1994

The development of integrated navigation systems and their impact on navigational safety

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ANZB

WORLD MARITIME UNIVERSITY
Malmö, Sweden

THE DEVELOPMENT OF INTEGRATED NAVIGATION SYSTEMS AND THEIR IMPACT ON NAVIGATIONAL SAFETY

By

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A dissertation submitted to the World Maritime University in partial fulfillment of the requirements for the award of the degree of

MASTER OF SCIENCE

in

MARITIME EDUCATION AND TRAINING
(Nautical)

1994

(DECLARATION)

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred upon me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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ACKNOWLEDGEMENTS

I am extremely grateful to ALLAH. The Beneficent, The Merciful. I would like to express my profound gratitude to Professor Peter Muirhead, my course Professor, who gave me the initial stimulus for this study and has been a source of knowledge, offered all the help, and encouragement to me from the very beginning.

Special sincere and deepest gratitude to Dr Gamal Mokhtar, President of Arab Academy of Sciences and Technology, who gave me this great chance to pursue my professional education and to get exposed to the international shipping environment at WMU in Sweden. The credit is his who never failed to encourage and support me during the last two years.

I would also like to extend my gratitude to Captain Ahmed Fahmy; Dr El Sayed Abdel Galil; and Dr Waddah Abou El Ata. My grateful thanks are given to Cdre Ibrahim Hussein and grateful acknowledgement is made to all my colleagues who encouraged me.

Last, but by no means least, I would like to express my thanks and appreciation to my family, especially my wife Mona, and my daughter Happy for being a perpetual source of encouragement and inspiration to me, and to their sufferance in managing alone during my absence .

The preparation and successful completion of this paper has been made possible thanks to the help of many people, who I am deeply indebted to for providing me with the guidance, relevant information, material and encouragement.

ABSTRACT

There are limitations in accuracy in using operational navigational aids separately.

The aim of this study is to construct an integration model of high accuracy that can be used on board merchant ships in order to improve navigational safety.

The study examines the theoretical concepts and benefits of an integrated navigation position fixing scheme. In particular, the study concentrats on the aspect of integration between two radio navigational positioning fixing systems; GPS which is used as the prime source, and Loran-C which is used as the back-up system. The integration between these two systems will be developed in a manner which produces a hybrid receiver.

The study also examines the types of errors and classes of accuracy measures.

In addition to the integration between GPS and Loran-C, the study deals with the design of a navigational system which includes most essential marine navigation sensors and systems within the hybrid Loran-C/GPS system in order to provide a high level of performance over the widest possible area on board merchant ships.

Special attention is paid in chapter Five to the problems encountered in congested waters, especially in the Gulf of Suez (GOS). This chapter discusses with the

problems and difficulties of safe of navigation in the GOS, in addition to traffic separation schemes (TSS) and vessel traffic services (VTS). The chapter examines how the proposed system can ensure the safe movement of vessels passing the GOS.

In chapter six, a brief look is taken of present methods of Maritime Education and Training (MET), and the effect of simulators in all fields of MET.

Finally, a number of recommendations are made concerning the need for a hybrid Loran-C/GPS system, the need to establish a Loran-C system in Egypt, and the need to upgrade all kinds of marine services in the GOS.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER ONE

THE DEVELOPMENT OF INTEGRATED NAVIGATION SYSTEMS

1.1 INTRODUCTION:

Navigation is the process and the art of finding a vessel's position from time to time to check its progress, and conducting it safely along a route from one place to another. In the widest sense, the process also embraces the avoidance of collision and the handling of the vessel.

The art of navigation has been as much an aim of accelerating technology as any other facet of marine science, and such art is based largely on scientific principles. Thus the technology involved enables the mariner to proceed out of sight of land and be reasonably confident of returning to his departure point. Such an ability does, perhaps, make the art of navigation appear all too easy. No matter what aids technology may produce they are only aids, and the art of navigation therefore now embraces the sensible integration of these aids.

> The requirement for safety is universal; safe and accurate navigation is the mariner's united aim, whatever his purpose upon the seas.
>
> Redford K.M (1985,1).

If the navigator does not have adequate and sufficient navigation information, then the safety problems start to come into existence, but as soon as he receives new and up-to-date navigational information regularly, and the ship's position is displayed on several navigation aids and radar, then safety problems begin to disappear, and it leads to proper navigational safety. The navigator should keep in mind when he needs to improve safety, that the safety and efficiency have the same thing in common. It is so difficult to separate them in order to accomplish operational efficiency because the factors which cause lack of efficiency can also affect operational safety.

1.2 I.M.O AND THE SAFETY OF NAVIGATION:

In the February 1990 edition of Focus on I.M.O, a statement clarified the attitude of INTERNATIONAL MARITIME ORGANIZATION (I.M.O) to the safety of navigation.

I.M.O has always paid great attention to the improvement of navigational safety. A whole series of measures have been introduced in the form of conventions, recommendations and other instruments. The best known and most important of these measures are conventions, the following three of which are particularly relevant to navigation :

1.2.1 The International Convention for Safety of Life at Sea, 1974; (SOLAS): This is the most important of all maritime safety instruments. The first version was adopted in 1914 and other versions were drawn up in 1929 and 1948. In 1960, I.M.O's conference on Safety of Life at Sea adopted the fourth version. It was decided to adopt a completely new version incorporating all amendments to the 1960 convention. The convention covers various aspects of ship safety, including safety of navigation. Measures dealing with the safety of navigation appear in Chapter V, which includes 21 regulations.

1.2.2 The Convention on the International Regulations for Preventing Collisions at Sea, 1972; (Collision Regulations): Rules to prevent collisions at sea have existed for several hundred years. The 1960 conference on Safety of Life at Sea adopted new regulations for Preventing Collisions at Sea which were annexed to the Final Act of the conference.

The developments in shipping which took place in the 1960s, such as the development of ships with a draught much greater than anything known before, made it clear that the regulations would have to be further amended.

An international conference to amend these Regulations was held in 1972 and the convention entered into force in 1977. The latest amendments, adopted in 1989, came into force in April 1991. The regulations consist of 38 rules and are divided into five parts.

1.2.3 The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978 (The STCW Convention): The basic aim is to establish internationally recognized minimum standards of training, certification and watchkeeping which all parties must endeavour to attain. It is desirable that such standards are exceeded. This is important, because in some countries standards are higher than those contained in the convention and it would hardly help maritime safety if they had to reduce their standards simply to comply with convention requirements.

This is not a feature unique to the 1978 STCW convention. The minimum standards established by any IMO convention may be exceeded by standards applied by any state party to it to ships entitled to fly its flag.

1.2.4 Worldwide Navigation system: In 1989 the I.M.O Assembly adopted resolution A.666 (16), a policy document for the future development of a recognized and accepted procedure for international navigation use. Its purpose is to determine the operational requirements of a worldwide Satellite Navigation System to meet the needs of coastal and ocean navigation, to determine the organizational structure and arrangements which would be needed by an international organization or consortium for it to be recognized by IMO as being suitable to provide, implement and operate such a system, and to determine the arrangement, if any, by which such a system might be provided, including the possible use of the system by other mobile services and the possible use of the facilities providing the system to meet other operational requirements.

1.3 LIMITATION OF THE MAJOR OPERATIONAL NAVIGATION SYSTEMS:

With the anticipated developments in the field of radio navigation systems, there may be a decline in the requirement for some conventional aids, and some radio aids presently in operation.

It is anticipated that the provision of conventional navigational aids will continue to play an important but reduced role in the overall mix of navigational aids used by the mariner. The level of this importance bears a direct relationship not only on the function of the aid itself but on the level of shipborne navigational aids carried by the various classes of vessel, and the internationally agreed changes to mandatory requirements for these shipborne aids.

> It should be borne in mind that the need will still remain for the mariner to evaluate the mix of navigational aids available to him in a prudent manner with the aim of maintaining the professional standards and practices expected of him.
>
> Wingate M, (1986,325).

Consider now a definition of the limitations of navigational aids. Limitations of navigation systems means Accuracy, Availability and Reliability.

Accuracy: The accuracy of any reading, position line or fix can only be defined in terms of the probability that the result will lie within a defined range. Accuracy may be expressed in a number of ways, e.g root mean square (drms); one, two or three sigma, (1σ, 2σ, 3σ); circular error probability (CEP). Equally, and more simply, it may be expressed by radius in nautical miles in terms of percent of probability. The accuracy limits of navigational position lines, fixes, etc. should be such that there is a 95 % ($+ 2\sigma$) probability that the actual position line or fix concerned is within the limit quoted.

Availability: Is defined by the International Association of Lighthouse Authorities (IALA) as the probability of an aid, or system of aids, performing a required function, under stated conditions, at any randomly chosen instant in time.

Reliability: Is defined also by IALA as the probability of an aid, or system of aids, performing a required function, under stated conditions, for a stated period of time.

Individual navigational aids are subjected to these limitations to different degrees, and these are highlighted in the following sub-sections :

1.3.1 Dead Reckoning: This is limited by the accuracies of the compass and the log and also by the errors in the estimates of the leeway and the tidal streams. For the gyro compass, the interruption for any length of time, could be long enough for the gyro to become disoriented. Generally, the error of a modern, properly adjusted gyro compass seldom exceeds 1 degree.

1.3.2 Astro-navigation: This has limited accuracy and limited availability. Generally, the accuracy " R 95 = 1-5 N.M ", depends on the kind of fix (i.e Sun's altitude, Star fix). The availability is from about 1-3 hours to several days depending on meteorological conditions (i.e. visibility). The reliability is worldwide although there are areas where the prevailing weather conditions cause a large average interval between fixes.

1.3.3 Visual compass bearing of land marks: These have limited availability. Generally, accuracy is from $\sigma = 0.4$ to 0.6 degrees (gyro compass). Availability depends on suitable navigational marks being continuously accessible. The reliability mainly depends on meteorological visibility.

1.3.4 **Radio direction finding:** This has limited accuracy and limited coverage. Generally, accuracy depends on the user's skill (especially with conventional aural receiver), the station's relative position (land effect) and time of day (influence of sky waves), O = 0.7 to 1.3 degree. The reliability is unpredicable and cut out of stations is reported regularly.

1.3.5 **Decca system:** This has limited coverage. Generally, the accuracy ranges from a few tens of metres to a few N.M depending upon time of day (sky wave interference) and location in the hyperbolic system, but can be accounted for by the application of accuracy contours, R 95= < 0.15 N.M to 3 N.M, easily found in Decca data sheets. The availability is 99 + % (continuously available). The reliability is cut out of the stations and it has been reported that it is unreliable during high static level conditions.

1.3.6 **Loran-C system:** This has limited coverage. Generally accuracy, R 95 = < 0.25 - 1 N.M (ground wave) & R 95 = 10 - 20 N.M (sky wave), depends on the type of receiver, time of day (ground / sky wave interference), distance to transmitting stations (ground / sky wave receptions, cycle matching possibility) and the location in hyperbolic system. The availability is 99 + % (continuously available). The reliability is 99 + %, no data available, and great unreliability has been reported from the stations covering the South China Sea and Luzon Strait.

Differential loran-c: Generally, the accuracy is 22 metres depending upon chain geometry. The availability is 99 + %. The reliability is 99 + % .

1.3.7 Omega system: This system has limited accuracy. Generally the accuracy is too inaccurate for coastal navigation and R 95 is between 2 and 7 N.M. The availability is 99 % 95 % (continuously available). The reliability and possibility of lane slip, depends on mission time.

Differential omega: Generally the accuracy is 0.3 N.M at 50 N.M, 1 N.M at 500 N.M. Availability is 99 % when in range. Reliability is 99 %.

1.3.8 TRANSIT Satellite navigation: Generally the accuracy is very good, independent of visibility, but will be affected by long interval between fixes. The accuracy is from 5 to 500 metres depending on the system. Availability is 99 + % depending on the system, up to 4 hours on the equator depending on latitude if no transits are missed for position fixing. The reliability is high.

1.3.9 Radar: This has a limited range and problems with target identification. Generally, the accuracy for distance is $\sigma = 0.5 - 1$ degree of set range, and for bearings: $\sigma = 0.5 - 1$ degree (under gyro stabilized display condition).
Reliability, i.e Mean time between failure " MTBF ", is about 5 months, estimated according to the manufacturer's data.

1.3.10 Echo sounder: In many cases it is difficult to define position line from sounding information.

1.3.11 Inertial navigation system: This has errors that grow with time.

1.3.12 Global position fixing (G.P.S): Generally the accuracy is "R 95 = 100 metres or less". The availability is continuous. Reliability, the high accuracy of the system combined with its continuous availability, will induce a navigator to follow, if necessary, narrow passages promising short cuts.

1.3.13 Integrated navigation systems: Generally the accuracy, the availability, and the reliability can never be better than that of the best system used. Every system has its own advantages and disadvantages and these in turn can compensate each other by giving the navigator a more reliable and more accurate system than either system can provide alone. If the user places too much trust in the computer"weighting system" and suspends his own professional judgement, he may be misled.

1.4 THE CONCEPT AND BENEFITS OF INTEGRATION:

Usually, integration is the term which is used to express and represent the concept of combination between two or more systems operating as one system to provide a beneficial act more excellent than one system working alone. The application of that kind of integration concept is to provide the best monitoring and independent system.

It is therefore very important and practical to integrate two or more electronic navigation position fixing systems in a manner which produces a hybrid receiver. By combining in this way a performance, which is better than that of the individual constituent systems, is achieved and provided over the widest area.

The concept and purpose in this case seems promising, due to possible improvements in navigational safety, efficiency for passage making and the ship's operation as a transport unit.

While the integration between two or more radio navigation systems can provide high accuracy and precise position fixing and reliability, the process can also act as counter balance between the advantages and the disadvantages of the two (or more) systems included. Additionally, the concept is to improve system integrity and availability.

One of the good features of integration is that one Nav-aid can calibrate the other, by mixing Nav-aid information with that from another and by using differences as a means of correction.

1.4.1 Integration Benefits: The advanced progress in the development of the integration between some navigation systems has lead to numerous obtainable, available options and variant levels of integrated systems. By the application of the new science of technology including the new generation of computers and navigation technology in the integration processes between navigation systems, numerous benefits accrue to commercial marine navigation.

These benefits are:

. The need for greater accuracy than that attainable by individual aids must be weighed against the added cost and complexity of the integration processes.

. The continuous updating of ship position must lead to less uncertainty and therefore to greater navigational safety.

. It may be possible to identify and eliminate fixed and systematic errors,instrumental and other biases.

. System malfunction may be recognised and treated.

. Human errors may be eliminated or in other cases recognised and treated.

. The automatic collection and computerising data is performed at a faster rate than that by a man.

. The reduction of the operational costs due to the advent of the inexpensive seagoing computer makes it feasible to dedicate such a computer to the task of combining observations from the Nav-aid sensors.

. Better information to aid voyage management and passage economy is provided.

. The use of new technology can quickly benefit most ship operators because it can make the job of a ship's officer of the watch easier, less stressful, and safer.

. On-board implementation of integration will allow the minimization of a ship's deviation from the desired track, thus contributing to a more precise maintenance of ship sailing schedules and, consequently, to a reduction in running time and fuel losses.

1.5 ASPECTS OF INTEGRATED G.P.S AND LORAN-C:

> Integration of different radio navigation systems improves system integrity, availability, accuracy and reliability. If one system is not available there are other systems to serve as back-up.
>
> Aardoom and Nieuw Land (1993, 1).

In order to make the performance standard of integration process of radio navigation systems much better, then the international standards of the main sources of navigational information should be accepted. According to most views, GPS and LORAN-C are the basic sources of navigational information.

Global position system LORAN-C/G.P.S has the ability and capability of being used as a single global navigational system, and the integration process will improve the performance of each system individually.

In comparison between G.P.S and LORAN-C and in general terms, one may specify that the average of the absolute accuracy of position taken by G.P.S, experienced over a length of time, and which is higher than that from a LORAN-C position, (even after conductivity corrections are used), is enough to take away the influence of selective availability. In the same comparison, the repeatability of LORAN-C is usually even better than that of G.P.S because of G.P.S's selective availability.

Unfortunately, sometimes there are no more than two transmitting LORAN-C stations available for plotting the position, and these will cause ambiguity for the position, but the G.P.S position fix can serve to resolve these problems. Furthermore, Per K.Enge & James R.McCullough (1988-1989,469) state that:

> Even with the full constellation, a G.P.S receiver will not always be able to monitor signal integrity unless some external aid is used and then Loran-C can be employed effectively to aid G.P.S.

Because of all the previous reasons, there is existing and developing support for integration between G.P.S and Loran-C. The combined receiver for the two systems can offer and provide good prospects which give the high absolute accuracy of G.P.S with the superior repeatability of Loran-C. The level of the redundancy as a result of this interoperability between G.P.S and LORAN-C allows both system to recognise any failures in the signals autonomously.

1.5.1 The proposed system: The approach is to develop a system which will provide the navigational process with great integrity, reliability and time availability. This can be achieved by the combination of both standard position fixing systems G.P.S and Loran-C receivers on one chip as a hybrid unit, and by interoperation between G.P.S lines of position (L.O.P G.P.S) and LORAN-C lines of position (L.O.P LORAN-C). In fact each system and the process of receiving the signals is independent of each other, and it will be helpful to the system because the LORAN-C receiver can detect in these cases any failure in the G.P.S system, or in the receiver itself.

The hybrid receivers however must incorporate elaborate LORAN-C propagation models, in order to allow for the spatial and temporal irregularities and inconsistencies of the propagation paths.

> Fortunately, G.P.S can be used to efficiently gather the data for these models. Furthermore, G.P.S observations could be used to calibrate (or tune) these models in real time.
>
> Enge & McCullough (1988-1989, 469).

Finally, precise position, and real time for the transoceanic ships can be provided from the integration process which combines the advantages of both and minimises the disadvantages of each. One of the requirements of an integrated navigation systems is to minimise in some way the random errors associated with the position fixing systems.

A Kalman filter is used in the integrated navigation system to minimise as much as possible the random errors that are present in the navigational positioning systems. The other random errors or factors which disturb the process of navigational measurement are the wind, tide, and the current. Moreover the equipment which is used to determine the position and the speed of the ship, may also be disturbed by noise, and it will cause random errors. In summary, a Kalman filter reduces such "noise" to a minimum thus keeping random errors to a minimum.

CHAPTER TWO

TREATMENT OF NAVIGATIONAL ACCURACY

2.1 INTRODUCTION:

To discuss or deal in any way with position fixing or navigational systems, one should know something about the accuracy of that system. In order for accurate information to have some value, one needs some more information about the kind of accuracy. The problem is that sometimes, one cannot get more information, and other times one can get the information but cannot interpret it. The expert navigator can know very well that navigation is not an accurate science. Thus, errors can exist in accurate positioning and big mistakes and blunders can occur also.

The problem for the navigator is how can he deal with a science that is full of inherent errors and a lack of accuracy? He must know the affects of probability of the errors on navigation and on position fixing. Additionally the navigator must judge the likely accuracy of every position line obtained in any way (visual observation, celestial navigation, radar bearing and range, radio fixing aid), and thus the accuracy of the fixing position as a result of the intersection of two or more of those position lines.

How then can navigation science give a good definition of an error. An error is the difference between the reading or observation obtained from navigational equipment and the true position line or position fixing. After this, the navigator must know how to realize and how to make a distinction between the type of errors which may be caused at random, or an error of the equipment itself which may be allowed for to some limit, and an error caused by a mistake or blunder.

2.2 TYPES OF ERRORS:

2.2.1 SYSTEMATIC ERRORS: Systematic or fixed errors are the errors of the particular system being used which follow some regular pattern or some form of law, and can often be predicted or measured or foreseen. They can be eliminated or allowed for by calibration curves, or compensated for, and can also be computed from a known equation. The simplest type of systematic or fixed error is one which is constant, Adm.Manual of Nav Vol 1 (1987).

The best method of determining the systematic or fixed error is by local surveys, not by mathematical models only, and efforts should be taken to provide the navigator with the systematic error of radio navigation positioning systems in every geographical area, as given in the Decca data sheets. However, if there is no information available about the systematic error of the radio navigation positioning system in the area, then the navigator can make an estimation of these errors by comparing the reading or measurement from the equipment and the higher accuracy positioning methods, if available.

Sometimes the systematic error moves very slowly with time or location or both. Then the navigator must check these errors from the navigation instruments and equipment regularly, and the error may be measured and corrected. These systematic errors could be actually constant for some hours per day. Later the error may start to change. In this case systematic errors become semi-systematic errors and should be treated as random errors. Newman (1985,17) argues, that:

> The degree to which they can be compensated for, depends upon how well the underlying law is known, an example is the magnetic variation which varies with the time and geographical location.

2.2.2 RANDOM ERRORS:

Random or variable error, refers to those errors which cannot be measured directly, and are governed by the law of probability. They are moving and change very quickly with the change of time, this can be described by their frequency distribution.

Thus, random errors should be unpredictable errors, and the causes of these errors in radio navigation positioning systems can be from the temporary variations existing in the receiver, or from short-term changes in the propagation of electromagnetic waves, atmospherics and interference.

> Obviously, on average, a succession of observations will tend toward the true result. Many observations will be nearly correct, less will be not quite so

correct, fewer will have larger errors and even smaller numbers will be grossly out.

Fifield (1980,254).

This means that in the case of random errors when the sign and magnitude cannot be predicted, then the calculation of the average of a number of observations can be useful to determine the value of the error.

Random errors of measurement can be shown to follow the Gaussian distribution of normal errors, which is usually referred to as the normal probability distribution. This is seen in fig 2.1, which shows that the errors are symmetrical about the mean distribution μ. The area beneath the curve over a given interval measures the probability of an error occurring in that interval. The standard deviation sigma "σ" can be used to give confidence intervals of defined probability. The whole shape of the distribution is fixed by standard deviation and it is possible to say that the percentage of errors will lie within any multiple of sigma.

All values of practical significance lie between x = - 3 and x = + 3, as indicated in fig 2.1, and the important figures are as follows :

50 % of the errors fall within 0.674 σ of the mean. The 50% error, where any individual error has an equal chance of being greater or

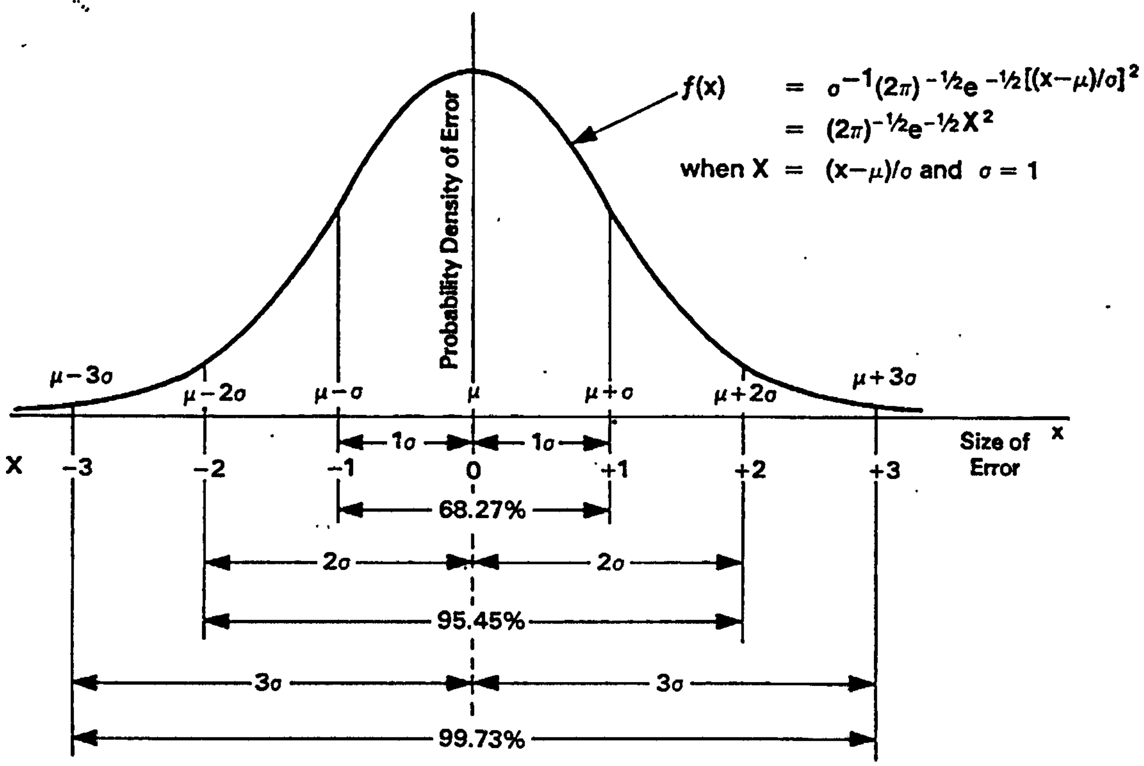

Fig.2.1 The normal distribution of random error
Source: Admiralty Manual of Navigation. Vol.1-1987

less than this value, is often referred to as probable error or linear error probable (LEP).

68.27 % of the errors fall within one sigma (1 σ) of the mean. That is to say, if a large number of random measurements are made and it is known that the error distribution is normal fig 2.1, then 68.27 % of these measurements may be expected to fall within one sigma (1 σ) value or one standard deviation from the mean.

95 % of the errors fall within 1.96 σ of the mean.

95.45 % of the error fall within 2 σ of the mean.

99.73 % of the error fall within 3 σ of the mean.

The 95 % error is the value which may be considered for practical purposes as being equivalent to 2 σ.

Adm Manual of Nav Vol 1. (1987).

2.2.2.1 RANDOM ERRORS IN ONE DIMENSION: Fig. 2.2 The normal value used in navigation to represent the accuracy of one-dimensional position lines is a 95 % probability which is equal to two sigma (2 σ) or equal to twice the Standard Deviation (2 SD). Moreover, about 95 % of numerous measurements of random errors which have normal Gaussian distribution, could lie inside the value two sigma (2 σ) or twice the linear standard deviation about the mean value U. The opportunity for any position line to lie in the two sigma (2 σ) limits is 19 in 20.

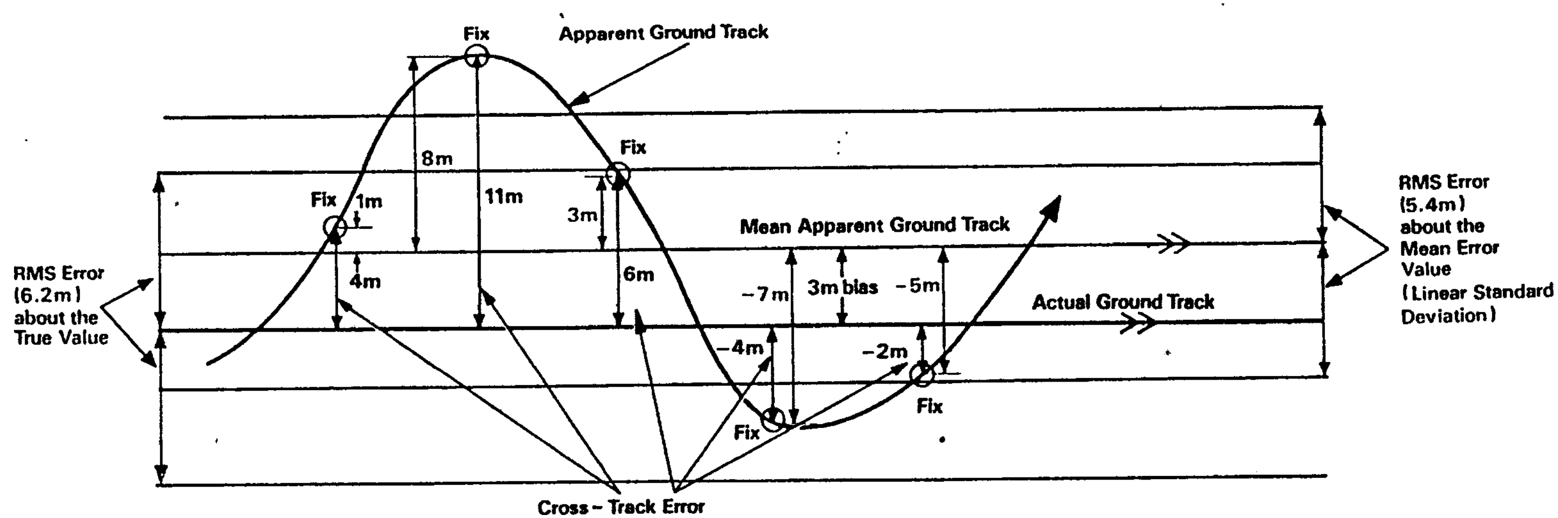

Fig.2.2 Errors in one dimension
Source: Admiralty Manual of Navigation. Vol.1-1987

2.2.2.2 RANDOM ERRORS IN TWO DIMENSIONS: Fig 2.3

Sometimes in the two-dimensional error functions, as in one-dimensional functions, we can use the same system of signs and names or terms. This is almost the same when the error ellipse is a circle. So, it is very important to know how to state precisely the term, because the error ellipse is usually not placed centrally and it is difficult to know if X m (2 σ) is related to a one-dimensional standard deviation or to a two-dimensional circular standard deviation and this means that the probability of the error shall be less than X m if there is 95.4 % or 86.4 %. It can be said that if an uncertain error should not exist or cannot occur, then instead of 'X m (95 %)' or 'X m (86 %)' the accuracy must be given, but even then uncertain error can occur.

Usually, the error is indicated as a radius of a circle, the most ordinary of all measurements which can be found is 50 % and the mentioned radius is then called the circular error probability (CEP). In three dimension, the definition is the spherical error probability (SEP).

2.2.2.2.1 BIAS: Fig 2.2 shows that bias will appear about the actual value when a group of readings or observation is taken. The two main reasons for the bias are the small numbers of observation or readings and the large numbers of readings, but in a short period, which contain unclear systematic or semi-systematic errors. If the error is truly random, and if the largest number of readings and observations are made, then there will be no difference between the mean and actual or true values, fig 2.3, and accordingly there will be no bias. The bias is not fixed or constant and the rate of change of bias with time is different from one type of navigational aids system to another.

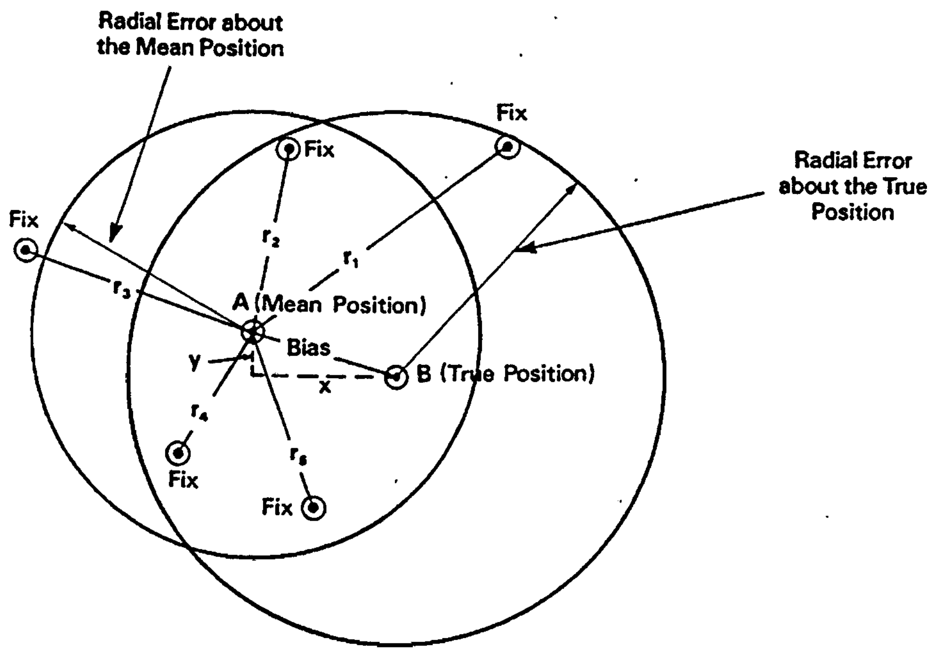

Fig.2.3 Errors in two dimensions
Source: Admiralty Manual of Navigation. Vol.1-1987

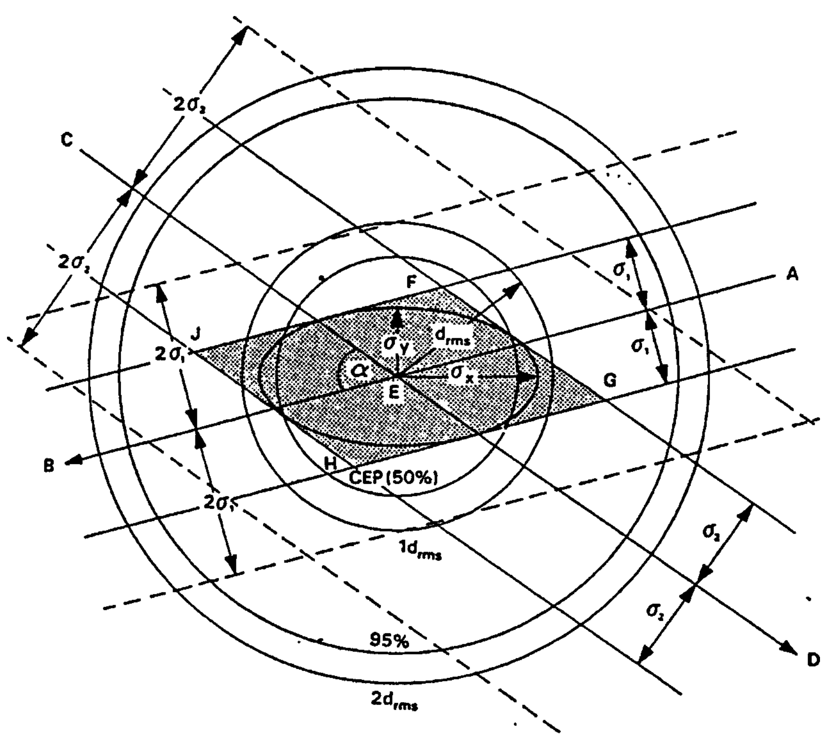

Fig.2.4 Error ellipse and equivalent probability circle
Source: Admiralty Manual of Navigation. Vol.1-1987

2.2.3 FAULTS AND MISTAKES:

Faults and mistakes include malfunctions of equipment which can result in unrecognised but significant error in reading or complete breakdown. Mistakes may range from erroneous equipment readings, wrong correction of the compass deviation or variation, errors in sight reduction and plotting. Faults and mistakes can be identified by their magnitude, and by cross checking. The frequency and magnitude of such errors are difficult to predict.

Newman,(1985,17).

A blunder on the navigator's part can also cause faults and mistakes. The navigator may keep a log of reading from any particular radio navigational aid to ensure that the pattern is consistent. Any departure from this consistent pattern may indicate some kind of malfunction or other fault.

Adm Manual of Nav Vol 1 (1987).

2.3 CLASSES OF ACCURACY MEASURES:

The term accuracy, used without modification with respect to position determination, generally refers to the difference between the stated position of the craft and its actual position.

Moody,(1980,26).

Many of the accuracy measures have been used to state uncertainty in navigation. Nevertheless, reference shall be made to those which are most frequently used. In general there are three often used definitions which are absolute accuracy, relative accuracy, and repeatable accuracy.

2.3.1 ABSOLUTE ACCURACY: May be called predictable or geodetic accuracy. It is a measure of the accuracy on which navigation systems have the ability to determine actual or true geographic positions with reference to a known point, or the variability between observation from navigational aid and the actual value. The reference coordinate system is separated from that of the navigation system involved in position determination.

2.3.2 REPEATABLE ACCURACY: Repeatable accuracy or repeatability is a measure of the accuracy when using the same receiver for calculating the differences between the navigational readings. In other words, it refers to the accuracy of a measurement of a vessel's ability to go back to a given position on the basis previously determined.

2.3.3 RELATIVE ACCURACY: This is a measure of the accuracy between two different receivers which calculates the variability between the observations from these receivers.

According to Moody (1980,26), relative accuracy refers to the difference in error of the position of two craft using the same means of position determination.

Usually, repeatable and relative accuracy are best and larger than absolute accuracy, because any error ordinary to both precisely determining position is not completely included. Moreover, system accuracy directed and related to the accuracy of the navigation positioning system, which does not include any error, can be inserted by the operator, geodesy and cartography, and for this reason repeatable and relative accuracy are better and larger than absolute accuracy.

The previous arrangement of the classes of accuracy means that proper and better absolute accuracy implies proper and better repeatable accuracy, which implies relative accuracy. However, it is normal and happens to any navigation positioning system that bad repeatability but proper and best relative accuracy occurs and so on for the distance between them up to a specific value until the anomalies propagation effects them both.

2.4 SIMPLE ACCURACY MEASUREMENTS:

Many accuracy measurements have been used to state doubts in navigation. The three most commonly used are the radial error (root mean square error "RMS"), the circular error probability (CEP), and the spherical error probability (SEP).

2.4.1 RADIAL ERROR: The calculation of the radial error (σr) about the mean of a true position can give a measurement of the distribution of the error, fig 2.3. The root mean square (RMS) or root mean square distance (drms) are the terms which express radial error.

The radial error about the mean position is often referred to as the radial Standard Deviation (radial SD):

radial error about the mean position (1drms) =

$$\sqrt{\frac{r1^2 + r2^2 + r3^2 + \ldots\ldots\ldots\ldots + rn^2}{n}}$$

where n is the total number of individual errors, also:

$$(\text{radial error about the true position})^2 =$$

$$(\text{bias})^2 + (\text{radial error about the mean position})^2$$

Adm Manual Of Nav Vol 1,(1987).

2.4.2 THE CIRCULAR ERROR PROBABILITY (CEP): This is often used to indicate the accuracy of navigational aids, and it is defined as the radius of the circle that has its centre at the mean, fig 2.4. It contains 50 % probability and there is an equal chance that the position lies outside or inside the circle. By multiplying the CEP radius by an approximate factor of 2.1, a 95 % probability circle may be found.

2.4.3 SPHERICAL ERROR PROBABILITY (SEP): For the three-dimensional error, the SEP is defined as the radius of the sphere that has its centre at the mean and contains 50 % probability.

2.5 IMPROVING ACCURACY:

There are two ways and procedures to improve the accuracy of position fixes. The first way, which is called the differential method, is available for radio navigation systems. This requires the construction of a monitoring station on shore, which can locate lines of position "LOPs" when receiving the signals from the transmitting station. The correction is the difference between each of the receiving lines of position and the theoretical corresponding LOP's for the monitoring station's location.

Any ship in the area covered by these monitoring stations, can receive the corrections which are frequently transmitted from these stations and should be used to correct the LOP's determined before on board. As the distance increases from the monitoring station the reliability decreases.

The second procedure to improve accuracy is available for any types of navigational aids. This is achieved by counting the average of a large number of readings and observations at the same position. Through this procedure the variable error can be eliminated or reduced, particularly if these readings are taken over a long time.

CHAPTER THREE

EQUIPMENT REQUIRED FOR THE PROPOSED POSITION FIXING SYSTEM

3.1 INTRODUCTION:

The required elements for position fixing which are essential to the navigator and user in the merchant marine, can be given without attention to details or formalities as to the limitation of the system in use. These include coverage and accuracy, availability and reliability, user skill and workload; the way to present information; and the way to control the system. The required elements, one with another, should be suitable for the two main objectives of the navigator in the merchant marine which are to provide and maintain satisfactory services for safety and to increase the quality of services for economic benefit.

With the production of new methods and navigational systems, the navigator has the ability to locate and determine his position in different ways. The problem with some navigational systems is that they have some limitations related to environmental conditions, and in addition, any system can become bankrupt.

The development of technology with the increasing use of electronics and the development of the digital computer in navigation, should give good consideration and care to the integration process between more than one source to provide a single result. The application of the principle in a sophisticated way, is to use the result from one radio navigational system to improve the result of another and to determine the most precise and accurate position. In addition, the intention of the improvement is to provide all users with high availability of radio position fixing with high accuracy and reliability of timing signals.

This will lead to expanded improvements on extensive networks of LORAN transmitting stations and equipment which will extend LORAN-C operational life beyond the year 2000. At the same time, the advent of G.P.S with its high level of precision and continuous data transmission regarding the terrestrial position and timely warnings of potential of danger, has had a intense influence on the proposed life span of the current radio navigation system LORAN-C. The system capable of being developed includes G.P.S and LORAN-C, both being well known navigation systems.

3.2 GLOBAL POSITION FIXING:

3.2.1 Introduction: The increase in power and vigorousness of launching rockets and their payload abilities brought about the advent of satellites so that G.P.S became a reality. The main disadvantage of the process of putting forward maritime navigation in relation to the recent space system of satellites was the high cost of such sophisticated systems and the requirements to decode the satellite data. By using the microprocessor, the cost and size of the required equipment has fallen to such an extent that a great number of the vessels, civil and military, can now carry and use the satellite navigation equipment required.

To provide the users with a worldwide navigation, three dimensional position fixing navigation system with high accuracy 24 hour a day, in place of the existing transit satellite navigation system and for other activities, the G.P.S was particularly designed and established as a navigation system.

3.2.2 System principles and overview: The principle of the global position system, G.P.S, is a planned satellite system based on the passive radio navigational aid system which contains a number of satellites. It is also based on measuring the ranges (one way range) to a number of satellites (usually 3 - 4 satellites) instantaneously.

The technology which supports the simple principle of measuring the ranges is quite sophisticated. The system configuration consists of 21 satellites plus 3 active spares making a total of 24 satellites, uniformly placed in six circular orbital planes of 4 satellites each. The six circular orbital planes are inclined at 55 degrees to the equatorial plane, and each orbit at an altitude of about 20,000 kilometres above the earth, at which the orbits will be less affected by the asymmetric mass distribution of the earth. The circular orbital period is 12 sidereal hours, i.e 11 h 58 min, and the travel velocity of the satellite at such an altitude is 3.9 KM/S. Fig. 3.1.

The final G.P.S configuration, with the precise orbital planes will guarantee that any actual position on the earth's surface will have not less than 5

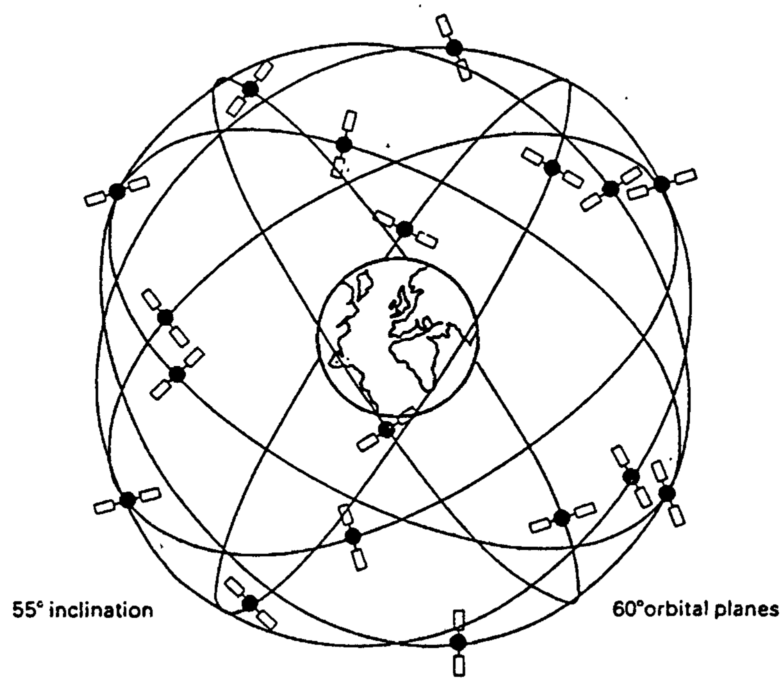

Fig.3.1 GPS satellite coverage
Source: Electronic Aids To Navigation 1991,230.

satellites in the visual plane at any time. Because the requirements for fixing position in marine navigation is only three satellites, this proves that there will be a superfluous number of satellites even if one of them fails.

3.2.2.1 Fundamentals of the G.P.S: From the navigational point of view the system consists of three perceptible segments, the space segment (i.e the satellites); the user segment (i.e the navigation receiver/processor); and the control segment (i.e control and management function of the signals of the satellites). Fig. 3.2.

The space segment, which consists of 24 satellites, is equipped with computer hardware for data processing, transmitting and receiving devices of radio signals and three high precision atomic clocks (oscillators). The clocks are used to produce two highly stable radio frequencies for transmitting the data message. Each satellite transmits three signals; the C/A (coarse and acquire) and P (precision) on L1 frequency, and the P (precision) only on the L2 frequency.

The function of this segment is to transmit navigation data on two frequencies in the L1 and L2 band respectively, L1 = 1575.42 MHZ & L2 = 1227.60 MHZ. The series of the transmitting signals is modulated on the carrier frequency by phase modulation techniques which are in the form of a code; C/A code and P code which is more precise than the C/A code, hence the dual channel receivers are able to correct the error resulting from ionospheric refraction. Fig. 3.3.

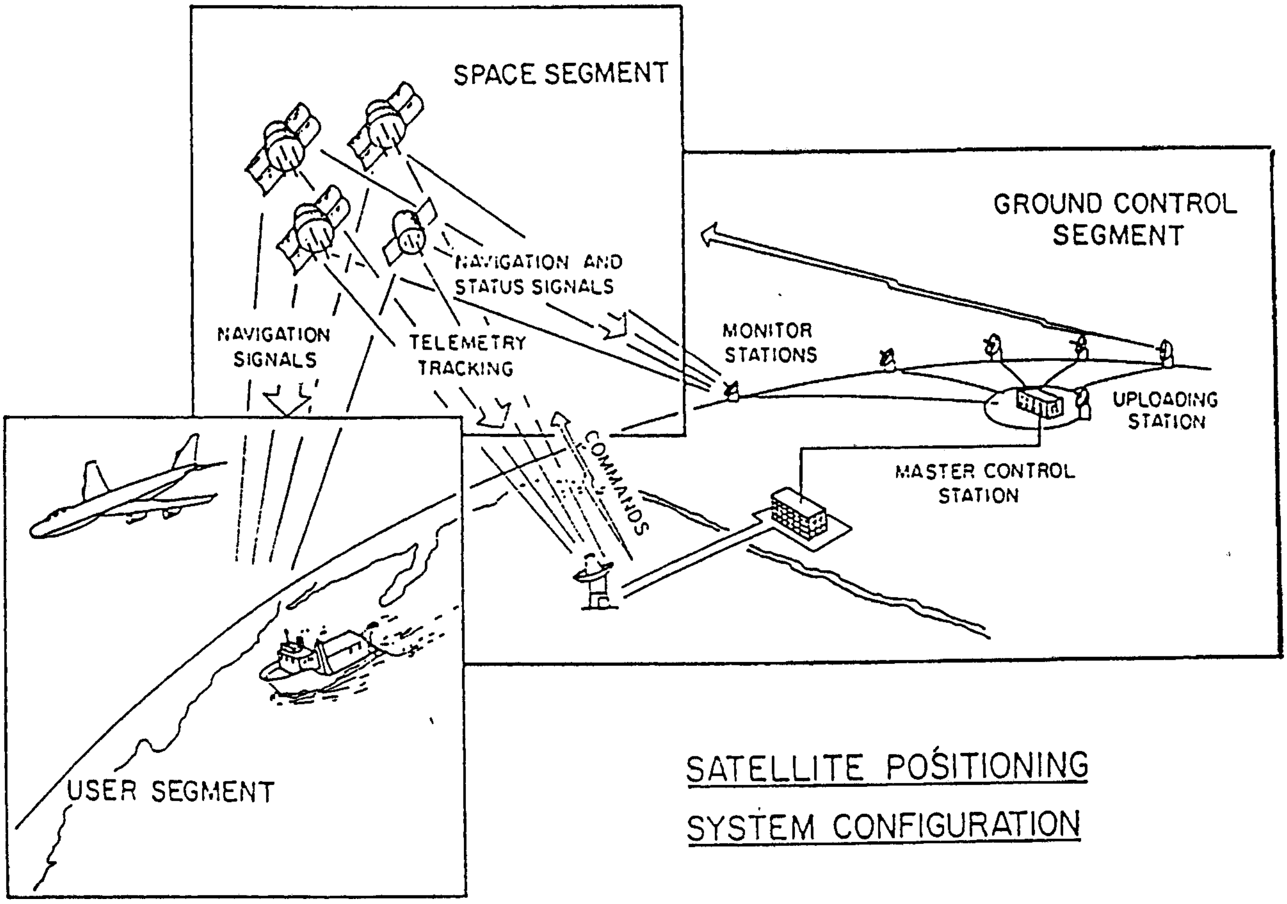

Fig.3.2 Satellite positioning system configuration
Source: Global Navigation A GPS User's Guide 1990,120.

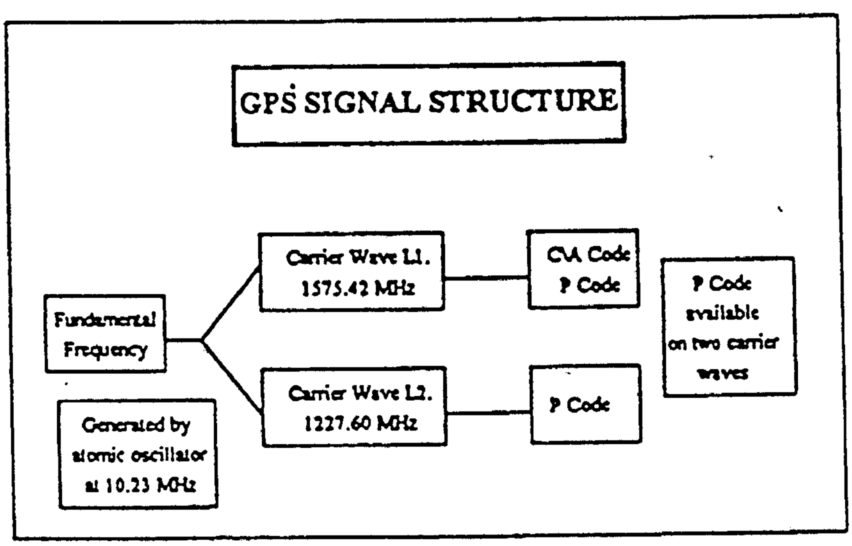

Fig.3.3 GPS Signal Structure
Source: GPS Overview and Status 1993,5

The satellite data message is contained in a 30 second long segment. The message contains satellite ephemeris, satellite clock drift information, the information regarding the position of all the satellites in orbits at the time and which will be used by the receivers to locate their position. In addition the message includes certain parameters which are used primarily for the measurement and correction of the pseudo-range due to the ionospheric refraction error. The navigation message transmits every 12.5 minutes.

The user segment or the navigation receiver is used to perform user mission, representing diverse applications of the navigation data. In general, the GPS receiver must have a computation unit which is divided into another two main parts; the receiver processor and the navigational processor. New developments in computer capabilities and the energy of the navigational receiver makes the ability of these receivers to deal with at least four satellites by tracking them and determines the arrival times of the signals, thus presenting a quantity of data easily. By modulation the navigation message makes pseudo-range measurements which can selects satellites and process these measurements in real time to provide and present the best estimate of the receiver position, velocity and system time with other navigational information.

The accuracy of the user's clock is lower than that of the satellite clock, and because the user's clock is not synchronised to the satellite's clock it gives an error which can be resolved by using three independent range different components.

The control segment is the ground segment which indicates to the ground component of the system which in turn manages and controls the functions and the signals of the satellites, while performing the tracking and keeping watch on the clock. Basically the ground control segment is used for the maintenance and daily control of the system. The control segment involves three main parts, which facilitate the operation of this segment. The first part is the master control station which is responsible for processing the data received from all monitor stations to determine the predicted satellite ephemeris and clock bias parameters for each satellite in the system. These data are then used to generate upload messages for each satellite to correct its navigation message to the users. The second part is the four monitor stations, the location of each being precisely known. It is responsible for tracking the satellites and gathering the transmitted navigation data from each of the GPS satellites to produce ephemeris information. The third part is the up-link ground antennas, receiving the data of the performance of every satellite, up-dating and transmitting navigation message data and commands to the satellites.

3.2.2.2 Determination of the user's position: The GPS position fix is achieved basically by the precise determination of the distance from three or four selected satellites to the receiver (the users) instantaneously. The solving of the three or four ranges will state precisely the receiver's position in three dimensions and is dependent upon the quality of the receiving equipment. Fig. 3.4.

The receiver on board ship, which is restricted to the earth's surface, requires only two dimensional

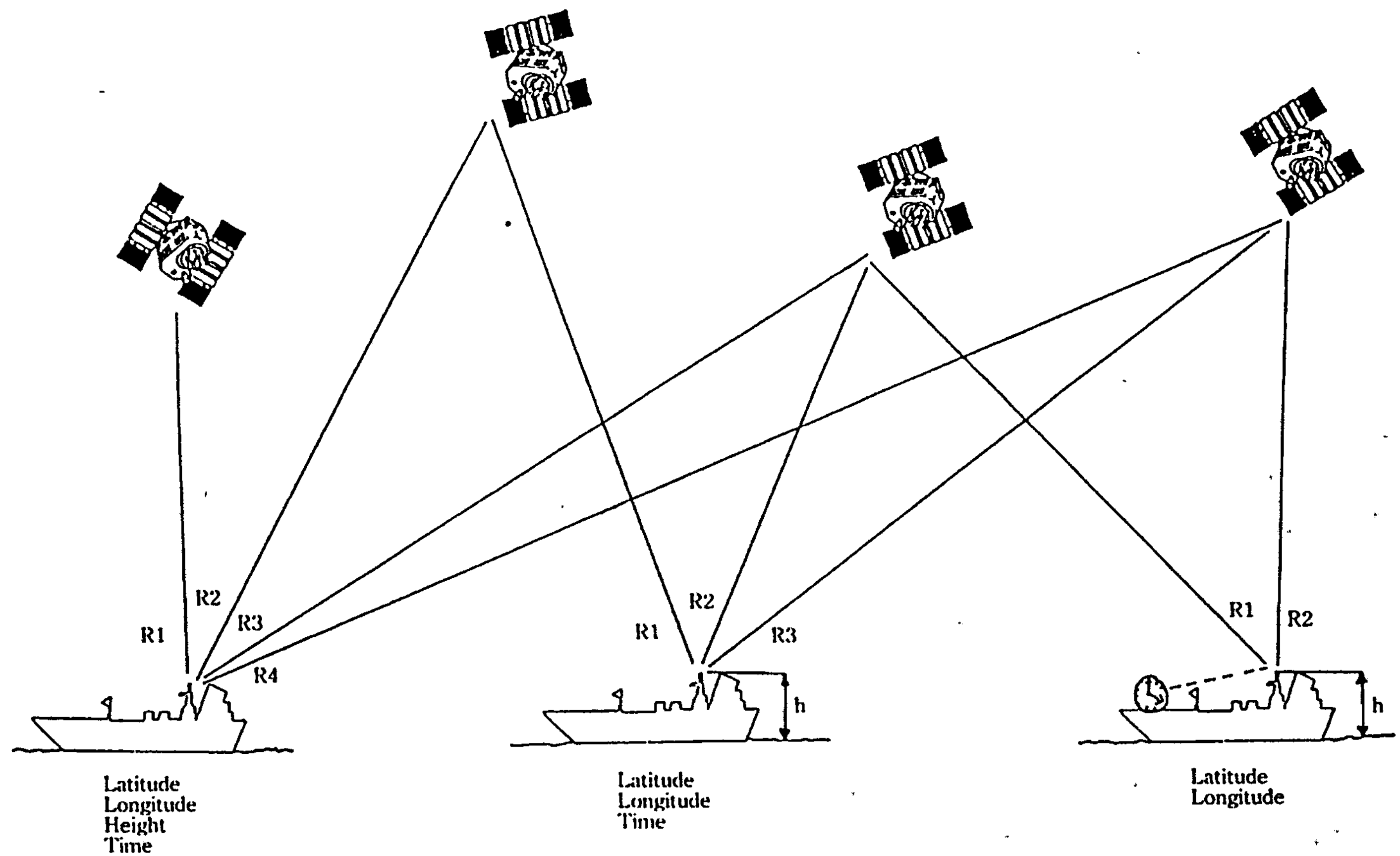

Fig.3.4 GPS and position aiding
Source: Global Navigation A GPS User's Guide 1990,22.

position fixing. It needs information from three selected satellites only. To achieve the process of the precise measurement of the propagation time from the satellite to the receiver one supposes that the position of the three satellites is defined accurately, and both of the satellites and receiver are equipped with highly accurate time clocks. The satellite clock is monitored from the ground and is corrected by atomic standard time. But the problem is that the receiver clock is not precisely synchronized with the satellite clock, so it will be in error and accordingly the measurements of the range will be inaccurate and termed false or 'pseudo-ranges'.

In addition, the ionosphere and the troposphere cause propagation delays which is the second factor of 'pseudo-ranges', and the receiver microprocessor should corrects these 'pseudo-ranges'. The 'pseudo-range' (PsR) measurement for a receiver is stated precisely as:

$$PsR = Rt + C.\ 70\ tA + C\ (\ tu - \ ts).$$

Where:

PsR = pseudo-range between the satellite and receiver.

Rt = true range to the satellite.

C = the speed of light (300m / μs).

70 tA = propagational delays and other errors associated with measurements to the satellite.

tu = receiver clock offset from GPS system time.

ts = satellite clock offset from GPS system time.

The task of the GPS receiver is to acquire and recover GPS satellite messages, make pseudo-range measurements to selected satellites, and process these measurements in real time to provide the best estimate of the user position, velocity and system time.

Range and range rate measurements to three or four satellites and after compensation for ionosphere, troposphere, satellite clock errors, and receiver clock error; provides the GPS receiver with sufficient information to solve the three components of the user position, receiver velocity, and receiver clock error. The comparison between the local code generated from the GPS receiver with measured phase shift of P code is used to calculate the pseudo-range time taken for the transmission. Finally, the ship's position is solved from the three unknown in a two dimensional position fix. The three pseudo-ranges will not intersect at a specific point, but after the clock error is corrected, the fixed range, when removed from the pseudo-ranges, will cause the radii to intersect at a specific point corresponding to the user's position.

3.2.2.3 **The GPS codes:** There are two codes transmitted simultaneously and continuously by each satellite known as Pseudo-random codes; the C/A code (clear or coarse acquisition) and the P code (precise code). The function of these codes is for satellite identification and for defining the transmission time. Fig.3.5.

In the C/A code, which is decoded by all GPS receivers, civilian and military, the chip frequency (the number of chips/second) is 1.023 MHZ. In the P code, which is available for military receivers only and more

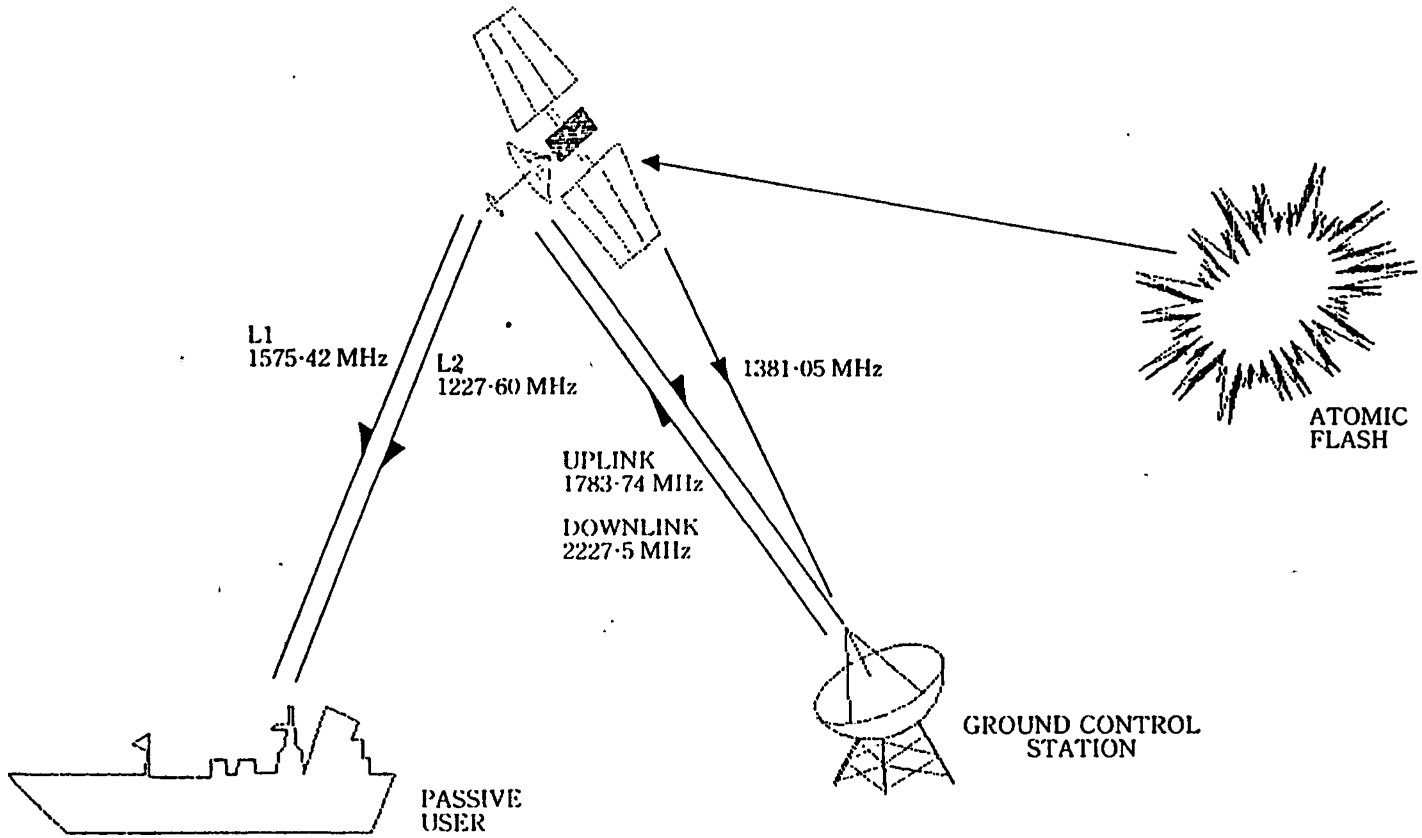

Fig.3.5 The GPS carrier frequencies
Source: Global Navigation A GPS User's Guide 1990,142.

accurate than C/A code with a smaller code bit interval, the chip frequency is 10.23 MHZ. In addition, the P code is designed to provide higher resolution and have some exception to some special civilian users.

Although the C/A code is designed for all civilian GPS receivers to define the range, it is also used to assist a military receiver by obtaining means of approach to the more precise P code.

As mentioned before the L1 carrier (1575.42 MHZ) uses the C/A code, and the P code use L1 (1575.42 MHZ) and L2 (1227.60 MHZ) carriers. Phase quadrature modulation process used by both transmitter and receiver of GPS system is used to separate the two codes in the receiver, and so the range difference measurements can be taken.

There are alternative names to P code and C/A code respectively called Precise Positioning Service (PPS) and Standard Positioning Service (SPS).

3.2.2.4 Selective availability: The performance of the C/A code and P code demonstrated that the difference in precision between the two codes is a very small code bit interval, which the designer did not expect. Thus followed the introduction of the selective availability (SA).

Selective availability (SA) is the deliberate degradation of the GPS signal for military needs. The technique of SA limits the accuracy of GPS, resulting in 100 metre 2 drms (95% confidence level) accuracy instead of 15 metres.

For the ocean phase of marine navigation SPS can be acceptable but is not enough for approaching and entering a harbour. The 100 metres accuracy is acceptable for some land applications but is grossly inaccurate for applications such as surveying. To overcome the effects of SA and achieve accuracies necessary for certain applications, a civil user must either apply access to the PPS or use differential GPS.

3.2.3 Errors in the G.P.S system: Error contributions have been allocated to the various system segments, the space segment (satellite), the user segment (receiver), and the propagation link in between. Tetley & Calcutt (1991,234), argues that:

> The total error produced by combination of the error producing factors is very slight. A position fix in four dimensions (latitude, longitude, altitude and velocity) for military users can be as good as 5 metres. However for commercial users in the future, the system is to be downgraded to an accuracy of approximately 100 metres (95 % probability).

System accuracy is a function of the product of two random variables. The first is variability of the errors in making the pseudo-range measurements, and the second is associated with the geometry of the satellites. One can simplify the error producing factors to the next main sources.

3.2.3.1 Pseudo-range measurement error: In one mechanization of providing the generic pseudo-range measurement by the user receiver tracking function, the

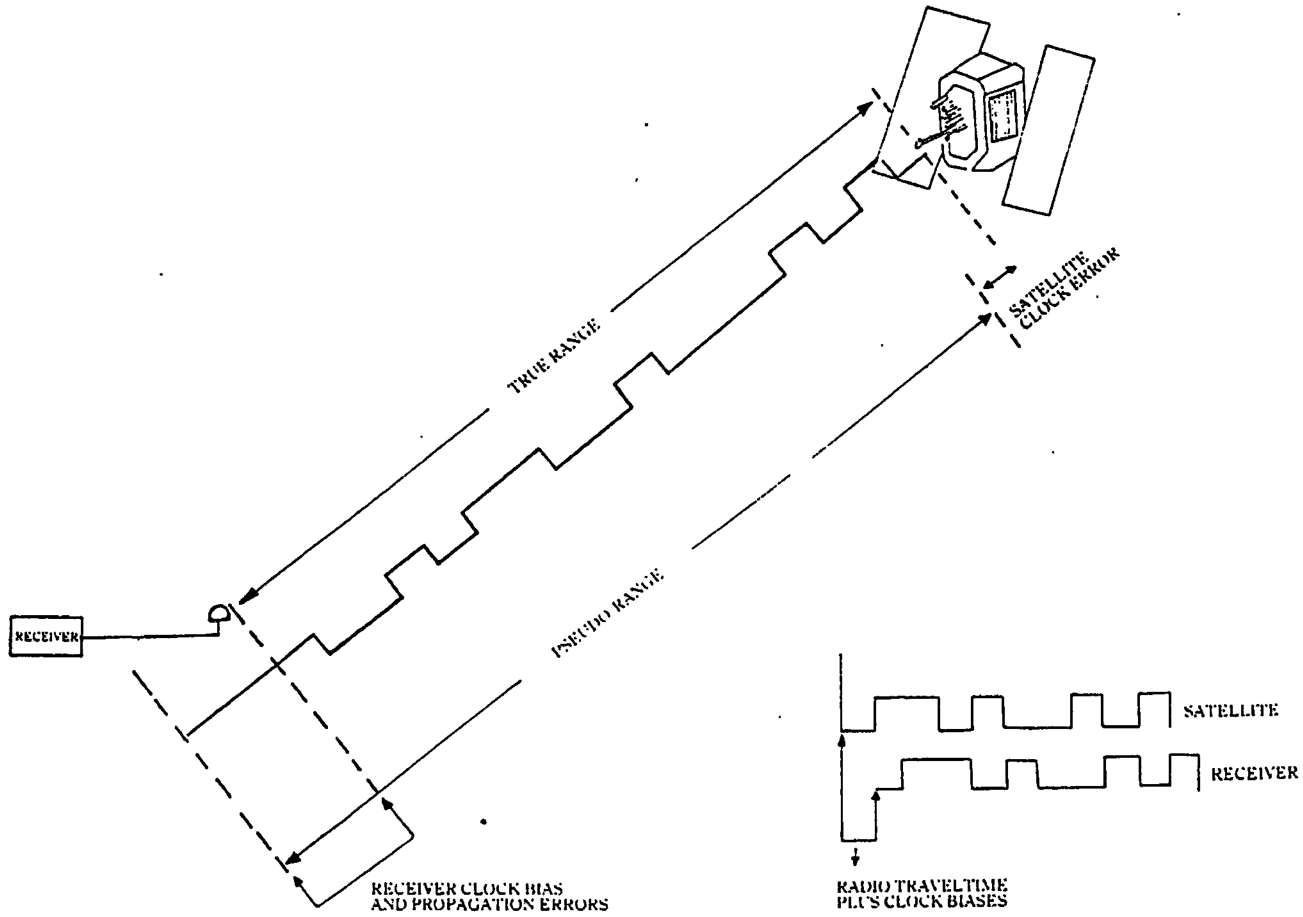

Fig.3.6 The pseudo-range
Source: Global Navigation A GPS User's Guide 1990,153.

code replica phase is dithered between early and late samples separated by one code bit interval, and the difference in the cross-correlation function is computed. Fig.3.6. It is possible to formulate generalized measurement noise expression in terms of noise variance for the code loops. The correlated nature of the code loop measurement noise must be accounted for in the navigation filter estimation process.

3.2.3.2 Receiver range quantization error: The selection of the receiver pseudo-range quantization is a variable parameter which can be chosen to be a negligible error.

3.2.3.3 Mechanization error allocation: The implementation of the GPS navigation solution in any specific computer introduces mechanization errors. The source of these errors is due to finite computer list resolution, mathematical approximation algorithm uncertainties, and execution or timing delay mechanization errors. It is about 1 metre.

3.2.3.4 Satellite clock error: Although the latest generation of satellites carries atomic standard clocks on board, even these clocks are subjected to drifts, and there is a need to readjust by using a clock correction signal which is uploaded from the ground support network to each satellite for relay down to each user as a part of the satellite data.

The development technology is used to improve the satellites' clocks. Accordingly the latest satellites' clock error will be very small and so improve the fix accuracy. Unfortunately, the fix error is a combination between clock error and ephemerids error and it is very difficult to distinguish between the two errors. The fix error from both resources will not exceed 2 metres.

3.2.3.5 Relativity error: Einstein stated that time is compressed by the mass of the earth. In comparison between the time on the surface of the earth and time in free space, Einstein detected that the time on the surface of the earth compressed by 1.4 * 10 ms. Time compression at the altitude of a GPS satellite is equal to 0.4 * 10 ms.

Between the satellite and the receiver, the rate range time error is 1 nano second and which corresponds to the range error of 0.3 metre. In addition, the velocity of the satellite error shall cause time compression and so produce the second time error. The two errors can be compensating by slightly offsetting the clock oscillator frequency.

When the receiver's antenna receives the signal from the space segment, the pseudo-range can be calculated precisely because the effect of the relativity error will not take place and is automatically cancelled.

3.2.3.6 Propagation link error: The error has been identified as being due to ionospheric delay, tropospheric delay and multipath error.

A. Ionospheric delay error: The effect is dependent on both the character of the ionosphere at zenith and the elevation angle to the satellite. The delay error comes from the speed of the two signals (1575.42 MHZ & 1227.60 MHZ) reduced as a result of passing through ionosphere layers. The system uses the two transmitted frequencies in order that the receiver can calculate the delay by a comparison of both and introduce the error correction figure to the final calculation.

B. Tropospheric delay error: The finite propagation media of the troposphere results in code phase delay uncertainties due to the unknown refractivity index alteration. Troposphere delay causes the greatest fix error, which is an uncontrolled error and cannot be compensated. For both ionospheric and tropospheric delay error, Tetley & Calcutt (1991,236) argue that:

> A dual channel, high quality receiver will produce position errors of approximately 5 metres due to ionospheric delay, whereas a lesser quality signal channel receiver could have errors in excess of 20 metres because of this effect.

C. Multipath error: Multipath error results from the combination of data which is received from the same satellite but from more than one propagation path that distorts the signal characteristics from which the range measurements are made. The reception of the wave from the constructions very near to the receiving antenna is the main source of this error. It is different from ship to ship up to the position of the receiving antenna relative to the construction. Thus it is not constant and its effect can produce errors from 3 to 5 metres.

3.2.4 GPS system accuracy:

Ackroyd & Lorimer (1990, 23) argues that:

> Great care is needed when assessing the accuracy of any system as it is a function of

many different sources; the user to station geometry, the noise characteristics and resolution of the frequency, range separation, system monitoring tolerances and many more.

When measuring the accuracy of the system, there are several factors and conditions which may or may not be affected by the user. Fig. 3.7.

The factors in the first case which can be affected by the user are defining time, quality of the receiver, operation after obtaining data and choice accurately the point of measurement and point of time. The other cases which cannot be affected by the user are factors such as, the means of approaching L2 and the P-code, space segments and system's integrity and reliability.

The accuracy of the GPS system has two levels of mode or service, SPS and PPS. Both of them include a single receiver perceiving to three to four satellites to define precisely its position.

SPS "Standard Positioning Service" is a positioning and timing service which is available to all GPS receivers. The mode is used on L1 frequency (1575.42 MHZ) which have a C/A code and a navigation data message. The horizontal accuracy of this mode is designed to give 100 metres (95% probability) with 140 metres vertically, and 300 metres (99.99% probability). The P code which involves L1 frequency is not a part of the SOS mode.

PPS "Precise Positioning Service" is a highly precise military positioning, velocity and timing service. The mode is used on both L1 frequency (1575.42

MHZ) and L2 frequency (1227.60 MHZ). PPS was designed particularly for US military use. The horizontal accuracy of this mode is designed to give 18 metres with 27 metres vertically.

The new consideration from the system management for GPS is the deliberate downgrade of the system for military uses by reducing the stability of the clock or by changing the code. This decision has been taken since the accuracy of the SPS code is about 36 metres (95% probability). The errors, especially the ephemerids and clock data, should be added deliberately, and accordingly the result will be 100 metres (95% probability). This is known as Selective Availability (S.A) or Accuracy Denial (AD).

The best geometry of configuration of satellites with the most favourable positioning is the aim of the receiver's designer, and by reducing the number of unknowns or increasing the number of satellites, geometry can be improved. Sonnenberg (1988,231) argues the accuracy depends on:

1. Receiving The C/A code or the P code;
2. The errors in the orbit prediction;
3. The unknown delays in the signal propagation, caused by tropospheric and ionospheric refraction;
4. The variable errors in the travel time measurements of the coded signals between satellite and users;
5. The geometry of the satellite configuration at the time of the fix determination, i.e. the direction of the satellite in relation to the user's position. Each range measurement of a

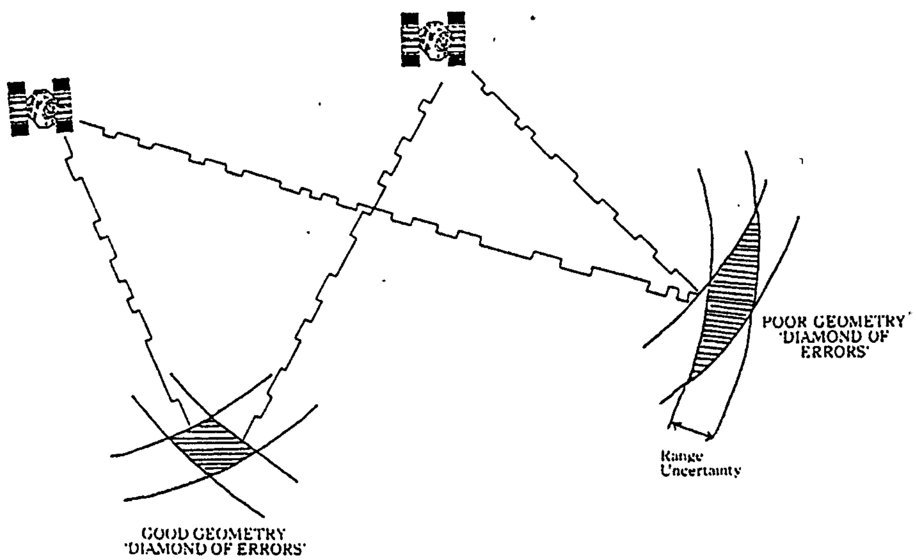

Fig.3.7 Diamond of errors
Source: Global Navigation A GPS User's Guide 1990,164.

satellite has an error in the direction of the line between the satellite and the user (or its extension). The configuration of two satellites is optimal when the two small circles (loci), which determine the ship's position, intersect at right angles.

3.2.5 The technique of differential GPS: The fundamental reason for Differential GPS was to reduce a large part of the errors which exist in the GPS system and dilute the pseudo range of a satellite. The logical purpose of this technique is the influence of SA which affects ordinary to all the receivers working in the same time and in the same zone.

The technique of DGPS is to fix a complicated monitor station (GPS reference receiver) at a precise geographical location, preferable near to the coast. The function of this monitor station is to track every satellite in view and calculate the corrections to GPS parameters by comparing the receiving signal and the calculating position fix with the expected signal and the accurate surveyed position. The difference between the two is the differential corrections message which is then transmitted in real time to the GPS users within the coverage area. The automatically received corrections, especially those which are received by SPS users, can improve navigational accuracy under all conditions from 100 metres (2 drms) to better than 10 metres (2 drms). Fig. 3.8.

Mainly, there are two kinds of corrections broadcasting from monitor stations; corrections of defined distances and corrections of defined position. Alsip, Butler and Radice (1993,79) state that,

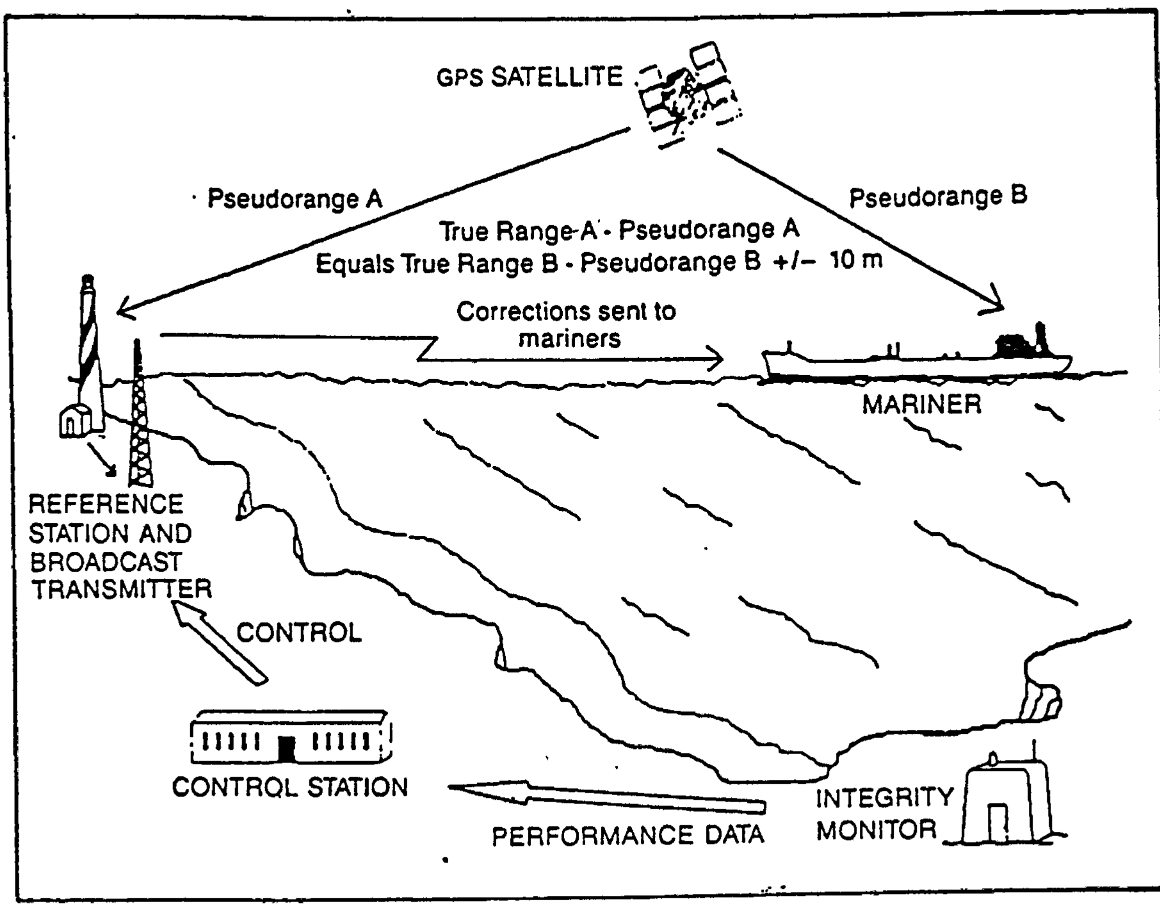

Fig.3.8 DGPS system concept
Source: The Journal of Navigation 1/93.

> In addition to providing highly accurate navigational signals, DGPS also provides a continuous integrity check on satellite health. System integrity is a real concern with GPS.

3.2.6 The future of G.P.S: A very good feeling of certainty is taking place in the future of GPS. The GPS system has a great likelihood of providing continuous navigation services for more than a decade into the coming century and to provide widespread and accurate navigation services in marine navigation to commercial shipping, research vessels and as a reference system for greatly determining world survey operations.

DGPS will be the standard used, leading to accurately positioned buoys and markers and for commercial users in the coming years. Thus when shipowners decide to establish a shipborne GPS receiver, they should ensure that this receiver is able to work with the DGPS system.

The GPS carrier phase tracking provides centimetre accuracy and may be eventually used to guide heavily loaded vessels more accurately in dredged channels. Pittam & Ladson (1992,10) state that,

> A further area of development will be the integration of GPS into the computer system to create a so-called 'smart' navigation tool. Integration with computerised navigation charts, radar echo sounders etc will provide a complete navigation and autopilot system with added efficiency and safety.

3.3 LORAN- C SYSTEM:

3.3.1 Introduction: The hyperbolic radio system Loran-C (LOng RAnge Navigation) is an electronic land based transmitting system for position fixing in all weather. The system plays an important role in navigation by broadcasting low frequency pulsed signals which enable ships and aircraft to allocate their position with high accuracy and high reliability.

Loran-C chains are spread throughout the world and are widely available in the Northern Hemisphere where they provide coverage in most strategic and geographical areas.

3.3.2 System principles and overview: The Loran-C system uses a chain system. The chain consists of a master station (M), which always transmits first, and up to four secondary or slave stations, designated by the letters W, X, Y and Z. The secondary stations are synchronized with the master and transmit at precise time intervals.

All the transmitters, the master and each slave radiates groups of eight pulses, spaced 1000 microseconds (us) apart on the 100 khz frequency, the pulse width is being 250 us. For the purpose of identification and warning of errors the master transmits a ninth pulse, spaced 2000 us from the eighth pulse.

To prevent mutual interference between chains, each Loran-C chain is transmitted at a specified group repetition interval (GRI), and all the stations in the chain have the same GRI. For identification, particularly in automatic receivers, some of the eight pulses are 180 degree out of phase, in which they nominated phase coding of pulses.

To measure the difference in arrival time of pulses from master and from each slave, and to get great accuracy, there are two electronic operations used simultaneously, **Pulse matching** and **Cycle matching.**

Pulse matching is the operation of measuring the difference in arrival time between the reception of a master pulse and corresponding secondary station pulse. Fig. 3.9.

Cycle matching is the process of measuring the phase difference between a tracking point, usually the third cycle of the master pulse, and corresponding tracking point for the secondary station. The accuracy of the measurement of phase difference is about 0.01 cycle. Fig 3.10.

The time difference is displayed on the Loran-C receiver and is updated at least five times per second. Latitude and Longitude can be calculated by a computer and displayed after the time difference of a third station pair has been determined.

3.3.3 Accuracy and Range: Two factors affecting the range of Loran-C, are the direction to the transmitting station, and the time of year and the time of day. In addition to these two important factors, the range is affected also by the quality of the signal processing and the quality of the receiver. In general, the ranges over sea in the day time are considered to be 2000 to 3000 km, decreasing by about 30 per cent at night. The range also

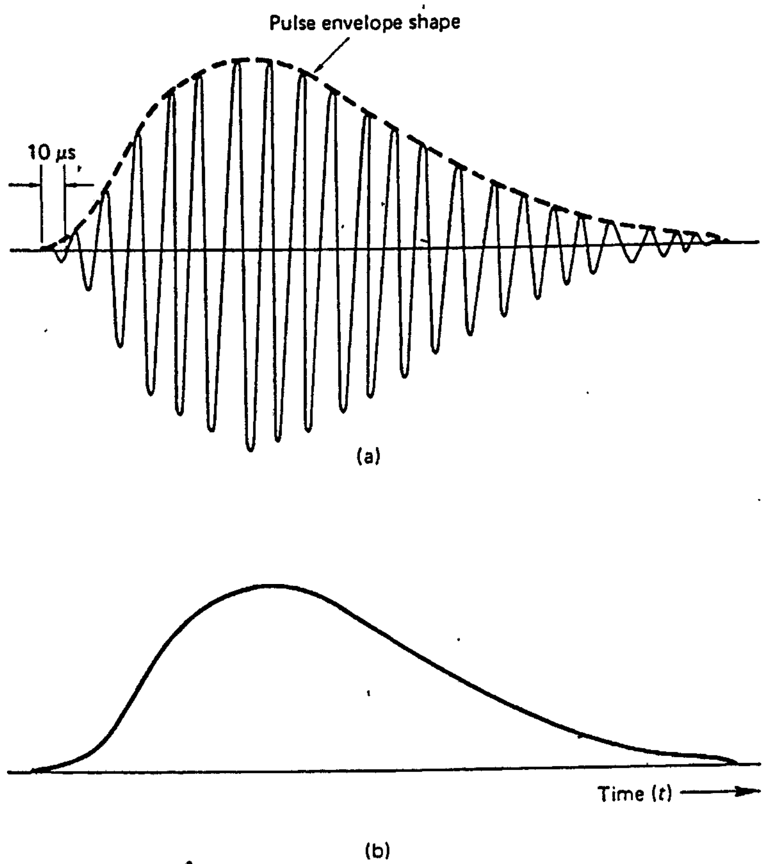

Fig.3.9 (a) The shape of the pulse oscillation
(b) The received pulses after detection
Source: Radar and electronic navigation 1980,172.

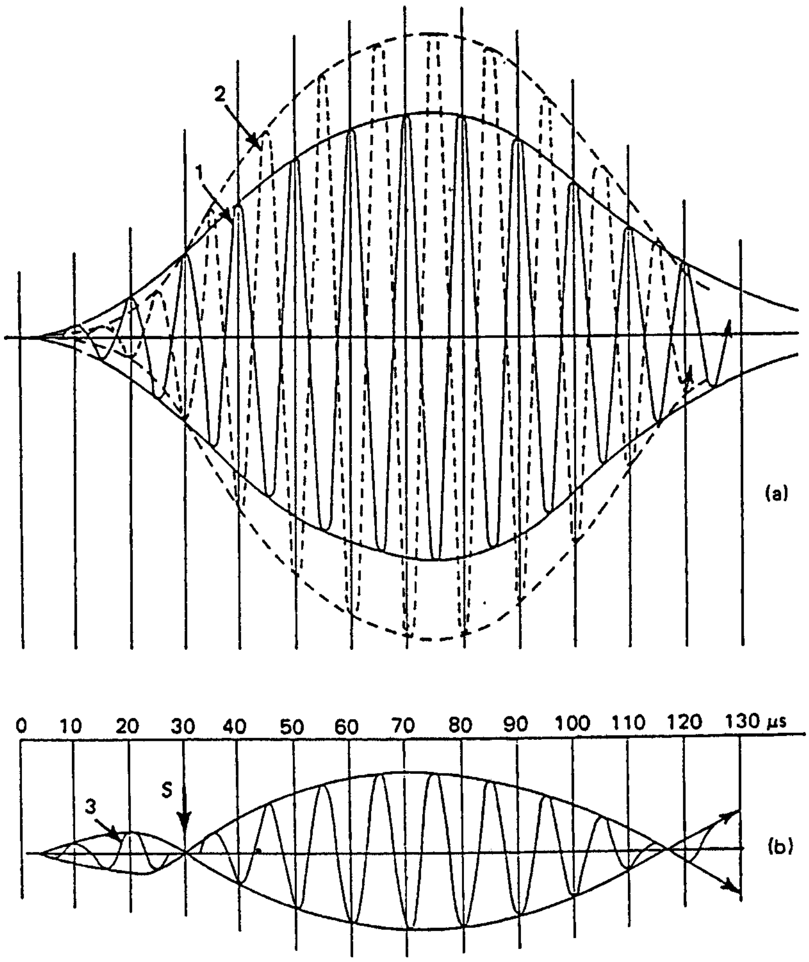

Fig.3.10 Loran-C cycle matching
Source: Radar and electronic navigation 1990,173.

decreases by about 10 to 15 per cent if the propagation from the transmitting station passes over land.

The variation in the velocity of the electromagnetic waves is the main source of error in the Loran-C system. The velocity of the ground waves varies with the change of the earth's surface conductivity and the parameters of the atmosphere. This means that the range and the signal stability of Loran-C are therefore better for radiation over sea than over land.

3.3.3.1 The types and concept of Loran-C accuracy: Accuracy is often a relative thing, and is affected as much by location, lane expansion and angle of cut which are common to all hyperbolic navigation systems and individual requirements as anything else.

Before Loran came into existence, navigation was done primarily with dead reckoning. In those days to have a 0.25 mile accuracy was considered "right on". Now, with Loran, 0.25 mile accuracy often is not good enough, such as when approaching a tight entrance in the fog.

Some of the confusion concerns talking about Loran-C accuracy because of the fact that there are different types of accuracy: overall accuracy, repeatable accuracy, relative accuracy, and absolute accuracy:

. **Overall accuracy**, Loran-C has a good reputation for accuracy and reliability.

. **Repeatable accuracy**, is a measurement of the ability to go back to a given location on the basis of previous readings, which can vary depending on the position within Loran coverage. The factors which can affect repeatable accuracy are those which affect signal transmission and reception, position in relation to transmitting station, and those uncontrollable factors, such as weather, which can cause extremely small changes from one moment to another in signal propagation speed.

This type of accuracy is important to the Loran-C user because the Loran-C system really excels in repeatable accuracy being much better than 0.25 miles. Practically, in the areas of good chain geometry, repeatable accuracies of 50 to 300 ft are constantly accomplished.

. **Relative accuracy;** the Loran-C system has a high capability to meet at a rendezvous.

. **Absolute accuracy;** it may also be called predictable or geodetic accuracy. It is a measurement of the ability to determine the actual or true geographical position.

There are a number of factors which can affect absolute accuracy such as: receiver installation, signal stability, geometric location related to transmitting stations, signal interference, cycle slip, land propagation errors, operator error, and sometimes weather.

With Loran-C absolute accuracy usually varies between 0.1 to 0.25 nautical miles of the actual position. An absolute accuracy of 0.1 n.m (600 ft) is quite common in many areas and if the corrections are known and made for signal propagation distortion over land- Additional Secondary phase Factor (ASF)- one can get absolute accuracies of 200 ft.

3.3.3.2 Land propagation errors: (Additional Secondary Factor "ASF").

When radio waves travel through space, the speed is the same as the speed of light. On passing through any medium, as for example the earth's atmosphere, radio waves are slowed down. This speed is further affected by the terrain over which they travel, land will slow them down more than water. Then, one can say that the delay over water is called the secondary factor. The delay over land is called the Additional Secondary Factor or ASF because it is in addition to that which is caused by an only sea water path. In addition, not all types of land will affect radio waves in the same way.

The Loran-C system, which is based on the calculated time differences between receiving radio signals from the master and slave stations, depends on the accurate measurement of these time delays. The calculations are made on the assumption that the radio waves are travelling over an all sea water path at a fixed speed. This is not always true because many stations are based on land and the signals must travel over some interfering land to arrive at the sea water. So, signals may not be received at the precise time, and the result is that position errors may vary anywhere. It is clear that ASF is the greatest factor which affects the accuracy of Loran-C fix.

ASF is constant for a given area, so the error can be measured theoretically or from actual observed data, and with this information, it is possible to correct for the error and obtain the accuracy for which the Loran-C system is reputed.

3.3.4 Loran-C activity: Regarding the IMO Sub-Committee on Safety of Navigation -37th session. Agenda item 5.1 on 25 June 1991, a note was submitted by (IALA) relating to:
Navigation Aids and associated equipment and is quoted below:

<u>World-wide radio navigation system</u>
<u>Note by IALA</u>

1. Resolution A. 666(16) recognizes that, within the limits of their coverage, terrestrial radio navigation systems may be suitable for recognition and acceptance by IMO as a suitable system for international use under the conditions set out in the Annex to the resolution.
2. In addition, the sub-committee, at its 36th session, noted that IEC had prepared technical standards for Loran-C shipborne receivers.
3. Many Members of IALA have recognized the need for a terrestrial radio navigation system to cover their waters and the adjacent seas, studies have shown that the technical characteristics of Loran-C system are sufficient to be considered as one radio navigation system.
4. The USA Government has indicated its intention of withdrawing its support for Loran-C stations, other than those sited on the land mass of the USA, at the end of 1994. In this regard the following is understood to be the current situation world-wide:

USA:

Loran-C system covering the land mass of the USA and its coastal waters will continue into the next century, with support from the US Coast Guard until 2015.

USSR:

It is intended to cover the whole of the Soviet Union with chains of the Chayka system. The Soviet Union is also keen to link Loran-C with Chayka wherever geographical configuration of the system permits.

North West Europe:

Agreement between the countries in the area to take over the existing stations from the US and extend the service to cover from Northern Norway to the East coast of Canada, including the North Sea and the Bay of Biscay.

Discussions between Norway and the USSR concerning a joint Loran-C/Chayka in the Barents Sea and between Germany, Norway and the USSR to joint chain in the Baltic Sea.

Mediterranean Sea:

Discussions are taking place between several Mediterranean countries who are interested in the continuation of the present chain after the withdrawal of support by the US Coast Guard.

In addition, France, Spain and Portugal are studying means of providing Loran-C coverage of the entire Iberian Peninsular as well as the Azores, Canaries and Maderia.

Asia:

Japan, the Republic of Korea, China, and the

USSR have met to discuss the way ahead to provide coverage by Loran-C and Chayka in the Far East.

Middle East:

Two Loran-C chains are installed in Saudi Arabia.

Venezuela:

A Loran-C chain to cover the coast of Venezuela and Southern Caribbean has been under consideration for some time.

India:

A decision has been made by the Government of India to install Loran-C chains at Bombay and Calcutta. Contracts have been placed for the Loran-C transmitters.

South Africa:

Consideration from the Government for the installation of Loran-C to cover the country.

5. In recent years, IALA has been involved in discussions on Loran-C and Chayka in several parts of the world.

6. It is proposed that the sub-committee keep in mind the policy of IALA on terrestrial radio navigation systems and the expanding use of Loran-C and Chayka worldwide when considering candidate radio navigation systems for adoption in accordance with the policy set out in resolution A.666(16).

3.3.5 How good is Loran-C ?: Without any doubt there are limiting factors which could possibly affect the accuracy of a Loran-C fix, as there are when using any other navigational instruments. However, most of the time it will be found that Loran-C improves its reputation. These limiting factors are rarely present to the point

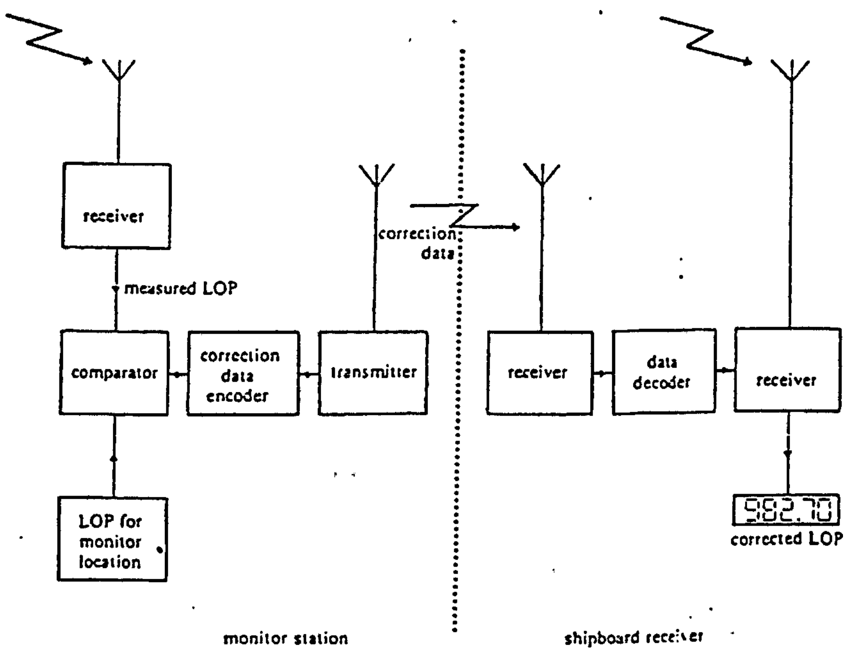

Fig.3.11 Differential Loran-C system
Source: Naveguide,IALA 1990,124.

where Loran-C cannot deliver a level of accuracy according to the original intentions of the system which were 0.25 nautical miles accuracy, 95% of the time, within the coastal zone (50 nm offshore).

Yet, as many are finding out, how good Loran-C is depends a lot on the area to be navigated. Because of this, when sailing into a new area for the first time, and once the area is learned, and it is known if large ASF errors, or sources of errors are present, corrections can be made, and Loran-C used with confidence in continued navigation.

3.3.6 Differential Loran-C: Fig. 3.11.

Differential Loran-C may meet the requirements for applications requiring higher precision than the predictable or repeatable accuracy of the Loran-C system (0.25 N.M predictable, 19-90 metres repeatable), through the use of offset corrections provided by benchmarked monitors. A master monitor station polls a number of secondaries (depending on the desired area of coverage) via land lines and computes a correction based on the quality of each station's data. It automatically transmits this correction(digital transmission) via an appropriate communications channel. The Differential Loran-C receiver recovers the data through the same channel and applies the correction to the position.

Differential Loran-C is a position fixing system giving high accuracies over a limited area for local applications such as harbour approach or surveying.

Navguide, (1990, 123).

3.4 COMBINATION OF G.P.S AND LORAN-C IN ORDER TO ENHANCE SAFETY:

3.4.1 Introduction: The intention of the proposal of the combination of G.P.S and Loran-C is to enhance and develop the accuracy of navigation and to achieve an improved performance which may provide coverage over the widest possible area.

The utilization of Loran-C and G.P.S systems as the initial aids to marine navigation, may enable the navigator to navigate wherever with safety, thus following the rules of SOLAS Convention. In order that for whatever the reason, G.P.S might become unavailable due to a temporary interrupt, an expedient situation has been produced for the retention of Loran-C as a very convenient back-up terrestrial radio navigation system. However, one should examine the facts:

. G.P.S is a military system and is enormously costly.

. The military Authority (USA) can switch off or alter the system at whim.

. The military Authority presently takes out a satellite for maintenance without warning the civil user.

. Other countries have no influence on the operation of the system.

Malcolm Edge, (1993,4).

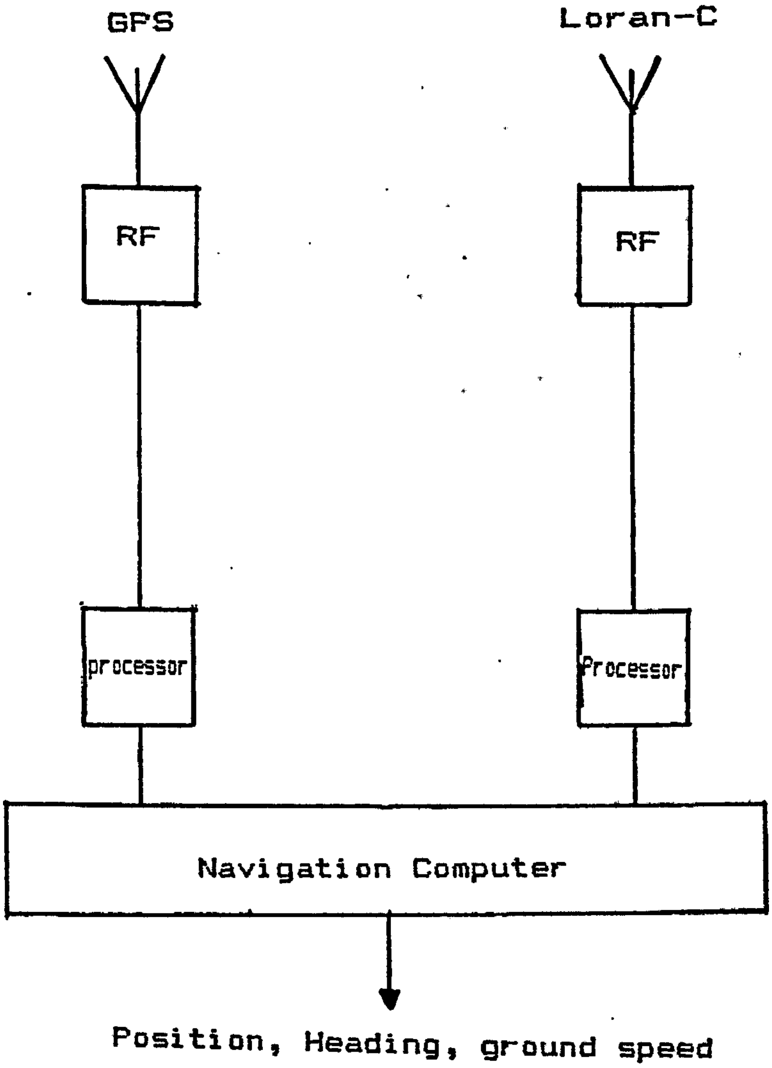

Fig.3.12 Hybrid Loran-C/GPS system

As the system is already in existence, the user will only have to bear the cost of the receiver which is not expensive and is readily available.

The interfacing capability of the Loran-C and G.P.S systems will increase expected availability and reliability, provide resources for independent integrity checks, redundant LOPs checks, keeping from radio frequencies interference and any external influences. In addition, one can expect from this proposed system, technical, operational and economic benefits.

3.4.2 The hybridized model of Loran-C/G.P.S system: In order to invent a phenomenal hybridized model, the invention design could utilize the G.P.S system as the main source of navigational data and the Loran-C system as a back-up source aiding the G.P.S system. Fig. 3.12.

The main and important point in the design of the hybrid Loran-C/G.P.S system is that a failure of one of the two main parts of the system should not affect a failure in the other, and the two main receivers could not be exposed to criticism from the same environment influences or interference phenomena.

The view of both source transmitters G.P.S and Loran-C is seen as they are from the same family, but one from this family is moving and broadcasting regularly, and the other is firmly fixed and transmitting pulses frequently. Each of them provides pseudo-range measurements of importantly equal function to a processor. The Loran-C measurements are called Loran-C pseudo-ranges because the design considers, as mentioned, that Loran-C transmitters are from the same family of G.P.S transmitters. In addition to ensuring this consideration, the receivers of each source can perform ranging or time of arrival measurements.

The resulting hybrid system has the potential for generating highly reliable navigational data for control of the ship and offers much scope for improvement in safety at sea. Thus, the system could provide a quite extraordinary radio navigation service.

In addition to the integrity, reliability, and time availability, in which there are the beneficial acts of combining Loran-C lines of position with G.P.S lines of position in a hybrid receiver, is the utilization of the independent Loran-C receiver to detect G.P.S system or receiver failures.

The integrated operation between G.P.S pseudo-ranges and Loran-C pseudo-ranges in the hybrid Loran-C/G.P.S receiver could be used to avoid, or at least reduce, the probability of G.P.S interruption which may occur because of G.P.S failure. Indeed, the Loran-C pseudo-ranges could be a worthy aid to G.P.S integrity monitoring and thus clock-aided integrity monitoring.

The hybrid Loran-C/G.P.S system can perform a simple integrity check, only by comparison between the latitude-longitude output from each of the independent Loran-C and G.P.S receivers. In case of differences between the two independent position fixes from the two main sources G.P.S and Loran-C exceeding a certain threshold, then the system should warn the operator.

The system should have the capability to detect and to give estimates of positional error. The positional error is the result of the pseudo-range measurement errors which present uncertainties in the Loran-C broadcasting time. The pseudo-range measurement errors are considered as having the largest influence on the hybrid system.

As mentioned before the main source of navigational data is the G.P.S receiver which should be used continuously in order to calibrate Loran. The system should also use the calibrated Loran when G.P.S is unavailable. In this case, to develop the hybrid system and to improve Loran accuracies by calibrating ASF factor, the system must include appropriate means to predict the affective behaviour of the ASF of the Loran wave, and a means to reduce errors caused by Loran cycle slip and ambiguities.

Similarly, because the Loran and G.P.S pseudo-ranges are combined in the hybrid system, then, the development of the system must also include the appropriate means to measure the differential front-end delay.

Finally, these ideas may improve the performance of the hybrid Loran-C/G.P.S interoperation.

3.4.3 Integrated EUROFIX and IALA'S DGPS: IALA projection is integrated EUROFIX and IALA'S DGPS, in order to improve integrity and availability during GPS outages. Fig. 3.13 and Fig. 3.14.

EUROFIX is an integrated system which combines Differential Loran-C and DGPS for position fixing. The IALA DGPS system has been devised by IALA to broadcast DGPS data through existing LF radio beacon transmitters.

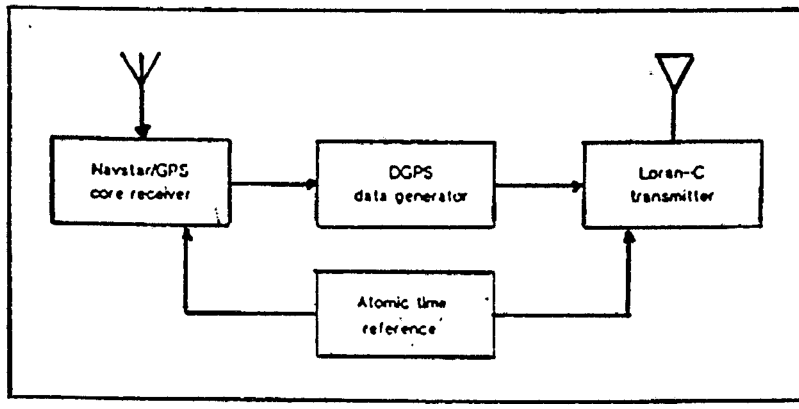

Fig.3.13 Block diagram of an EUROFIX/Loran-C transmitting station.
Source: Nave 91, 42/91.

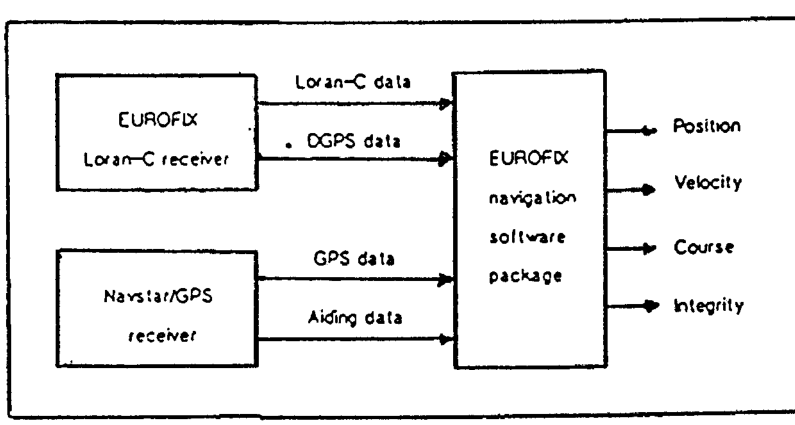

Fig.3.14 Block diagram of a EUROFIX receiver set-up
Source: Nave 91, 42/91.

Additionally, IALA aims to establish a network of LF stations (separated by a distance of 250 to 500 N.M) in order to provide coverage for all Europe.

CHAPTER FOUR

PROPOSED NAVIGATIONAL SYSTEM

4.1 INTRODUCTION:

The navigator combines data from the sensors to obtain the best estimated position and other information. It is possible to design a system which is similar to the decision process performed by the navigator.

The design involves identifying, specifying, and implementing the interaction between the components. The interactions are classified as supplementary, complementary, bias parameter estimation and random error smoothing. The choice of any navaids could be selected for the output of the navigational system to obtain maximum benefit.

The aim of the design is to achieve a performance which is better than that of the individual constituent system, and to improve the navigation accuracy, efficiency and reliability, providing this improved performance over the widest possible area on board merchant ships.

The scope of the navigational system, which includes the tasks of the central computer, is to integrate most essential marine navigation sensors and systems within the hybrid Loran-C/G.P.S system. The sensors and systems include items such as gyrocompass, speed doppler log, echo sounder, adaptive auto pilot, radar and ARPA, and Electronic Chart Display unit (ECDIS).

The design, which includes these sensors and systems, must be strong, economical and within a very flexible network with microprocessor controlled interfaces to collect sensor input from different models of the systems and sensors. This design should make all the data available at the same time to one central situation. The central situation must allow a single watch officer to maintain operative mastery over his ship.

Thus, with this design, the information can be concentrated in a closed circuit for general use. Additionally, with a small crew, the needs for primary information on the bridge of the ship has become essential.

The navigation devices generally have different errors with particular characteristics. Errors that change slowly in time can be estimated as bias parameters, and can be reduced. Errors that change rapidly can often be treated as having some random characteristics and can be smoothed or filtered.

4.2 NAVIGATION EQUIPMENT:

Any navigational system provides the data from the following sensors:

4.2.1 Heading sensor "Gyrocompass": The gyrocompass is considered to be a vital navigational instrument. Indeed, the gyro compass is a worthy element in the safety of navigation of every type of ship. It is the principal unit of navigational instruments which is designed to indicate accurately the true geographical North.

The gyrocompass provides directional information to a variety of other navigational equipment such as, auto pilot, radar and ARPA as a collision avoidance system, direction finder (D.F), course recorder, inertial navigation system, etc.

Continuously, the gyroscopic compass provides the navigational system with synchronous pulses. The developed gyro compass is able to correct the induced latitude and velocity errors automatically.

4.2.2 Velocity sensor 'Doppler log': A two-axis doppler log works in a sophisticated system to overcome the error introduced by the difference in measuring velocity "over the ground" and velocity "through the water". The output data from the system provides the navigational system.

The Doppler log uses the phenomenon of Doppler-shift by measuring the frequency shift of an acoustic wave to determine the speed of a moving vessel. The transmitting transducer of the Doppler log fixed in the ship's keel, transmits a sonar beam which can be reflected from a fixed reflector. The system must include a special sensor to measure sea water temperature and salinity, and counteracts the unwanted influence of the variation in the velocity of acoustic wave.

To measure the forward and athwartships motions of the ship, and to overcome the unwanted influence of the vertical motion of the ship, it is necessary to install a Janus configuration which comprises two transmitting transducers, to transmit forward and backward beams, and two transmitting transducers at 90 degrees with the along-ships transducers, to transmit starboard and port beams.

The Doppler log is very useful for all kinds of manoeuvring as well as dropping or weighing anchor for which the log can measure the speed to the nearest 0.01 knot or 5 mm/second.

4.2.2.1 Operational data:

*** Simrad NL Doppler speed log**

- Speed accuracy is better than + 2% above 5 knots. Within + 0.1 knot below this figure.
- Minimum speed indication is 0.1 knot.
- Distance accuracy is + 2%.

*** The Krupp Atlas "Dolog" speed log**

- Longitudinal speed accuracy is 0.2% of measured value.
- Transverse speed accuracy is 0.2% of measured value or 0.1 knot whichever is greater.
- Transverse speed accuracy (stern) is 0.2% depending upon rate gyro measurement.
- Distance accuracy is 0.05 to 0.2% depending upon distance travelled.

Tetley & Calcutt, (1991,46 & 51).

4.2.3 Depth sensor 'The echo sounder': The echo sounder apparatus is purely a timing and display system. The system in its simplest form is an electronic device for measuring the depth of the water beneath a vessel by calculating the time taken for a transmitting pulse to go and return from the sea-bed. It becomes an essential aid to the navigator, and is now installed on almost every ship.

There are many methods for displaying the depth of the water as for example, the chart recorder, the digital display, the rotating light emitting diodes (l.e.d), analog l.e.d display and the visual display unit (VDU).

4.2.4 Auto pilot and Adaptive auto pilot: There are two ways which the proper auto pilot can make the useful margin of a ship become better. The first way is to reduce the number of the crew, and the second, which is a very economic way, is saving fuel and time. This can be very useful if the ship retains its course with very little deviation.

When there is any difference between the two input signals of the course to steer data (fixed by the helmsman) and the ship's actual course data (taken from a gyro compass), the auto pilot can detect this difference and the apparatus can use the rudder correction to keep the ship's course.

Because of changes in the environmental conditions which affect the behaviour of the ship, and in order to maintain the course, the helm must be provided with some additional facilities in order to help the auto pilot to act as helmsman.

4.2.4.1 The adaptive auto pilot: It is very difficult to find a helmsman who has the ability to instantaneously predict all the ship's and environmental effects, to control the steering in such a way as to be the most favourable in relation with the most usual environmental conditions and also use a low band width to reduce as much as possible the losses. Further, he should be steering on the best course by using the corrective rudder. These circumstances need a helmsman who has the ability to react as soon as possible and to faithfully change the parameters. This should be a helmsman equipped with a computer.

In the simplest form, the adaptive auto pilot is a steering device, equipped with a microcomputer, which contains the available data of the dynamics of a "model ship" in order to predict the suitable rudder commands for the real ship.

The input data from the adaptive auto-pilot system provides the navigational system.

> Sperry Ltd designed their adaptive autopilot model ship dynamics around the following criteria:
>
> (a) Ships operating envelope; the vessel's speed, load factor and external environmental condition,
>
> (b) Precise dynamics of the vessel which relate to its steering control,
>
> (c) The dynamics of the ship's steering system,
>
> (d) The dynamics of the gyrocompass,
>
> (e) The dynamics of the seaway.

Racal Decca Marine Controls Ltd

The model ship has been programmed with three parameters.

1st parameter: (the only manual preset).

"Tau" setting. Derived from the ship's length and normal cruising speed, the speed factor is thereafter continuously updated by input from speed log or engine revolution indicator.

2nd parameter: (adaptive).

"Gain coefficient" setting. This parameter covers the ship's response (in rate of turn) to rudder movements.

3rd parameter : (adaptive)

"Ships Characteristics" setting. The parameter covers the ship's response to its own inherent ability to increase or to decrease its own rate of turn, without any rudder movement.

Tetley & Calcutt, (1991,322 & 328).

4.2.5 Radar and ARPA:

This is an electronic-mechanical aid that not only detects the presence of ships, buoys, the coast, etc., but also determines their bearing and range and often indicates the nature of these objects. In navigation radar can serve not only for position finding but also as an anti-collision aid. It is evident, then, that radar is very important aid to navigation, especially since it supplies the same information during the night and the fog as in more favourable

> conditions. A great advantage of radar is that, unlike other navigational aids, it does not require the cooperation of other stations.
>
> Sonnenberg, (1988, 234).

There are two main functions of the radar system. Firstly, the collision avoidance function which enables it to detect, track and present the targets, by range/bearing, and course/speed. Secondly, radar navigation functions which enable it to accurately plot and fix the position of own ship.

How can the radar be used as an aid to navigation, and be operative in preventing collisions ? Regular and orderly observations of the radar display will help the navigator to avoid collisions and may prevent them from occurring. Many times one can observe numbers of new targets, approaching unobserved at close range, especially in the interval time between the observations. The navigator should consider all the information of these targets and the prevailing environment conditions and the decision of the interval time between observations.

Two display units on the bridge could be very suitable. One which is most important and provided with ARPA facilities, is relative motion North-up stabilised presentation. This method of presentation is very useful in detecting the targets at a great distance. They can then be tracked and their information can be easily determined. The other display unit has true motion presentation. In this way it will help the navigator to perceive and understand the overall navigation situation.

4.2.5.1 Automatic Radar Plotting Aid (ARPA): In manual plotting, comparison must be achieved between the information from the same target at different times, such as bearings and distances of the presented targets, the problem being that after one or two scanner revolutions, the information is lost as the target moves.

In automatic plotting, the radar is equipped with a computer to allow the previous information to be available for achieving the comparison with the latest information. The ability of the computer is to track more than 20 targets in a short time and at the same time, determine safe manoeuvres to avoid or prevent collision. Automatic Radar Plotting Aids can achieve all these operations by using the memory of the computer.

The IMO Performance Standard for an ARPA requires that it should '... reduce the workload of observers by enabling them to automatically obtain information so that they can perform as well with multiple targets as they can by manually plotting a single target'. It also state:

> The display may be a separate or integral part of the ship's radar. However, the ARPA display should include all the data required to be provided by a radar display in accordance with the performance standards for navigational radar equipment.

The computer of the modern integral ARPA, which is included in the radar/ARPA system, can help the ARPA data and other information to be presented as conventional radar data. In this case it is easier to compare the data from the radar and the data from ARPA.

4.2.6 Electronic Chart Display and Information System: (ECDIS)

> It means a navigation information system which can be accepted as complying with the up-to-date chart required by regulation V/20 of the 1974 SOLAS convention, by displaying selected information from a system electronic navigational chart (SENC) with positional information from navigation sensors to assist the mariner in route planning and route monitoring, and if required display additional navigation-related information.
> IMO/IHO Harmonization group on ECDIS,(28 April 1993).

What is ECDIS ? It is the electronic chart display which, when provided with the electronic navigation chart data, changes to be the ECDIS. The Initial task of the ECDIS is to be one of the vital elements contributing to the safety of navigation.

The practical ECDIS has the ability of being an extraordinary system, by which the integration of the system technology will permit the mariner to have in real-time chart presentation with a distinctive characteristic, ship's position, control ship's track, sailing directions information, and other activities in addition to ARPA connection for collision avoidance.

ATLAS ECDIS

The ATLAS ECDIS has been designed in accordance with the provisional specifications established by the IMO and the HGE (IMO/IHO HARMONIZING GROUP ECDIS).

Characteristics:

. ECDIS in compliance with IMO/HGE draft.

. Object structure (layers) allows detailed information on each object.

. Display of planned and actual ship's track within electronic chart.

. Automatic check of ship's position versus safety depth contour.

. Dead reckoning and position control.

. Display of route information, way-points, ETA, bearing and distance to next WayPoint, etc.

. ECDIS update, service, track planning via ATLAS PCS-LAN/ECDIS.

4.3 TECHNICAL EQUIPMENT:

4.3.1 Navigational computer: Great developments in the field of the technologies used in many areas have been seen in the past three (or more) decades; navigational systems, integrated ship control systems, bridge and navigation systems, bridge manoeuvring systems, etc.

Today, the available instrumentation for ships should be equipped in different types of computer systems to function for various operations. On the bridge the computer exists in many forms, for example in the ARPA system and modern positioning systems which depend upon the microprocessor and partnering software. At whatever time a modern electronic set is established on a ship, it almost certainly includes (as a part) a computer. The modern bridge therefore consists of numerous computer systems each providing the mariner with an interactive information device.

Although there are some standard arrangements of transferring data between systems, the computations and information provided by these systems may be similar. Therefore, it would seem that the great quantity of computing power available on a developed bridge is duplicated, as each navigational aid performs individually. Such a plan is, however, recorded as modern computer technology.

Indeed, the bridges of the ships have seen the important development of many sources of navigation. The operation of connecting and interpreting the information which is provided by the sources of navigation, is liable to personal error at some stages of the operation.

Regarding the challenge of new technology, a design of modified installations has been developed for distributing, presenting, connecting, and logging shipboard data. In order to reduce the stress and to give the bridge watchkeeper enough time for doing the job of making decisions, the developed installations, which are equipped with a computer can automatically perform most duties of the navigational operation at sea.

In general, the most important vital data sensors on the bridge of any ship are the navigation information which is provided with geographical positions from various types of position systems such as G.P.S and Loran-C; headings from the gyro compass; the radar, anti-collision system and ARPA; the Doppler speed log; and depths from the echo sounder. In the navigational system, a navigation computer can correlate all of the data sensors and distribute the data to the other equipment in the network which may use it.

Voyage planning is a very important task in navigation. The navigation computer can facilitate the calculation of any voyage planning by computing track headings, estimated time of arrival (ETAs) to waypoints (WPs), and great circle routes calculations. ECDIS in the navigational system can display an electronically recorded voyage planning track in order to present the planned route and to compare it with the vessel's position with respect to the plan. In the system, the navigation computer can differentiate between the actual progress of the plan. According to any voyage plan, the destiny of the ship is stated as a function of time, and the current position is also known. After that the navigation computer can plot the ship's position. If there is any variation, the navigation computer signals a command to the adaptive auto pilot to maintain the ship on track and on the plane.

Navigational computers, however, have been successfully and widely applied in many of the navigational systems in different ways, particularly in the electronic position navigation system. They are considered as a vital part of any integrated navigation and bridge system.

4.3.2 Kalman filter: The origins of the kalman filter lie in the late eighteenth century with the usage of the least squares idea by Gauss. The definition of Gaussian distribution of random errors is standard deviation, and hence variances. This has led to the use of minimum variances or Kalman-Bucy filters which have been developed and are used widely in aerospace and marine navigation.

There are four important characteristics of the Kalman filter, operation in discrete time, optimality, linearity, and finite dimensionality.

The Kalman filter is a recursive computational algorithm which remembers the past data, receives present data and calculates the best estimate of the present and probable future position. It is based upon the combination of past and present information. All electronic navigation aids will develop error patterns and by trading one error parameter against another, it may be possible to obtain improved estimates of position, speed, and heading. Indeed, the main function of the Kalman filter is to clean up the navigational data.

4.3.2.1 The theory and principles of the Kalman filter: The Kalman filter is a technique which is designed to mix noise spoiled measurements of a dynamic system with other known information about the system in order to get useful estimates of the parameters or modes which control that system. It is a digital computer software programme which estimates the parameters from the measurements which include randomly irregular noise.

The principle of the Kalman filter is that it contains a mathematical model of the true system, to which are fed the known inputs which drive the system. The filtering process removes noise from the sensors and obtains an accurate state of the vessel at discrete time intervals for use by the controller. It achieves this by combining observations with predictions made by the mathematical model. The model is divided into two parts. The first part is the low frequency model, which estimates wind, current, and wave forces, the ships dynamics, the engine and rudder forces and movements, and the interaction effects between hull and current flow. The second model is the high frequency model which is used to get estimates of the wave motion.

The high and low models are combined together to compare the two models' outputs with the measured noisy values of position and velocity. The result of the comparison returns as feedback to the proper parts of the model. The output result is an excellent estimation of the position and speed. The estimated position and speed shall be the inputs to the controller, and to get the position and speed error, the estimated position and speed should compare with the requested values.

4.3.2.2 The operation of the system: The system is working while the vessel is sailing by using the control systems such as engine, rudder and thrusters to counteract the disturbing actions such as wind and tide.

While the vessel is sailing the sensors and systems such as G.P.S and Loran-C, gyrocompass, and log measure the parameters (position, speed, and heading of the vessel). However these indicators contain certain random errors. The task of the Kalman filter is to identify the levels of 'noise' (or errors) in various inputs, and to remove or clean up the signals by filtering out unreliable or unsatisfactory 'noise' elements. This is does by comparing the system errors against those expected for the prevailing conditions. The result should be a most reliable and accurate position (most probable position 'mpp'), speed, and heading output which will be used as an input to the controller. The controller provides the control system with new values for the action of the rudder, engines, and thrusters thus completing the feedback circle.

4.3.2.3 Marine uses and applications: The Kalman filter as a technique has only recently become known as a useful tool in the marine world. The technique has established a variety of uses at sea. For example, the development of an integrated navigation system has coincided with the increased use of the Kalman filter along with the need for position fixing accuracy in the offshore oil industry. Also, the development of the G.P.S satellite navigation system, the improvement of the performance of the auto-pilot (adaptive auto-pilot), integrated bridge systems, and the hydrographic survey positioning system are integrated with the useful help of the Kalman filter.

Kalman filter techniques have been usefully used in many fields concerning navigation, especially with the increase in confidence in the integrated electronic navigation systems and bridge systems.

CHAPTER FIVE

HOW CAN THE PROPOSED SYSTEM OVERCOME THE PROBLEMS ENCOUNTERED IN CONGESTED WATERS

5.1 INTRODUCTION:

Congested water is a passage which due to traffic flows is overcrowded and requires safety precautions when passing. The coastal state needs to arrange and control ships passing the area with the aid of a traffic separation scheme (TSS) and vessel traffic service (VTS) systems. Ships passing this area need a high accuracy of navigation to plot their position.

Examples of these congested waters are the Straits of Dover, Straits of Gibraltar, the Turkish Strait, the Gulf of Suez, and Strait of Malacca.

The Strait of Dover: The Strait as maritime entrance to and from Western Europe and as a trade route, is one of the most important, busy international waterways of the world. North of the Strait is the North Sea, and to the South lies the English Channel. The Strait and its approaches are relatively shallow, the sea floor slopes down steeply to a depth of between 20 and 30 metres. See fig. 5.1.

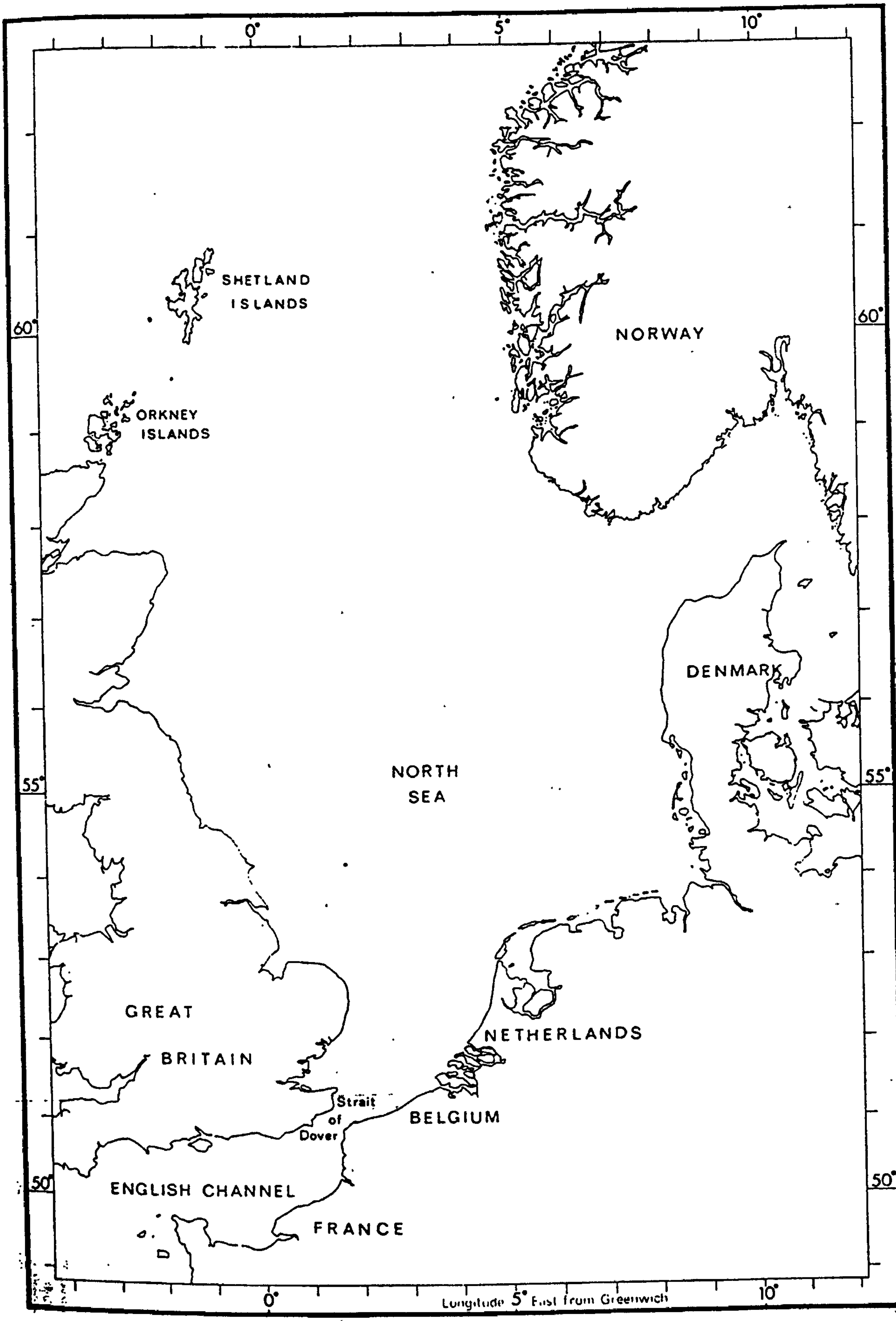

Fig.5.1 The strait of Dover and its approach
Source: The strait of Dover, Vol.8.1986,15.

To or from the many ports on the western European coastline, there are about 300 ships per day navigating in the narrow straits between Dover and Cap Griz Nez. As well a great number of fishing vessels operate in and near the Strait, plus a number of car ferries, hovercraft and jetfoils moving and crossing the Strait particularly in the summer.

In addition, the area around and in the Strait has much wealth in marine resources. The exploitation of these resources and the dense traffic brings up interesting management and safety results.

The Straits of Gibraltar: This Strait connects the Atlantic Ocean to the Mediterranean Sea. The Strait is 36 miles long and narrows to less than 8 miles wide between Point Marroque, Spain, and Point Gires, Morocco. The Mediterranean Sea and the Strait of Gibraltar are very important passageways for the movement of trade.

The Strait is also a very important connection between Europe and the lands south and east of Suez, and has also been of great trade importance after the opening of the Suez Canal in 1869. See fig. 5.2.

The Turkish Strait: This Strait includes the Dardanells, which connect the Aegean Sea in the north-eastern part of the Mediterranean sea to the Sea of Marmara. The Strait also includes the Bosporus which connects the Sea of Marmara to the Black Sea, shown in the fig. 5.3. The total navigable length of the Strait from the entrance to the Dardanelles to the Black Sea is about 160 miles. The width at the entrance is two and one half miles. The breadth near the northern end of the Strait is one mile, see fig. 5.4.

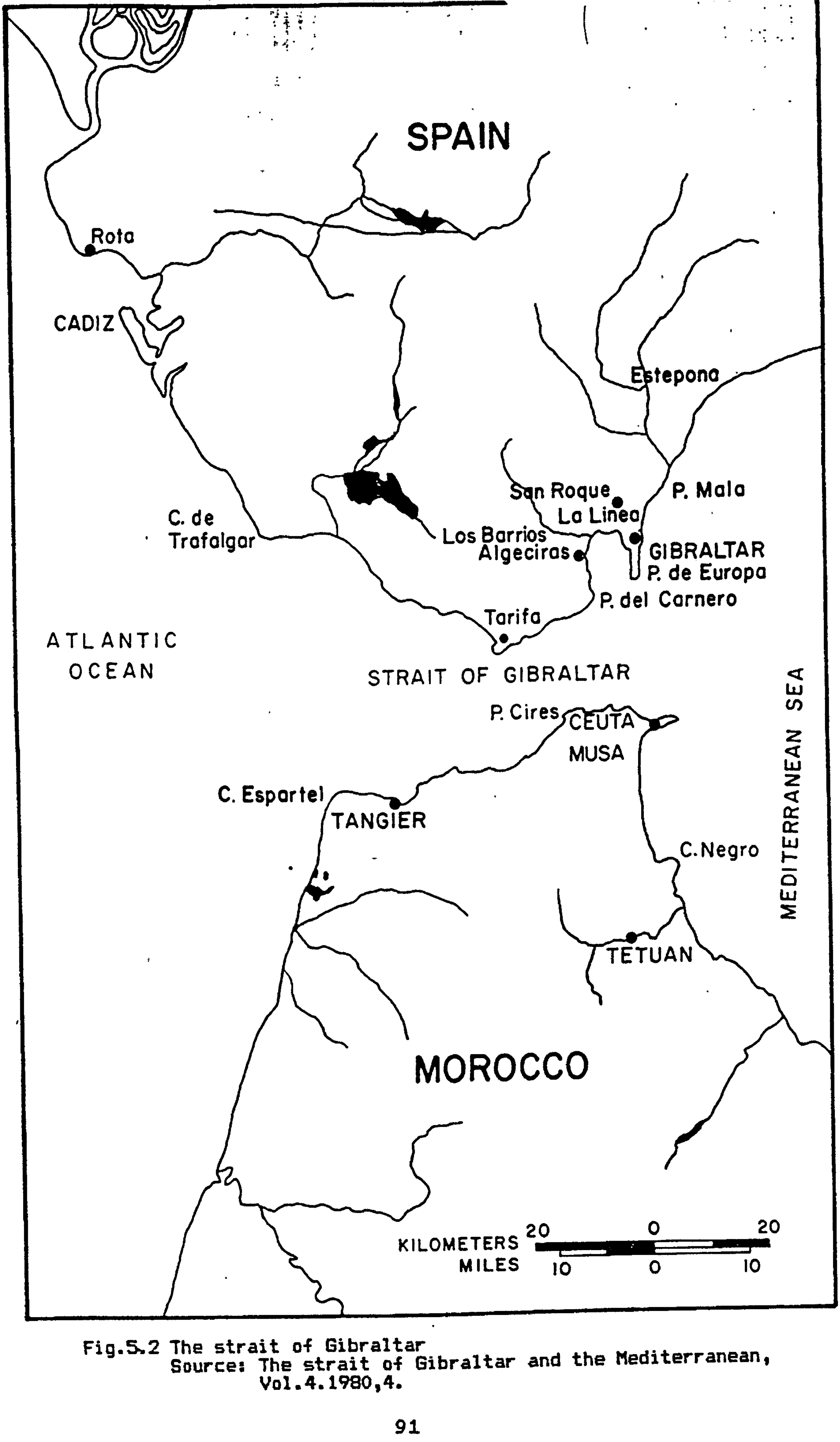

Fig.5.2 The strait of Gibraltar
Source: The strait of Gibraltar and the Mediterranean, Vol.4.1980,4.

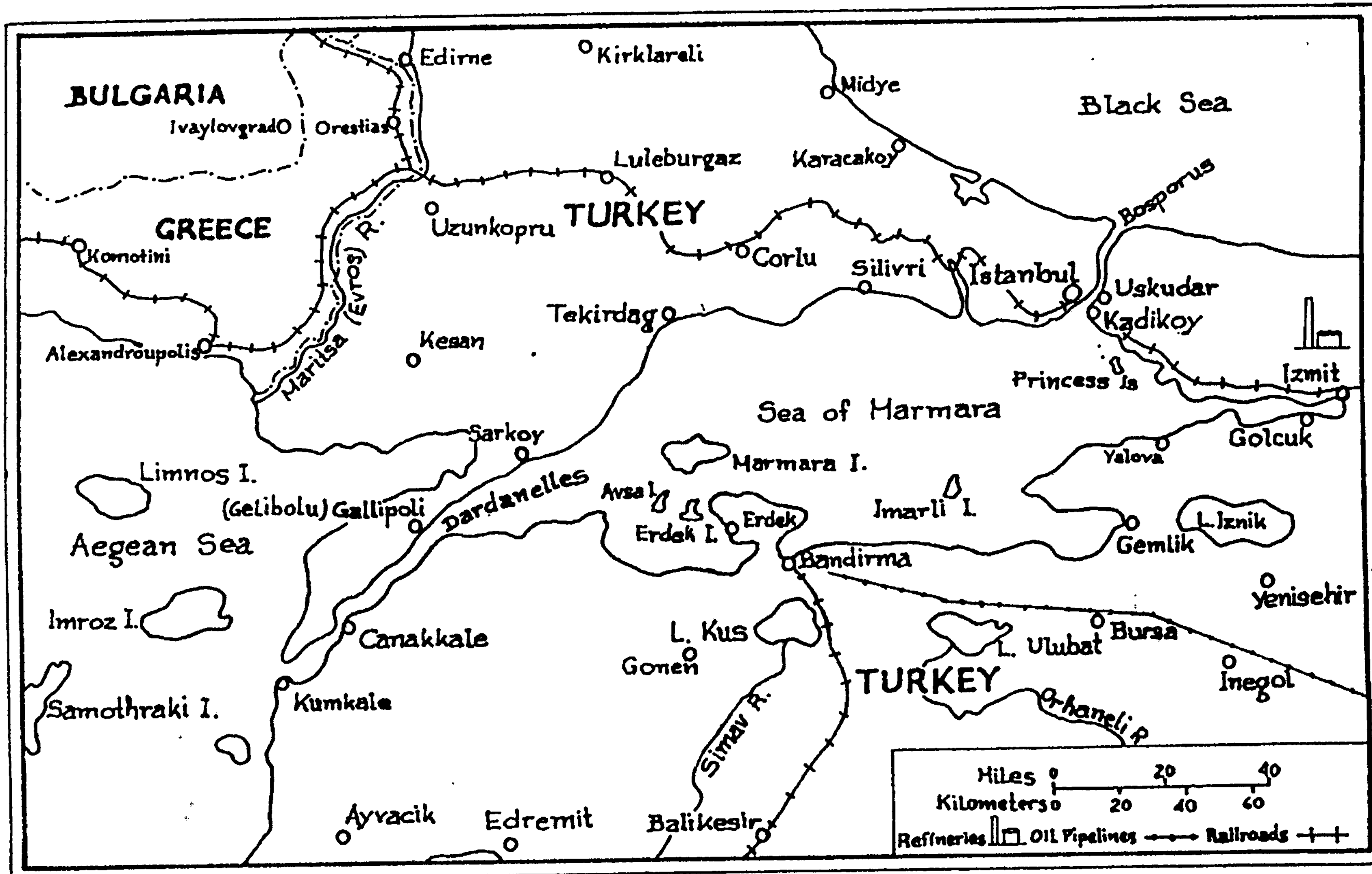

Fig.5.3 The Turkish straits
Source: The Turkish straits, Vol.9.1987,2.

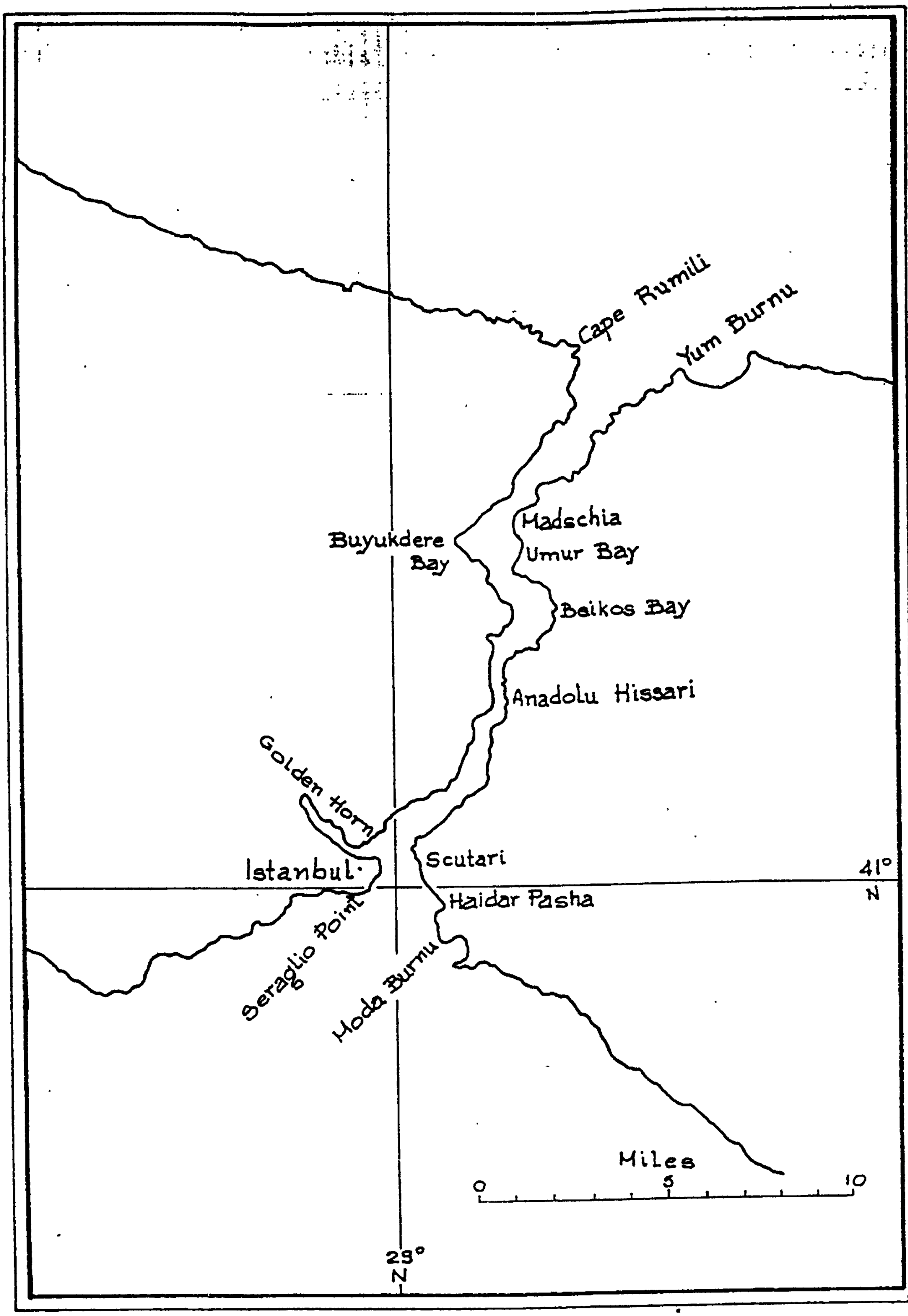

Fig.5.4 The Bosphorus
Source: The Turkish straits, Vol.9.1987,8.

The Gulf of Suez (GOS): The Red Sea is a narrow water extending south-eastwards from Suez for about 1200 miles to the Strait of Bab al Mandeb. Its shore to shore width increases from north to south, with an average breadth of 280 kilometres. The average depth of the Red Sea is about 490 metres, see fig. 5.5.

The length of the Gulf of Suez is about 175 miles, and its width differs from about 10 to 22 miles. There are many reefs and shoals along the extension of shore of the Gulf which cause difficulties to navigation. The Gulf of Suez is rich in oil, see fig. 5.6.

The traffic separation scheme (TSS) was established in the GOS in the 1970s. The traffic lanes are not in the middle of the Gulf, but lie in its western half because of the banks and shoals in the centre.

The Strait of Malacca: The Strait is located between the east coast of the Indonesian island of Sumatra and the west coast of Malaysia. The Strait provides the shortest sea route between the Indian Ocean and Pacific Ocean, see fig. 5.7. The Strait, which extends for approximately 600 miles, is the vital passage in the region used by trading vessels, and from the 1950s has been used by the very large crude carriers (VLCCs) to carry fuel oil between the Arab Gulf and Japan, see fig. 5.8.

The problems of navigation in the Strait may be from the danger of collision of vessels due to an increase in the number, the size of the ship and the consequent congestion of the narrows. Further the problems may be from grounding, and this is also due to the size and draft.

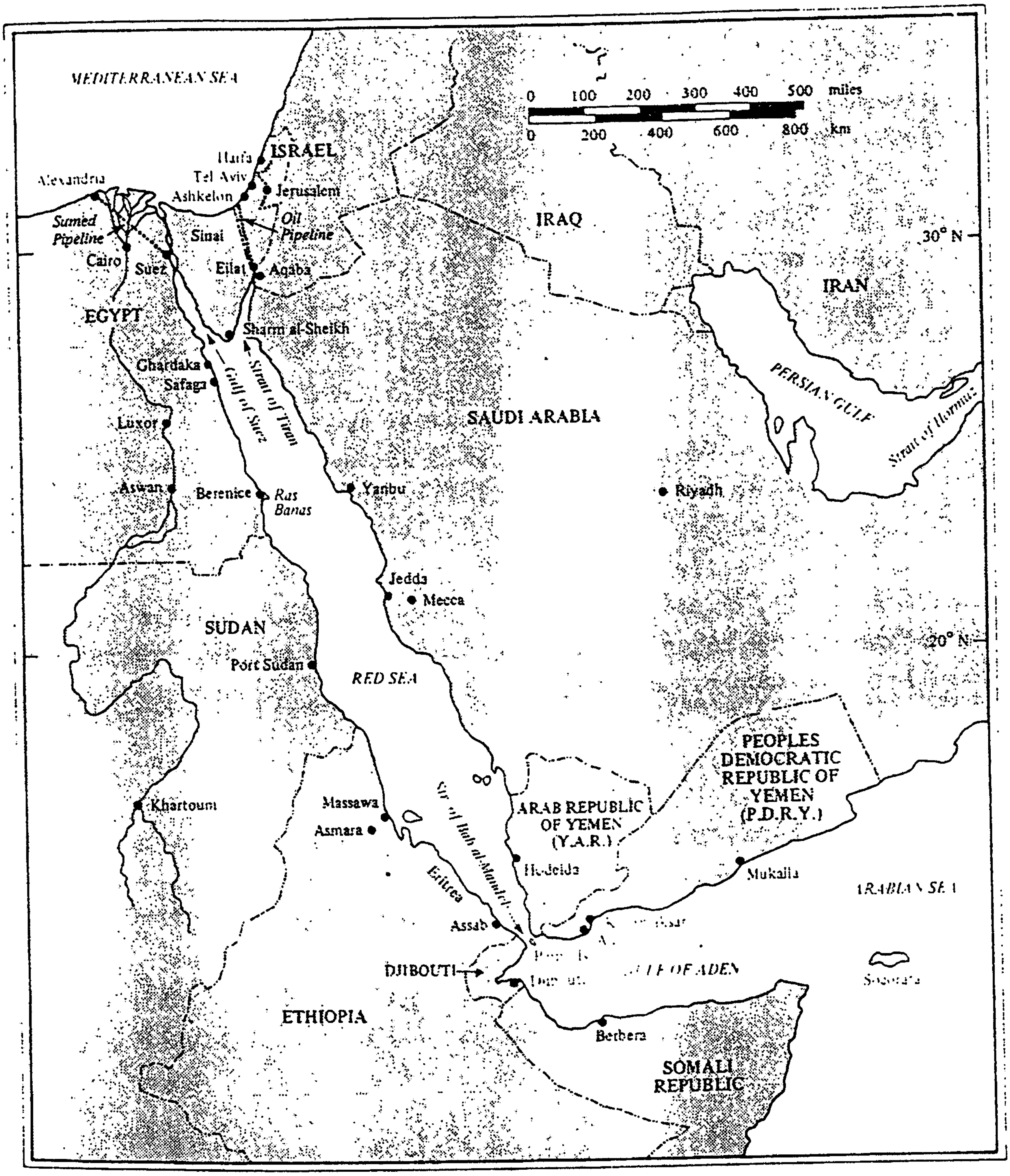

Fig.5.5 Red Sea & Gulf of Aden
Source: The Red Sea and the Gulf of Aden, Vol.5.1982,3.

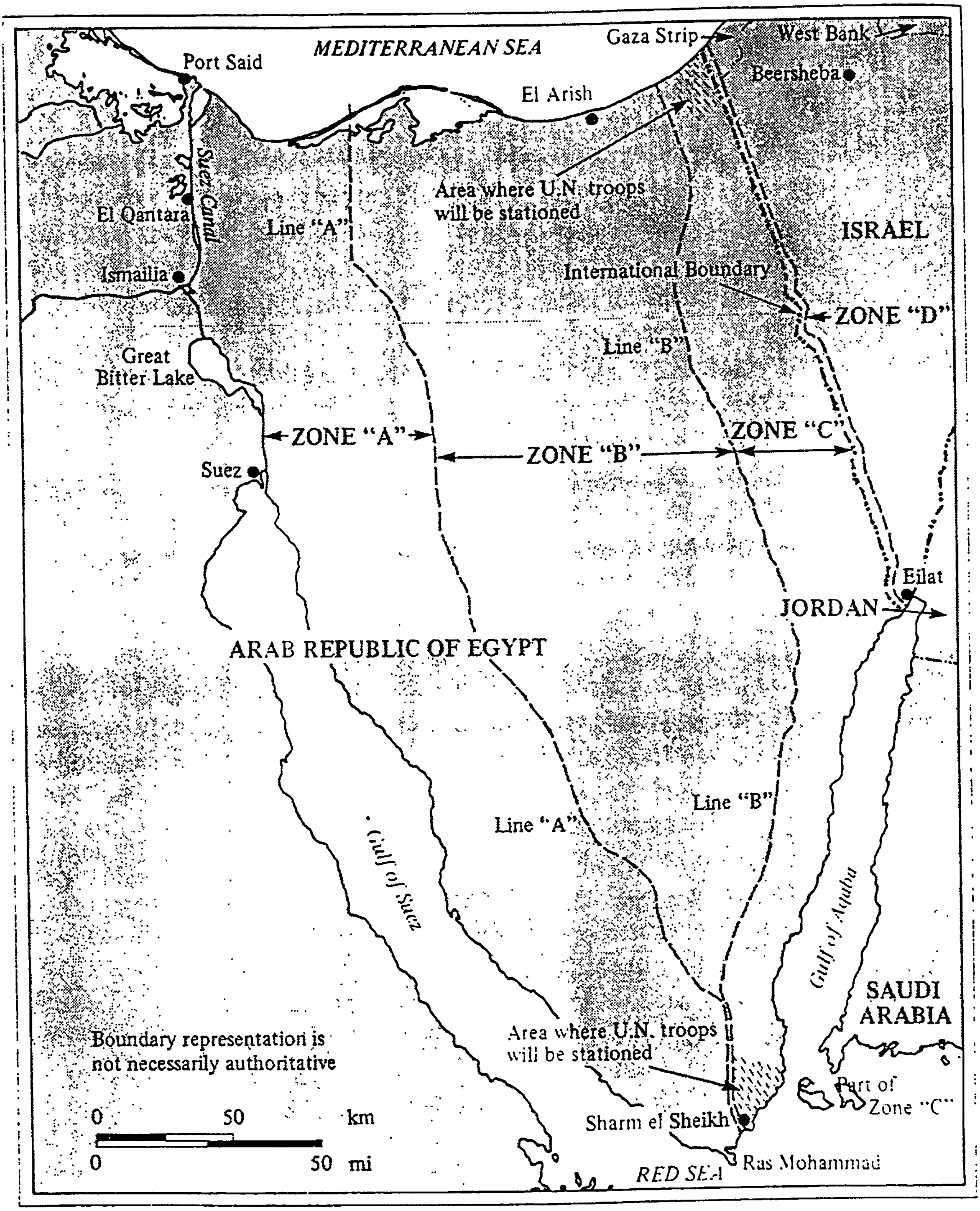

Fig.5.6 Gulf Of Suez
Source: The Red Sea and the Gulf Of Aden,
Vol.5.1982,46

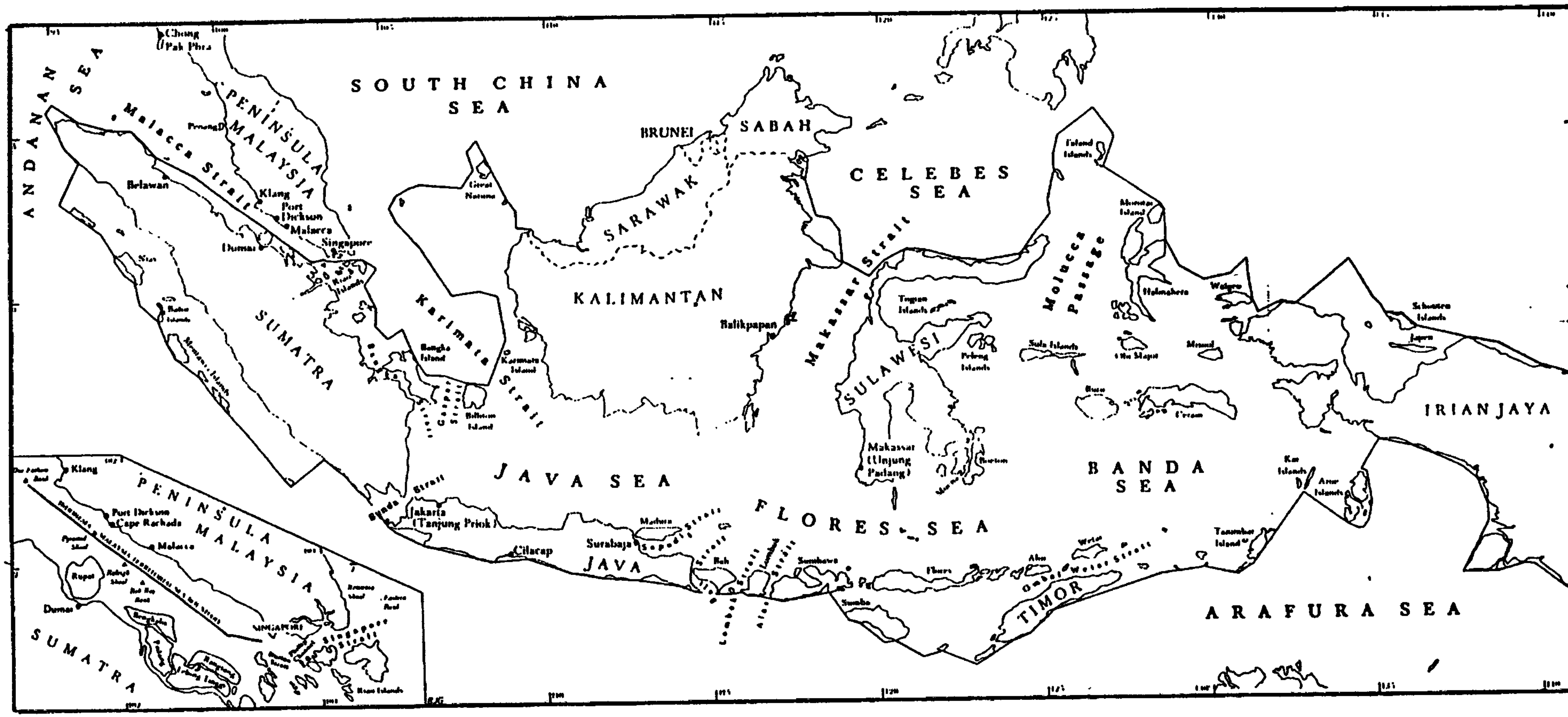

Fig.5.7 The Indonesian Straits and Archipelago Water
source: Mallacca Singapore and Indonesia,Vol.2.1978,18.

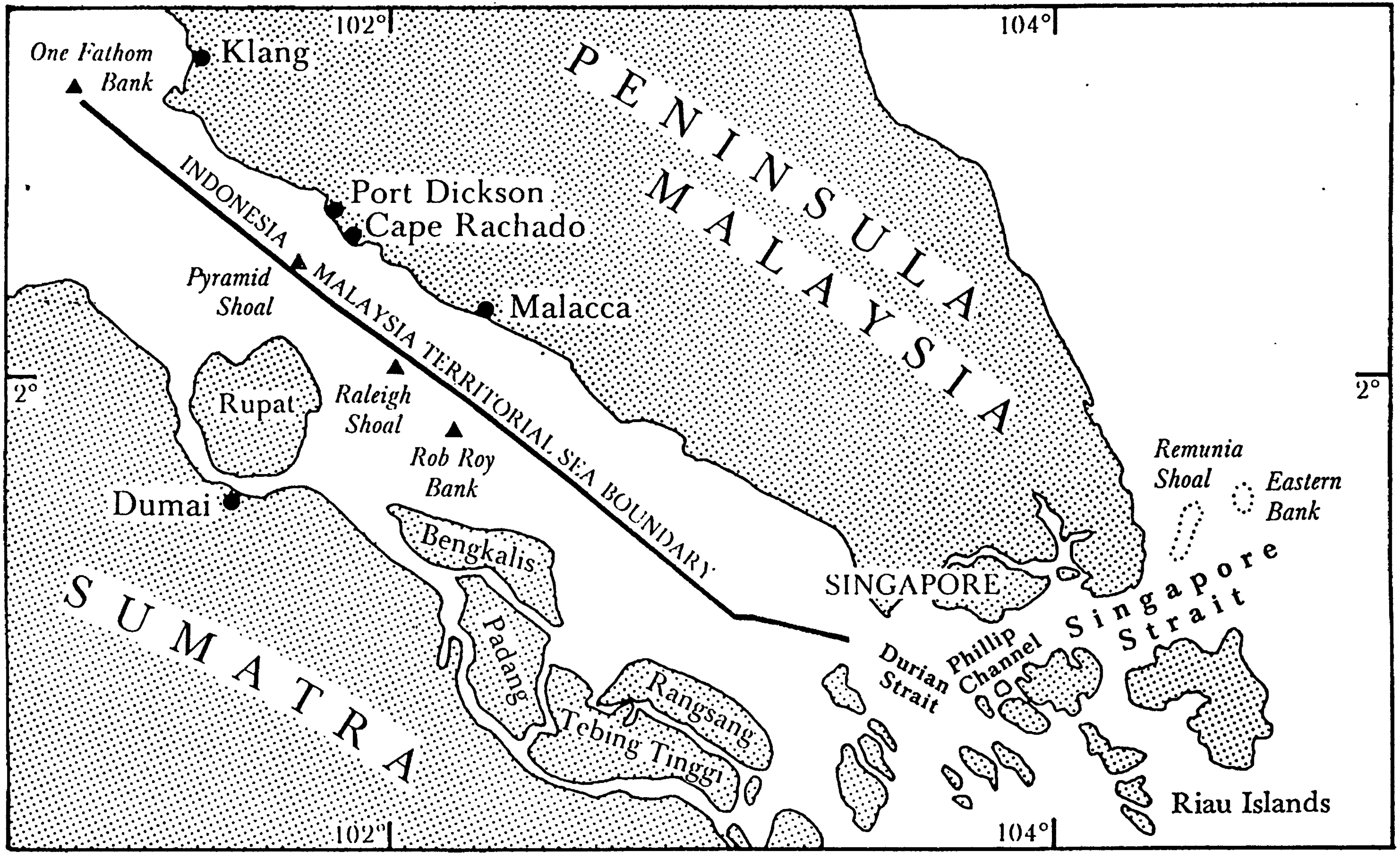

Fig.5.8 The strait of Malacca and Singapore
Source: Mallacca Singapore and Indonesia,Vol.2.1978,54.

5.2 CONSEQUENCES OF THE SYSTEM IN THE GULF OF SUEZ:

5.2.1: Introduction:

> The Gulf of Suez is a natural extension of the Suez Canal. Both together form one of the most important seaways used by ships of all nations to link the eastern and western cultures and trade.
>
> Long years of political instability in the Middle East in general and the Gulf of Suez area in particular caused the destruction of almost all aids to navigation in the Gulf. Rapid growth and development of oil exploration/exploitation of the sea-bed and shores of the Gulf of Suez added to the deterioration of the safety of navigation in the area.
>
> Moukhtar & Hussein (1987, 319).

After easing the political and military situation around the GOS area in 1973 and with the re-opening and developing of the Suez Canal in 1975, the world economy in general and maritime commerce in particular prospered considerably. The traffic along the GOS/SC increased to a large extent, the number of vessels and the amount of tonnage also increased. The increase in the carriage of dangerous goods, bulk cargo and general cargo has been remarkable. This has led to the introduction of different types of vessels such as containers, roll on-roll offs (RO-RO), oil bulk and ore vessels (OBOs), liquid natural gas (LNGs), liquid petroleum gas (LPGs), etc. Consequently, marine traffic in waterways and harbours has increased and diversified creating risky and hazardous conditions for navigational safety and traffic efficiency as well as threatening environmental quality.

In view of these developments, when combined with the deteriorated condition of aids to navigation and growth of oil exploration/exploitation, the traffic safety standards in the GOS are at stake.

5.2.2 Problems and difficulties of safe navigation in the GOS: In addition to numbers, size, and speed of vessels navigating in the GOS, plus protection of the environment, society has become more conscious of the dangers of pollution caused by marine traffic. The GOS is an area which is greatly affected by the growth of marine traffic. The problems of navigation in the GOS affecting the safety of navigation are specifically:

- The problems and troubles with the safety of navigation.
- The marine traffic.
- The overtaken encounter situation.
- The risks of contact and stranding.

5.2.2.1 The Problems and troubles with the safety of navigation: The GOS, with its width varying from 10 to 25 nautical miles, further restricted for safe navigation by reefs and an ever developing national offshore oil and gas industry, is regarded as an area having special local problems. Even if the size of the ship using the area does not increase, safe and efficient transit through the Gulf can only be maintained if the limited sea room available is used to best advantage. Its depth varies from 40 metres in the north to over 100 metres in the south. Visibility is normally good except in dust or sand storms which sometimes reduce visibility below fog limits.

Safety of navigation in its turn is dependent on adequate aids or systems of the right sort and in the right place, to assist the passing mariner. The Gulf at the southern approach to the SC extends to about 175 nautical miles. The effectiveness of visual aids to navigation is decreased seriously when the atmospheric conditions impair visibility and the situation becomes extremely difficult when ships pass through or near the jungle made up of the numerous oil rigs and offshore constructions.

Extensive activities of the oil producing companies operating in the GOS extend along an area of about 160 nautical miles. Numerous oil rigs and platforms exist, some marked by signal lights, and in some cases by fog horns and racons. Many of these oil rigs and platforms are temporary and marked on the chart after a lapse of time.

As the oil industry expands its exploration and develops the exploitation of resources in the area, the greater the traffic legitimately crossing and re-crossing the traffic in the scheme will become.

Ships pass through the oil field narrows where the navigable water is reduced by geographic constraints, further reduced by the traffic separation scheme and still further reduced by the encroachment of the oil industry activities into the traffic lane. A ship-to-ship or ship-to-platform collision could involve a spillage of an inflammable cargo.

5.2.2.2 The marine traffic: The amount of marine traffic in the GOS is determined by the convoy system, the northbound traffic, the southbound traffic and traffic to gulf ports. The main traffic flow is generally related to the Suez Canal, whether north or south bound. South of Suez, there is also the Sumed pipeline oil terminal which laden VLCCs (Very Large Crude Carriers) and ULCCs (Ultra Large Crude Carriers) (from 100.000 to 500.000 DWT) use to discharge their cargo.

Cross traffic is attributed to supply vessels servicing oil rigs, offshore activities, some fishing and some cargo vessels.

The traffic pattern is not uniform in area or time. It is generally related to the Suez Canal convoys, south and north bound. A high density traffic at the northern part of the GOS disperses at its southern end. The distance apart between consecutive vessels has been estimated to be about 2 miles in the northern part and about 6.5 miles in the southern part.

5.2.2.3 The overtaken encounter situation: Ships travel in the southbound convoy, with ships leaving the Suez Canal one after the other, each having its own type, size manoeuvring elements, navigational aids, and speed. Such a traffic pattern might place faster ships behind slower ones. This eventually causes an overtaking situation in the GOS.

5.2.2.4 The risks of contact and stranding: The risks of casualties are high in an area dependent on the characteristics of the traffic, traffic lane, ship behaviour and the features of the area.

The factors which may causes the case of risk are:

(a) Engine failure.
(b) Capsizing.
(c) Sinking.
(d) Contact and collision.
(d) Standing.
(e) Fire and explosion.

Cases of risk in the GOS are mostly from contact and stranding. The risks of contact and stranding in a traffic lane are functions of the characteristics of the lane itself. The following variable characteristics may be considered to have a dominant effect on the risks of contact and stranding between ships in the GOS:

(a) Visibility.
(b) Number of fixed targets.
(c) Distance offshore.
(d) Distance off shoal.

5.2.3 Traffic Separation Scheme (TSS) in the GOS: In order to reduce the risk of collision or interaction with the offshore petroleum construction, separation of the growing traffic in the GOS has become an essential demand.

A "separation line" was extended from northward up to the southward entrance to the Gulf. This was the first attempt to separate the traffic in the Gulf in the early 1960s.

In 1975, and in order to secure some deep navigable waters to keep international traffic through the Gulf, and hence to and from the Suez Canal (SC), a Traffic Separation Scheme (TSS) was drawn up. This TSS was adopted and entered into force on the 15th May 1978.

The amendment of the 1978 TSS in the Strait of Gubal to the south established two lanes with a separation line between them, fig. 5.9. Two years later, another

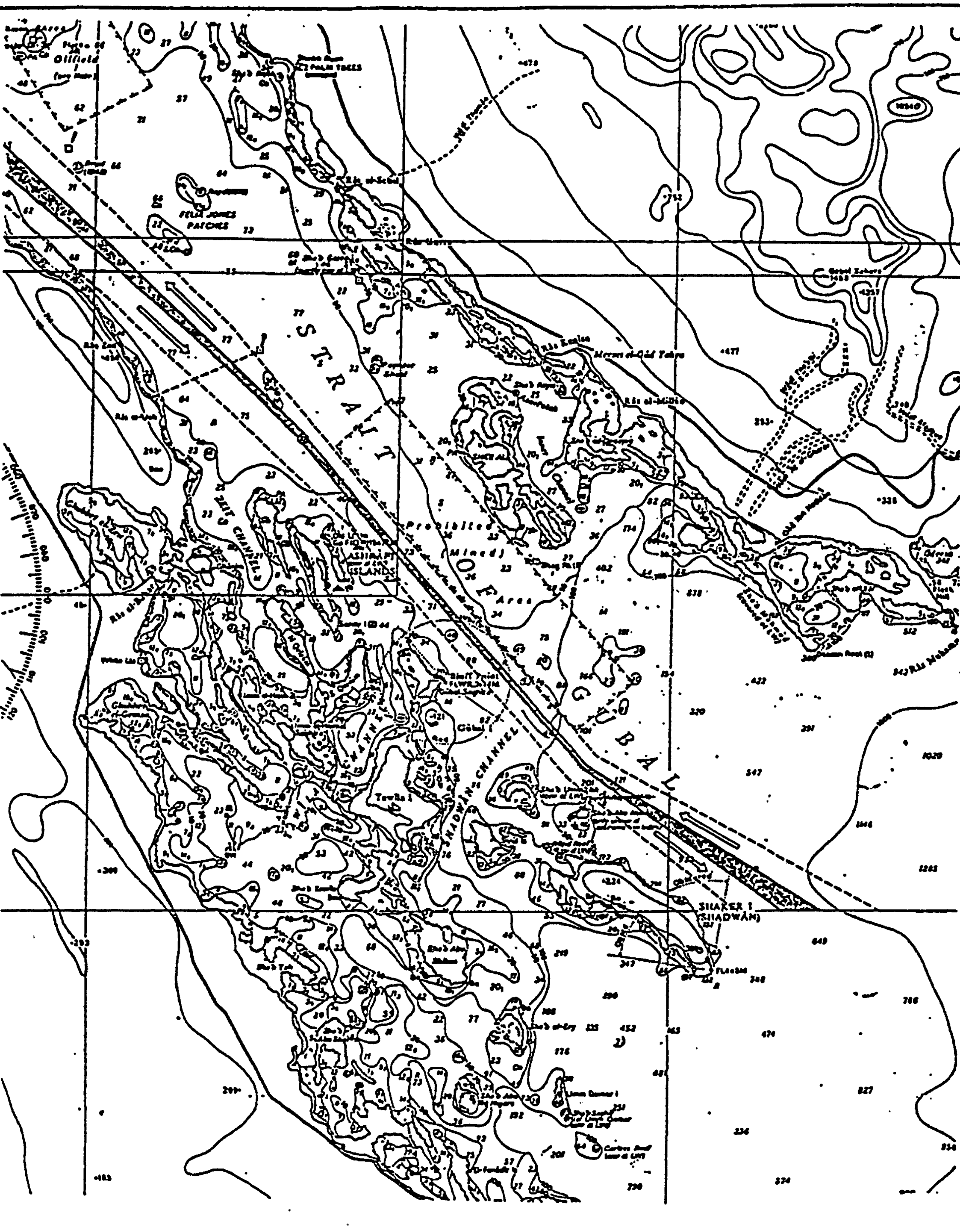

Fig.5.9 1978 TSS in the Strait of Gubal
Source: The Journal of Navigation, 305/87.

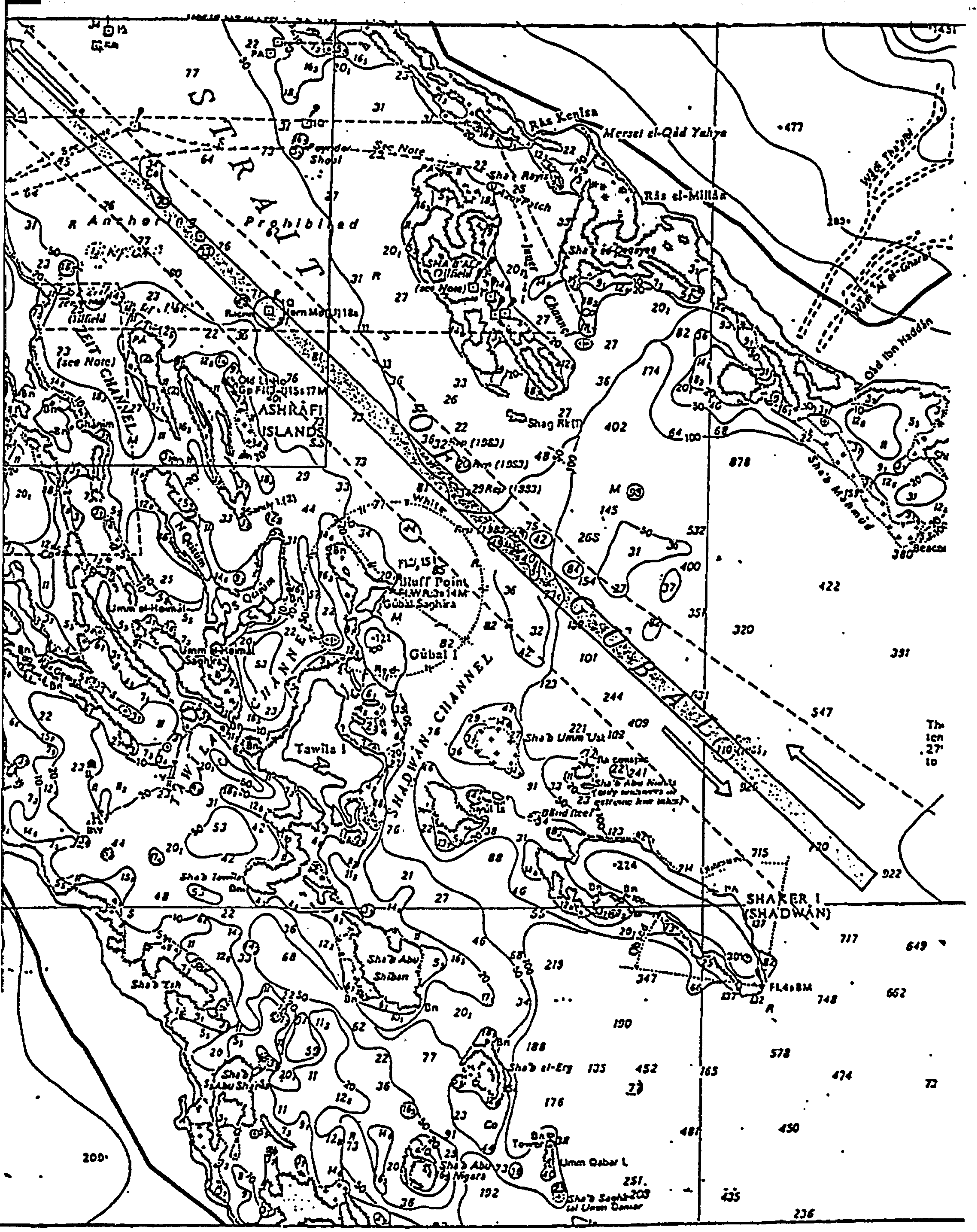

Fig.5.10 1983 TSS in the Strait of Gubal
Source: The Journal of Navigation, 306/87.

amendment of TSS 1978 was implemented which increased the lane width of the northbound and lane width of the southbound at the entrance, and kept a separation zone between them, fig. 5.10.

In 1978 new amendments to the TSS in the oil field area adjacent to Ras Shukheir were necessary because there were some problems with TSS in this area. These problems were:

(a) existence of large structures of three main oil fields,
(b) the influence of the oil rig marking lights to the lighthouses,
(c) the existence of a large developed petroleum port at Ras Shukheir,
(d) narrow navigational waters,
(e) cross traffic between the oil fields in the Gulf and Ras Shukheir port,

All these problems plus the convoy system and some curves in the TSS, in addition to the impulsiveness of some ship-masters increased the probability of ship collision situations. See fig. 5.11 and fig. 5.12.

In addition, there are some ship traffic problems on the approaches to Ain Sukna Southern Terminal of Sumed pipeline, which needed an amendment. See fig. 5.13. Most of these problems related to the convoy system, because some of the ships try to cross the TSS and head for the Sumed Terminal, while others try to cross the eastern boundary of the TSS to the anchorage area of the VLCC. In addition, some VLCC loaded or in ballast try to join the north or south bound lanes.

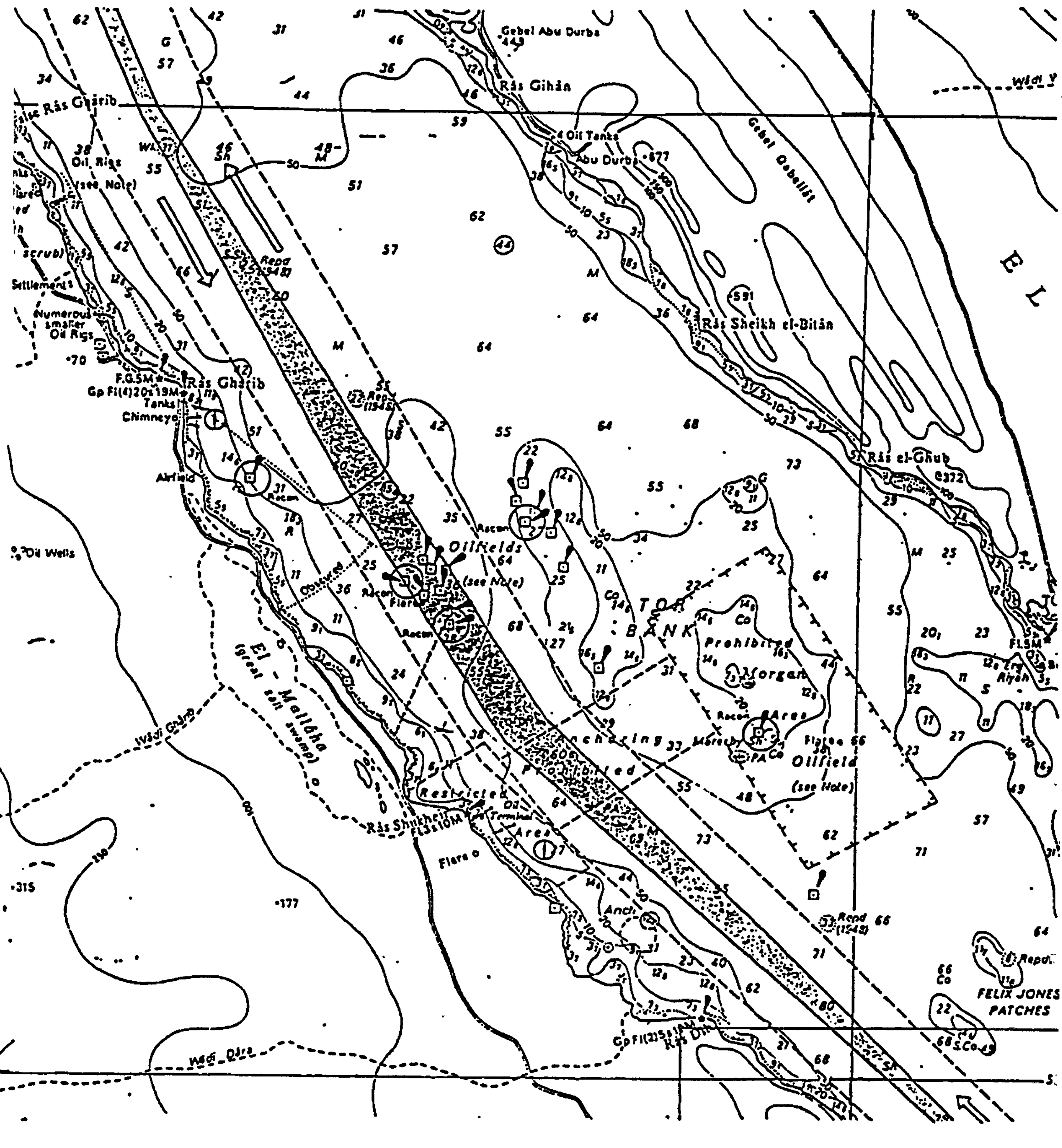

Fig.5.11 TSS off Ras Shukheir before amendment
Source: The Journal of Navigation, 307/87.

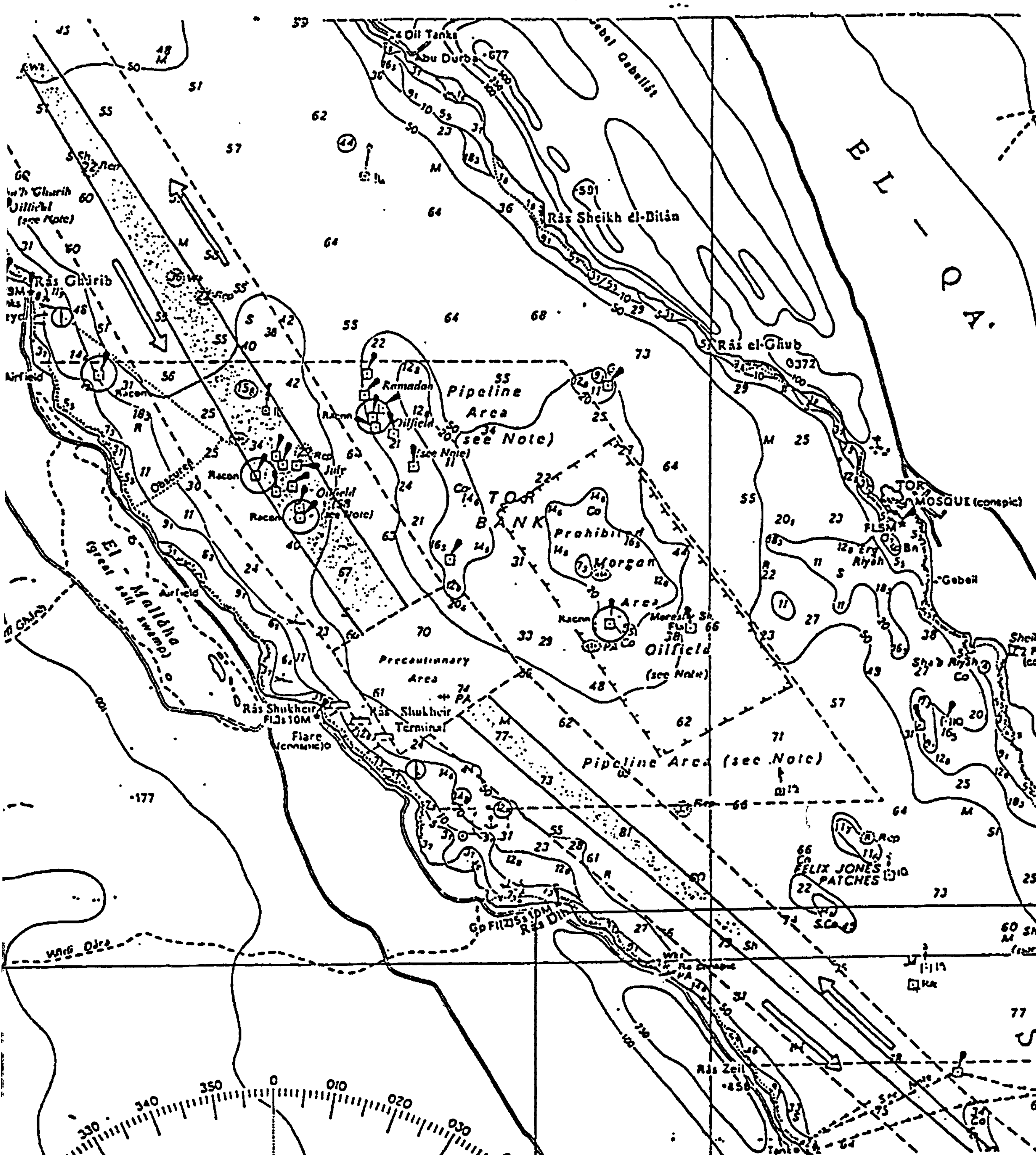

Fig.5.12 TSS Ras shukheir after amendment
Source: The Journal of Navigation, 308/87.

Finally, and after studies to solve the problems and secure the navigation of ships in this area, the appropriate design emerged as shown in fig. 5.14.

The proposed re-amendment of the TSS in the GOS, consisted of widening the separation zone to contain oil fields GH 404-1 and GS 391-3 and re-delineating the eastern boundary of the northbound lane to avoid oil field GH 451-1. See fig. 5.15.

5.2.3.1 Aids to navigation in the GOS: In the past, there were some separate visual aids, which could be used as landfalls and landmarks. A network of visual aids to navigation is the new design, where the aim is to have overlap coverage extended to any part of TSS, and with possibilities of fixing any ship with good accuracy.

The worst accuracy of the system from the final design of the new TSS and its supporting system of aids to navigation network should be not less than 25 per cent of the narrowest lane width which is equal to 0.9 nautical miles. So, the design of the network of visual aids has fulfilled the international recommendations for accuracy standard norms.

At the critical area of the TSS, light-floats were recommended to be moored at a particular position within the separation zone. Most of the visual aids are recommended to be equipped with RACONs (Radar Responding Beacons) as a back-up system to the visual aids in order to improve the fixing accuracy, particularly in case of bad visibility.

When the GOS Project of the total network which includes visual/radio/electronic aids to navigation, is

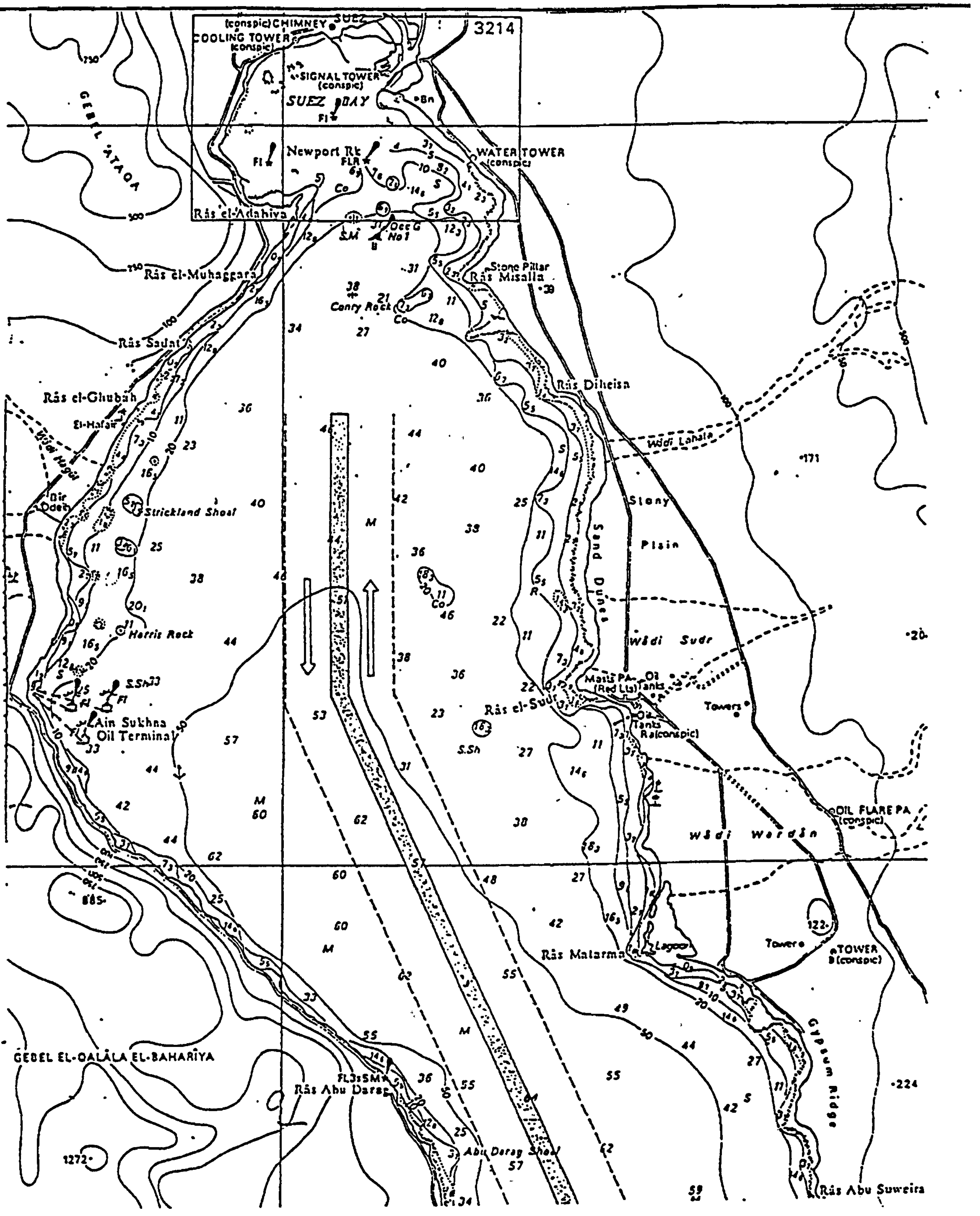

Fig.5.13 TSS off Ain-Sukhna before amendment
Source: The Journal of Navigation, 310/87.

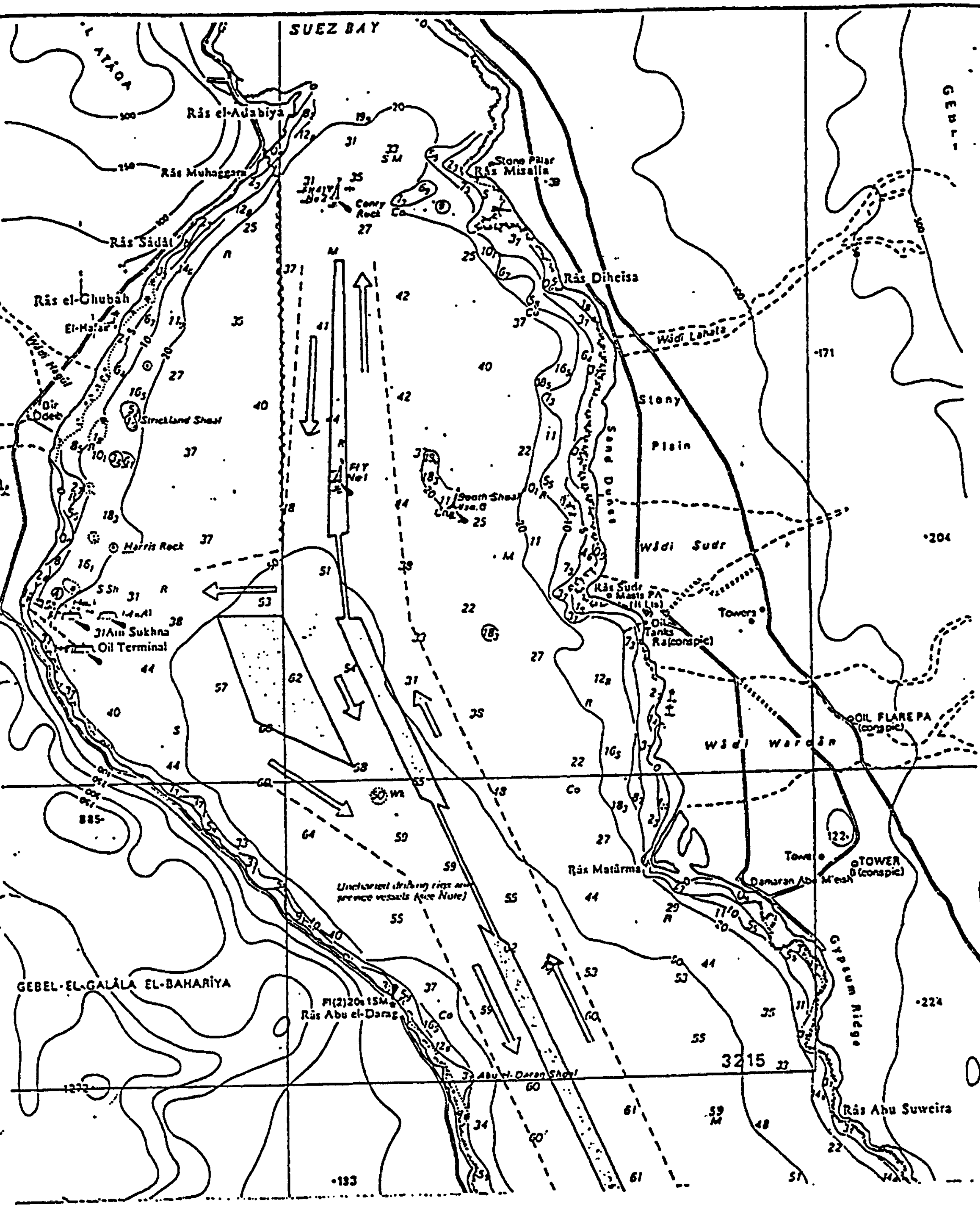

Fig.5.14 TSS off Ain-Sukhna before amendment
Source: The Journal of Navigation, 311/87.

complete and working to support the TSS in the Gulf, the Project will then comprise major high power lights (luminous range (LR) not less than 20 n.m.); medium power lights (LR not less than 15 n.m.); low power lights (LR not less than 9 n.m.), some of these power lights are being modernized and some are new; radar responding beacons "Racons"; a radio broadcasting station to broadcast information on ship traffic, rig moves and other warnings throughout the GOS; a radio monitoring system, which is equipped with every visual/radio/ electronic aids to navigation in the Gulf to detect and relay any defects in the light floats system. All of these aids to navigation shall be very suitable to the vessel traffic services (VTS).

5.2.4 Vessel Traffic Services (VTS) in the GOS: 'IMO Guidlines for Vessel Traffic Services' Resolution A.578(14), adopted on 20 November 1985, defines vessel traffic services as:

> Any service implemented by a competent authority, designed to improve safety and efficiency of traffic and the protection of the environment. It may range from the provision of simple information messages to extensive management of traffic within a port or waterway.

In January 1982, following international anxiety over the state of navigational safety in the GOS, a Note by the Government of Egypt was prepared by a Ministerial Committee (MC), and was delivered by a member of the MC on the 12th February 1982 to the IMO Secretariat for the immediate consideration of the Sub-Committee on Safety of Navigation at its meeting scheduled 15-19 February 1982.

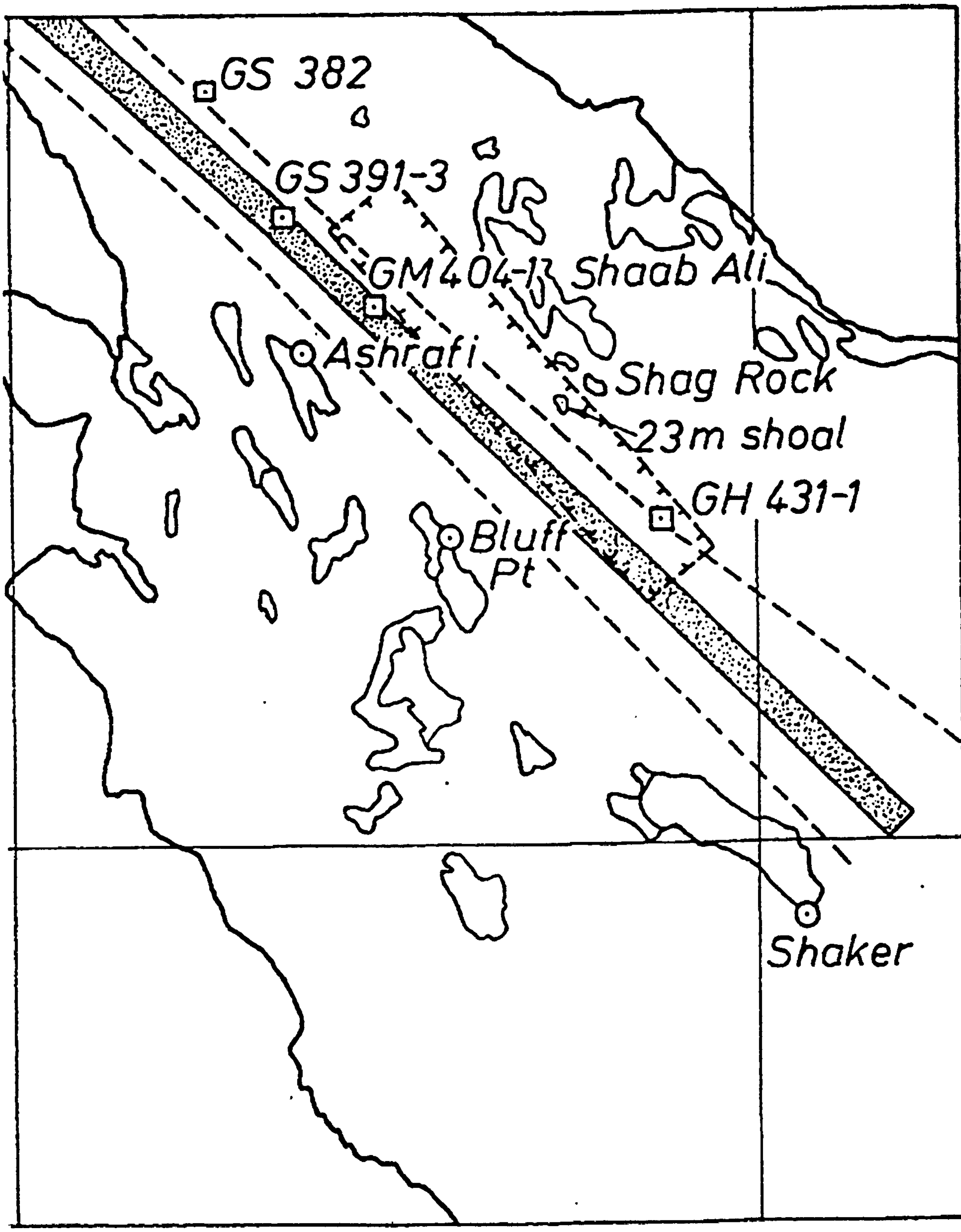

Fig.5.15 Re-amended TSS in the Strait of Gubal to avoid the three oil fields:
GS 391-3; GM 404-1; GH 431-1
Source: The Journal of Navigation, 313/87.

The Egyptian note included a comprehensive study of an integrated project, phased into 4 phases, supported by navigational charts for the GOS on which showed the newly designed TSS with its supporting elaborate aids to navigation system.

Deliberations between the Egyptian Government representatives and IMO specialized committees continued during the period February 1982 to September 1982 when the re-amended TSS was adopted by the Maritime Safety Committee (MSC) at its 47th session, with an implementation date of not before 15 March 1983.

In phase III of the GOS project, it is recommended that VTS stations should be established in three areas in the GOS, and in phase IV it is recommended integrating the VTS system to cover the whole GOS.

The NAVIGOS Conference in October 1986 in Cairo has identified a number of factors which were aimed to be important for the safety of navigation in the GOS. One concerns the general recommendation about VTS as 'whether there is a need for a VTS system and its functions together with the study of possible need for a pilotage system'.

There were two recommendations to establish a VTS system in the GOS. Resolution A. 578 (14), mentioned before, recommends the establishment of VTS if one or more of the following conditions exists:

. high traffic density;
. traffic with noxious or dangerous cargo;
. navigational difficulties;
. narrow channel;
. environmental sensitivity.

All the above conditions are applicable to GOS.

The VTS system in the GOS will be under radar coverage with one or more VTS centres aided by a VHF communication system. In addition, there are 24 out of 34 visual aids equipped with Racons.

Resolution .A.578 (14). dealing with Reporting within a VTS recommended that ships participating in a VTS should report, if required, at the designated positions and times in accordance with the agreed reporting format. As far as practicable, the Master should ensure a correct and timely reporting.

The information which the authority requires from the vessels passing the GOS VTS system may include time, position, course, speed, draft, passage plan and ETA at the next reporting position. The hybrid Loran-C/GPS system can become the available navigation system to vessels on their routes passing the GOS VTS system, and maybe the 'Navigation System' (chapter four) is also available to provide the VTS authority with all the information required.

Through monitoring the traffic, any vessel that is in any dangerous navigational situation will be warned and given the required navigational assistance service. Also, all necessary information will be provided to the traffic in the area. However, in order to achieve the purpose of implementing VTS i.e. organising traffic, rules and regulations have to address the specific risk factors associated with the existing conditions of the GOS.

Additionally, the GOS encompasses a number of navigational problems. As such, special vessels should be given traffic priority to reduce the duration of their sailing time through the waterway. These special priority vessels need to be identified by GOS VTS authority and necessary actions should be taken to facilitate their fast passage.

5.3 THE PROPOSED SYSTEM TO OVERCOME THE PROBLEMS ENCOUNTERED IN THE GULF OF SUEZ:

The current status in the GOS can be stated as follows:

- The safety of navigation and offshore oil structures still depends on the human element, even after implementing visual, electronic, and radio aids to navigation.
- Current studies to develop the Suez Canal so as to increase its capacity are in hand.
- There is a proliferation of activities associated with oil production, seafood harvesting and tourism.

This status, when added to the conditions stipulated in resolution A.578 (14) indicates the urgent necessity for better accuracy standards in the GOS.

The navigation systems considered as candidates for meeting navigation requirements in the GOS are GPS and Loran-C as a hybrid system mentioned in Chapter Three, and in which GPS is used as the main source of position fixing and Loran-C as a back-up radio navigation aid in the event that, for whatever reasons, the GPS might become unavailable.

Compliance of a navigation system with technical performance requirements is one for several conditions for determining acceptability. The criteria used to determine the acceptability of both systems to be used in the GOS are divided into the following categories:

. Technical/operational which include accuracy, coverage, integrity, reliability, and operational suitability;
. Economic considerations which include the initial investment, operating, maintenance, and replacement costs; and
. Institutional consideration which is concerned primarily with the effects and resolution of political issues such as international standardization, distribution of costs, system ownership control, and operation and maintenance .

In the technical considerations, the most significant amount of attention considered in this selection process is given to investigation of the proposed system of accuracy and signal coverage supporting and ensuring the safe movement of vessels on their routes via the GOS.

GPS, is the navigation system capable of satisfying the accuracy and coverage requirements in all operational environments on a global scale. The system was particularly designed as a navigation system to improve and to fulfil all navigation requirements 24 hours a day in all weather conditions and to provide high accuracy, velocity information and accurate time. The final constellation will provide complete four satellite coverage world-wide at all times.

Certain techniques can be adopted even within an environment of selective availability to further improve on the real-time system accuracies. Primarily this is through the use of differential techniques.

The Loran-C system was developed to extend Loran coverage with fewer stations. High precision is obtained by both envelop matching of the pulse and phase matching of cycle within the pulse. The high accuracies obtained with Loran-C resulting from the ability to separate the ground wave from the sky wave at the receiver and to identify a particular ground wave cycle within the pulse. Its accuracy is limited mainly by the range of ground wave reception rather than by geometrical factors or sky wave interference.

In the institutional considerations, Loran-C system is recommended (The NAVIGOS Conference in October 1986) to be adopted as a regional navigation system in Egypt. The recommendation is given on the basis that the system will be compatible with the Loran-C chains being installed in Saudia Arabia which cover the Red Sea and Arabian Gulf; and the southern Europe chain which covers the Mediterranean Sea.

SAUDIA ARABIA CHAINS: The Saudia Arabia Loran-C system, which was established in 1980, consists of two chains, covering the Red Sea, the Arabian Gulf, and the total land mass of the Kingdom. The North chain, GRI 8990 was developed first. It consists of a master (M) located in the central area of the country, and a large number (5) of secondaries located at periphery points. The South chain, GRI 7170, was established by just adding one more station for the master, and doubling up on station

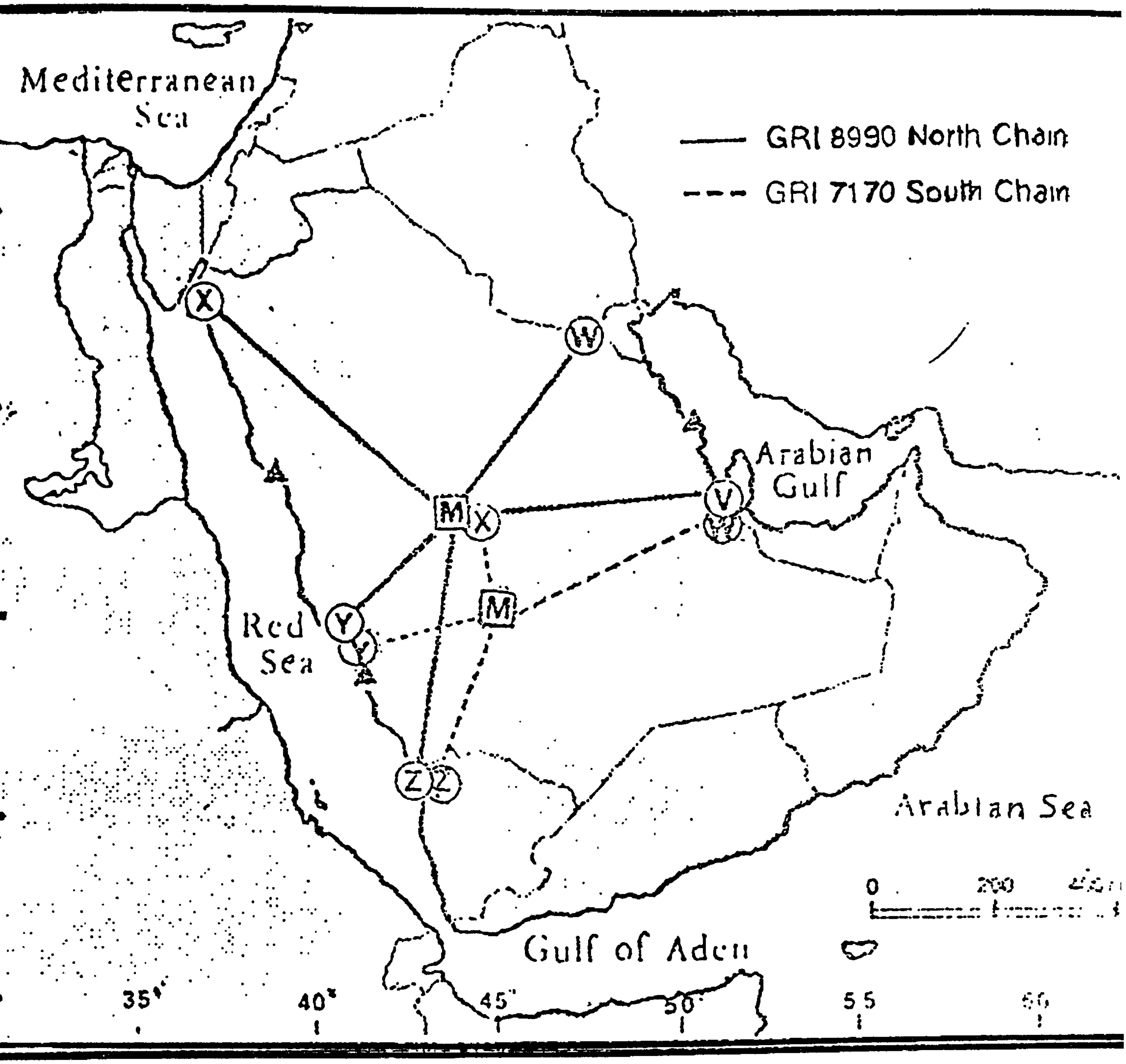

Fig.5.16 Loran-C Chains in Saudia Arabia
Source: The Loran-C Users Guide for cruisers racers fishermen, 135/1986

functions with some of those stations in the North chain. The secondaries are shown in the fig 5.16.

Between the two chains, the Saudia Arabia system provides primary coverage for all navigable waters surrounding Saudia Arabia and adjacent countries. These include the Red Sea, the eastern end of the Mediterranean Sea, the Arabian Gulf, the Gulf of Aden and the northern end of the Arabian Sea.

MEDITERRANEAN CHAIN: Coverage for the Mediterranean Sea is provided by the Mediterranean chain with GRI 7990. As the name implies, primary coverage for this chain includes most of the Mediterranean sae, with only the extreme eastern and western ends and a section off the African coast lying outside this area. Secondary coverage, which involves utilization of sky waves, provides coverage for all of the Mediterranean, fig 5.17.

Mokhtar & Hussein, (1988, 5,6) put forward a proposed Loran-C system for Egypt in the following words:

> Bearing in mind all aforementioned considerations and accuracy requirements, several options were sketched for different locations of transmitters. Finally, we believe that Fig 5.18 represents the optimum configuration that can realize almost all accuracy requirements for different users in Egypt. It covers the GOS and its approaches by 25 m repeatable accuracy; Gulf of Akaba, all of the Western Desert and approaches to all northern ports on the Mediterranean by accuracies better than 50 m; All of Egyptian territories and East Mediterranean up to the

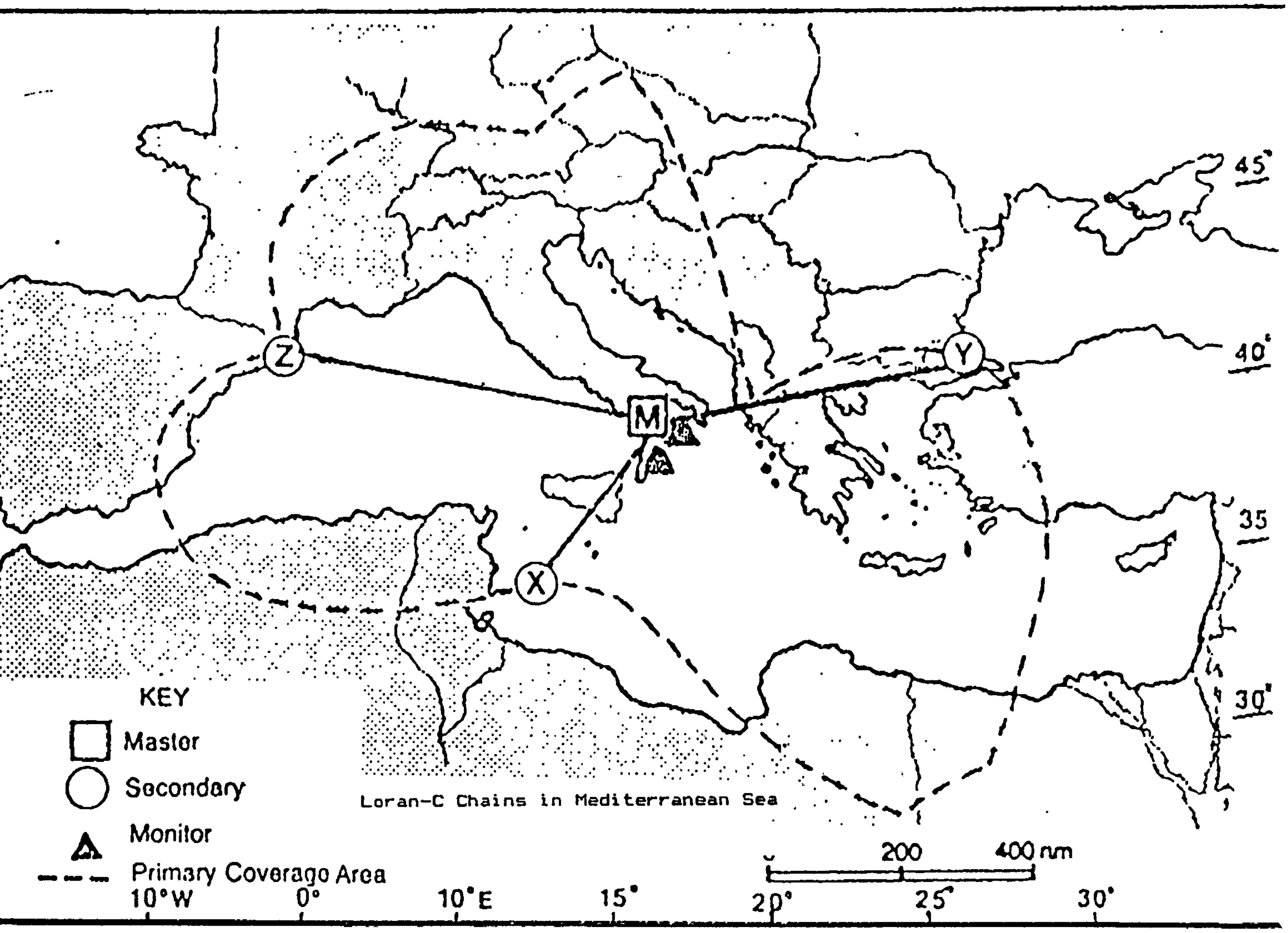

Fig. 5.17 Loran-C Chains in Mediterranean Sea
Source: The Loran-C Users Guide for cruisers racers fishermen, 134/1986

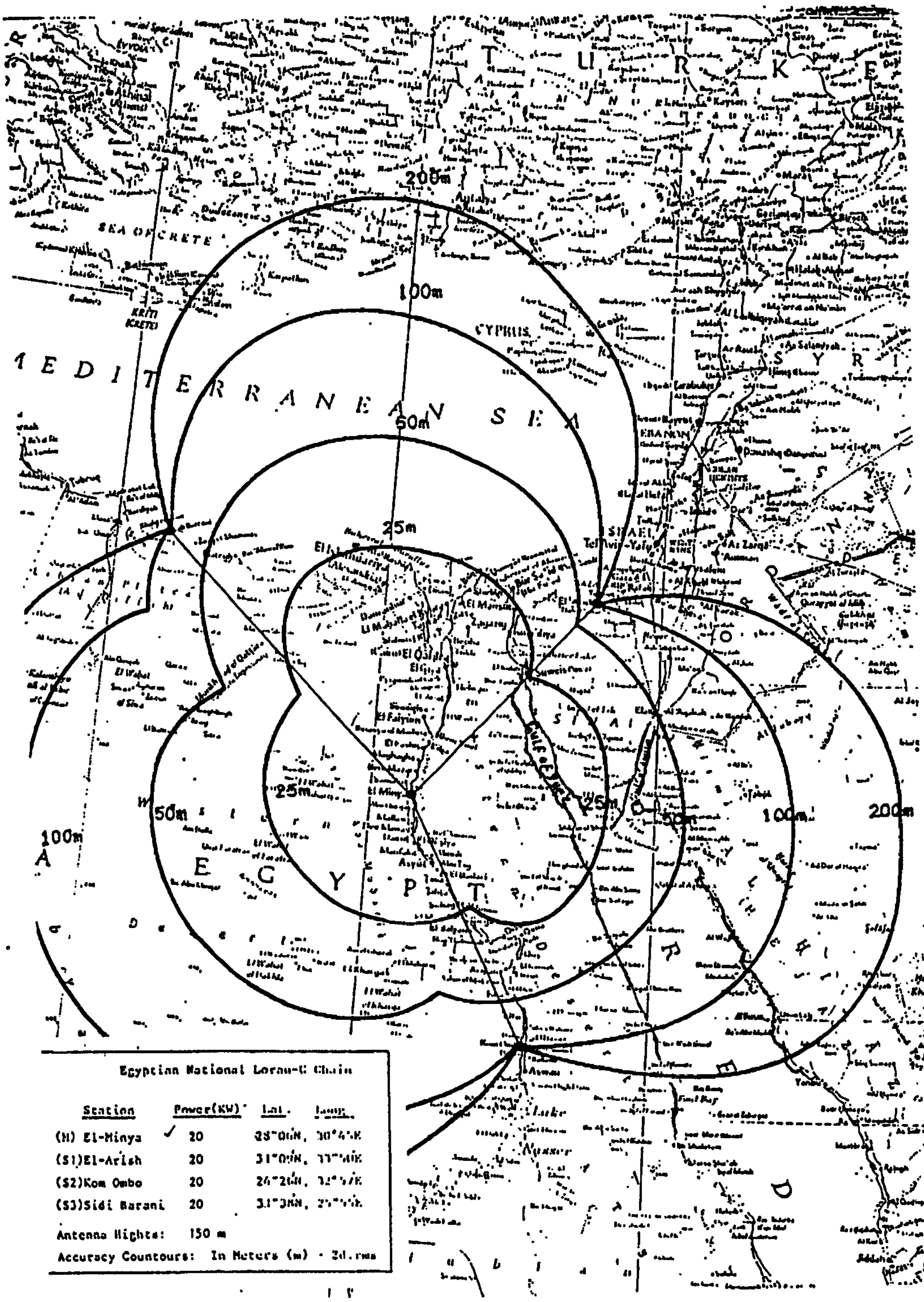

Fig. 5.18 Egyptian National Loran-C Chain
Source: Nave 88, 30/88

southern coasts of Turkey with accuracies better than 100 m.

CHAPTER SIX

THE IMPLICATIONS OF INTEGRATED NAVIGATION SYSTEMS FOR MARITIME EDUCATION AND TRAINING

6.1 INTRODUCTION:

> Education and training are two aspects of the teaching process, and can best be differentiated by considering learning objectives to be directed in a general sense in the former case but towards specific objectives in the training context.
>
> Muirhead, (1994,1).

The initial goal of maritime education and training (MET) is to provide and develop the knowledge and skills for seafarers which will raise the levels of safety of life at sea for the efficient and effective carriage of goods and passengers. Maritime education and training also makes realization and knowledge of the sea more active. Indeed, maritime education and training includes the different ways to provide seafarers with the ability to do the daily work on-board, and the ability to respond correctly and effectively to emergency situations.

Today, the function of the crew is often in a supervisory role over technically developed systems. When the crew understand the capability, the characteristics, and limitations of the developed system, beside their functions and duties in the organized system, training will enhance their action taking and decision making ability. Additionally, promoting education for seafarers means that they are better educated with the ability to have greater functional adaptability.

Developments in the field of technology, especially when applied to the many aspects of ship operation such as electronic navigation aids, telecommunications, information technology, computers etc, should change the functions and performance of seafarers significantly.

However, technology is causing important crew reductions in favour of economic influences, hence the manning of a ship is greatly dependent upon the shipboard technology fitted, i.e type, amount, and reliability of equipment which will determine the level of manning and distribution of on-board skills.

The question now is what are the necessary requirements to achieve a successful process of maritime education and training so as to meet the continuously increasing requirements of technology in accordance with the STCW Convention? To achieve proper levels and related capabilities to carry out the tasks as well as possible, the skilled operative, will need to be effective and efficient in responding to the new technology. This will require new training programs.

The continuous expansion in the field of electronic navigation systems, bringing new theories in the same field, together with the improvement in system designs, instruments, and applications are introduced as a continuous flow, and take different forms. Now the initial function of the crew member is to monitor, verify, manage resources and encounter emergency cases, rather than to participate actively and continuously in the control loop.

As systems become more sophisticated and automated, it is very important for the watchkeeper to understand how the performance and functions of the system work, how to optimize the resource efficiency, how it could fail, and what the signs of failure are. All this is in addition to the practical knowledge and skill in understanding its uses.

Finally, the officers should always be able to react to any changes in technology and be able to adopt the benefits the developed technology offers.

6.2 THE CONSEQUENCES OF SIMULATION TECHNOLOGY:

In general, it requires much effort to achieve the objectives of a maritime educational scheme through traditional training and vocational learning methods only. To achieve some objectives safely, marine simulators are probably the best medium, and for this reason, support to develop simulation training programs is increasingly justified and required from maritime administrations and training institutions.

Simulators have been used as an effective and efficient training medium in all fields of maritime education and training, and has been accepted worldwide due to its flexibility and effectiveness. In addition, Cross argues, (1993,2) that:

Simulator training can be considered somewhere in between teaching and training. It is not only transfer of knowledge we are aiming for, but is certainly not only a matter of mastering skills either.

Knowledge achieved through teaching is used here in a training scenario, to perform in the right way, exhibiting skills in order to reach the set objective.

When students encounter the expected and unexpected parameters of the task in ship handling, navigation, cargo transfer, etc, and in order to solve the problem of human error which is a major cause of accidents, simulation technology has been developed for the fundamental and additional training of operators of technical systems, plants and equipment of all types. It is a kind of exercise training medium designed to improve the skill which depends upon the person's mental and physical ability, whilst also reducing the possibility of human error thus saving money for the shipowners, operators and insurers.

Of course, much depends on how effectively simulators are used in training. The following comments illustrate the factors that need to be taken account of:

Effective simulator based training is reliant upon several factors:

. The development of specific training objectives.

. The selection of tasks relevant to the training purpose and operational skills needed on board.

. Exercise pre-briefing, control, monitoring and debriefing techniques are understood and used effectively by the instructor.

. The simulator provides a suitable operating environment for the selected objectives and training tasks.

Muirhead & Zade, (1994, 6&7).

There is a further advantage provided by simulator training. It reduces the time of training relative to the time spent in training at sea, where the situation may not always be conducive to carrying out practical training tasks. For the simulator environment, no loss of time occurs due to these other factors.

6.3 THE CAPABILITY AND LIMITATION OF THE PLANT AND THE EQUIPMENT USERS':

Perceptibility is a prime skill which allows a mariner to resolve problems. For many, a lack of perception limits their ability to achieve these objectives. The main limitation of the user has changed now due to the new level of awareness and information processing created by the use of modern technology and training.

With the introduction of new technology and marine computer systems, which cause changes in the number and type of navigational systems and navigational equipment, it has been found necessary to design the equipment to harmonise with the user's ability and capability, and to provide him with quick access to information in a suitable form. Thus the user should be required to understand how to use the navigational equipment effectively; how to care for and maintain the equipment; and finally understand the limitations of the equipment.

Therefore, there have been many attempts to determine the quantity of the information that could be collected, processed, arranged systematically, and displayed to enhance the user's processing skills and understanding of the situation.

Nowadays, the navigator's skills initially are not dependent upon what is presented to him, but relate to what he has in his mind, what it is he understands, and how he can use the information received.

6.4 OPERATIONAL PROCEDURES:

6.4.1 Setting standards: The setting of standards and qualifications emanates from organizations which have the responsibility to set those standards and qualifications such as Governments, IMO, educational and training institutions or authorities, insurers and shipowners.

As mentioned before in section 6.1 each person requires a wider range of skills than in the past. Such smaller crews require different management skills, partnered with effective team work.

The operation of electronic systems, does not require a high level of skill, but the user does require good information and understanding of the operation of the system. In addition, on-board maintenance is not probably required to a high level of skill as electronic board replacement is probably to be the standard.

6.4.2 New developments:

One Man Bridge Operation "OMBO"

> The impetus to reduce manning levels in ships in the past decade has been stimulated by development in new technology and increased economic competition from developing nations keen to break into traditional trade routes. Recent years have witnessed further manning reductions leading to an outcome that has culminated in the introduction of 24 hour one-man bridge operations.
>
> Muirhead, (1992, 1).

The concept of OMBO requires development towards automation and more reliability for all the ship's systems including machinery, deck and bridge systems. In order to reduce the workload on the bridge system, it requires more automation of the navigation equipment. Further, Muirhead, (1992, 1) added that the one man bridge system has an impact upon bridge ergonomics and design, operational effectiveness and safety, man-machine interface and training needs.

How can the concept of the OMBO process improve safety of navigation practically, and in particular, in narrow waters? It demands a bigger reduction of workload on the bridge. This can be done by an integrated navigational system including adaptive auto-pilot with a back-up and OMBO dead man alarm which has to be operated at set intervals, satellite navigation system, electronic chart and ECDIS, radar and ARPA, and automatic logging of all bridge data including communication facilities. ALL of these systems which are involved in the new developments of OMBO will make it possible to maintain the level of safety of navigation.

For the time being IMO has put a limitation on using the system. However, at the same time, IMO is developing "provisional guidelines for conducting trials with the officer of the watch acting as solo look-out at night".

6.5 TRAINING NEEDS DEVELOPMENT:

Much of social science research points to seafaring as being preoccupied with two problems, namely the quick turnover of seafarers and the training of seafarers, especially in the light of new developments in technology, the complexity and automation of the systems, and new design features of modern sea-going vessels.

Since its inception, IMO has given a high priority to the development of maritime training. One of the subjects given high priority has been the establishment of acceptable international provisions in the training, examination and certification of seafarers and the measures to improve the standards of watchkeeping.

Ideally, maritime training should be progressive and undertaken in step with increased levels of industrial services, professional experience and executive responsibility. Today's officers need a high level of technical competency to operate specialised ships. Officers need to be competent in navigation, engineering, communications, cargo operations, etc, and have sufficient knowledge of administration, safety, and disciplinary procedures.

The purpose of development training should be to provide vocational training to develop skills and techniques, to enable the application of fundamental knowledge to problems in real practical situations, to improve communication skills, and to develop the ability to make the correct judgements.

In addition, one of the more realistic proposals is the use of flexible officers and flexible ratings. It is time for new training programmes to be introduced whereby flexible roles can be truly and effectively implemented. Job functions on-board ships need to be analysed and task training developed to meet those specified job functions.

> Future developments will have to determine the role and qualifications required of the ship master and chief engineer. At the integrated rating level, the initial phase should be modified to give the ratings further skills to enable him/her to give increased support to the bridge team, and to better contribute to overall maintenance programs on-board.
>
> Muirhead, (1992, 11).

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS:

Today, the navigator's problem is no longer one of lack of information. With the development of marine technology and level of accuracy there can be no doubt about the ship's position. Although this development has not prevented accidents, navigational safety has now become a matter of information management to a large degree. In addition, the navigation systems have reached a very high level of sophistication, with the trend to greater accuracy and reliability.

During the last decade, the integration of available navigation data on-board of a ship has been a major development. Such an integrated navigation system has to process different kinds of data such as position, heading, and speed, in order to obtain an improved position estimation.

The advantage of such an integrated navigation system is that a better navigation performance can be achieved in comparison with the use of stand-alone sensors. Combining different types of sensors, it is possible to eliminate systematic errors of the sensors.

The development of marine technology and the digital computer in navigation, has provided an impetus to the development and use of the integration process.

The advent of G.P.S has had an major influence on the future life span of current radio navigation systems. The integration of two basic navigational position fixing systems (GPS and Loran-C) as proposed by the author, have together to produce a better performance standard under an integration process than when they are in stand-alone operation.

It Is evident from the development and operation of the GPS system that it is capable of delivering a very high level of accuracy and reliability, world-wide coverage 24 hours a day and the ability to be used in an integrated shipboard operation system.

Regarding the future of Loran-C the author feels that this system has demonstrated a high degree of accuracy with its stated limits of operation, and is the best medium to act as a back-up system to GPS.

In view of the above, the retention and integration of both systems in the area under consideration i.e Middle East, is the major outcome of this investigation.

In relation to the Gulf of Suez area (GOS), the investigation looked at the problem of navigation safety in view of the continual increase in traffic flows. This is particularly relevant to and from the Suez Canal with many ships carrying hazardous cargoes.

In view of the foregoing, it is author's view that:

The hybrid combination of a Loran-C and GPS has proven very valuable in marine operations. The GPS, with its superb velocity accuracy is a dream to use. Loran, always there, builds confidence and trust. Hybrid systems extend the usefulness of both.

When looking at the two systems, GPS and Loran-C individually, it is seen that both have some deficiencies. In the long run, the combination of both systems together, is the most promising of possible process of solving problems of GPS drawbacks, and Loran-C ground wave delay.

The author proposes as a long-term objective to compensate the insufficiencies of GPS system integrity, limited availability and selective availability (SA). In addition, the author developed the idea of Loran-C aid GPS. Specifically, it describes combining Loran pseudo-ranges with GPS pseudo-ranges in the receiver. The approache makes an estimation of Loran-C ground wave delay, which is due to propagation over land (the additional secondary factor "ASF"), which means that Loran-C accuracy can be helped by GPS- corrected ASF correction. Moreover Loran pseudo-ranges might aid GPS integrity monitoring. More importantly, however, the advantages of one system can compensate for the advantages of the other giving the navigator a more reliable and more accurate system than either system alone can provide.

However, integration of positioning navigation systems provides more than one input to the navigation solution, thus warning of malfunction and, if sufficient inputs are available, indicating which system is at fault. Hybrid Loran-C/GPS represents the simplest form of integrated navigation position fixing system.

The next stage is the integrated navigational system, which takes inputs from more than two systems, removes noise and arrives at a single solution by means of mathematical filtering which weights each input according to the confidence in the system from which is derived. Integrated navigational systems overcome the integrity problems with hybrid Loran-C/GPS system and are likely to have a major role in maritime operations.

Differential system are being installed to overcome the denial of precision operation. Unless differential techniques are employed, GPS alone is unable to provide the repeatable accuracy of 20 to 50 metres. GPS and Loran-C are natural complements and provide an inherent solution to the deficiencies of both systems.

The facts presented in this proposal provide strong support to the argument that a hybrid Loran-C/GPS system is not only desirable but is an absolute necessity to provide acceptable accuracy, signal availability, and redundancy while satisfying the need for navigational safety.

In considering any upgrading to a hybrid Loran-C/ GPS system in GOS, it should be noted that the Saudia Arabia Loran-C system, which consists of two chains, covers the Red Sea area. In addition, GOS can be covered also by the proposed Loran-C system which is recommended in NAVIGOS 86 and/or the other system proposed in NAV 88 by Mokhtar and Hussein.

Regarding the GPS system, and as mentioned before, the system provides widespread and accurate navigation 24 hours a day. Consequently, a hybrid Loran-C /GPS system can become the available navigation system to vessels on their routes passing the GOS V.T.S system, and can provide the authority with the required information such as time, position, heading and speed, etc. obtained from this system.

Regarding the implication of the system for MET, the revolution in the field of information technology will support the demand to reduce the cost effect for ships in order to reduce the workload and consequently the manning level. So, the concept of One Man Bridge Operation (OMBO) capability requires the integration and control of multiple ship systems, such as navigation.

7.2 RECOMMENDATION:

The aim of this study is not only limited to examining developments in navigational systems, but also to try to find some solutions and recommendations for the safety of navigation. The author recommends that:

.1 Terrestrial radio navigation systems such as Omega and Decca be phased out. The Loran-C system be maintained and renewed.

.2 IMO adopt the hybrid Loran-C/G.P.S by amending the appropriate conventions and resolutions.

.3 The existing Loran-C chains in Saudia Arabia and Mediterranean be retained and maintained.

.4 The recommendation relating to Loran-C, made by NAVIGOS 86, and the NAV 88 paper prepared by Mokhtar and Hussein, be adopted and put into place by IALA.

.5 All ships of (500) gross tonnage and upwards be required to carry a hybrid Loran-C/GPS integrated system, or as a minimum, be required to carry a GPS receiver capable of operating with a D.G.P.S system.

.6 DGPS be made available in major areas of marine traffic including the Dover strait, Gulf of Suez, and the Malacca strait for example.

.7 The Egyptian Ministry of Maritime Transport in conjunction with the Suez Canal Authority develop and upgrade the existing V.T.S services to current IMO and European VTS standards.

.8 IMO drafts new training standards that require maritime institution to conduct appropriate training to meet the need of the new navigational systems. In this regard simulator training should be utilised to the optimum extent.

7.3 A FINAL COMMENT ON THE FUTURE:

Looking towards the next century, it is the author's view that the integration of multiple navigational aids will continue at a fast pace. Therefore it will be the prime method of calculating position to very high degree of accuracy. Additionally, it is observed that all future development of integration will be based on G.P.S, ECDIS, and radar & ARPA.

An outcome of this technology will be access to very accurate data regarding knowledge of position, ship velocity and heading. Their applications to other function on the ship for safe navigation, and ship controllability opens up an extending range of possibilities in data presentation to the ship master, his officers and VTS operator ashore.

IT is noted that IALA proposed to use an integrated EUROFIX (reference 3.4.3) and IALA DGPS system in order to improve current integrity and availability during GPS outages. This will further enhance the availability of this technology for the maritime world.

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