramar, 1963, p. 135. Luís de Albuquerque studies very deeply the precious information about the techniques of navigation in the Indian Ocean included in the manuscript.

([36]) His article has been reproduced by Gabriel Ferrand in his *Instructions Nautiques* …. See *op. cit*. pp. 1-24.

([37]) It was the *Muhit* of admiral Sidi Ali Celebi that described this instrument. This nautical guide was produced by this Turkish admiral who was in charge of conducting the Turkish fleet in its return to Egipt after being attacked by the Portuguese in the mouth of the Persian Gulf being after scattered by a storm. While anchored in Gujerat he produced this important nautical guide based mainly in the Ibn Majid and Sulaiman al Mahri works, although many comments of his own were introduced.

([38]) The explanation given by Prinsep or his interpretation of the Muhit is very confusing. The following text, which I am not sure if it is a quotation of the translation of the Muhit, says: «The method of taking the measure is as follows: You take the table with the left hand and the thread that passes through the middle in the right; you stretch your left hand firm and take the elevation which gives …». I do not understand the need to take the thread with the right hand unless for separating the undesired tablets from the one that was being used.

the eye, that while the lower edge seems to touch the oceanic horizon, the upper edge meets the star: the division or knot is then read off as the required latitude([39]).

His description shows that now the idea was to have a constant reference with a known height (the piece of wood) and a variable length of string adequately graduated.

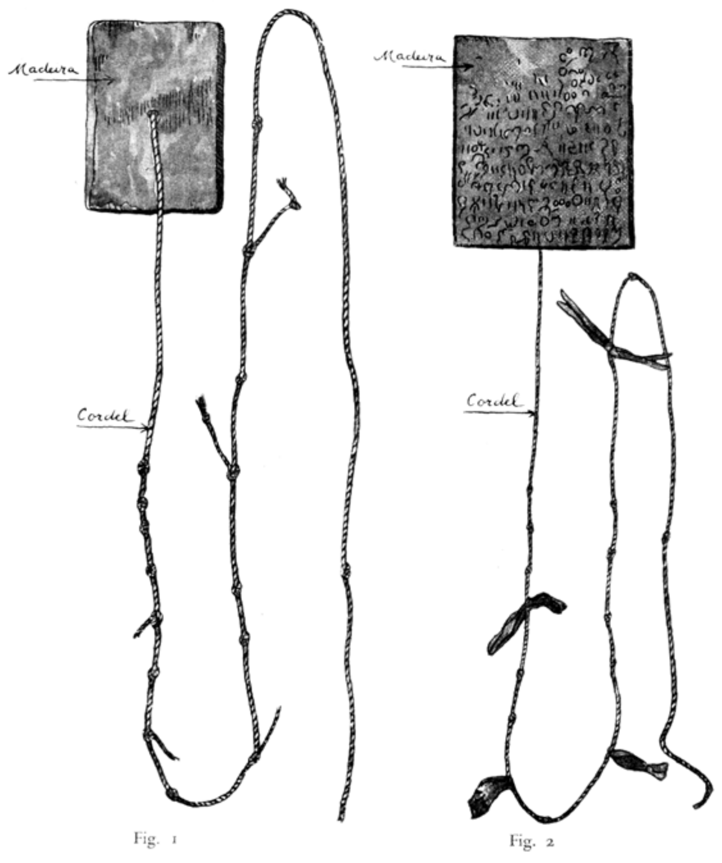


Fig. 11 – Two examples of Kamal, according to Pereira da Silva.

([39]) *Op. cit.*, p. 2.

Luciano Pereira da Silva published an excellent work in 1924 about this subject. The objective of the work was mainly to comment the meeting of Vasco da Gama with the Muslim pilot in Melinde and the instrument that he showed to him consisting of three tablets([40])

Trying to understand the instrument he finally found in the Ethnographic Museum of Hamburg, two instruments called Kamal, from which he got a drawing.

Figure 12 reproduces the drawing received by Pereira da Silva, being the instrument on the left been offered by an Hindu pilot to captain Doher of the Steamship Line of Calcutta in 1892.

The same instrument is in wood of 4 millimetres thickness and has 6.65x4.8 centimetres. The rope has 16 knots, which correspond to the height of the Pole Star in 16 harbours of the Gulf of Bengal([41]).

The designation kamal to this simple instrument is probably very modern. Tibbetts comments that «he measurer’s instrument is never called this by the navigators»([42]).

Experiences with replicas of the Kamal

Following my belief that to better understand history is very important to experiment techniques of the ancients, I made replicas of the kamal taking as reference the first one described by Luciano Pereira da Silva. I ordered the making of some pieces of hardwood of 4 millimetres of thickness and of 70x50 millimetres, being its width and height very near the 6.65x4.8 millimetres of the original.

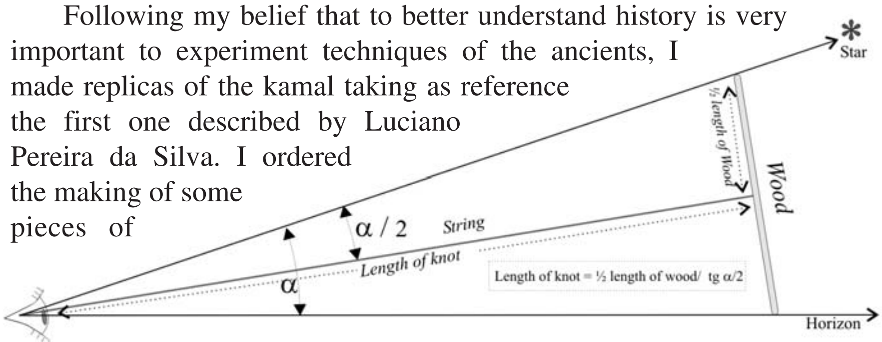


Fig. 12 – Geometrical principal of the Kamal.

([40]) See, Luciano Pereira da Silva, «Kamal, Tábuas da Índia e Tavoletas Náuticas», in *Lusitânia*, vol. I (1924), published in *Obras Completras de Luciano Pereira da Silva*, vol. III, Lisboa, Agência Geral do Ultramar, 1924, pp. 31-41.

([41]) See *op. cit*., p. 32. The instrument on the right is similar in nature, have in one of its faces a list of harbours in Tamil.

([42]) See *op. cit*., pp. 315-316.

The principle of graduating the instrument with the appropriate knots, which now will represent *isbas*, and is equivalent to the principle of graduation of the cross staff, is explained in fig. 13.

Taking into consideration the dimensions adopted for the instrument and the value of the *isba* of 1° 37' adopted by de Saussure([43]), the table bellow has been produced.

Isba (97')	(1/2 Isba) (°,')	1/2 width (m/m)	Length of the knot (m/m)
1	0° 43'	**25**	1998.6
2	1° 37'	"	885.8
3	2° 25'.5	"	590.3
4	3° 14'	"	442.5
5	4° 02'.5	"	353.8
6	4° 51'	"	294.6
7	5° 39'.5	"	252.3
8	6° 28'	"	220.6
9	7° 16'.5	"	195.8
10	8° 05'	"	176.0
11	8° 53'5	"	160.0
12	9°42'	"	146.3
		1/2 height (m/m)	
1	0° 43'	**35**	2532.92
2	1° 37'	"	1240.09
3	2° 25'.5	"	826.46
4	3° 14'	"	619.55
5	4° 02'.5	"	495.35
6	4° 51'	"	412.49
7	5° 39'.5	"	353.25
8	6° 28'	"	308.79
9	7° 16'.5	"	274.17
10	8° 05'	"	246.44
11	8° 53'5	"	223.72
12	9°42'	"	204.76

It can be seen that I obtained the graduations for the kamal used in its vertical position (values for the 35 m/m) and horizontal position (values the 25 m/m column).

Instead of one instrument with two strings attached with the two different graduations I used the other string with the different graduation in another piece of wood. The resultant instruments are in Plate 2.

([43]) We could adopt the value of 1º 36' as was the one used by the navigators, but this is irrelevant to the experiences, because I will find the errors in degrees and the gra duations will be in any way proportional, although each knot will have a slight difference in position relative to the piece of wood. See *Instructions Nautiques* …, p. 162.

It is clearly seen that the interval among graduations has not a linear variation but in accordance with the variation of the co-tangent of the angle.

I made the experiences aboard our sailing boat at sea last month. I have chosen for observation two stars of low altitude and with a magnitude similar to Polaris and for all the needed information I used the program *Starry night* installed in my computer.

The aspect of the night ski during the two nights of the observation was schematically the one shown in fig. 14, taken from the computer. I observed the stars Adhara and Diphda, which fulfilled the conditions wanted.

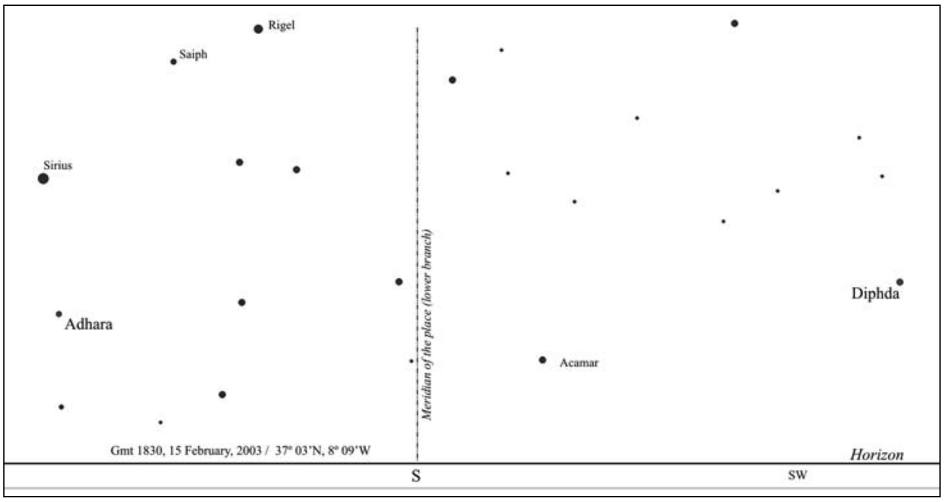


Fig. 13 – Some of the stars of the southern sky during the observations.

We sailed near the coast, being the wind light to moderate and some light swell from the southwest. There was moonlight, which was not a good thing for observation because the somewhat faint stars observed were not very clear. Ibn Majid gave a big amount of suggestions for good conditions and procedures for observation and moonlight was not welcomed([44]).

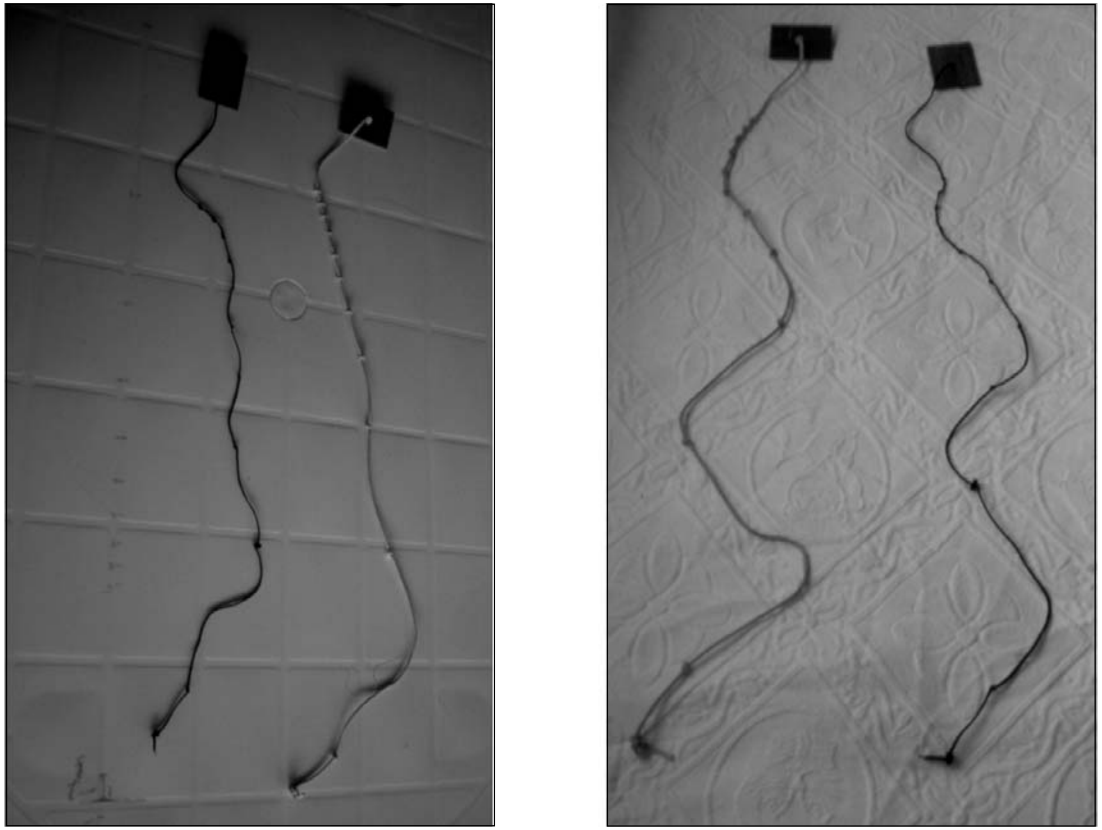
I made all the observations with the help of my wife and a friend. The instrument used has been the one graduated for the upright position, because the altitudes were sufficiently high for it. The attitudes of the observers are shown in the photographs of Plate 3.

([44]) See *Arab Navigation* …, pp. 319-324, where Tibbetts comments the suggestions of the navigators for good star observation.

15th February 2003; 37° 03’N, 8° 09’E						
Gmt	**Star**	**Altitude (isba)**	**Altitude corr. (isba)**	**Altitude corr. (°)**	**Altitude Calc. (comp.)**	**Error**
18 50 24	Adhara	7.8	7.5	12° 07’	11° 46’	-21’
18 55 44	Adhara	7.7	7.4	11° 58’	12° 26’	+ 28’
19 01 24	Adhara	8.5	8.1	13° 06’	13° 08’	+ 2’
19 03 29	Adhara	8.4	8.0	12° 56’	13° 22’	+ 26
19 05 43	Diphda	10.2	9.75	15° 46’	15° 57’	+ 11’
19 07 00	Diphda	10.1	9.85	15° 55’	15° 45’	- 10’
19 08 35	Adhara	8.9	8.65	13° 59’	13° 58’	-1’
19 10 24	Diphda	9.8	9.3	15° 02’	15° 13’	+ 9’
19 12 00	Adhara	9.1	8.9	14° 23’	14° 22’	- 1
19 16 32	Diphda	9.6	9.1	14° 43’	14° 14’	- 29’
19 17 33	Adhara	9.4	9.0	14° 33’	14° 59’	+ 26’
19 18 52	Adhara	9.4	9.0	14° 33’	15° 08’	+ 35’
19 20 07	Diphda	9.4	9.05	14° 38’	13° 39’	- 59’
19 21 00	Diphda	9.2	8.9	14° 23’	13° 30’	- 53’
19 21 55	Adhara	9.8	9.3	15° 02’	15° 28’	+ 26’
19 24 46	Adhara	10.0	9.75	15° 46’	15° 47’	+ 1’
19 27 26	Diphda	8.2	7.95	12° 51’	12° 27’	- 24’
19 31 14	Adhara	10.4	9.9	16° 00’	16° 28’	+ 28’
19 32 12	Diphda	8.0	7.8	12° 37’	11° 40’	- 57’
19 33 23	Adhara	10.6	9.95	16° 05’	16° 41’	+ 36’
19 34 52	Diphda	7.7	7.5	12° 07’	11° 13’	- 54’
19 36 13	Adhara	10.9	10.25	16° 34’	16° 58’	+ 24’
19 37 16	Diphda	7.1	6.95	11° 11’	10° 49’	- 22’
19 40 57	Diphda	6.7	6.45	10° 26’	10° 12’	- 14
19 41 56	Adhara	11.0	10.6	17° 08’	17° 32’	+ 24’
19 44 06	Diphda	6.3	6.1	9° 52’	9° 40’	- 12’
19 47 07	Diphda	6.2	6.0	9° 42	9° 10’	- 32’
16th February 2003; 37° 03’N, 8° 09’E						
18 55 29	Diphda	11.1	10.65	17° 13’	16° 56’	- 17’
18 56 53	Diphda	11.0	10.55	17° 17’	16° 47’	-30’
19 03 19	Adhara	9.4	9.0	14° 33’	13° 49’	- 44
19 04 29	Diphda	10.0	9.6	15° 30’	15° 31’	+ 1’
19 06 06	Adhara	9.6	9.05	14° 38’	14° 08’	- 30
19 08 36	Diphda	10.2	9.8	15° 50’	14° 52’	- 58’
19 09 37	Adhara	10.2	9.8	15° 50’	14° 33’	- 77’
19 10 46	Diphda	10.0	9.6	15° 30	14° 31’	- 59’
19 12 42	Diphda	9.5	8.95	´14° 28’	14° 13’	- 15’
19 13 31	Adhara	10.0	9.6	15° 30’	14° 59’	- 31
19 16 29	Diphda	8.7	8.2	13° 15’	13° 36’	+ 21’
19 17 25	Diphda	8.7	8.2	13° 15’	13° 27’	+ 12’
19 23 41	Diphda	8.4	8.0	13° 06’	12° 26’	- 30’
19 24 41	Adhara	11.0	10.55	17° 17’	16° 11’	- 66’

Plate 2

Two views of the same two instruments, being one for observation in the vertical position and the other on the horizontal position.



The observations made in two consecutive nights are registered on the table above. The heights of the stars are in *isba* and tenths, estimated by eye. Each reading is converted in degrees and minutes making each *isba* to 97' (1° 37'). The correct value for the altitude of the star was obtained from *Starry night*, introducing on the computer the coordinates of the place, height of the observer and time of the observation.

When I was studying all the collected data I found that almost all the observations were uniformly too high, which corresponded apparently to any systematic error. After some thinking about this problem I recognized that as I was holding the string in my mouth to make the observation and the graduation was calculated for the eye of the observer so the readings should only be correct if these two distances were equal. Fig. 15 exemplifies this problem.

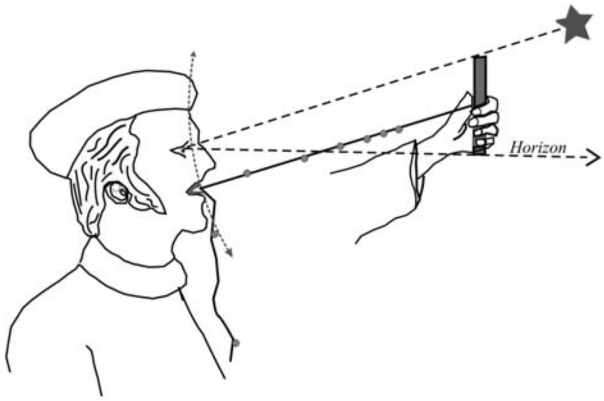


Fig. 14 – The *Kamal* and its use at sea. A need for correction when the rope is held by the teeth.

In fact they were not, and I found a difference of around 15 millimetres between the two([45]). I found that I was observing the star nearer then the reality and so I had to apply a correction to all the observations. The result of that is shown on the appropriate column having myself made all the corrections graphically.

The errors found are very scattered in absolute value, but except for two values of more than one degree (77' and 66') the other ones are

([45]) It is necessary to note that the image in the eye is formed on the retina, which is the anterior part of the visual organ, so the correction can probably be higher than 15 millimetres. About this problem and when dealing with observations at sea with the cross staff, acceptable and within the range of the errors I found with the cross staff in my previous experiences.

But it is necessary to note that it was the first time I used the instrument and I am convinced that with some training the errors will be much lower.

Besides that, there is an important handicap for old people, which is *long sight*. In fact I had difficulty on focusing at the same time the Kamal, which was some centimetres away, and at the same time, the star and the horizon.

So, a young person will have much better results and I have checked that with my son and the results were much better although the conditions of observation were worst.

It is also important to mention that the rope has to be very rigid to maintain its length after being stretched. The material in which the string was made has to be better investigated because although I was using pre-stretched therylene line, it stretched a little bit, which is not good for accuracy.

The fact that the error of using the teeth for reference instead of the eye was variable according to the anatomy of the person, indicates that the kamal was gradated for a definite user and could not be used by others.

So, those are some of the interesting conclusions that resulted of a practical use of the instrument.

The practical use of the stellar compass

My interpretation of the stellar compass's practical use, based in the reading of some of the known books of the ancient Indian Ocean navigators, also the experimental voyages of David Lewis, the idea briefly stated by de Saussure and my personal experience, is materialized with this simple instrument. See fig. 15.

It is a disc of wood with one handle, the stellar compass being bonded to its surface. Two small pínulas will allow the sighting of the Pole Star.

After that simple operation, the course previously wanted relative to the north will be found. Any star in the bow or the stern will be used to maintain the course wanted during long periods.

The instrument can be mounted on the rail and used when necessary.

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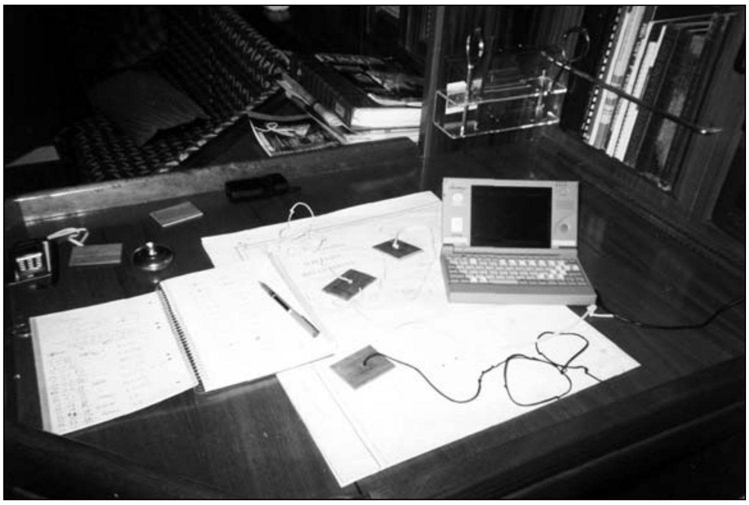
para as Comemorações dos Descobrimentos Portugueses, 1994, pp. 165-192. See also, José Manuel Malhão Pereira, «*Norte dos Pilotos, Guia dos Curiosos», de Manuel dos Santos Rapos, Um Livro de Marinharia do Século XVIII. Estudo Crítico.* Tese de Mestrado, Lisboa, 2001, pp. 201-220. And also from the same author, *Experiências com Instrumentos e Métodos Antigos de Navegação*, Lisboa, Academia de Marinha, 2000, pp. 11-18.

Plate 3

Observing with the Kamal.


The attitudes of the observer. Note that it is apparent from the photographs that the distance between the teeth and the board is less than the distance between the eye and the board.

The registration table with the instruments, the chart and the computer.

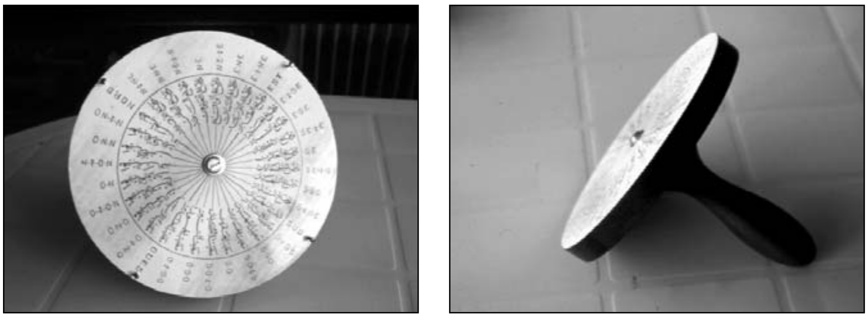


Fig. 15 – Two views of the same replica of the stellar compass.

If clouds cover the Pole Star other stars will be available for finding direction, although they were not the ones used in the compass. The stars of the compass were mainly used as the winds of the magnetic compass; that is they will only have the purpose of defining a course with a known angle relative to the real direction finder, the Pole Star.

The correct course by day will be maintained having as a reference the sun, the swell and the wind. Everyone knows, for example, that nowadays cruising sailors use the wind vane that maintains a course relative to the wind. In fact, as the wind in the high seas maintains its direction for long periods even electronic auto pilots are utilized maintaining the course relative to the magnetic compass.

With these simple but efficient techniques, the Indian Ocean has been sailed for many hundreds of years before the introduction of European techniques. I am deeply convinced that not only Arab or Persian sailors has been involved on that, but also Indian, besides Malay and Chinese.

So, a lot of research has to be made and I can suggest to you, dear archeologists and sailors, that to call the attention of the sponsors of your activities, we can sail, in a comfortable modern sailing boat from Cochim to Socotra using only these two simple instruments.

I can almost assure you that we will find the island if we have an young pilot with good eyes to guide us.

A last word to the Portuguese Embassy in Delhi and to Dr. Luís Moura Rodrigues who struggled to transport me here.

And also to our great Indian friend Dr. Lotika Varadaraja who, in my humble opinion is contributing very much to be better known the rich maritime Indian tradition.