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# Investigation into marine collisions

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# AN INVESTIGATION INTO MARINE COLLISIONS AND INTO METHODS FOR THEIR REDUCTION WITH AN EMPHASIS ON RADAR AND ARPA

Volume I

BY

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The contents of this paper reflect my own personnal views and are not necessarily endorsed by the UNIVERSITY.

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ABSTRACT:

Collisions at sea have been a problem to mariners since the earliest vessels engaged in commerce. When the first vessel was launched, the risk of collision was zero. However, with the launching of the second vessel there was some degree of risk that the two would collide. While early records fail to reveal the fate of these two ships, in more modern times thousands of vessels and lives have been lost due to collision.

Several methods have been developed to minimize the incidence of collision, the Rules of the Nautical Roads, V.H.F., Radar, Traffic Seperation Schemes, vessel Traffic Services, Automatic Radar plotting Aids, and other measures. Some were thought by many to provide the ultimate solution, but the improvement in the situation is still far behind the acceptable range .
Why do none of these measures provide the hoped ultimate solution?

This project analyses the collision risk and examines the major measures taken to reduce it´s incidence, trying to find out where the deficiencies could be and present a reasonable solution.

The examination of the various methods gives a light on the potential benefits / disbenefits of each with an emphasis on radar and ARPA as considered the most beneficial tools having a direct contribution to solve the problem.

INTRODUCTION :

Safety at sea has long been a preoccupation of maritime community. Collision between ships has always been a prominent problem in maritime history and continue to occur with alarming regularity.

Lloyds Register indicates that during the 2nd and 3nd quarter of 1978, 17.8% of the world fleet losses resulted from collision. The research division of Norske Veritas indicates that collision involving Norwegian ships comprises25% of all Norwegian ship's casualties. Liverpool underwriters statistics indicate that 50% of all ships casualties comprised collisions and grounding.

The developments occur in the shipping industry have led to this high percentage of collision and pushing strongly to always give a serious attention to the safety and efficiency of fleet operations.

Sea-going vessels are increased in number, speed, and size and becoming more complex. World trade itself is such that traffic flows lead to congestion at certain areas around the world.

Larger and larger amounts of cargoes of noxious or dangerous nature which have the potential for pollution of the earth's environment are being moved by sea-going vessels every year. At the same time many vessels in service are old and some are in questionable condition with respect to their systems and officers competency.

The analysis of marine casualities and their distribution is one of the most important methods to explore ways by which safety and accuracy can be increased, and the effectiveness of collision avoidance and navigation practices on board ships can be improved.

Merchant marine casualties are often the result of a number of factors involving a series or combination of events and circumstances. It has been estimated that the greatest number of collisions can mostly be traced to the complication in the traffic situation and the errors in human judgement.

In response to the persistent need to assist the watch officer in his collision avoidance tasks numerous extensive studies, research work, and experiments have been conducted and are still going-on leading to the development of several measures to reduce this risk and put it under control.

The implied promise in this development is that these measures will provide an answer to the collision avoidance problem. Some of these measures are related to the ship itself to increase its operational efficiency and some adopted at sea to improve the situation, while others are established ashore to cooperate in increasing the safety standard.

The question is : How much aid in avoiding collisions do the so-called collision-avoidance systems provide ?

The rules of the nautical roads were adopted and revised to organize collision avoidance actions. The rules are not a deterministic device, but a set of guide lines to help the navigator to take the correct collision avoiding action. Problems arised by the officers who did not abide by them, either by negligence or by taking conflicting action which made the situation even worse and mostly led to collision. It was found that the best is to make a contact between the ships engaged in a dangerous situation to ensure a consistent safe action, avoiding any risk. V.H.F. radio telephony is involved for ship-to-ship communication, but again some officers neglect this effective tool and others used inadequate calling methods.

To ensure the maintenance of a sharp visual lookout, good attention, and most efficient navigational operations, a suitable bridge design and arrangement is necessary. Much effort is given to provide the watchkeeping officers and captains with a well arranged operating centre to increase the nautical safety.

Some attention has been given to other ship systems to improve ship handling characteristics. The rudder effectiveness to give the required result, the reliability of the steering gear to avoid any failure in critical situations, and the engine procedures and maintenance to always answer the orders in time.

When radar was first introduced to the merchant fleets, many people felt that a practical solution to collision avoidance problem had been found. However, a review of the world-wide collision statistics for the past years reveals · that in spite of the expanded use of radar, the overall collision rate remains alarmingly high.

Beacause of radar´s less-than a perfect record for preventing ship collision, development of various types of threat assessment systems has taken place.
Vessel traffic systems start to contribute to solve the problem. Vessel traffic seperation schemes started in the congested areas to assist in reducing the encounter rate. Some captains did not accept this imaginary roadways inked in on the chart and proceed against the traffic causing a tremendous danger. Shore based stations for traffic surveillance start to interfere to put the situation under control and help in the threat assessment process giving navigational warnings and advices to those ships involved in a dangerous situation.

The introduction of ARPA has improved the effectiveness of these stations as well as the traffic data processing on board ships.
It basically provideSthe navigator with a quicker and better appreciation of the traffic around his ship which could lead him to an early and effective action to avoid collision.

All these measures and procedures provide the mariner with a precious information and good working conditions to assist in reducing the work load, minimize the human errors, increasing the ship reliability, and improving the situation as a whole.

However, a great burden still falls upon the navigator, requiring to always be attentive, competent, and cautious to arrive at the right judgment and take the proper action.

International organizations. national administrations and various institutions have taken great steps to provide the mariners with efficient education and training programmes to promote the competency, increase the practicle experience and attain an adequate standards on board ships. Moreover, due to the IMO requirements and the efforts of national administrations; a casualty investigation system is established in several maritime countries to contribute in finding general recommendations which could improve the situation.

Eventhough, some deficiencies still exist here and there which should be remedied and some positive steps still need to be taken hoping to have a better future and collision becomes some thing of the past.

# SECTION I

## I.I COLLISION AVOIDANCE PROBLEM :

Collisions at sea have been a problem to mariners since the earliest vessels engaged in commerce. The continous increase in the volume of marine traffic, the growth in size and speed of vessels, the increasing numbers of cargoes of noxious or dangerous nature, and, the number of ships not complying with internationally agreed standards, all stress the increasing seriousness of the marine safety problem. This situation has lead to increased numbers of collisions involving the probable loss of life and or pollution. In addition, if the hazardous nature of the cargoes carried today is taken into consideration, such casualties are no longer only the concern of the mariner, shipping companies and their insurers. They have a direct effect on populations and their governments and therefore these risks have become unacceptable.

The collision avoidance problem is seen as a co-operative game, involving (most often) two players who have to choose a course of action independently. The concept of level of safety is not one that can be defined very easily, it need to determine the combinations of actions that are good and those that are bad. The matrix of possible actions for each ship, and the outcomes of these combinations presents the general collision avoidance game.

The level of safety in a situation is improved by consistent action on the part of both ships, remains the same if neither ship takes any action, and is decreased if they take conflicting action.

Before the wide spread use of the radio and radar on merchant vessels, the primary collision avoidance tools of the mariner were:

| | | |
|---|---|---|
| Look out | - | The Pelorus |
| The Binoculars | - | The Rules of the Road |

The pelorus and binoculars were certainly not as the compass repeaters of today. In fact any stationary object on the ship was used for determining a change in relative bearing of a traffic ship-crude but effective.

The rules for manoeuvring to avoide collision at sea were derived from rules designed for quite a different purpose. These original rules were primarily commercial lows concerned with the apportionment of damages after a collision had occured, ruther than guide lines to help ships avoid collisions. The first record of a specific rule of the road dates back to Lord Howe in 1776. By 1864, a code of conduct for ships at sea had been defined and agreed to by over 30 maritime nations. The rules were revised three times in 1948, 1960 and 1972 to suit the infinite variety of maritime circumstances and conditions after studying most of the collisions and taken into account the development of technology such as the use of radar and the introduction of traffic seperation schemes.

The introduction of radar to the maritime community has not brought a definite dramatic reduction in collision freguency. Manual radar plotting with its several aids was thought by many to provide the ultimate solution but these thoughts were severely jarred by the Stocholm and Andrea Doria collision in 1956. The reason could be due to the following factors:

1- The increase in the number of ships at risk.

2- The growing number of fast ships.

3- Misuse / misinterpretation of radar information.

4- The tendency of ships using radar to proceed at higher speeds in restricted visibility.

5- The emergence of large, deep draft ships.

6- Lack of knowledge of the manoeuvring characteristics of own ship.

7- Failure to keep a good lookout.

8- Technological improvements that, along with scheduling pressures, increase incentive to risk exposure.

In the period between the two world wars there was relatively little change in the world-wide pattern of marine traffic. The total number of ships in service and the average size and speed of trading vessels remained fairly constant. During the last thirty years considerable changes have taken place. There has been a six-fold increase in international trade by sea which has been accomplished partly by an increase of over 100% in the number of ships and partly by increases in the size and speed of ships and by reduction of the time spent in port. In 1975, 2530 new steam and motor ships went to sea compared with 1006 in 1965 and 134 in 1955. In 1978 the total world ships of over 140,000 tons gross (270,000 tons dead weight) were 59 ships.

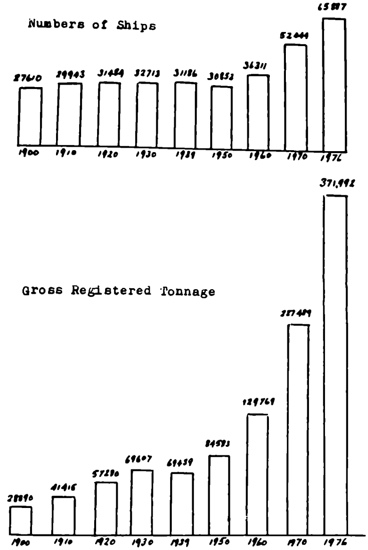



Figure ( 1 )

The growth in world shipping

Table ( 1 ) Numbers of trading ships in service according to size category (g.r.t)

| Year | 100-999 | 1000-9999 | 10000 and over | Total |
|---|---|---|---|---|
| 1950 | 5,100 | 11,200 | 1,100 | 17,400 |
| 1960 | 7,400 | 12,300 | 3,000 | 22,700 |
| 1970 | 11,400 | 13,000 | 6,200 | 30,600 |
| 1980 | 11,800 | 13,600 | 9,500 | 34,900 |

The figures are based on the statistical tables of Lloyd's Register of shipping and on data published by the General Council of British shipping.

Table ( 2 ) Trading vessels in commission by type 1950 - 1975

| Type of ship | 1950 | 1955 | 1960 | 1965 | 1970 | 1975 |
|---|---|---|---|---|---|---|
| Oil tanker | 2,783 | 3,538 | 4,146 | 5,209 | 6,067 | 6,577 |
| General cargo | 14,598 | 15,914 | 18,500 | 20,540 | 22,400 | 22,600 |
| Bulk carriers | | | 300 | 1,000 | 2,100 | 3,400 |

Table ( 3 ) Comparison of the estimated daily traffic flow in certain sea areas 1969 & 1980

| Region | Ships Per day | |
|---|---|---|
| | 1969 | 1980 |
| English channel | 400 | 340 |
| Coast of Japan | 100 | 190 |
| Cape of good hope | 211 | 225 |
| Strait of Gibraltar | 160 | 180 |
| Malacca strait | 85 | 180 |
| Masqat (Arabian Gulf) | 80 | 180 |

Increasing the size and speed of ships and the density of traffic tends to bring greater risk of collision.

During this period various measures have been taken to improve the safety at sea.
A rather comprehensive work was performed to assess human factors in radar utilization. In this study, the effect of different types of radar displays were investigated using a simple radar simulator. A substantial report regarding radar problem-solving capabilities was published. The results indicated that the reason for unsatisfactory degree of progress that would be expected with wide spread use of radar could be due to deficiencies in training, knowledge, attitude, or experience of mariners. Accordingly, a radar observer certifi-

cate is now required before the award of a second mate's ticket.

In 1959 Oudet proposed a traffic separation scheme for congested areas as Dover strait. The establishment of routing schemes caused a significant reduction in collision where traffic density is high particularly in restricted visibility.

The first traffic scheme was introduced in Dover strait in 1967, and such schemes have since spread rapidly throughout the world. IMO recommend the use of the existed ones, and its use became mandatory by 1972 regulations.

Another approach to the problem is the attempt to find a methemetical model of manoeuvring for collision avoidance, the first substantial attempt was presented by Hollingdale in 1961. During the subsequent 15 years, there have been a number of attempts at analyzing, understanding, and then solving the collision problem. Many journal articles have appeared describing ship manoeuvring diagrams which purport to provide the solution. However, deficiencies have been noted in each of the manoeuvring diagrams and no particular diagram has gained wide spread acceptance.
In 1975 Liverpool Polytechnic Maritime Operations Unit, (recently CAORF research centre at kings point), has compared the effectiveness of various electronic collision avoidance systems. The resultsobtained from test subjects in an artificial environment, indicate that use of a CAS causes a dramatic improvement in performance.
Accordingly, united states required a collision avoidance system to be fitted on vessels carrying hazardous cargoes arriving in their waters since 1982, and it became compulsory for all

new ships of 10,000 g.r.t. and over, and all existing tankers of 40,000 g.r.t. and over to be fitted with an ARPA since first of January 1984.

A new concept is "collision avoidance from the shore". The vessel traffic management services (V.T.M.S.) offered by the maritime surveillance centres for preventing collisions is a new factor in maritime operations.
The objective of this concept is to provide a shore service for preventing collision which is a much more ambitious task. The criteria is to alert the operator in the centre before a near miss and once the operator has been alerted, he himself interpret the situation and warn the ships concerned. The officer of the watch on board will naturaly retain full responsibility for manoeures. Provided the ships involved in an encounter situation have been identified, the only thing the operator can do is to warn the vessels concerned and possibly put them in touch.
The system still under development, and areas covered need to be extended.

As a result of these analyses, studies, and research work, IMO have taken effective steps to tackle the collision problem, some of which are:

1- The amendment of the collision avoidance regulations to always suit the present situation and conditions.
2- The 1974 SoLAS (came into force 25th of May 1980), and the 1978 SoLAS protocol (came into force 1st of May 1981), which contain a detailed regulations covering ship's safety, equipment etc.
3- The STCW convention 1978 which came into force in 28 of April

1984, which set up the minimum requirements of training and certification to ensure a certain standard of knowledge and training of seafarers.

4- The significant financial and technical help to new established academies particularly those in developing counttres to enable these countries to improve the level of their maritime industry.

5- IMO requirements concerning the investigation of marine casualties by contracting governments, and the regular examination of these investigations by the Maritime Safety Committe to recommend actions which increase safety at sea.

6- The establishment of the World Maritime University (WMU) in July 1983 to help the mariners of all nations particularly those of developing countries to improve their training and their practicle background.

Efforts and developments still going on trying to reach a significant improvement in the situation hoping that the following years will show a considerable reduction in casualty figures.

Table (4) Annual incidence of collisions of merchant ships in open sea, coastal waters, and narrow straits.

| Year | Reported By Lloyd's | Additional Japanese cases | Totals | Both Ships over 1000 tons | Detailed cases |
|---|---|---|---|---|---|
| 1948-55 | — | — | — | — | 18 |
| 1956 | 80 | — | 80 | 46 | 4 |
| 1957 | 68 | — | 68 | 46 | 6 |
| 1958 | 65 | — | 65 | 41 | 4 |
| 1959 | 76 | — | 76 | 45 | 11 |
| 1960 | 70 | — | 70 | 50 | 17 |
| | 359 | | 359 | 228 | |
| 1961 | 77 | — | 77 | 51 | 25 |
| 1962 | 27 | — | 57 | 41 | 9 |
| 1963 | 87 | — | 87 | 48 | 19 |
| 1964 | 83 | — | 83 | 51 | 22 |
| 1965 | 94 | — | 94 | 41 | 21 |
| | 398 | | 398 | 232 | |
| 1966 | 81 | 6 | 87 | 48 | 28 |
| 1967 | 63 | 10 | 73 | 36 | 30 |
| 1968 | 77 | 10 | 87 | 45 | 39 |
| 1969 | 94 | 11 | 105 | 55 | 52 |
| 1970 | 89 | 11 | 100 | 52 | 55 |
| | 404 | | 452 | 236 | |
| 1971 | 80 | 25 | 105 | 41 | 60 |
| 1972 | 67 | 18 | 85 | 45 | 45 |
| 1973 | 68 | 9 | 77 | 34 | 44 |
| 1974 | 70 | 23 | 93 | 40 | 54 |
| 1975 | 77 | 17 | 94 | 57 | 57 |
| | 362 | | 454 | 217 | |
| 1976 | 69 | 10 | 79 | 34 | 44 |
| 1977 | 61 | 20 | 81 | 36 | 43 |
| 1978 | 68 | 7 | 75 | 46 | 24 |
| 1979 | 71 | — | 71 | 43 | 1 |
| 1980 | 65* | — | 65* | 35* | |
| | 334* | | 371* | 194* | |
| Totals | 1857 | | 2034 | 1107 | 732 |

* Estimates have been made for 1980 based data obtained for 11 month

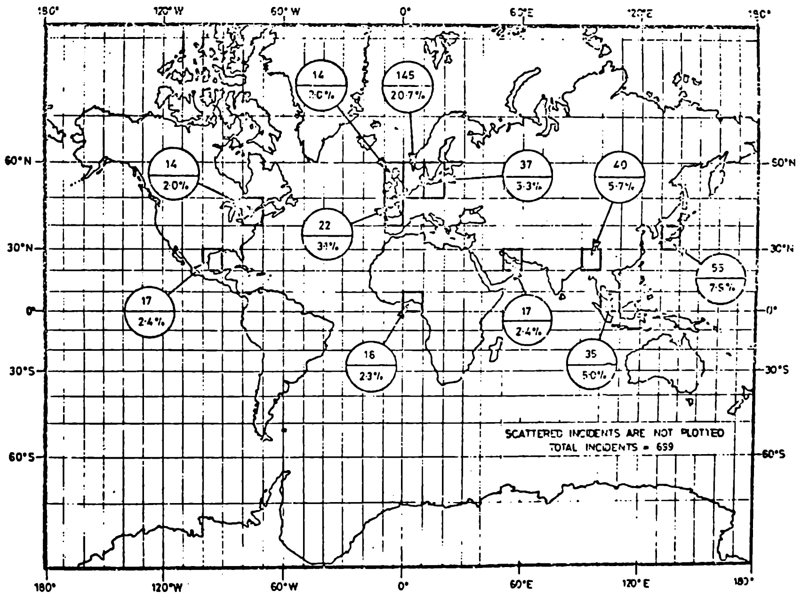



Figure ( 2 ) <u>GEOGRAPHICAL POSITION OF COLLISION INCIDENTS</u>

1.2&3 The concept of collision point and dangerous area:

In any encounter, risk of collision may exist. If target true motion is known the point of possible collision can be estimated and defind as a point on the earth surface. When a certain passing safe distance is required in a two ship encounter, the probable area of danger can also be estimated and defind on the earth surface.

1.2 The concept of collision point:

The collision can be defined and, its position depends on;

a) The speed ratio (E)     b) The relative heading (H)

c) The position of the two ships.

1.2.1 Sample definition of a collision:

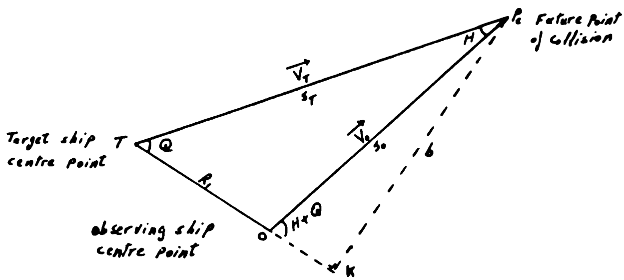



Figure ( 3 )

Consider the dynamic situation of a two-ship encounter involved in exact collision.

Such a situation appears in the above Figure which illustrates the geometry of a collision situation between two ships on converging courses. At an instance ($t_1$) the two ships (O) and (T) are at a distance ($R_1$) and are moving according to the speed vectors ($v_o$) and ($v_T$). For the sake of simplification the two true velocities are assumed to be uniform.

The relative bearing of ship (O) in relation to ship (T) is the angle (Q) or the aspect.

If both ships maintain their velocity they will collide at point (Pc). The intersection angle at this point is the relative heading (H), and the following relation holds constant:

$$Vo / v_T = So / S_T = E$$

Where E is the speed ratio

From the two triangles (O $P_c$ K and T$P_c$K)

$$\text{Sin } (Q) = b / S_T \quad \therefore \quad S_T = b.\text{Cosec } (Q)$$

$$\text{Sin } (H+Q) = b / So \quad \therefore \quad So = b.\text{Cosec } (H+Q)$$

Then

$$1/E = S_T/So = \text{Sin } (H+Q).\ \text{Cosec } (Q) = \text{Sin } (H+Q) / \text{Sin } Q$$

$$\therefore\ 1/E = (\text{ Sin}(Q).\ \text{Cos } (H) + \text{Cos } (Q).\ \text{Sin } (H)\ ) / \text{Sin } (Q)$$

$$= \text{Cos } (H) + \text{Cot } (Q)\ .\ \text{Sin } (H)$$

And $\text{Cot } (Q) = (1 - E \text{ Cos } (H)) / E \text{ Sin } (H)$

$$\therefore\ \text{Tan } (Q) = E \text{ Sin } (H) / (1 - E \text{ Cos } (H))$$

This equation gives a sample definition of a collision situation in a two-ship encounter in terms of two indepentent variables (E) and (H).

Q is the limiting aspect for collision.

This case is a sample when the relative speed (E) is less than one. To find the circle of collision points and the limiting aspect of collision for the different cases of the relative speed (E) when $E < 1$, $E = 1$, and $E > 1$ the following technique can be used.

### 1.2.2. Locus of future point of collision:

#### 1.2.2.1. When the relative speed E is less than one:

Assuming that, the relative speed $E = V_O / V_T = 0.25$

e.g:

$V_T = 4\ V_O$ and the initial distance between ownship and target equal 10 miles.

To find the radious of the circle of the limiting aspect we can proceed as follows :

1- $S_T + S_O = 10$

$S_T = 10 - S_O$

$4\ S_O = 10 - S_O$

$\therefore S_O = 2$ and

$S_T = 8$

2- $S_T - S_O = 10$

$S_O = 0.25\ S_T$

$\therefore 0.75\ S_T = 10$

$\therefore S_T = 13.33$

Then the radius of the circle of limiting aspect of collision (centra point C) equal $(13.33 - 8) / 2 = 2.665$

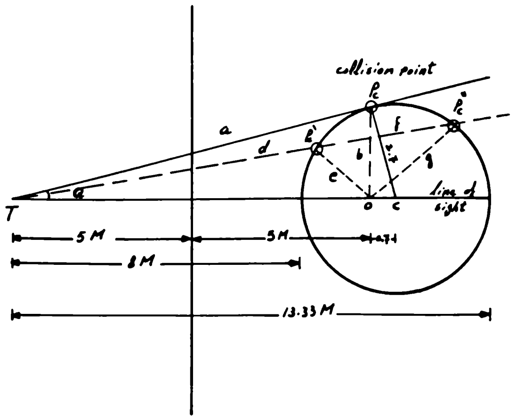



Figure ( 4 )

$Q = 14.5^{o}$ is the limiting aspect of collision, $P_c$ will be the only collision point where b /a = $E \simeq 2.57 / 10.3$. $OP_c$ will be the course of own ship to produce one collision which will exist at a distance equal to b.
If the aspect is reduced to be less than Q then collision will occur at $P_c^{'}$ or $P_c^{''}$ where

$e / d = g / ( d + f ) = E$

For $P_c^{'}$ to occur own ship course should be $oP_c^{'}$ and
For $P_c^{''}$ to occur own ship course should be $oP_c^{''}$

<u>The principle of the previous method:</u>

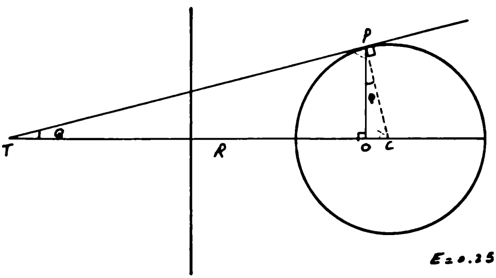



Figure ( 5 )

If own ship's speed = $V_O$ and target speed = $V_T$

$\therefore V_O / V_T = \frac{OP}{TP}$ = say 0.25

P = P.P.C. the point of possible collision

Q = target's aspect which is the limiting aspect for collision.

R = Distance between own ship and target say = 10 M

Sin Q = OP / TP = $V_O / V_T$ = E

then Q in this case = $14.5^o$

Tan Q = oc / op = op / R $\therefore$ oc = op tan Q

but op = R tan Q $\therefore$ oc = R $\tan^2$ Q

=0.67 in this case

If TP is made to equal unity

$\therefore$ OP = E and $R^2 = 1 - E^2$ $\therefore$ R $= (1 - E^2)^{1/2}$

$\therefore$ tan Q = OP / R $\therefore$ tan Q $= E / (1 - E^2)^{1/2}$

$= 14.5^o$ in that case

$\therefore$ OC = R $\tan^2$ Q $\therefore$ OC $= RE^2 / (1 - E^2)$ =

= 0.67 in that case

Sin Q = OC / PC $\therefore$ Pc = oc / sin Q

but Sin Q = E

$\therefore$ Pc = OC / E = R $E^2$ / E $(1 - E^2)$ = RE $/(1 - E^2)$

So equations to be used are

OC $= R E^2 / (1 - E^2)$

Radius $= RE / (1 - E^2)$

Sin Q = E

1.2.2.2. <u>When the relative speed E is greater than one</u>:

Assuming that E = 1.25, initial distance between the two ships 2 M

1- $S_T + S_O = 2$ $\therefore S_O = 2 - S_T$

$E = 1.25 = V_O / V_T$ $\therefore V_O = 1.25\ V_T$

$\therefore 1.25\ S_T = 2 - S_T$ $\therefore S_T = 2 / 2.25 = 0.89$

2- $S_O - S_T = 2$ $\therefore S_O = 2 + S_T$

$\therefore 1.25\ S_T = 2 + S_T$ $\therefore S_T = 2 / 0.25 = 8$

then the radius of the circle of limiting aspect of collision aqual to ( 8 + 0.89 ) / 2 = 4.445

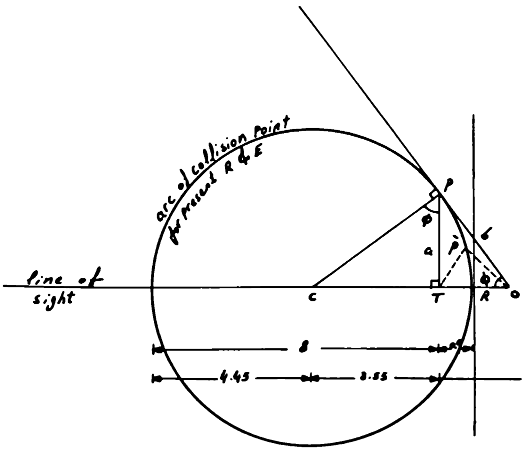



Figure ( 6 )

$\phi \simeq 53^{o}$ is the limiting angle for own ship (course OP) which produce one collision at P at a distance b where $b / a = E$ For smaller angle say $44^{o}$, collision point will exist at different position on the arc ( P`) produced by different course of own ship and target but for same value of R and E which means that the position of collision point (for a particular target course) and the associated own ship course can be found if $\phi \lesssim$ the limiting angle.

By following the same mathematical procedure as in case of $E < 1$ the needed equations can be found:

$$\text{Tan } \phi = \frac{TP}{R} = \frac{CT}{TP}$$

$$\therefore CT = TP \tan \phi \quad \text{but} \quad TP = R \tan \phi$$

$$\therefore CT = R \tan^2 \phi$$

$$\frac{OP}{TP} = E \quad \text{, if OP is made to equal unity}$$

$$\therefore \text{Sin } \phi = 1 / E$$

$$\therefore (OP)^2 = (TP)^2 + R^2 \qquad \therefore R^2 = 1 - \frac{1}{E^2}$$

$$\therefore R = (E^2 - 1)^{1/2} / E$$

$$\therefore \text{Tan } \phi = TP / R$$

$$\therefore \text{Tan } \phi = \frac{1/E \times E}{(E^2 - 1)^{1/2}} = \frac{1}{(E^2 - 1)^{1/2}}$$

$$\therefore CT = R / (E^2 - 1)$$

$$\text{Sin } \phi = \frac{CT}{PC} \qquad \therefore PC = \frac{CT}{\sin \phi}$$

$$\text{but Sin } \phi = 1 / E$$

$$\therefore P C = R E / (E^2 - 1)$$

so equations to be used

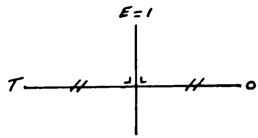
$$C T = \frac{R}{E^2 - 1}$$

$$\text{Radius} = \frac{R\ E}{E^2 - 1}$$

$$\sin \emptyset = \frac{1}{E}$$

1.2.2.3. <u>When the relative speed E = 1</u> :

For the case when E = 1, the collision point is always located on the bisector of the line between own ship and the target. There will be only one possible collision.



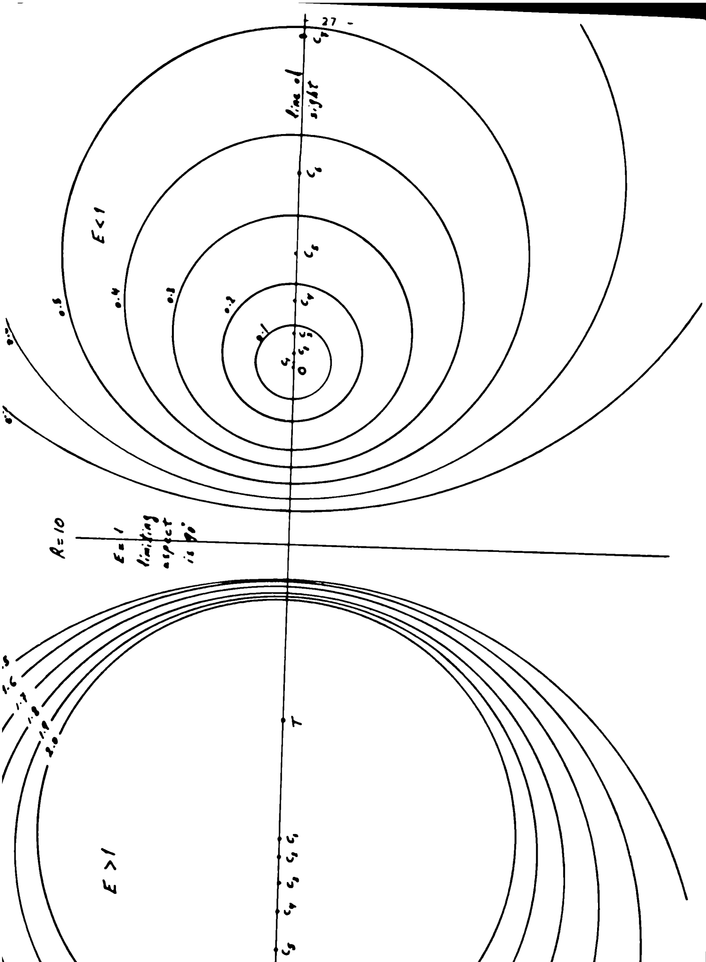



Figure ( 8 )

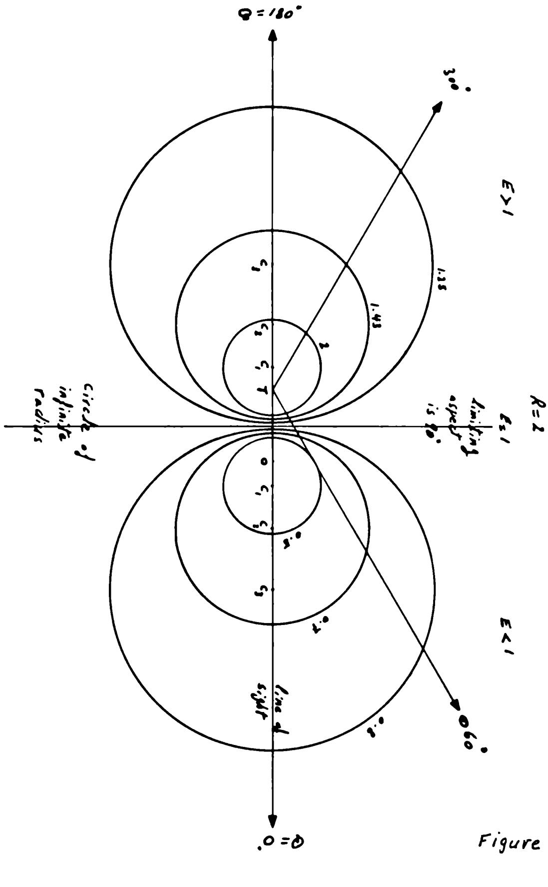


Figure (9)

1.2.2.4. <u>CONCLUSION</u> :

1- If the target is slower than own ship (e.g. E>1). It is always possible for own ship to produce a collision since it can pursue the target if necessary but one and only one collision could exist. This collision point is always on the track of the target.

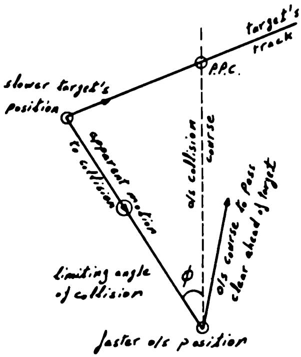



Figure ( 10 )

2- If the target is faster than own ship (E<1), there are three possibilities:

- No collision can be produced by own ship if it is not fast enough to reach the target's track ( Q > arc sin E ).

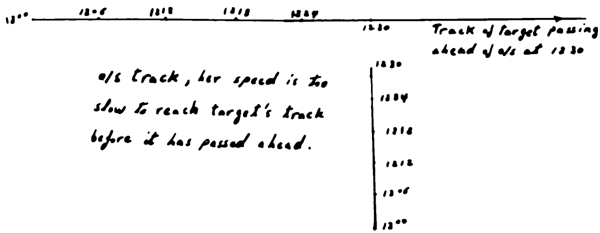



Figure ( 11)

- One collision point on target´s track when the aspect is equal to the limiting aspect.

e.g. $Q = \arcsin E$

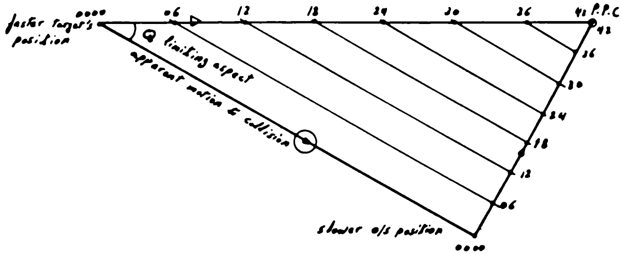



Figure ( 12)

- Two collision points if Q< arc sin E. Both collision points must be on the target's track. One exists where own ship heads towards the target and intercepts it and the other exists where own ship heads away from the target but is struck by it.

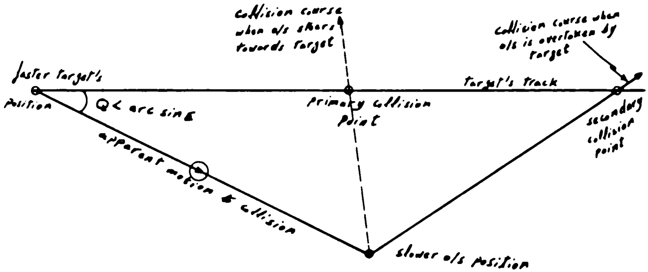



Figure (13 )

In this particular case it is possible if own ship reduce her speed (e.g. E becomes smaller), the two collision points approach eachother and emerge in one collision point at certain value of E.

If ownship stops, E will equal Zero and collision could only occur when the aspect is zero.

If the target stop, E will tend to infinity and the redius of the collision circle will be zero, collision then could only occur if ownship proceed directly to the target.

We can say, the larger the E the greater the radius of the dangerous circle will be if $E < 1$ and

The smaller the E the greater the radius of the dangerous circle will be if $E > 1$.

3- If the target speed and ownship speed is the same ( $E = 1$), only one collision could exist and the collision point is always located on the bisector of the line joining the two ships.

The greater the aspect the further away the collision point will be. Theoretically the limiting aspect in this case is 90 degrees, but in that case the collision point would be at infinity, and hence the aspect of some $85^{\circ}$ is considered the practical limit.

4- If $E < 1$ the collision points, if any, will be at ownship side of the bisector of the line joining the two ships, but if $E > 1$ the collision point, if any, will be at the target's side of this bisector.

5- When the target is the faster ship and one collision does exist it will lie on the perpendicular through (O) the own-ship position but if two collision points exist they will lie either side of the perpendicular through (O) and not equally spaced.

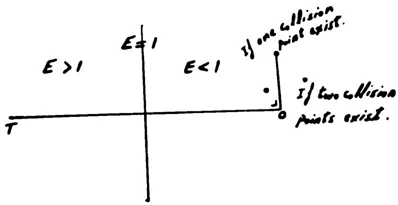



Figure ( 14 )

6- The movement of the collision point when E > 1 and

Q = arc Sin 1 / E

In the following situation, the collision will exist at 1230

own ship speed = 20 knots

target's speed = 10 knots

E = 2 and limiting angle of collision Ø = 30°

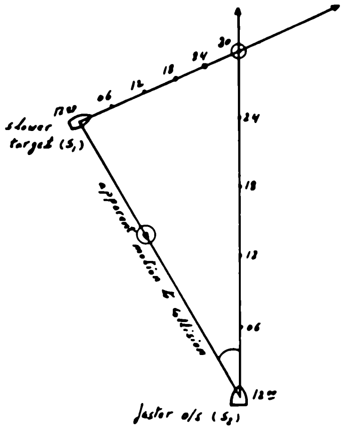
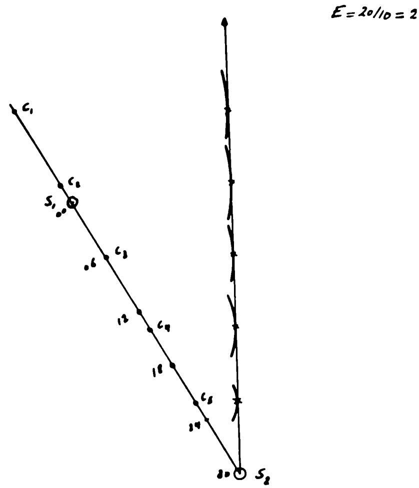



Figure ( 15 )

The radar display (Relative motion ship head up) of ownship ($S_2$) will predict the single collision point on the heading marker moving down as the collision situation develop.




| R | $S_1C$ | rad |
|---|---|---|
| 9.0 | 3.0 | 6.0 |
| 7.2 | 2.4 | 4.8 |
| 5.4 | 1.8 | 3.6 |
| 3.6 | 1.2 | 2.4 |
| 1.2 | 0.6 | 1.2 |
| 0 | Collision | |

Figure ( 16 )

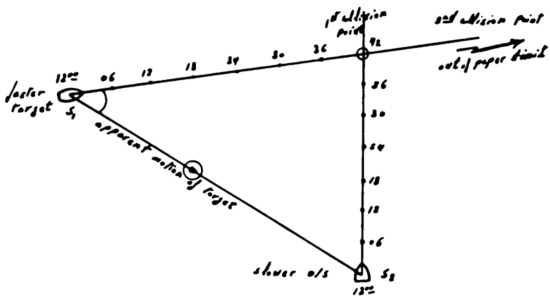
7- The movement of the two collision points when $E < 1$ and $Q <$ arc sin E

In the following situation, the two collision points exist

ownship speed = 9

Target's speed = 12

$E = 0.75$ , and $Q = 40°$



| R | $S_2E$ | rad |
|---|---|---|
| 9.68 | 12.4 | 16.6 |
| 8.30 | 10.7 | 14.2 |
| 6.92 | 8.9 | 11.9 |
| 5.54 | 7.1 | 9.5 |
| 4.16 | 5.3 | 7.1 |
| 2.78 | 3.6 | 4.8 |
| 1.40 | 1.8 | 2.4 |
| 0.00 | Collision | |

Figure ( 17 )

One of the collision point will move down the heading marker while the other towards own ship on a fixed bearing at faster rate, the two points will always be on the target's track.

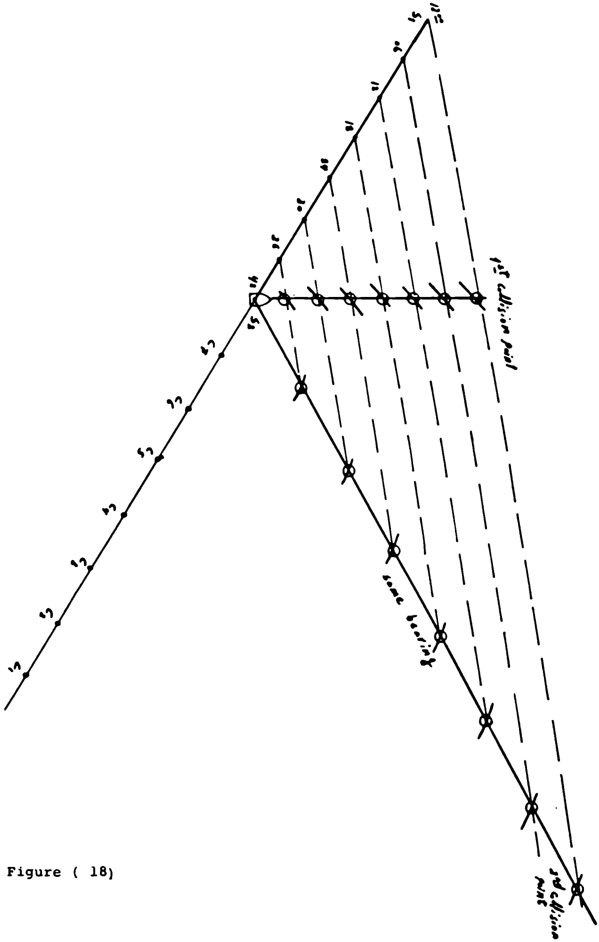



Figure ( 18)

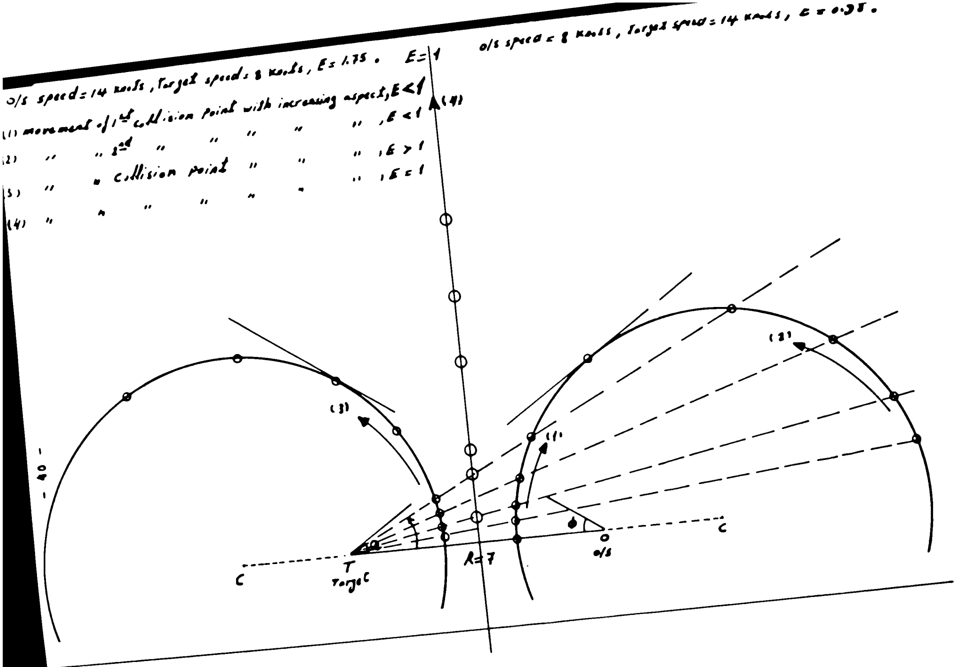

o/s speed = 14 knots, Target speed = 8 knots, E = 1.75.
E = 1
o/s speed = 8 knots, Target speed = 14 knots, E = 0.35.
(1) movement of 1st collision point with increasing aspect, E < 1
(2) " " 2nd " " " " , E < 1
(3) " " collision point " " " , E > 1
(4) " " " " " " , E = 1
(1)
(2)
(3)
(4)
T
Target
o
o/s
C
C
R = 7

Figure ( 19 )

Example:

A target (T) steering 050$^{\circ}$ true with a speed of 12 knots at a range of 5 miles.
The aspect is 40$^{\circ}$ green
Ownship speed is 9 knots

Find: 1- Course (S) for ownship to produce collision (S)

2- Distance (S) at which collision (S) occur.

3- Speed of ownship to just miss the target.

4- Speed of ownship to clear the target by 1 mile.

$E = 9/12 = 0.75$, $R = 5$, $\therefore$ $OC = \frac{R\ E^2}{1-E^2} = 6.43$, radius $= \frac{R\ E}{1-E^2} = 8.57$

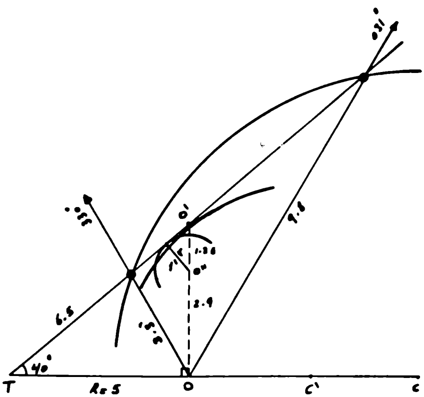



Figure ( 20 )

Two collision points exist with course $330^{\circ}$ at 3.3 miles
and with course $031^{\circ}$ at 9.8 miles

$\sin 40^{\circ} = E = 0.64 = OO'/ To' = 4.15 / 6.5 = 0.64$

Since targets speed is constant 12 knots and $E = V_O / V_T$

$\therefore 0.64 = V_O/12$ $\therefore$ Ownship speed should be just less than 7.7 knots.

To clear the target by one mile, E should equal $OO^{*}/ To'$

$\therefore E = 2.9 / 6.5 = 0.446 = V_O/12$ $\therefore V_O = 5.35$ knots

So to clear the target by one mile own ship's peed should be equal to or less than 5.35 knots.

The following formula fits well for this particular request. To satisfy a particular miss-distance, Q should be greater than, arc sin E plus arc sin r / R

$$Q > \arcsin E + \arcsin r/R, \text{ if } r \ll R \text{ then}$$

$$\sin Q > E + r / R$$

if we try it here, it gives the correct answer.

$$Q > \arcsin E + \arcsin 1 / 5$$

$$\sin Q - 1/5 = E$$

$$0.643 - 1/5 = E = 0.443 = V_O / 12$$

$$V_O \leq 5.32 \text{ knots}$$

## 1.3 The concept of dangerous area and the arc of dangerous courses:

### 1.3.1. The arc of dangerous courses:

In a two-ship encounter, there will be two possibilities to satisfay a required miss distance, either own ship steer to pass ahead or astern of the other ship. The arc between these two limiting courses is the arc of danger. If ownship course is within this arc the missdistance will be less than that required giving a close quarter situation except a particular course which will lead to collision. The dangerous arc depends on; the speed ratio (E), the desired miss-distance (R), and the target aspect (Q).

1.3.1.1. <u>If ownship is faster than the target:</u>

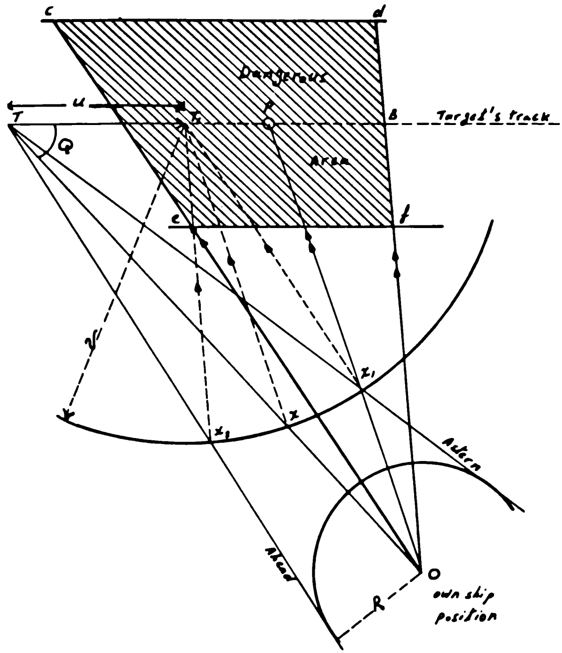



Figure ( 21)

If two lines are drawn parallel to target's track at a distance equal to the required miss distance, the area bounded by the two limiting courses (the one for passing ahead and the other for possing astern), and these lines is the dangrous area. If ownship should cross this area then she will be at a distance less than the desired distance from the target.

U = Target speed for a certain period of time.

V = Own ship speed for same period of time.

R = Required miss distance.

oP = Own ship's course which lead to collision.

P = Expected collision point (P.P.C.)

oB = Own ship's course to pass ahead of target at dist. R.

oA = Own ship's course to pass astern of target at dist. R.

AoB= Arc of dangerous courses.

cdef= Dangerous area.

Q = Target's apect.

B = Point of passing ahead of target.

A = Point of passing astern of target.

So if own ship is faster than the target (E > 1), only one collision point could be exist (as previously shown) at a particular course and a single cross ahead and cross astern position could be generated.

### 1.3.1.2 If own ship speed ( V ) is less than or equal to target speed ( U ):

In Both cases different situations could happen depending on the speed ratio (E) and the aspect (Q), but in case of $V < U$ or $E < 1$ much more possibilities may occur.

When $V = U$ ( $E = 1$ ) the expected situations are:

a- One collision, one cross - ahead, one cross astern.

b- One cross - astern only.

c- None.

When $V < U$ ($E < 1$) the possibilities are:

a- Two collision, two cross- ahead, two cross - astern.

b- Two collision, one cross - ahead, two cross - astern.

c- Two collision, two cross - astern.

d- One collision, two cross - astern.

e- Two collision only.

f- Two astern only.

g- One astern only.

h- None.

1.3.1.3 <u>Case one</u>:

When the angle between the target track and the cross-ahead motion line (m) is greater than $90^{\circ}$

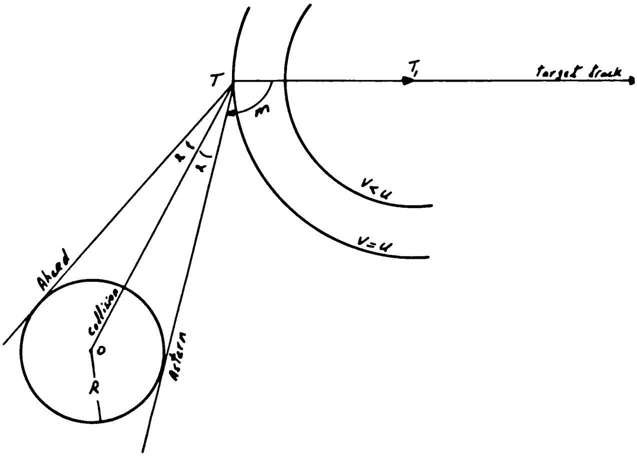



Figure ( 22 )

When: V < U , no collision, no cross-ahead, no cross-astern (None).

V = U , no collision (at infinity) also no cross-ahead or astern (None).

1.3.1. 4- Case two:

When the angle between target track and cross - ahead motion line (m) is less than 90° but the aspect (Q) is greater than 90°.

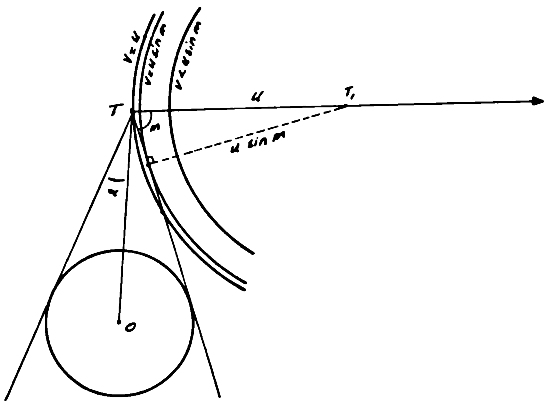


Figure ( 23 )

When:

| | |
|---|---|
| V = U, | one cross-astern only |
| V = U sin m, | one cross-astern only |
| V < U sin m, | none |

1.3.1. 5- <u>Case three</u>:

When $Q < 90^{o}$, but $m > 0$

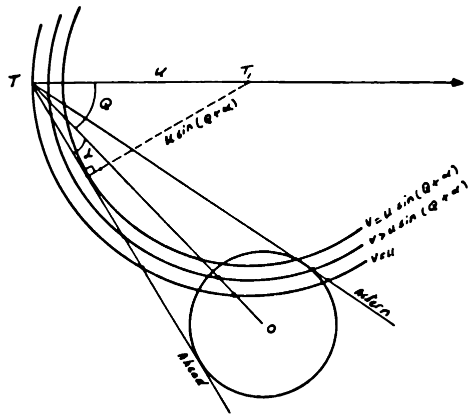



Figure (24 )

When :

$V = U$, one collision, one cross- ahead, one cross - astern

$V > U, \sin (Q + \alpha)$. Two collision, two cross-ahead, two cross - astern.

$V = U \sin (Q + \alpha)$. Two collision, one cross ahead, two cross - astern.

$U \sin (Q + \alpha) > V > U \sin Q$, Two collision, two cross- astern.

$V = U \sin Q$, One collision, two cross - astern.

$U \sin Q > V > U \sin m$, Two cross - astern.

$V = U \sin m$, One cross - astern

$V < U \sin m$, None

1.3.1. 6- <u>Case four</u>:

When target aspect is reduced such that:

$\alpha = Q + B$ , but $Q > B$

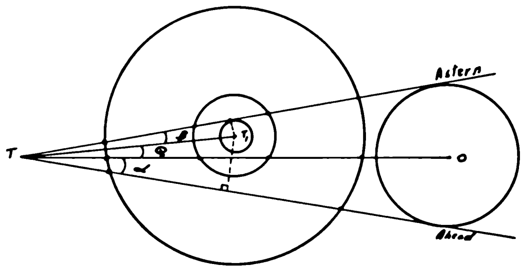



Figure ( 25 )

When :

$U > V > U \sin (Q + \alpha)$, Two collision, two cross-ahead, two cross-astern.

$V = U \sin (Q + \alpha)$, Two collision, one cross-ahead, two cross-astern.

$U \sin (Q + \alpha) > V > U \sin Q$, Two collision, two cross astern.

$V = U \sin Q$, One collision, two cross-astern.

$U \sin Q > V > U \sin B$, Two cross-astern only.

$V = U \sin B$, One cross-astern only.

$V < U \sin B$, None.

1.3.1.7 Case five:

When target aspect is reduced such that:

$\alpha = Q + B$, but $Q < B$

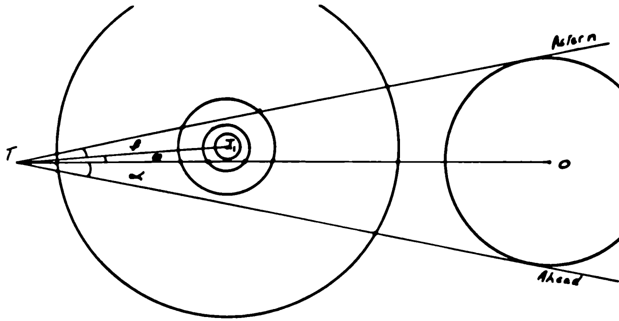



Figure ( 26 )

When :

$U > V > U \sin (\alpha + Q)$, two of each

$V < U \sin (\alpha + Q)$, two collision, two cross-astern

$V < U \sin B$, two collision points only

$V < U \sin Q$, none

1.3.1.8 <u>Conclusion</u>:

1- If V < U, two sectors of dangerous courses could occur.

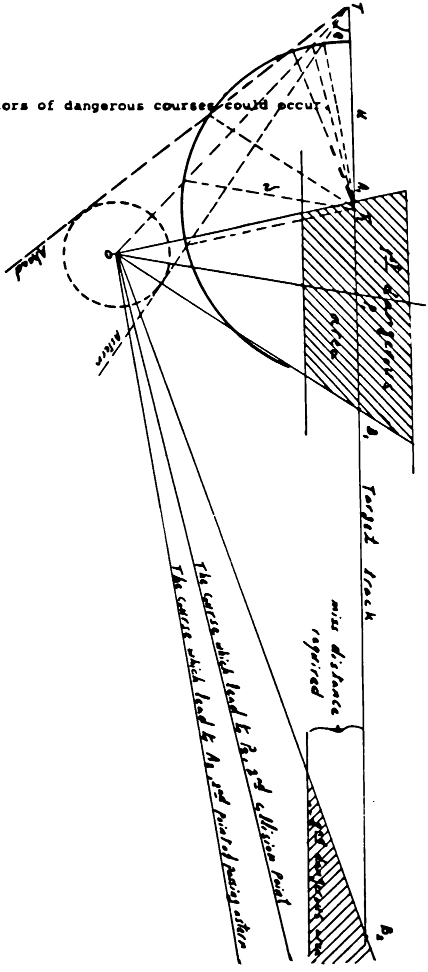



Figure ( 27 )

$A_1O\ B_1$ & $B_2\ O\ A_2$ defining two dagerous areas.

$P_1$ and $P_2$ are the two collision points.

$A_1$ and $A_2$ are the 1st and the 2nd point at which own ship pass astern of target.

$B_1$ and $B_2$ are the 1st and the 2nd cross-ahead point.

It is noticed that $A_1$ is closer to the target than $B_1$ while $B_2$ is closer to the target than $A_2$.

If $V > U$,only one dangerous area exist and always the cross-astern point is closer to the target than the cross-ahead point which even further away than the collision point.

<table>
<tr><td rowspan="3">Case</td><td colspan="3">E = 1</td><td colspan="9">E < 1</td></tr>
<tr><td rowspan="2">Q > 90</td><td rowspan="2">Q < 90</td><td rowspan="2">m > 90</td><td colspan="3" rowspan="2">m < 90 but Q > 90</td><td colspan="6">Q < 90</td></tr>
<tr><td colspan="2">V < U sin Q</td><td colspan="2">V = U sin Q</td><td colspan="2">V > U sin Q</td></tr>
<tr><td rowspan="2">Colli-sion</td><td rowspan="2">none (at infi-nity)</td><td rowspan="2">one</td><td rowspan="2">none</td><td colspan="3" rowspan="2">none</td><td colspan="2">none</td><td colspan="2">one<br>Where Q here is the limit-ing aspect</td><td colspan="2">two</td></tr>
<tr><td colspan="2">V < U sin (Q+ α )</td><td colspan="2">V=U sin (Q+α)</td><td colspan="2">V > U sin(Q+α)</td></tr>
<tr><td>Cross-ahead</td><td>none</td><td>one</td><td>none</td><td colspan="3">none</td><td colspan="2">none</td><td colspan="2">one</td><td colspan="2">two</td></tr>
<tr><td rowspan="3">Cross-astern</td><td rowspan="3">none</td><td rowspan="3">one</td><td rowspan="3">none</td><td rowspan="2">V < U sin m</td><td rowspan="2">V = U sin m</td><td rowspan="2">V > U sin m</td><td colspan="3">Q > α</td><td colspan="3">Q < α</td></tr>
<tr><td>V<U sin m</td><td>V = U sin m</td><td>V >U sin B</td><td>V<U sin B</td><td>V=U sin B</td><td>V>U sin B</td></tr>
<tr><td>none</td><td>one</td><td>two</td><td>none</td><td>one</td><td>two</td><td>none</td><td>one</td><td>two</td></tr>
</table>

So;

- If the target's aspect is greater than $90^{o}$, No cillision is possible what ever own ship speed is equal to or less than target speed.
- If the target's aspect is less than $90^{o}$, No collision is possible when this aspect is greater than the limiting aspect as previously shown in the concept of collision point.

Table ( 5 )

3- Since the two side limits of the dargerous area are the own ship courses for cross-ahead and cross-astern points, then the shape of the dangerous area will vary considerably with:

a- Desired miss-distance (R) b- Relative speed (E)

c- Aspect (Q)

4- In the two cases four and five (where $Q = \alpha - B$), for own ship to pass astern of the target, course involved steering away from traget´s track e.g. the course is divergent. There-fore, the dangerous area is more easly defined as a circle around the collision point with a radius equal to the desired miss-distance,

5- When $Q = \alpha - B$ and $V < U \sin B$, no collision is possible but it is also impossible to keep clear from the target by the required miss-distance.

There-fore, the dangerous area is more suitable to be defined as a circle around own ship with a radius equal to the desired miss-distance.

1.3.2. <u>Real area of danger</u>:

In a two-ship encounter, the dangerous area within which the collision point exist can be defined as follows:

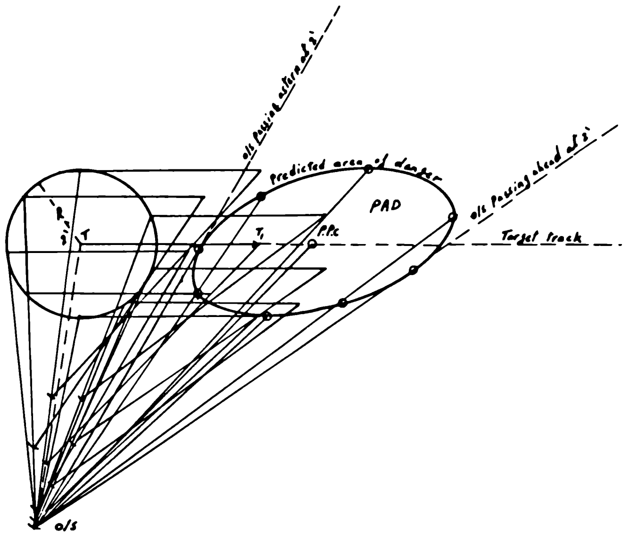



Figure ( 28 )

**COMMENT:**

The produced shape for the dangerous area looks like an ellipse, the major axis is nearly equal to the difference of the cross-ahead and cross-astern distances as measured from the target, the minor axis is also nearly equal to twice the desired miss-distance.

It should be noted that the point of possible collision (P.P.C.) is not necessarily at the centre of the area.

As time advances, both P.P.C. and the PAD will change their position on the screen, the target will move accross the radar screen on its relative track with its P.P.C. and its PAD attached.

If the P.P.C. lie on own ship heading marker only the range will change but if the PAD is not intersected by the H/m it will change in position and shape as time progresses.

### 1.3.2.1 How the concept of dangerous area is adopted in practice:

#### 1.3.2.1.1 PPC / PAD Fundamentals:

The following figure illustrates a hypothetical encounter with a slower target detected on the starboard bow. A head-up stabilized display is assumed. Heading marker is subdivided into 6 min. elements depicting ownship W.spd / HDG vectors.

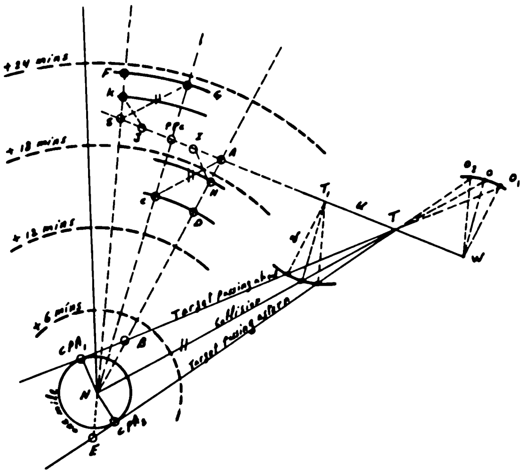



Figure ( 29 )

Point (N) = relative position of ownship at all cases ( passing ahead or astern, collision, C.P.A.)

Point (N) = relative position of target in case of collision

Point (B) = relative position of target when passing ahead of ownship

Point (A) = true position of target when passing ahead of ownship

Point (D) = true position of ownship when target passing ahead

Point (D) can be estimated by drawing a line parallel to (TN) from pont (A) to intersect the collision course at (c), then taking same distance (NC) on the course of ownship which let the target passes ahead.

Point (E) = relative position of target when passing astern of ownship

Point (s) = true position of target when passing astern of ownship

Point (F) = true position of ownship when target passing, astern point (F) can be estimated by same way as point (D)

Point (I) = true position of target at the closest point of approach when passing ahead.

Point (H) = true position of ownship at the closest point of approach in that case

Point ($CPA_2$) = relative position of target at the closest point of approach when passing astern

Point ($CPA_1$) = relative position of target at the closest point of approach when passing ahead

Point (J) = true position of target at the closest point of approach when passing astern

Point (K) = true position of ownship at the closest point of approach in that case

Point H,I,J and K can be obtained by constuction.

1.3.2.1.2 <u>The practicle construction of the PAD</u>:

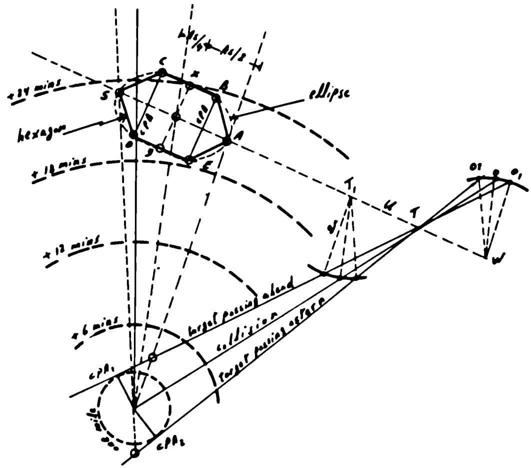


Figure ( 30 )

At the mid point of the line (AS), a line is drawn perpendicular to the target's track and extend in both direction (for a distance equal the CPA) to point X and Y.
The ellipse is drawn passing through (AXSY).
The hexagon is drawn by joining the points A, B, C, S, D and E.

COMMENT:

The concept of presenting CPA data in a true motion format superimposed on a relative motion PPI is beneficial. The computer aided radar data processor provide the flexibility to display target data in respect to each of the relative motion lines (passing ahead,collision, and passing astern) in a true motion format in relationship to the fixed single ownship time scale established by the heading marker.

The critical heading for collision is visualized as being projected from the PPI centre to a point of intersection with the target track. This intersection defines the location of the PPC which represents a future position that the target will occupy and separated from ownship´s present position by a specific time interval and azimuth. Hazard category is established immediately in term of the location of the PPC in respect to ownship´s marker.

A PPC on or near the heading marker represents Real HAZARD which relates to ownship´s present motion and will require subsequent evasive action, while a PPC located else-where on the PPI represents. POTENTIAL HAZARD which must be taken into consideration whenever ownship contemplates a manoeuvre. The location of the PPC, there-fore, conveys more intelligence about the hazard the target is capable to present to ownship than does any specific target parameter such as range and bearing,speed, heading or even alphanumeric indication of CPA data, which is associated with a specific value of ownship´s motion.

A characteristic of the collision heading is that the target´s bearing remains fixed if ownship were to adopt it. Hence, for any future location of ownship on the collision course, it is possible to estimate the position of the target on its track. The future location of the target can thus be related to a specific time, and hence to the location of ownship anywhere on the PPI. This permits the future passage of ownship in the vicinity of future positions of the target to be visualized.

The concept of the predicted area of danger emerges from this visualization. The PAD defines an area about a location on the target track that the target will entre at some future time which if intersected by own ship heading marker will result in CPA distance less than stipulated. Ownship should always steer well clear of PADS. Hazard representation by means of a PAD is independent of ownship´s heading at the moment of observation, though the subsequent motion of PADS on the relative motion PPI is determined almost exelusively by the reciprocal of ownship´s vector. Hence CPA data can be seen directly, for all possible headings of own ship at present speed, or on request at any other trial speed.

A simple evasive manoeuvre recommends it-self instinctively; whenever ownship´s heading marker intersects one or more PADS, real hazard is predicted and the heading marker must be moved away byan alternation of heading, or alternatively the PADS may be moved off the heading marker by an alteration of speed, taking into account other PADS exist on the PPI.

The first generation of sperry CAS displays an elliptical PAD, but the 2nd generation displays a hexagonal PAD.

1.3.2.1.3 <u>Information content of PPC / PAD display</u>:

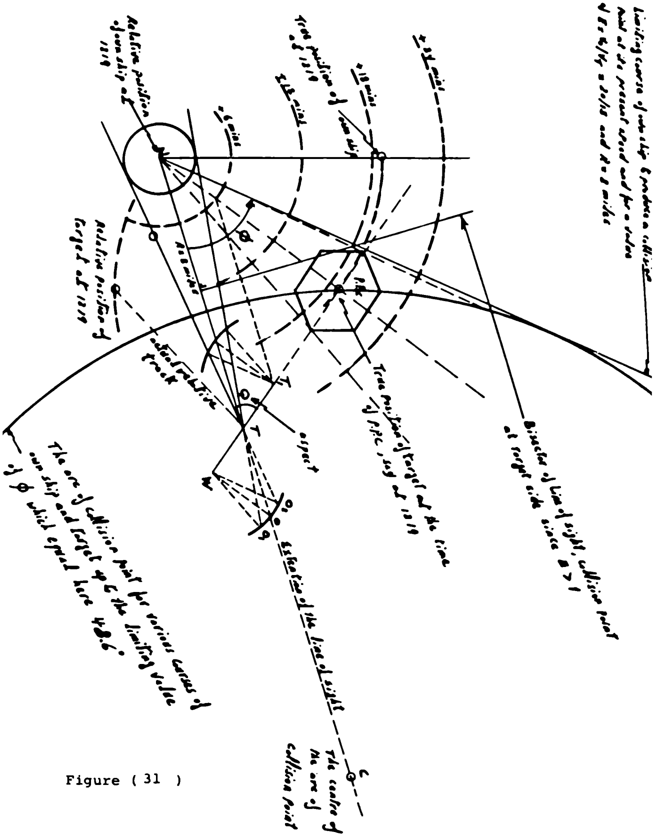


Figure ( 31 )

Data presented on a relative-motion indicator, stabilized in either north up or ship's heading up. Plot inputs are W. SPD / HDG.

This kind of presentation provide:

- CPA data consisting of; clearing ownship headings to preserve a CPA distance and available time to manoeuvre.
- Ownship and target 6 mins W. SPD / HDG vectors.
- Target aspect and estimate of speed ratio.
- Relative track for data confirmation.
- Time interval to PPC and crossing target track.
- Independent confirmation of PPC location.
- Estimate for time of CPA on clearing heading.
- Estimate for future PPC / PAD locations for any ownship heading.
- Direct and simple indication of Real and potential hazard and its variation as ownship manoeuvres.
- Manoeuvre convention for hazard elimination by taking heading marker away from PADS.
- Eliminate sequential trial and error variation of vector modes and prediction time, firstly to determine hazard and subsequently to select an adequate manoeuvre.

1.3.2.2 Movement of P.P.C. with time:

1.3.2.2.1 If ownship is faster than target E > 1 :

a- Target passing astern:

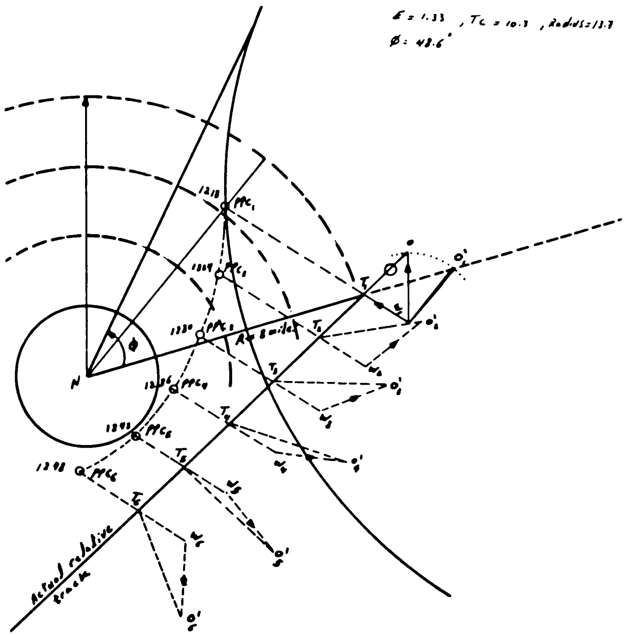



Figure ( 32 )

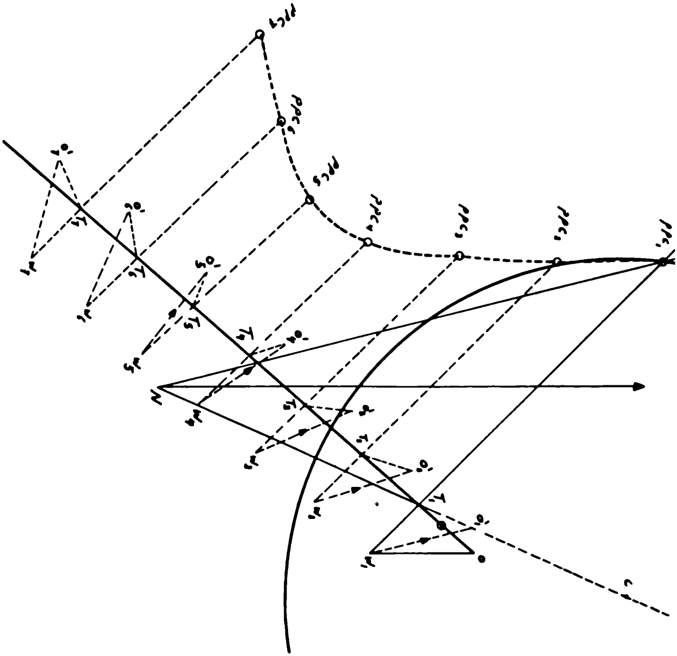
$$E = 2 / 1.5 = 1.33$$

$$TC = R / ( E^2 - 1 ) = 10.3$$

$$Radius = RE / ( E^2 - 1 ) = 13.7$$

$$\phi = \arcsin 1 / E = 48.6^\circ$$

1.3.2.2.2 b- **Target passing ahead:**



E = 3/2 = 1.5

Tc = = 6.4

Radius = 9.6

Q = $42^{o}$

Figure ( 33 )

1.3.2.2.3. <u>If ownship is slower than the target</u>

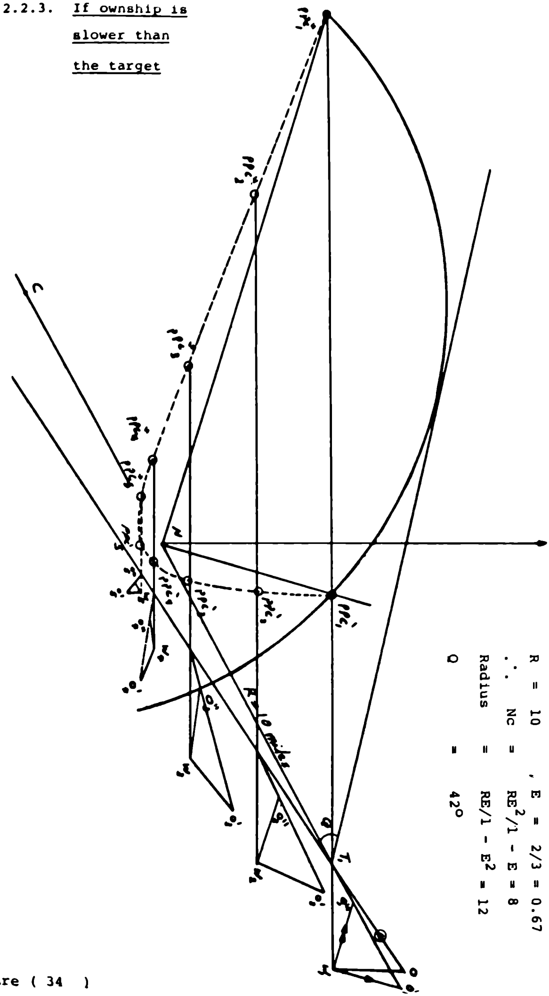
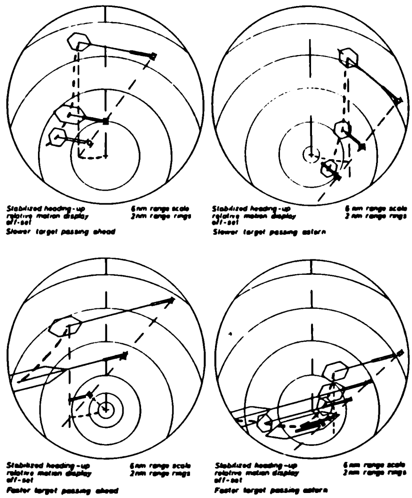



Figure ( 34 )

1.3.2.3 The movement of the PAD:

Own ship will pass either ahead of or astern of a slower or a faster target respectively.

These four cases are illustrated in the following figure.




Encounter categories

Figure ( 35 )

In the case of the slower target, either sense of passing produces controlled and predictable event.passing in front of the PAD is equivalent to passing in front of the target & vice-versa.
Hazard is established by relating PAD locations to ownship line of progress.
Comparision of the tips of ownship and target vectors provides an accelerated forecast capabilities.

Hazard will be seen to diminish before the target reaches its CPA position though slower target are classified as non-hazardous, i.e. displayed with a 6-minutes unit vector without a PAD, only when the PAD is beyond the display range of the P.P.I.

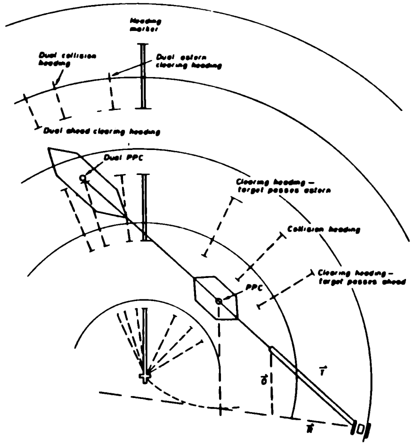
A more complex set of events occurs when manoeuvering in the vicinity of the PAD of a faster target.
In general, if ownship is clearing such a target whose PAD is off the heading marker, inevitably the target will change its status during the encounter to non-hazardous and the PAD will disappear. Prior to this, a dual PAD will come into display range and merge with the primary PAD.
An example of this phenomenon occurs with a faster overtaking target which will be declared non-hazardous when it begins to draw ahead of ownship. The sequence of events is different for cases of passing ahead or astern of the target.
The additional complexity in the case of passing ahead of a faster target is a clear indication of the risks associated with this type of manoeuvre. The dual PAD of the faster tar-

get is an important item of information which can not be ignored.

<u>High and low speed navigation</u>:

In low speed navigation, where the general sample of targets is faster than own ship, the dual PAD phenomenon will come into play.
Manoeuvring in the vicinity of a dual PAD follows the convention established for the single PAD of the slower target:
Pass behind the primary PAD, pass behing the target.
Pass infront of the primary PAD, pass infront of the target.
The late situation is equivalent to passing between the primary and dual PAD.
It follows that passing outside both PADS or on either side of merged PADS results in the target passing ahead. A merged dual and primary PAD represents the disappearance of the ability to cross ahead of a faster target.

In high speed navigation, the speed ratio Vo / $V_T$ is large, so the PAD lies close to the target at all times. Hence, a rule of thumb is that by steering away from targets, one is steering away from hazard. Displaying the PAD makes this activity more certain.




Slow speed navigation – dual PAD

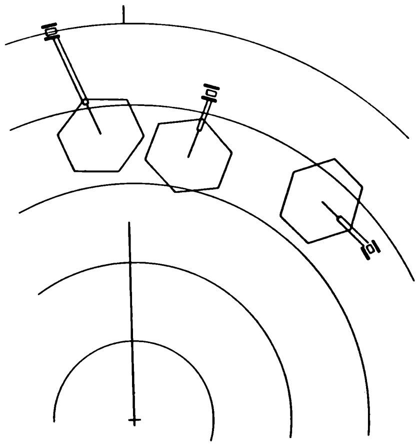
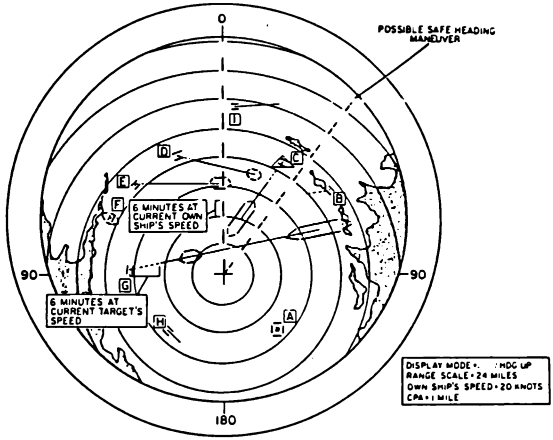


Figure ( 36 )

High speed navigation - single PAD




A ACQUISITION SYMBOL POSITIONED ON TARGET

B TARGET JUST ACQUIRED WITH SEGMENTED SPEED VECTOR SHOWN

C TARGET CLOSING FAST AT SPEED GREATER THAN OWN SHIP, COLLISION THREAT TO OWN SHIP, CA DATA SYMBOL POSITIONED ON TARGET.

D TARGET MOVING SLOWER RATE THAN OWN SHIP.

E TARGET MOVING APPROXIMATELY SAME SPEED AS OWN SHIP, COLLISION PROBABLE WITHOUT MANEUVER

F TARGET IN TRACK IS STATIONARY

G TARGET SPEED GREATER THAN OWN SHIP'S WITH TWO PADS, SAFE PASSING IS BETWEEN PADS

H TARGET PAD IS OFF PPI, NO PRESENT DANGER TO OWN SHIP, SOLID-LINE 6-MINUTE VECTOR IS FORMED

I TARGET MOVING AHEAD AND FAST, NO INTERCEPT POINT WITH OWN SHIP POSSIBLE, 6-MINUTE VECTOR IS DISPLAYED

Figure ( 37 )

# SECTION II

## 2 Marine collision causes and reduction methods:

### 2.1 The major Collision causes:

In order to analyse marine accidents and initiate preventative action, it is necessary to have a clear understanding, based on good information, of the causes of the risks involved.

The nature of accidents at sea is rather complicated and to collect enough information it is not that easy. The actual sequence of events prior not only to a collision but also to a near misses should be accurately known. An automatic recording of the operational data on board could provide a good clarification of the events prior to a casualty.

Potential causal factors of the casualty are often circumstances or conditions present to a varying extent during all ship transport operations and not only in the cases where casualties occur. A collection of data on near-misses can there-fore provide insight into potential causal factors, and should one make comparisons with situations that led to that cesualty,one then possibly identify the most critical circumstances or conditions that lead to casualties.

Det Norske Veritas research devision carried out a research work to find out the cause relationships of collisions and groundings, the project done in the period 1977-80 and has given a good light on that problem. Veritas was interested in finding out the reason for the large number of collisions and groundings on a world wide basis.
Veritas wanted to evaluate its classification rules for ships

in light of the conclusions from such an analysis and to determine its rate in the endeavour to minimize such casualties.

Collision risk problem could be constructed in three parts:

a- The ship itself with its social and technical system and man/machine communication.
b- The environment represented by traffic, weather and waters.
c- The society represented by shipyards, manufacturers, national and international organizations, marine authorities, owners, and classification societies.
The latent risk can manifest itself in many ways such as; accidents, incidents or near misses and "lived through" or experienced risks.

In the operation and maintenance of a ship there are men and machines involved and they cooperate. This cooperation is controlled by a system of rules concerning procedures and the distribution of tasks and responsibilities. These rules are established by authorities, classification societies and shipping companies and only a fraction of them originate on board. The rules, the men, and the machines encounter each other in different interfaces, of which the best known is ergonomic: How well is the machine fitted to man? The ship operates in an environment which can be of various kinds.

The casualty can thereby be regarded as a result of the interplay between the conditions and situations that the man/machine system is set to operate under, and the system's inability to fulfill the requirements.

2.1 The probability of marine collision could be affected by many factors, the major ones are:

1- Traffic condition;

a- Ships engaged in the traffic (size, speed and standard)

b- Type of encounter (heading on, overtaking, crossing or fine crossing).

c- Traffic density.

2- External influences;

a- Weather condition (visibility, darkness).

b- Waterways.

c- Other ship fault or deficiency.

3- Ship technology;

a- Manoeuvring quality.

b- Ship´s control system.

4- Navigational system;

a- Bridge design and arrangement.

b- Bridge routines and procedures .

c- Bridge equipments.

5- Navigational aids;

a- Sailing regulations.

b- Communications.

c- Vessel traffic systems (traffic seperation schemes, vessel traffic surveillance and services).

6- Human factors;

a- Violation.

b- Comptence and experience.

c- Work load and social climate.

Therefore, the following factors could be considered as the major factors causing collision risk;

1- Traffic condition

2- External influences

3- Sudden technical failure

4- Human errors

2.2 the major measures taken to minimize the effect of these causes are:

1- Navigational system

2- Navigational aids

3- Greater reliability of ship´s control system

4- Education and training philosophy

In addition

5- Marine casualty investigation technique to check the effectivness of the above measures and explore new adequate ideas.

Now we can analyze the items of these measures to highlight how each item is contributing in solving the collision problem, trying to find out the defeciencies, to be able to present the recommendations which could improve the situation.

2.2.1. Navigational system:

2.2.1.1 Bridge design and arrangement:

The difficulties facing watchkeeping officers while conducting safe navigation, particularly in congested areas, are increasing with the increment in ships size, speed and number which are considered as contributing factors enhanceing the occurance of collision risk. These circumstances are pushing strongly towards seeking for the most efficient navigational operations. Since the bridge is the operational centre of the ship, its design and arrangement is very important and must be optimized to improve the safety of navigation under all operating conditions.

Several analysis of marine casualties, especially collisions and grounding, show that many were attributed to failure to keep a good lookout, which must be interpreted in the broadest terms. In addition to keeping a visual lookout it has meant failure to observe changes in the weather, including visibility, failure to observe properly the movements of approaching vessels, failure to observe the radar and /or echo sounder, and failure to observe that the course is accurately steered and that helm orders are carried out correctly.

To avoid all these possible deficiencies more emphasis on bridge design, layout, and arrangement are needed.

It is probably true in the case of many vessels that insufficient attention is paid to the design of the nav igating bridge, design being often left to the builder or, even the engineer superintendent.

Traditional bridge layouts are shown to be inefficient with respect to the work utilized by mariners at sea. Massive instrument panels often sited so as to deny the officer of the watch, the ability to get close to the bridge windows, poor instrument layout within these panels, and a random scatter of equipment making a mockery of ergonomics have all been too readily accepted by too many officers for too long time.

This short coming is very significant today with the current impact and range of modern equipment and the tendency to reduce manning, making it necessary to examine not only the individual instruments found on the bridge, but to step back and take an objective look at the whole. The bridge arrangement should ensure that the officer can more effectively discharge his duties. There is a need of wide arcs of visibility and a sensible layout of instrument and equipment for the most efficient operation. The benefits to the operator should be ease of operation of instruments, comfort and considerably improved working environment.

International organisations, national administrations, various institutions and the navigators themselves are now increasingly concerned about bridge functions, layout and instrumentation for increasing nautical safety. The operational safety is considered as an important sector of the total safety of the ship and its complement,

The bridge design should be evaluated in relation to the requirements of functional analysis and forthcoming international regulations, it should allow the housing of new technology without negatively affecting existing functions and routines. If an owner's design is evaluated on the basis of functional analysis, with consideration to possible future changes in instrumentation, the result should ensure operational effeciency and safety while being of maximum benefit to the user.

It is impossible to produce one basic design which will be suitable for all classes of vessels as the space available, the manning and the equipment will vary considerably. However, it is possible to lay down certain lines of guidance. This is best expressed by grouping equipment according to function, which means having regard to inter alia usage, circumstances, presentation and back-up facilities.

The first requirement of a bridge officer is to be able to keep a good lookout visually, as well as having the ability to move about freely without obstruction and observe such instruments as required. Further, only equipment which are actually required for the navigation and manoeuvring of the ship should be placed in front of the navigator and all other equipment relegated to the back of the bridge.

Before showing one of the proposed bridge design and layout, it is perhaps desirable to give a few examples of common faults:

a- Wheelhouse structure does not provide enough arc of visibility and its windows vertical causing light reflection problems.

b- The fore end cluttered up with switches and controls, many of which are not required for navigation, and so placed that when anyone leans on the fore-end they may be inadvertently activated.

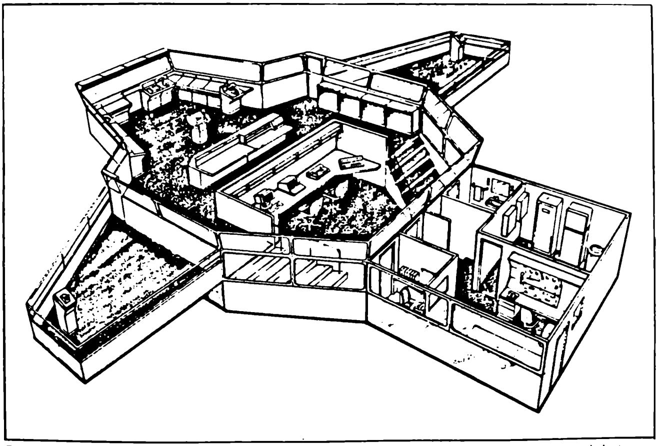
c- Failure to duplicate controls or place them where they may be required.

d- No consideration to possible future changes in instrumentation.

e- Instruments sited outside normal reading range.

f- Instrument so sited that the data is not instantly visually available.

The number of alarms on the bridge is tending to increase, and to avoid confusion in moments of stress, a centralised alarm and control panel is required.



*The sketch shows the principles of a bridge design arrived at in the Norwegian SDS project in the mid-70s. The solution meets the basic requirements of today and the near future*

Figure ( 38 )

Det Norske Veritas has compiled a draft proposal for a classification service entitled "Nautical safety", to contribute in increasing operational safety and to offer relevant professional assistance in this field.

Anyway, a continuous contact with ship designers, builders and operators is essential to ensure that the wheelhouse designer is supplying what the user needs for most efficient actions. A concern for ergonomics has become a necessity in today's maritime industry.
A well planned wheelhouse layout is surely a positive step towards greater safety.

2.2.1.2 Bridge routines and producers:

The causes of many casualties are found to be related to inadequate watch keeping, lack of planning, and lack of systematism in carrying out the bridge functions. More emphasis should therefore be placed on better watch keeping organization and on greater use of established procedures. This will ensure that the necessary tasks are carried out at the right time and an adequate contingency plan is available during critical phases of the voyage.

Adeguate coverage of the watch, avoiding slovenliness in executing properly the vital tasks is a very important matter which seriously affect the safety at sea.
Watchkeeping officer leaving the bridge staying long time in the chart room, inadequate attention and absent lookout, officer felt asleep on the watch or affected by alcohol, no frequent check of navigation lights, course, speed, compass error, and visibility, not calling the master is case of poor visibility or in situations where his skill and experience are needed, lack or rong fog, manoeuvre or warning signals, insufficient distance when passing other ships, excessive speed under the circumstances, neglect bridge to bridge communication, not listening to navigational and traffic warnings in congested areas, ignorance of the rules of the nautical roads, neglect visual observation, and depending on one source of information without considering its limitations, are all dangerous factors generated by the carelessness and violation of the watchkeeping officer and affect the navigational safety.

They are contributing factors which lead mostly to serious accidents and consequently must be completely avoided. That could be achieved by well defined job requirements, extensive bridge procedures, and strict watch rules and orders followed by consecutive check and serious control by the master until he is sure that all officers obide by them.

Good bridge producers may depend on:

1- Bridge manning

2- Bridge instruction

3- Bridge organization, referring to the division of responsibilities between the persons involved in the execution of the passages

4- Pre-planning and briefing of sea passages

Safety could be improved to a considerable extent by proper manning of the watch in various conditions. Double manning of bridges in certain areas is advisable. Two officers on watch may be necessary where navigational hazards (ice, several oil-rigs, severe weather condition with heavy deck cargo etc.), high traffic density, or restricted visibility is expected.
These areas can be recognized by the beforehand planning and briefing of the voyage.
The traditional way of pointing only one seaman per watch at night should also change during these conditions which need enough vigilance during all watch period.
Ship's safety and efficiency greatly be rectified and increased by the issuance of extensive watch instuctions and procedures for the bridge functions. Formalizing work routines and practices on the bridge is necessary and not the traditional belief which is to leave it up to the individual navigator.

Shipping has long traditions which often are said to be the strength of this industry, but from a safety point of view these traditions in the attitudes are quite often the weakness in shipping.

Shorebased management as well as the masters on board ships are both responsible for the establishment of efficient operating procedures on board their vessels.
Captain instructions must be extensive and clear enough, specially the night orders, taking into consideration all the watch phases and particulars including; procedures for radar plotting, procedures of passing other vessels in restricted waters, checking of marks and lights, alternative references for positioning, procedures in poor visibility, exchange of information when encountering other vessels, ... etc.

If we shall overcome the wide spread improvisation on the bridge which too often results in accidents in the merchant fleet, a change in attitude is of the greatest importance.
Several nautical colleges have bridge-instuctions and preplanning of seapassages in their curriculum, but bridge teamwork training however still seems to be far behind.
Nautical colleges can make a valuable contribution by implementing bridge organizations in the sense of bridge teamwork in their education as a special subject and in a modern way.

2.2.1.3. Bridge equipment:

Navigation is that science which enables a craft to travel from one place to another in safety. For marine navigator this implies that, he must be able to obtain and plot ship's position frequently, monitoring of potential hazards to navigation, evaluating and processing the traffic situation to avoid collision with other ships. The advent of electronic navigational aids has alleviated the problems to a considerable degree, particularly in conditions of reduced visibility.

In the past 50 years there have been increasing developments in electronic equipment for the operation of ships and many of them have been applied in all vessels.
These equipments can be devided into two main categories:

1- Systems which have a direct contribution to collision avoidance procedures, such as V.H.F., Radar. and ARPA
2- Systems assisting in collision avoidance which either provide ship's position such as Decca, Loran, Omega and satellite or help in estimating the ship's position such as the echo sounder and logs.

V.H.F. radio telephony has been used for ship-to-shore and ship-to-ship communication and when used effeciently successfully reduce the incidence of collission. It's effect will be mentioned in more details later in this section.

Radar is, perhaps, one of the most useful aids that has been given to the navigator. Despite initial problems, it is recognized today as an extremely useful piece of equipment which, if used correctly, can provide an immense amount of information to the navigator.

Fixed objects and prominent landmasses are visible on the PPI display, as well as other ships in the immediate vicinity. Collision between ships have always been a serious problem, particularly in poor visibility. Weather conditions have little effect on the use of radar, so that it can be used in collision avoidance in both clear and foggy weather. By plotting, the course of an approaching vessel on the PPI, the closes point of approach and the necessary avoiding action can be determined.

However, in a multi-ship situation, which is typical of many coastal waters, the job of plotting the tracks of more than one vessel can be time consuming. By using the recently introduced computing radars (ARPAs), the navigator is able to obtain rapidly the closest point of approach of up to 20 targets. Also the proposed change in course or speed, or both, can be fed into the equipment to check the effectiveness of the manoeuvre to avoid a dangerous target and that will not result in another hazardous situation. Full details about radar and ARPA will be given in the next section.

The second category of the electronic navigation aids is containing the equipments used in position fixing technique, their exsistance had increased the ship's safety and efficiency by obtaining it's position when needed for economical operation and to avoid known hazards. Accordingly, they share in reducing the work load of the watchkeeping officer leaving more time for him to evaluate the traffic situation and take the correct action in time to avoid collision or any dangerous close quarter situation.

Echo sounders are used to get the water depth to determine not only that the vessel may be approaching a grounding situation but also to provide location information using contour navigation.

Radio direction finders receivers make use of the directional properties of a loop aerial to get the bearings of known radio beacons.

Conventional logs measure both speed and distance through the water while doppler logs can measure the speed of the vessel over the ground.

Hyperbolic systems; Decca, Loran and Omega use the concept of an imaginary hyperbolic grid superimposed on the earth's surface. The constituent hyperbolea are derived by measuring the time and /or phase difference between the arrival of synchronised transmissions from two station pairs giving a position line.
Decca, is used for coastal navigation, Loran-c, is suitable for use in both oceanic and coastal naviagation, Omega is, normally used for oceanic navigation but it may be good enough for coastal navigation if the differential mode is used.

The transit satellite system can provide accurate position fixes any where but the biggest drawback of the system is the interval occurs between reliable fixes which varies according to the ship's latitude.Navstar (Gps) satellite system is a mutch heralded system, which is expected to have extremely farreaching effects on not just position fixing but on the whole spectrum of navigation. The system is still in the developing stage, but the expected big advantage is its ability to provide accurate position fixes continuously, in all weather, throuhgout the world. It could become the ultimate navigation system.

Inertial navigation system is a recent introduction in marine navigation but it is still too expensive for general use.

Thus there is a great variety of systems available for navigational tasks on board ships, which overlap or complement each other in many aspects of their application. At present the task is to reduce those methods to the required extent and to intergrate them into a navigation system covers extensively the problems of the operation of the ship and track guidance. Integration of two system, such as Satnav/Omega and Loran/Satnav, provides the user with not only all the featurers of each individual system, it also helps to counteract each one´s deficiencies.

Therefore, one can say that technology is keeping up with the navigational system with consideration to increase service ability and accuracy, display enough and clear information in a simple form, and provide mariners with all needs and requirements during the various circumstances to reduce his work load.

Today a new technique is introduced performing the second half of the position fixing task to avoid leaving the bridge to the chart room at possibly vital moments. The instrument is called the Bowditch navigator which automatically and continously displays the vessel´s current position on a standard nautical chart.

It is used in conjunction with the ship's electronic position fixing aids.

The most important and essential procedure now is the necessary training for the proper use of all this equipment.
The mariners have to know the correct setting, adjustment, and reading of these equipments to avoid any faulty operation or mal-function of any system. They must well understand the advantages and limitations of each and know how to analyze and get the full benefits of the informations available.
The navigators should also check the performance of these systems prior to sailing, prior to entering restricted or hazardous waters and at regular and frequent intervals throughout the passage, never rely upon so completely on single electronic navigational device that its failure may jeopardise the safety of the vessel.

### 2.2.2 Navigational aids:

#### 2.2.2.1. Sailing Regulations:

The function of the international regulations for preventing collision at sea is to direct the actions taken by mariners so that a safe conduct results. They are the most important means of avoiding collision. Therefore, the rules must be well designed to deal with all classes of encounters, very clear to avoid ambiguity, and simple enough to be used easily and correctly. They should also be analysed and amended from time to time to cope with the development of technology and clarify certain difficulties if any.

The rules were established in 1864 and revised in1948, 1960 and 1972 to suit the infinite variety of maritime circumstances. The new regulations came into force since 1977, but there is still a prevalent tendency of the parties involved to disregard the basic rules. In many collision cases on which judgments have been passed, at least one of the two ships involved has been found to have contravened the international regulations.

Captain/Wylie, Kemp, Hopkins and others said that 1972 rules are still have some deficiences, Complex, and the verbiage is not likely to help matters. They said that; the regulations allow escape action on the part of the stand-on vessel when it becomes apparent that the give-way vessel is not manoeuvring as it should. The point at which a manoeuvre should be made is not, however, laid down in the regulations. Since the possibility exists that stand-on ship could make an escape action before the give-way vessel makes its manoeuvre, the give-way vessel will be aware of this possibility. The rules also do not specify what escape action should be taken in that case, either very drastic escape action is necessary or some kind of manoeuvre which takes into account the likely action from the give-way ship. It is desirable that the rules should prescribe manoeuvres which are geometrically and logically consistent. Moreover, under these regulations the restriction on the behaviour of ships in collision-avoidance situations in poor visibility is not enough.

In addition to that comment, they belive that the verbiage of some rules is poor and if the existing english version is going to be used as the basis for translation into other languages there certainly will be dangers ahead unless something is done beforehand to improve the text.

The problems developed in the analysis of the role and application of a collision avoidance rule are now being approached experimently. In particular, the extent to which the interpretation of the current regulations varies across individuals, the way in which navigators in practice overcome the various logical problems associated with the regulations, and the way in which the regulations are extended to cover multiple-ship encounters are under investigation.

To alleviate some of the problems, amendments take place from time to time. In June 1983 several amendments where made, mainly relating to the carriage of lights and shapes. Two new para-

graphs were added to rule 10, Traffic Separation Schemes, to exempt vessels restricted in their ability to manoeuvre, which are engaged in an operation for the maintenance of safety of navigation or in the laying or servicing or picking up of a submarine cable, from complying with the requirements for vessels navigating in or near a traffic seperation scheme.
Further amendments are being considered by the IMO Sub-Committee on Safety of Navigation to resolve some ambiguities or to clarify the Rules. Rule 10 will probably be amended to make it clear that, when crossing a traffic lane, it is the course steered which should be at right angels to the direction of traffic flow, and to give a better indication of which vessels are permitted to use inshore traffic zones.
There is also likely to be an amendment relating to the term "avoid impeding the safe passage", as used in Rules 9,10 and 18. At present there is some confusion as to the respective responsibility of vessels required to avoid impeding the passage and vessels required to keep out of the way. It will be several years before these further amendments will be agreed and brought into force.

Eventually it is hoped that the behaviour of mariners will be more predictable in the problem encounters by additional training and careful adjustment of the rules which will have to serve the mariners of many countries and the safety of their ships, passengers and cargoes, and not be a possible cause of some indecision or confused interpretation.

All ships officers must be well prepared and trained to abide to these regulations carefully, intelligently, and correctly in time without any hesitation since they are the most important means for avoiding collision at sea.

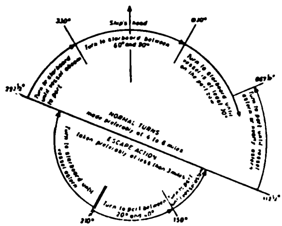


Figure ( 39 )

Course alteration diagram, intended primarily for use in avoiding a vessel detected by radar and out of sight.

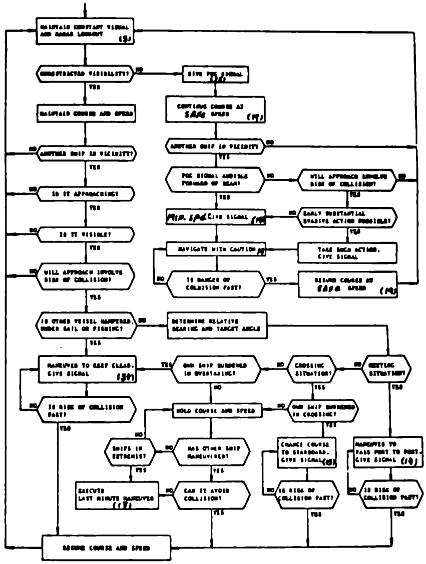


Figure ( 40 )

Logic flow diagram for two-ship encounter in open sea following International Rules of the Nautical Roads

### 2.2.2.2. Communications:

One of the most important violations for collisions is the insufficient and ineffective use of communication. It was found that failure in communication was either a causal or a contributing factor in many collision cases.
One example is the Delta Norte/African pioneer collision 18 February 1982 in the Gulf of Mexico, the conclusion indicate that the accident might have been prevented if the master of the Delta Norte and the chief mate of the African pioneer had contacted each other using the V.H.F. radiotelephone and had established a meeting arrangement.
Another example is the collision between a bulk carrier (14,000 g.r.t.) from Portsmouth (New Hampshire) and an oil tanker (17,000 g.r.t.) approaching Boston. The collision occured in Massachusetts Traffic seperation scheme at 1713 in daylight, the investigation indicated that the method of calling on V.H.F. radiotelephony used by the bulk carrier was inadequate, and if V.H.F. radiotelephony had been used properly by both ships the collision might have been avoided.

Communication is extremely important, the possibilities of communication with other traffic is a decisive factor. The safe conduct of shipping can be well improved if ships communicate their intention while approaching each other and exchange anti-collision advice.
To reduce accidents resulting from navigational encounters involving uncertainty about the other vessels intentions, effective bridge-to-bridge communication is required. It will be valuable if bridge-to-bridge communications is improved by,

for instance, regulations and training to ensure greater circuit discipline.

During last decade virtually every merchant vessel of any consequence has been equipped with V.H.F. radiotelephony equipment. It had been hoped by many that the emergence of this remarkable and widely available communication facility would have been recognized in the 1972 agreed international regulations for preventing collisions at sea, as a means of helping to ensure that no cancelling actions would be taken by two vessels trying to avoid each other. This opportunity was not grasped by the IMO working party on the collision regulations for a variety of reasons and consequently was lost at the international conference held in October 1972.

It should be noted however, that although the 1972 regulations do not specifically acknowledge the existence of V.H.F. they do state that "all available means" should be used to make a full appraisal of the situation and for determining the risk of collision (1972, Rules 5 and 7). It is quite likely therefore that such "means" could be considered by a court of law to include V.H.F. communication.

One of the possible difficulties related to V.H.F. communication is the lack of a language common to those wishing to communicate, which could be misunderstanding what was said and misconstruing intensious and agreements. The international code of signals provides an International phonetic Alphabet (IPA), and an International code (INTERCO) to help to overcome this difficulty, although, perhaps regrettable, an "anti-collision message" section has not been included in the codes. Such a section could be useful and its content would need to be closely aligned with the international regulations, it would be necessary amongst other things to be able to describe the class and aspect of a vessel. Moreover, adoption of a seperate world-wide V.H.F. channel for use during ship encounters in international waters will ensure that the passing of vital navigational and anti-collision information is not prejudiced.

Communications with other ship can further be improved by fitting the vessel with adequate equipment and by careful organization of the layout of the operator's place to avoid difficulties in establishing communications, the problem of identifying other vessels could be solved by using transpoder system connected to V.H.F. or radar.

However, more restrict regulations and training is still needed to avoid problems such as, not listening to proper frequency, not using bridge-to-bridge communication in situations where it would be of help or agreeing to an infeasible passing.

On the other hand, the link between ships and shore must be promoted to inform the ships off certain coasts of the world with the necessary intelligence of the traffic and local environment through which they pass, to know what is going on around them or ahead of them. This is quite useful in areas of heavy shipping traffic particularly when bad visibility is likely to occur such as Dover Strait. Where traffic separation schemes are used, it will be very important to inform ships in the area about the vessels and ferries intend to cross the lanes or moving in unexpected direction, this will help much in reducing the possibility of collision and thus increases the safety of navigation.

One of the new systems which is designed to serve ships and provide them with needed informations is the Navtex. It is an international single frequency system providing vessels with an edited series of coastal warnings or advisory messages printed out on the ship's bridge. The subjects covered include navigational warnings, meteorological forecasts and gale warnings, ice information, electronic nav-aids warnings and initial distress messages.

Generally, the development of satellite systems give an indication that satellite communication in the future will be the predominant communication tool on board ships.

2.2.2.3. Vessel traffic systems:

Vessel traffic systems of one form or another have been used for over thirty years. Early systems were primarily used for ports and canal approaches.

Due to the considerable increase in the volume of marine traffic and the growth in size and speed of ships, catastrophic collisions occured in the congested areas such as English channel, Dover strait, and North Sea, where shipping situation started to be completely out of control and a collision was taking place every few days. The loss of ships and men was both fearsome and senseless and pollution was extremely high.

In 1959 Oudet proposed a traffic seperation scheme in Dover Strait which was accepted by IMO, by 1964 other schemes are suggested for other areas such as North Sea, Baltic Sea and the Strait of Gibralter.

The first traffic seperation schemes were introduced on voluntary basis in 1967-68 off the coasts of North West Europe and the United States of America.

Compliance with the principles of traffic seperation was made compulsory for the ships of some countries in the period 1972-77, and for all ships in July 1977 when the revised Collision Regulations came into force.

Since the encounter rate bears a relation to the collision rate in a given area of sea, consequently it is desirable to minimize the encounter rate. the Effect of routing is to reduce the total number of encounters in sea area of a high density of shipping, hence increasing safety of navigation.

An analysis of collisions in the Dover Strait area in the seven years period before and after 1967 has been carried out by the Nautical Maritime Institute. The overall trend shows a decline in the number of collisions due to the introduction of routing.

While it may be comparatively easy to pass a law which has international application, the enforcement of such a law is quite another matter.
The supervising authorities were up against shipmasters of many nationalities and varying degrees of competency, all of them had one object in common and that was the prosecution of their voyage with the utmost dispatch. To them, the shortest distance between two points was in a straight line and not via an imaginary roadway inked in on the chart. The incidence of regues, or vessels proceeding against the traffic flow, or otherwise contravening the IMO recommendations was tremendously dangerous.

Studies accomplished by US Coast Guard, British and French authorities and other national and international bodies recommended the improvement of the effectiveness of the vessel traffic surveillance and services to ensure the safety conduct of shipping. The justification of this recommendation is the continuous increase in; traffic flow in certain areas (in English channel it is now at an average rate of one vessel every five minutes), the number of cargoes of a noxious or dangerous nature, and the number of ships not complying with internationally agreed standards and rules.

The use of radars increased the accuracy significantly. A number of vessel traffic systems, using specially developed radars, have been available for more than ten years. However, it has not been until last few years that standard marine radars have been adopted to provide low-cost, low-maintenance and highly reliable vessel traffic systems.

An example of this new system is that presented by Norcontrol. Norcontrol utilized the related experiance gained in the production of marine automation systems, marine training simulators, integrated navigation systems, and anti-collision radar systems to produce an accurate flexible system that fulfills the requirements of vessel traffic management. Tracking targets, together with the display of afterglow, their course, speed and identity may be initiated manually or automatically. Additional computer programmes provide alert or alarm strategies to warn the operator about hazardous traffic situations, such as, deviation from required routing, excessive speed in a channel, buoy damage, vessel dragging its anchor, etc.
In addition the display of traffic information, which can easily be seen in daylight, a data recording system for the storage recovery of vessel movements at any given time has also been developed. A full radar coverage of a given area can be obtained through a carefull assessment of available sites and the deployment of sensors.

Today a shipmaster entering a congested traffic area assisted by V.T.S. no longer has to look forward to a twenty-four hours passage through bedlam. The rules are strict and the shipmaster prepared to abide by them need have no fear. A network of

radar surveillance stations monitors his progress, correct his mistakes and warn him about any possible danger in his path.
Vessel traffic systems now provide information that will ensure the free, but planned flow of traffic in congested or difficult seaways so reducing the risk to life, environment, and ecology.

Traffic seperation together with developed traffic surveillance and services have been found to be very effective in reducing the incidence of collisions especially meeting and fine crossing collisions in poor visibility and particularly in the Dover Strait and Southern North Sea, as shown by the two following tables.

Table ( 6 ) Collisions in the Dover Strait according to encounter situation

| | 1957-61 | 1962-66 | 1967-71 | 1972-76 | 1977-81 |
|---|---|---|---|---|---|
| Opposite directions | 45 | 47 | 27 | 7 | 3 |
| Broad crossing | 0 | 0 | 0 | 0 | 2 |
| Same direction | 6 | 7 | 8 | 6 | 7 |
| Not known | 1 | 2 | 1 | 1 | 0 |
| Totals | 52 | 56 | 36 | 14 | 12 |

Table ( 7 ) Collisions in the Southern North Sea according to encounter situation

| | 1957-61 | 1962-66 | 1967-71 | 1972-76 | 1977-81 |
|---|---|---|---|---|---|
| Opposite directions | 51 | 58 | 46 | 11 | 11 |
| Broad crossing | 7 | 6 | 7 | 9 | 4 |
| Same direction | 11 | 9 | 6 | 6 | 3 |
| Not known | 10 | 8 | 7 | 3 | 1 |
| Totals | 79 | 81 | 66 | 29 | 19 |

*Could vessel traffic management have prevented this? The ferry "European Gateway" lies forlornly on her side after colliding with another ship in the approaches to Harwich. She is attended by the Wijsmuller salvage vessel "Super Servant 1".*

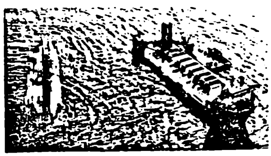


Figure ( 41 )

The next steps which could be needed to ensure navigational safety particularly in congested areas are:

1- Extend the requirement for compulsory pilotage (already practised in several parts of the world for different reasons) to cover all vessels of over, say 100,000 tons, and all vessels carrying dangerous cargoes, Toxic, inflammable or nuclear.

2- Extention of shore based radar surveillance system and improved identification methods to ensure the prosecution of offenders, perhaps including compulsory fitting of transponders and more severe penalties.

3- We may also need to improve buoyage. The buoyage system introduced in NW-Europe from April 1977, based on a combination of the cardinal and lateral systems removed ambiguity, but the buoys themselves must be made more reliable.

2.3 <u>Ship´s control system</u>:

A particular attention and high consideration has been given to the ship´s systems which have a direct relation to the effectiveness of the handling of the ship. Rudder, steering gear, main engine, and auxiliary machinery are very important systems which need special care. Any failure or serious defeciency in one of these systems could either be an accident or a cause of an accident. The risk that a technical failure could lead to a casualty is especially high in restricted areas where near-misses are likely to occur.

A vessel´s ability to avoid collision by manoeuvre can be expressed in terms of stopping and turning characteristics. In the same time the accuracy and success of an avoiding action will depend mainly on the degree of rudder effectiveness and the reliability of the steering gear and machinery.

In practice, ships are said to be dynamically stable when the spiral test shows a unique relation between rudder angle and the rate of turn. A normal ship will become increasingly stable as the rate of turn increases, e.g. as the rudder effectiveness increases.

The reliability of steering gear and machinery can be improved by using a back up or parallel systems which can be activated instantaneously , like the stand by spare units or components or using an alternative control path.

The navigator must know the exact rate of turn of his ship under various conditions and the forces affecting it, to be able to determine inadvance the behavior of the ship during the avoiding manoeuvres. The main engine must be well maintained, all machinery parts are checked frequently, and engine room routines are well arranged, clearly recognized, and strictly followed particularly during stand by periods to ensure that all bridge orders will be answered correctly in time.

The advanced technology and the rules and recommendations of SOLAS convention have added some improvements to the ship's process and technique. For example, SOLAS amendments require that the steering systems should be designed to permit isolation of a failed component and to permit the operator to promptly resolve lost steering using an alternative control path or component to avoid any dangerous sequences due to a sudden failure in the steering gear.

Today the standard of computing techniques on the one hand, and the possibilities of describing the track of ships under the influence of various forces on the other hand, have reached a level which enables a system to be developed for the determination of optimum rudder and propeller handling to steer the vessel. Thus subjective decisions by the navigating officer impairing the ship's safety can be eliminated and the risk of collisions is avoided or reduced.

There is a trend nowadays towards developing alarm and control systems for marine use which comply with stringent safety requirements. Norsk Hydro control systems has introduced a computerised system-Covac- for data collection, monitoring and remote control on board ships.

Accordingly, we may say that the situation can be generally further improved by greater use of fault-diagnosis and control systems, greater use of strict state of readiness procedures, using standardized formats for presenting clear concise manoeuvring data such as basic turning and stopping data for practical use, readily available in the ship´s wheelhouse, and by placing greater emphasis on the ergonomical aspects associated with the manoeuvring of the ship.

2.2.4. Eduction and training:

It is evident from statistics that an extremly high proportion of accidents at sea are caused by the erron ous behaviour of a human being. A quantitative assessment of the primary causes of maritime collisions indicates that about 85% of all collisions are due to faulty human judgement of the officer on watch of one or both encountering ships, associated with navigational and steering errors. Therefore, proposals are made by the authorities of nearly all traditional nations to prevent collisions by upgrading education and training of ship personnel.

The risk caused by human unreliability or deficiences in the social system manifests itself as erroneous, delayed or neglected actions. The individual may also be unaware of what the situation demands from him, which results in an omitted action. The bases for a correct action are serious intention, absence of fatal distractions, adequate decision and the capability to perform the action. Sufficient and efficient education and training are therefore necessary to fulfill the need and improve the situation.

College courses and educational tools must be well arranged and developed to meet the requirements of and keeping abreast the developments in the maritime industry. The courses must contain the necessary syllabus and sound as a long-term investment to an industry where techniques and technology are changing rapidly. Entry qualifications must be high and not less than "A level" with minimum accademic attainment in suitable subjects such as mathematics, english and science and I personally believe that the "hose pipe" system must be stopped. The first filter for applicants should be the academic prowess together with the physical fitness.

A course for navigators on procedures aimed at the avoidance of collisions ~~is~~ seems necessary. Within that course they have to study special cases with the aim of finding causes and recommend measures, plus discussion and analysis of the marine casualty statistics. Such a course ought to be made available in the education programme at the navigational colleges. It can be considered as a direct preventive measure.

Continual pressures to reduce manning, bigger and bigger ships with more and more equipments and greater use of automation suggest that providing ship crews more thorough training in ship's equipment, handling and operating procedures would result in significant safety benefits.

Environmental conditions do not inevitably lead to collisions but are only causes if the individuals facing the conditions do not know how to handle them or to respond effectively to their changes due to inadequate skills and training. Therefore, extensive training is essential to promote officers' skills to be able to act correctly and intelligently as required.

The failure to appreciate both visual and radar aided traffic information, insufficient ability to interpret data or complete utilization of information, errors in judgment, faulty operation of equipment and erroneous/delayed evasive manoeuvre, are serious deficiencies which considerably increase the probability of collisions at sea. These deficiencies can only be minimized by upgrading mariner's qualifications, developing the test materials and using advanced training techniques.

Whatever strict and comprehensive the rules, whatever sophesticated the equipment, it is all useless if an incompetent officer defies the rules or misuses the equipment. Poorly qualified and trained officers will have insufficient ability to cross the seas in safe.
Instruction in the handling of collision situations ought to be an integral part of upgraded and extended training.

Manoeuvring simulators are now accepted as an important training tool to promote the practical experience and overcome the navigator's failing shiphandling abilities. The training is close to reality and can be done under different environmental and ship condition. Simulators can make significant progress in identifying and improving the navigators skill to effectively handle their ships and avoid collision risk.

The Internatinal Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978 (STCW Convention) recently came into force and may eventually bring about some improvement but now is the time to look at the problems of implementation. IMO is trying to assist member states to ensure that all ships will maintain the required standard. Flag state and port state should also give a hand to find out any sub-standard ship.Ships not complying with internationally agreed standards can be considered as a moving hazard and must be stopped.They can easily cause disasters and often not only to themselves.

2.2.5 <u>Marine casualty investigation technique</u>:

Effective and competent investigation of accidents at sea are the foundation for all successfull safety work. A reduction in the probability of collisions can not be achieved to a significant extent unless a serious investigation for collision cases is carried out, which should be based on accurate informations, so that recommendations can be made which are likely to lead to the adoption of effective measures to prevent a recurrence of similar accidents.
Developing a successfull system for collecting, analysing and presenting marine casualty data is necessary to recognize where and how they occured to arrive at a quantitative and qualitative description of the causal factors, and accordingly determine the possible preventative measures.

Investigations are seen as a form of preventing medicine through the processes of finding out the causes of the occurrences, acquiring knowledge there from and recommending or sometimes imposing ways to prevent reourrences. Such investigations have resulted in major improvements in areas such as ship construction, navigational aids and equipment, levels of competence of seamen, saerch and rescue, traffic and other rules, such as the Internatinal Regulations for the Prevention of Collisions at Sea.

A modern system of casualty investigation can be characterized as follows:

1- The investigation system must be flexible and suitable for the country.

2- Independent investigation team, e.g. not belonging to the Marine Safety Authority.

3- The investigation team should consist of professional casualty investigators, the best qualified for getting as close as possible to the truth of how and why an accident occured. The investigator should have an open mind, able to express himself in speaking and writing, and clever enough to get contact with people built on confidence.

4- The type of casualty should determine the composition of the investigation group who should then have a specialzed experience about this particular type of casualty and have sufficient knowledge regarding the environment where the accident occured. The investigation team should also invite, if necessary, some organizations to join the work when it is related to their speciality.

5- It is vital that the investigation starts rapidly while the material to be investigated is fresh and before time has changed or wiped out important evidence, e.g. accurate recall of witnesses.

6- The investigation does not seek to be incriminating, i.e. the purpose is not to look for a scape-goat. The investigation board can be flexible about personnel and method of work. The investigation can take place on board the ship or elsewhere in informal surroundings. The witnesses should be more relaxed and co-operative. It will be easier to get at the complete truth.

The method of investigation also permits the examination of witnesses to take place at the same time as the technical inquiry. In this way findings at the casualty site can influence the interview of witnesses, and evidence given by a witness can influence the orientation of the investigation.

7- Public reports on investigation results should be given rapidly to the Marine Safety Authority.

8- A proposal for measures to be taken to prevent a recurrence is made as soon as the necessary facts have been gathered. The investigation board ensures that the Safety Authority gives further instructions about what steps to take on the basis of their proposal.

A suitable investigation technique could be as follows:

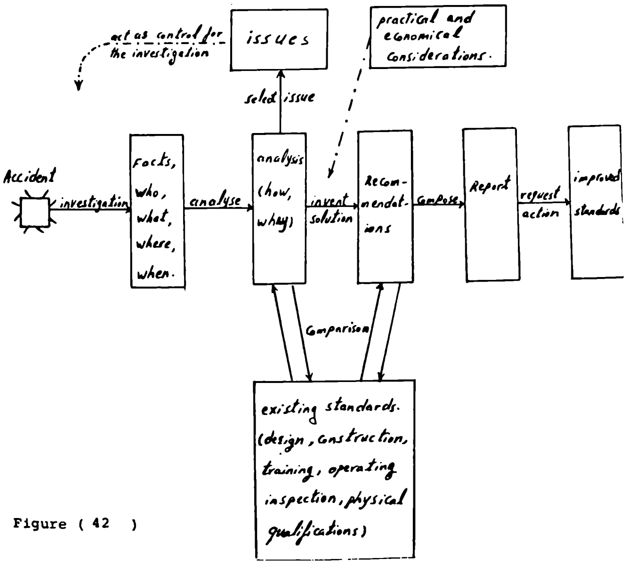



Figure ( 42 )

Obtaining all the facts which will be needed to explain the circumstances of the accident, making a thorough analysis of the issues what may be related to the causes of the accident and determining adequate recommendations which are practicable and economically acceptable while considering the existing standards and how the ship was complying with them, then presenting a formal report including the proposals which could improve the standards and/or prevent the recurrance of such type of accident.

Actually, the objectives of casualty investigation systems differ considerably from one country to another and vary from strictly penal systems to systems solely oriented towards safety, with many variations in between.
The investigation processes, as well as the reports and their use, are directly affected by the nature of the objectives pursueud, depending on whether strictly safety purposes or whether disciplinary or civil considerations are taken into account.
Most countries have two types of inquiries, preliminary investigations and formal hearings, with some of the countries placing emphasis on the former, and others on the latter, at least with respect to the number of investigations.

IMO has undertaken a somewhat limited role as regards marine casualties, at least compared to the International Civil Aviation Organization (ICAO), which has established a well structured and active international system for investigation and reporting aircraft accidents.

The following extracts from international Conventions (which are binding once adopted by a country) and Resolutions (which are only recommendations) indicate the extent of IMO requirements.

1) International Convention on Load Lines, 1966.
Article 23, Casualties:

1-Each Administration undertakes to conduct an investigation of any casualty occuring to ships for which it is responsible and which are subject to the provisions of the present Convention when it judges that such an investigation may assist in determining what changes in the Convention might be desirable.

2-Each Contracting Government undertakes to supply the Organization with the pertinent information concerning the findings of such investigations. No reports or recommendations of the Organization based upon such information shall disclose the identity or nationality of the ships concerned or in any manner fix or imply responsibility upon any ship or person

2) Resolution A. 147 (November 26, 1968). Reports on Accidents Involving Significant Spillages of Oil:
"The Assemlby,

For the purpose of promoting rapid action by the governments concerned in cases of significant spillages of oil following accidents, Having in mind the recommendation of the Council of the International Maritime organization at its third extraordinary session,

Recommends to governments that they

a- Require masters of all ships to report immediately through the channels which may be found most practicable and adequate under the circumstances, all accidents in which their ships are involved which have given or may give rise to significant spillages of oil. Such reports should, if possible, include details on the nature and degree of pollution, the movement of the oil slick and any other useful information as appropriate;

b- Appoint on appropriate officer or agency to whom such information may be referred. Such officer or agency would also be responsible for transmission of relevant details to all governments concerned;

c- Ensure that any such reports received by any authority in the country be forwarded to such an officer or agency with all despatch;

d- Provide the Organization with information concerning the appointment of such officer or agency for circulation to governments."

Resolution A. 173 (November 28, 1968). Participation in Official Inquiries into Maritime Casualties:

"The Assembly,

Noting that there is a variation in the practices of Member States with regard to official inquires into maritime casualties, and other proceedings directly consequent upon such inquires,

With a view to ensuring that States seriously affected by or having a substantial interest in maritime casualties, particularly where oil pollution to their coasts has resulted, shall have an opportunity of being represented at inquires into, or other such proceedings relating to, such casualties, and

Desiring to encourage international unification of practice in relation to such inquiries and proceedings,

Recommends to governments that if a State other than the State of the flag is know to have been seriously affected by or to have a substantial interest in a maritime casualty to a ship of the flag State (particularly where the coast of that other State has been polluted by oil) as a result of the casualty:

1) a) The State of the flag should, unless an inquiry is held by the State as a matter of course, consult with that other State as to the holding of an inquiry into the casualty by one or other of the States, complying with the provisions of sub-paragraph (2);

b) If such an inquiry is held as a matter of course by the flag State, the other State should be informed of its time and place;

2) Such an inquiry should be so conducted that, subject to the national rules relating to the special conditions under which inquiries are held in camera,

a) The public is permitted to attend; and

b) Arrangements are made which would, subject to the discretion of the authority holding the inquiry, allow a representative of the other State concerned to attend and participate in the inquiry at least to the extent of:

(i) questioning witnesses or causing questions to be put through the authority; and

(ii) viewing all relevant documents;

3 If an inquiry is held by a State seriously affected or haveing a substantial interest, a representative of the State of the flag should be given similar facilities.

If one or other of the conditions of sub-paragraph (2) above cannot be complied with at the inquiry itself, this recommendation shall be treated as being complied with if the condition not previously satisfied in proceedings directly consequent upon the inquiry. Nothing in this recommendation shall affect or apply to holding of any preliminary or informal inquiry or any other proceedings.

A State shall not be treated for the purposes of the recommendation as being affected by or having a substential interest in a maritime casualty by reason only that it is the flag State of one of two ships in collision, nor should the fact that one or more of its nationals has a commercial interest in the ship or its cargo in itself confer such an interest".

International Convention for the Safety of Life at Sea (SOLAS) 1974. Regulation 21 - Casualties:

a) Each Administration undertakes to conduct an investigation of any casualty occurring to any of its ships subject to the provisions of the present Convention when it judges that such an investigation may assist in determining what changes in the present Regulations might be desirable.

b) Each Contracting Government undertakes to supply the Organization with pertinent information concerning the findings of such investigations. No reports or recommendations of the Organization based upon such information shall disclose the identity or nationality of the ships concerned or in any manner fix or imply responsibility upon any ship or person.

Resolution A. 322 (November 12, 1975). The Conduct of Investigations into Casualties:

"The Assembly,

Draws attention to the obligations of Contracting Governments concerning the investigation of casualties set out in the above-mentioned Conventions.

Urges Contracting Governments to provide the Organization with relevant information regarding lessons to be learnt and conclusions derived from the investigation of casualties.

Requests the Maritime Safety Committee to examine regularly such reports supplied by Contracting Governments and to recommend action as necessary;

Further requests the Maritime Safety Committee in consultation with the Secretariat to consider whether the Organization should take the initiative in listing serious casualties and in requesting Administrations to give information regarding the inquiries held into them end their findings and thereafter to take any appropriate action to this end."

Resolution A. 440 (November 15, 1979). Exchange of Information for Investigations into Marine Casualties:

"The Assembly,

Nothing that the Maritime Safety Committee has considered reports of investigations into serious marine casualties and has recognized the importance of a free exchange of information between Governments and, in particular, the need for providing details of those casualties.

Being Aware that investigations into casualties, especially in the case of collisions, are often hampered by lack of exchange of information where ships under different flags are involved.

Having considered the recommendation made by the Maritime Safety Committee at its thirty-ninth session,

Urges Governments to co-operate on a mutual basis in investigations into marine casualties and to exchange information freely for the purposes of a full appraisal of such casualties.

It should be been noted that in the Load Line and Solas Conventions, the obligation of the participating to investigate and to report to IMO is conditionál upon their sole judgment as to whether or not an investigation may assist in bringing about changes to those Conventions. In the case of the Resolutions, only recommendations are made which are not binding although the majority of participating countries would generally feel morally obligated to comply.

Resolution A. 173, which recommends that participating of a foreig State be allowed, particularly where oil pollution to the coasts of that State has resulted, is applicable only where a public inquiry is held and not where preliminary or informal inquiries only are carried out, nor in the case of collisions nor where a national of the foreign State has a commercial interest in the ship or its cargo. In aviation, foreign countries representatives are given at least an observer status at all investigations where they have an interest.

On July 1, 1978, IMO started to require reports on "Serious casualties", which are defined as "casualties to ships of not less than 1,600 gross tonnage which are a total loss (including constructive total loss) and casualties to ships of not less than 500 gross tonnage involving loss of life", excluding pleasure boats, The process followed is that first a list of serious casualties is prepared, based on information contained in Lloyd's Register of Shipping Quarterly Casualty Returns and the Liverpool Underwriters Association Monthly Returns, and then a report on each casualty is requested from the Administration concerned. The report Form requires only a brief summary of the casualty, the probable cause, search and rescue assistance, damage, lives lost, and certain other particulars. From July 1, 1978, to December 31, 1982, 417 serious casualties were listed, of which only 123 reports (29%) were recieved from Administrations. A list of such reports has nevertheless been prepared indicating the principal findings and recommendations.

The only analyses carried out by IMO over the last few years have concerned serious casualties to seagoing tankers of 6000 deadweight and above; until 1980 the analyses were limited to 10,000 deadweight and above, The casualty data upon which the analyses are based are provided by Lloyd's Register of Shipping and not by the participating countries. Proposals to carry out analyses of casualties to all types of ships have so far been turned down, apparently because of budget considerations.

Accordingly, the role of IMO has been very limited and no success has been achieved in standardizing casualty investigations.

With very few exceptions, the efforts made by various maritime countries and their achievements in improving safety as a result of casualty investigations are not communicated to other countries. Thus, there must exist considerable duplication of investigations which might not otherwise be needed except to the extent required for statistical purposes.

# SECTION III

3.1 <u>RADAR</u>:

Radar was invented in 1922 and rapidly developed in the years leading up to. During world war II, it was used originally to detect and track hostile vessels and aircraft. Following world war II it became standard equipment on merchat vessels and soon became required navigation equipment internationally.
It was considered by many as the ultimate system to determine the correct action to prevent collisions using plotting technique, but ships continued colliding and in many cases the collision could actually be traced to the use of radar.

Analysis of many collisions indicate that the main problem is the limited capability of human beings in operating correctly and utilizing the information available on the PPI with an adequate speed and accuracy. As the radar picture is a present-value presentation only, and as the measurements normally are relative to a moving reference (own ship), the human interpretation of the situation is depending on considerable skill and concentration.

Many investigations have been done which led to the development of many devices, some of very simple design and others are highly sophis-ticated, to provide the navigator with a quick and better appreciation of the situation which can led to an early and effective action to avoid collision.

During the early years of development, effort was primarily directed towards improving component and unit reliability. Factors of immediate importance were seen to be the simplification of unit control to allow comparatively unskilled operators to obtain operable information, improvement in data accuracy by increased tube size, gyro stabilisation, scanner design and variable range measurement, and attacks on the rain and sea clutter problem to enhance the detection of marginal targets.

As time progressed, the ships increased in number, speed and size associated with high traffic density, and problems due to the difficult interpretation of radar data and the unadequate manual plotting on a plotting diagram became more prominent.
The second stage in radar development thus directed to solve these problems. Improved plotting faciities and true motion presentation were then introduced.

True motion used simple analogues to convert the log speed and compass course of own ship to a steady scaled deflection shift in the cathods ray tube origin. This shift could then extract own ship motion from the relative motion of the echoes, leaving displayed the real motion of the target. It was supposed that since most manoeuvres in clear weather were based on the real motion of the target ship, equal success would accompany manoeuvres made in fog if the real aspect of the target was available. This supposition was, unfortunately, not true and the advent of true motion made no noticeable impact on the radar collision statistics. Infact due to some original operator misconceptions, true motion was often wieved with suspicion and was only slowly accepted.

Much more significance was apparent in the introduction of plotting aids. Most wide spread influence in this area was due to an on-screen manual device termed the reflection plotter. Perhaps an unforseen but important feature of the reflection plotter was the contribution which it made to a wider appreciation of gyro stabilised displays and their related north-up presentation of the radar picture.

Among other plotting aids which were introduced were those which automatically recording the position of any echo, selected by range and bearing marker on the display, on an ancillary plotting surface.
Another more sophisticated equipment used a photographic record of the targets motion over a period of several minutes which was then made available for immediate presentation as a large scale projection on a plotting screen.

Apart from reflection plotter, none of these systems proved universally popular. They were followed by a second generation of what may be termed appraisal aids. These were installations which allowed the operator to asses the track of a target in either true or relative motion and to determine whether a collision risk existed without being required to produce an actual plot.

Most successful among these were the Decca Ac-marker system and the Kelvin Hughes S.D Radar.
Both these enjoyed a popular acceptance because they removed much of the drudgery normally associated with manual plotting but left the watchkeeper and his decision firmly in the loop.

In the late sixties microcircuitry and computer availability opened another development area in the radar field, and generated equipments which have been termed computer aided or collision Avoidance systems (C.A.S.) OR Automatic Radar Plotting Aids (ARPA).
The first of these systems, which transfer radar data into a computer and play out a synthetic picture on the display, was produced by the Norcontrol company (Databrideg). The system used dedicated computer. trackers units and synthetic display to show vectors attached to echoes.

Since that time, advances in both computer and display technology have been exploited by a number of companies who preduce systems with a wide variety of alternative combinations of facilities showing target vectors except a single company (SPERRY) which produced the Sperry C A S system which addresses the avoidance problem more particularly by difining the possible point of collision (P.P.C.) and showing the Possible Area of Danger (P.A.D.).
At the same time some small computing power was used in an advanced appraisal aids. This equipment stored the track of targets by recording on a video tape a complete series of

past radar pictures. The operator could play these back to envisage the positions which all echoes had occupied over a discrete historical period. At the same time, the history of own ship's motion is stored so that either true or relative motion may be played out.

Development still keep going on to improve the use of radars for both navigation and anti-collision purposes.
The Kelvin Hughes produced the Anticol ARPA with a ground-stabilised fairway chart formed by a series of parallel straight lines and with channel widht and length set by the user, similar but more detailed charts of selected port approaches can also programmed and stored in the computer memory for subsequent recall when required.
Atlas 7600 produced by Krupp Atlas Electronik with memory-backed rasterscan colour display on 67 cm high-resolution screen. Brilliant, steady presentation of all information on one display of excellent daylight quality, avoiding fade-away of radar signals and need for viewing hood.
Furuno has introduced a combined colour picture and plotter on one screen. With this system the vessel's posituion moves across the screen using information from position finding equipment and, at the same time, the radar display indicates land masses and other vessels.

However, to give a clear presentation of the developments in commercial marine radar and its devices, we may devide its life into three periods.

During the first two periods, evolution rather than revolution was the established pattern of marine radar development and plotting devices improvement, believing it is the best procedure for achievement of the high standard of reliability demanded by the mariner, at an acceptable operational cost.

In the third period, the majority of the equipments fall into the revolutionary category, using digital computers to track target movement, to process information and produce simulated graphics on the screen.

We may, therefore, distinguish three successive contributions to the present state of the art:

1- Traditional radar sets assisted by plotting aids such as; Track plotter, RAS plotter, Reflection plotter, Autoplot, and photographic radar plot.

2- Radar displays with built-in plotting devices not assisted by computer such as; Decca 66 Ac, Raytheon TM/CA, Kelvin Hughes situation Display, and Marconi predictor.

3- Computerized systems for automatic tracking and processing of data such as; Data bridge, Digiplot, Raytheon Raycas, selenia, sperry CAS, Racal Decca.

### 3.1.3 Manual plotting:

The traditional radar screen does not give a complete picture. Ships appear on the screen as points, both their bearing and their range can be observed and the observer must plot to complete the picture as given by the eye. This technique will provide the navigator with a detailed information upon which he can make decisions.
This detailed information is of two kinds, relative to ownship and true.
The relative data gives the degree of risk of collision of the target in terms of the closest point of approach (C.P.A:) on present course and speed, and the time interval before this point would be reached.
The true information comprises the course and speed of the other ship.

Therefore if the radar is properly used, accurate manual plotting can enable the navigator to appreciate the situation around the ship and recognise the collision risk by comparing the distance of the closest point with the accepted minimum safe passing distance and that will help him to find the effective action to avoid close quarter situations and collisions.
Relative motion presentation will be appreciated for collision avoidance in open waters while true motion may be preferred in narrow waters.

This method of tackling a collision avoidance problem may help the mariner to overcome the disadvantages of the visual observational method.

The manual plotting technique, however, have disadvantages of its own:

1- Inaccuracy:

(a) Errors in reading the ranges and bearings of targets and the time.

(b) Unsteady course and speed of own ship and targets during plotting interval.

(c) Errors in marking positions and in drawing lines on the plotting sheet.

2- Plotting is time consuming and requires the full attention of the navigator for several minutes per plot.

3- An unfortunate limitation in the number of echoes that may be satisfactorily handled.

4- The technique provides poor protection against human blunders.

5- A necessity for continous and regular plotting to detect any change in the situation.

3.1.1.1 <u>Errors in manual plotting</u>:

Errors in plotting can be due to:

1- Errors in the bearings taken.

2- Errors in the ranges measured.

3- Wrong estimation of course and speed of own ship during the plotting interval.

4- Errors in the time of the plotting interval.

<u>Effect of inaccurate bearings and ranges</u>:

The relative plotting normally done by taking three range and bearing of the target at regular intervals to construct the relative vector of the target (oA). If any of these ranges or bearings is not correct, the resulted (oA) will be inaccurate causing error in the estimated nearest approach, the time of nearest approach, and the aspect.
When the vector triangle is completed, the true motion vector of target will also be affected leading to inaccurate estimation of target's true course and speed.
Therefore, it is advisable to take at least three ranges and bearings when plotting and if the three positions of target were not laying on a straight line an average line should be used to reduce the error as much as possible.

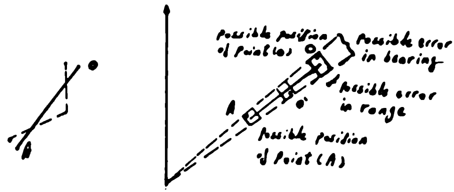



Figure ( 43 )

Joining (O O`) indicate that the target should pass astern of own ship joining (o`A) indicate that the target should pass ahead of own ship, while the situation is most probably a collision case.

In the case of true plot, the true vector of the target (WA) will be inaccurate causing an error in the calculated true speed and course of the target and also the aspect. When the triangle is completed. the relative motion of target will be affected leading to inaccurate estimation of nearest approach and its time.

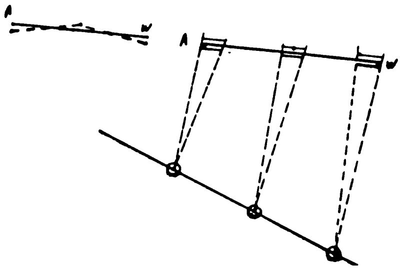


Figure ( 44 )

The existence of such type of error is always possible, its amount will depent on the accuracy of the means used for measurement and the observer skills.

Performance standards for navigational radar equipment require:

| Radars installed before 1.9.84 | Radars installed after 1.9.84 |
|---|---|
| Fixed range rings should enable the range of an object, whose echo lies on a range ring, to be measured with an error not exeeedind 1.5 percent of the maximum range of the scale in use, or 70 metres, whichever is the greater. | The fixed range rings and the variable range marker should enable the range of an object to be measured with an error not exceeding 1.5% of the maximum range of the scale in use, or 70 meters, whichever is the greater. |
| Any additional means of measuring range should have an error not exceeding 2.5% of the maximum range of the displayed scale in use, or 120 metres whichever is the greater. | |
| The means provided for obtaining bearing should enable the bearing of a target whose echo appears at the edge of the display to be measured with an accuracy of $\pm 1^{\circ}$ or better. | Same |

Wrong estimation of own ship course and speed;

This kind of error will cause incorrect true vector of own ship. In case of relative plot, the position of point (W) will be incorrect affecting the accuracy of the true course and speed of target. The aspect will also be affected.
In case of true plot, the position of point (o) will be incorrect affecting the relative motion line of target causing error in the estimated nearest approach, time of nearest approach, and the aspect.
The estimation of own ship speed will depend on the accuracy of the means used for calculation, (log, R.P.M. of the propeller, ship's positions).
The estimation of own ship course during plotting interval will be difficult if the ship was yawing. The skill of the observer is also important.

Relative plot

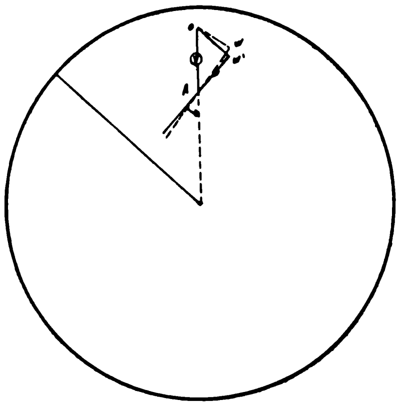


Figure ( 45 )

True plot

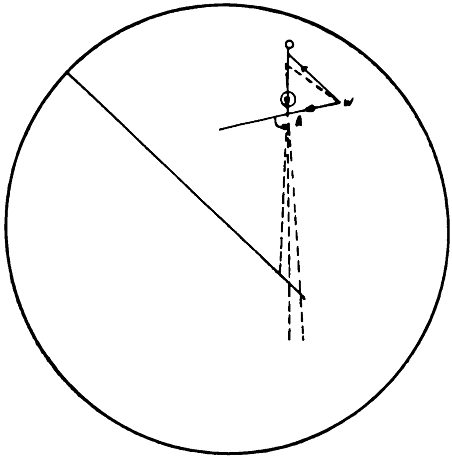



Figure ( 46 )

3.1.1.2 <u>Accuracy of manual plotting</u>:

When radar plotting is used to find out the target course and speed, and the risk of collision if any we proceed as follow in case of relative motion:

Assuming own ship course is $360^{\circ}$, its speed 16 knots, and plotting interval is 20 minautes. Initial range of target is 12 NM.

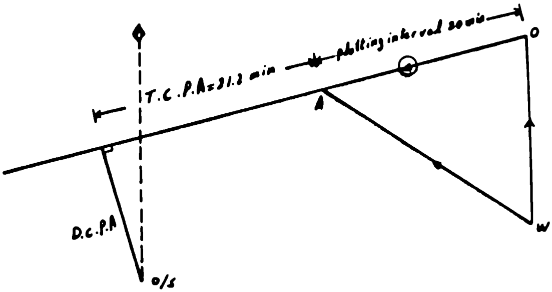



Figure ( 47 )

A- <u>The accuracy of own ship vector (Wo) will depend on</u>:

1- The accuracy of own ship course during the plotting interval.
2- The accuracy of the estimated own ship velocity during the plotting interval.

<u>The possible errors in heading are</u>:

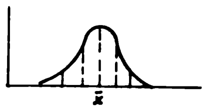
1- Constructive error.
2- Rounding off error (error in gyro alignement).
3- Drift error.

1- <u>Constructive error</u>:

The frequency distribution of error can be considered as normally distributed with a maximum value of $1^{\circ}$

e.g. $\sigma \simeq 1/3^{\circ}$

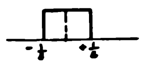
because the probility of plotting of an error of $1^{\circ}$ is considered to be the maximum.




2- <u>Rounding off error</u>:

The frequency distribution of that type of error is uniform also with a range of $1^{\circ}$

e.g. $\sigma^2 = \frac{1}{12} \cdot 1^2 \quad \therefore \sigma \simeq 1/3^{\circ}$



3- Drift error:

$\sigma = c_w^o \frac{W}{V} (AU/AL)^{1/2} \sin \alpha$

(initialy $3^o$, then $\sigma = 3/3 = 1^o$)

Where : $c_w^o$ is constant depend on ship's form assumed to be $1^o$

W is wind speed assumed to be force 7 BF = 28 knots

V is ship's speed assumed to be 16 knots

AU is lateral surface over water

AL is lateral surface under water

$(AU/AL)^{1/2}$ is assumed to be $(1)^{1/2}$

$\alpha$ is wind direction assume worst condition $90^o$ or $270^o$

$\therefore \sin \alpha = 1$

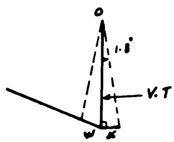
$\therefore \sigma = 1 \cdot \frac{28}{16} \cdot (1)^{1/2} \cdot 1 = 1.75^o$

then $\sigma^2$ of total heading error is $( (1/3)^2 + (1/3)^2 + (1.75)^2 )$

$= 3.28^{oo}$

and $\sigma = 1.8^o$

accuracy M95 = $2\sigma = 3.6^o$




$\sigma_x = V.T. \tan 1.8^o$

$= 16 \cdot \frac{20}{60} \cdot \tan 1.8^o = 0.1676$

Where T is assumed to be 20 minutes.

The possible speed errors are:

1- Log error

2- Constructive error

Log error can satisfactory be taken as 2% of own ship speed, and estimated constructive error about 0.1% of the speed.


$\therefore \sigma_{speed} = 2\%$ of $v \simeq 1/3$ knots

then the accuracy $\simeq 0.7$ knots.

$\therefore \sigma_y = (1/3).T = (1/3).(1/3) = (1/9)$ miles e.g. $R_{68}$ of point W $= 1.1\ (\sigma_x^2 + \sigma_y^2)^{1/2}$ / sin 90°

$= 1.1\ ((0.1676)^2 + (1/9)^2)^{1/2}$

$= 0.22$

and $R_{68}^2$ $= 0.048$

accuracy of point W $= R_{95} = 5/3\ R_{68} = 5/3 \times 0.22 = 0.37$
for T=20 minutes.

B- <u>The accuracy of oA will depend on</u>:

1- Bearing accuracy.

2- Range accuracy.

<u>Bearing accuracy</u>:

The disturbances and their contribution to the error are:

1- Azimuth error scanner / sweep max $\frac{1}{2}^{\circ}$

$$\sigma^2 = 1/36^{\circ\circ}$$

2- Heel or list of ship max heel $15^{\circ}$

$$\sigma^2 = 1/9^{\circ\circ}$$

3- Bearing cursor/EBL error max $1^{\circ}$

$$\sigma^2 = 1/9^{\circ\circ}$$

4- Rounding off to the nearest half degree

$$\sigma^2 = 1/48^{\circ\circ}$$

5- Error in total correction

$$\sigma^2 = 6/10^{\circ\circ}$$

6- Error in plot the lop into the plotting sheet

$$\sigma^2 = 1/36^{\circ\circ}$$

Total variancein Lop $\sigma^2 = 0.9^{\circ\circ}$

$$\therefore \sigma = 0.95^{\circ}$$

This normaly. distributed error in the direction of the bearing line causes an error equal to:

$$\sigma_{(Tangent)} = \tan 0.95 \times \text{Dist. of target NM}$$

$$= 1 / 60 \times \text{Dist. of target} = 0.2\text{NM}$$

$$= 30.87 \times \text{Dist. of target} = 370.4 \text{ metres}$$

Range accuracy:

The disturbances and their contribution to the error are:

1- VRM error with a max of 1.5% of the range

$$\sigma \leqslant 25 \text{ m}$$

$$\sigma^2 = 625 \text{ m}^2 \text{ , or}$$

in use, or 70 metres, whichever is the greater

$$\sigma \leqslant 0.5\%. \text{ range}$$

$$0.25 \ (10)^{-4} \ (\text{range})^2$$

2- Observer measuring error with a maximun

$$\sigma = 0.5\%. \text{ range}$$

$$\sigma^2 = 0.25 \ (10)^{-4} \ (\text{range})^2$$

of 1.5% of the range in use

3- Rounding off to 0.1 M readout of VRM

$$\sigma^2 = \frac{1}{12} \ (10)^{-2} \ \text{M}^2$$

The sum of these variances does not give an easy expression for the Lop error, the following approximation can be made:

If range in use $< 6$ M then $\sigma = 5 \times$ range in miles + 50 metres

If range in use $> 6$ M then $\sigma = 0.75\%$ of the range N.M

For our case $\sigma_{(normal)} = 0.0075 \times 12 = 0.09$ N.M

$= 13.89 \times 12 = 166.7$ metres

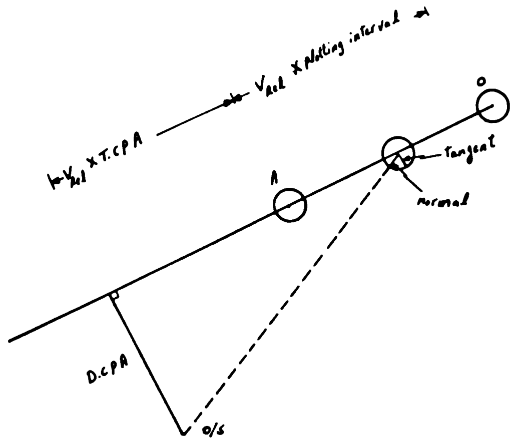



Figure ( 48 )

$R_{68}$ (one plot) = $1.1 \left( \sigma^2_{(tangent)} + \sigma^2_{(normal)} \right)^{1/2}$

$= 1.1 \left( (30.87)^2 + (13.89)^2 \right)^{1/2}$ X Distance (metres)

Since best fit relative track will be used, there-fore, it canbe stated that the error in this regression line will obey to the Average law. If the number of plots is indicated by (n) and the radius of the 68% confidence of plot by $R_{68}$, then the cross track error (CTE) in the relative track will have a standard deviation $\sigma_{CTE}$ which can be expressed as

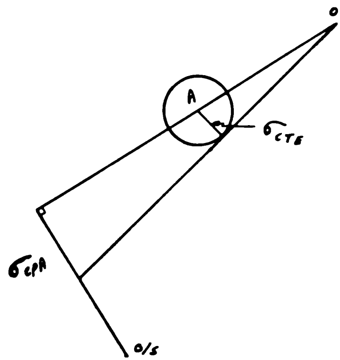



Figure ( 49 )

$$\sigma_{CTE} = \frac{R_{68}\ (1\ \text{plot})}{2/3\ (\ n\ )^{1/2}} = R_{68} \text{ at point (A).}$$

From geometry

$\sigma_{CPA}\ /\ \sigma_{CTE}$ = ( TCPA + plotting interval in minutes)/ plotting interval in minutes

$\therefore\ \sigma_{CPA} = \sigma_{CTE} \cdot$ ( (TCPA / plotting interval ) + 1)

In our case $R_{68}$ ( 1 plot ) = 1.1 ( $(30.87)^2 + (13.89)^2)^{1/2}$ X 12

= 446.8 metres

$\sigma_{CTE} = R_{68}$ (1 plot )/ 1.15 = 397 metre = 0.21 N.M

= $R_{68}$ at point (A) $\therefore\ R^2_{68}$ at (A)= 0.04 N.M

$\sigma_{CPA}$ = 387 ( ( T.CPA / 20) + 1 )

= 387 ( (21.2 / 20) + 1 ) = 797 metres= 0.43 N.M

accuracy $M_{95} = 2\sigma$ = 0.9 N.M

Taking 0.01 N.M as a safety margin

then total $R^2_{68}$ at point (W) = 0.048 + 0.04 + 0.01 = 0.098 N.M

$\therefore$ Total $R_{68}$ at (W) = 0.3 N.M

total occuracy of point (W) = 5/3 X 0.3 = 0.5 N.M

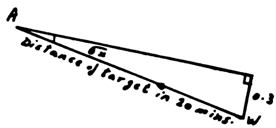



Figure ( 50 )

(X) will be the error in the true couse of target

$\sin \sigma_x$ = 0.3 / distance of target in 20 minutes

since (X) is small, then $\sigma_x$(red) = 0.9 / velocity of target

In our example distance of target is 7 N.M in 20 minutes

$\therefore \sigma_x = 2.5^\circ$ $\therefore$ the accuracy = $5^\circ$

$0.3 \simeq 1.1\ (\sigma^2 \text{ dist. of target} + \sigma^2 \text{ dist. of target})^{1/2} \simeq$
$1.1\ (2\sigma^2 \text{ dist. of target})^{1/2}$

$\therefore\ 0.09 \simeq 1.2\ (2\sigma^2 \text{ dist. of target})$

$\therefore\ \sigma^2 \text{dist. of target} = 0.09 / 2.4 = 0.037$ (in 20 minutes)

$\therefore\ \sigma \text{ dist. of target} = 0.19$ ( in 20 minutes )

$\therefore\ \sigma$ vetocity of target = 0.57 knots

$\therefore$ accuracy = 1.14 knots

3.1.2 Manual Plotting Aids:

To assist the navigator in speeding up radar plotting to handle a greater number of targets and increase plotting accuracy, several types of aids have been developed.

3.1.2.2. Track plotter:

It can be used for either true or relative plot on plain paper. The device enables the mariner to carry out the plot without the need of using parallel rulers, dividers or compass roses.

A fitted light over the graduation pointer permits its use without other lights at night.

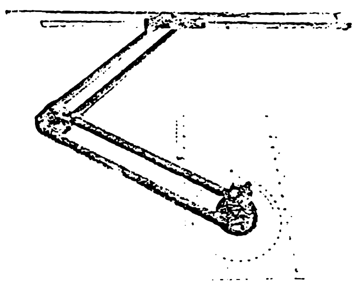
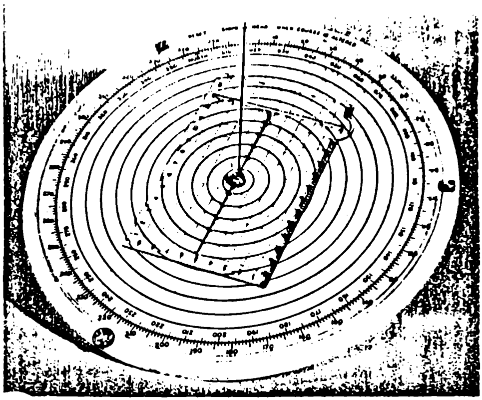


Figure ( 51 )

3.1.2.2 <u>The R.A.S. plotter</u>:

It is a mechanical compass-datum plotter, designed by the erstwhile Radio Advisory Service of the Chamber of Shipping. Plotting is carried out on a disc of transparent material free to rotate about its centre above a slightly larger circular disc. Attached to the axis of the plotter and free to slide over the face of the disc, a transparent protractor which can be used to draw the bearing lines and to obtain the direction and distance of any point.
The ship's true course on the inner scale must be set against the $000^{o}$ on the outer scale each time the course is altered.



*Compass-datum plotting device.*

Figure ( 52 )

The two main advantages of the R.A.S. plotter are; it is more durable, the true and relative bearing scales eliminate the need to convert bearings mentally, and the rotating plotting surface facilitates predictions and continued plotting when own ship alters course.

3.1.2.3 <u>The Anti-parallax Reflection plotter</u>:

It is a simple optical system which removes the parallax normally associated with plotting on the protective screen over the C.R.T., and permitted vector analysis to be conducted immediately over the echoes on the radar display.

The advantages are:

1- Reduction in errors of data transfer.

2- Quick and convenient marking on the screen directly.

3- Much larger number of ships could be handled.

However, its disadvantages are:

1- The need to use crude instruments as wax tipped pencils and soft rulers,

2- A new plot is always required when the range scale is changed.

3- When using a ship's head up display and a reflection plotter with a non-rotatable plotting surface a new plot may be required when own ship alters course, and predictions will be difficult.

4- When using an unstabilized display, for the sake of accuracy, it is essential to make sure that the ship is right on course at the moment the positions of the echoes are being marked on the reflection plotter. which is difficult when the ship is yawing.

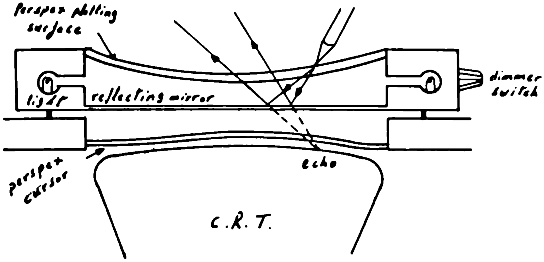

Perspex plotting surface
light
reflecting mirror
dimmer switch
perspex cursor
echo
C.R.T.

Figure ( 53 )

3.1.2.4 Autoplot Ltd:

Its principle is based on plotting by means of transparencies. It is a seperate pedestal mounted device which can be used to record both true and relative plots simultaneously from an existing radar.

It provides a simple and quick method of making a complete plot but practicaly not sufficient, need careful adjustment and training for accurate results, and still not efficient to deal with high traffic situation.

3,1,2.5 Photographic Radar plot ( P.R.P. ) :

This system was presented by Kelvin-Hughes and provides the observer with bright radar picture. The radar screen is photographed at regular predetermined time intervals and projected on the under side of a flat, horizontal square trasparent plotting surface.
The basis of the plot is made by pencilling periodically the projected echoes on the plotting surface.

The advantages are:

1- Bright radar picture which can easily be viewed in daylight without the aid of a viewing hood, so it is possible for several officers to view the picture at once.
2- Plotting can be carried out easily and large numbers of echoes can be detected at the same time and at regular time intervals which eleminate time errors.
3- All information over a time period may be viewed at one time and no chance of an echo being lost through inattention.
4- Weak echoes which may only point on infrequent sweeps of the scan have a better chance of detection due to continous exposure in the same position on the film. This also true to some extent for echoes in clutter.

The picture renewal rate selected by the observer must depend on the circumestances prevailing at any time. e.g. faster rate should be selected in congested waters.

The system is reliable and simple to operate but it is acknowledged that it has some disadvantages such as stocks of film and chemicals must be available for its operation.

Figure ( 54 )

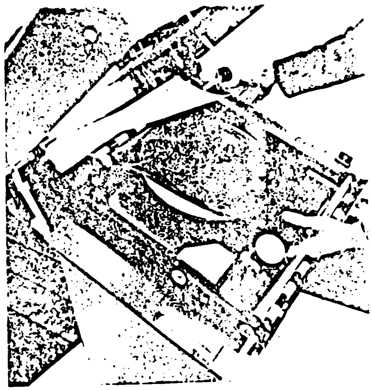


Figure ( 55 )

3.1.2.6 <u>Improving in accuracy using previous aids</u>:

The use of these aids have improved the accuracy of manual plotting by avoiding some of the error sources.
For example, if the reflection plotter is used instead of the plotting diagram the accuracy will be better as follows:

1- The radar-bearing error differs from the value derived in the previous example, only the first two disturbances mentioned before will contribute to the bearing error in the plot.
   The variance in the bearing thus amounts to $5/36^{oo}$ from which it follows that the error in the target position in a direction perpendicular to its bearing has
   $\sigma_{(Tanget)}$ = 12 X distance in N.M (metres).

2- The radar-distance error is only composed of the first two errors mentioned before for the distance. It follows that the error in the target - distance has a variance = $0.5 \times (10)^{-4} \times (\text{Range})^2$.
   And from this the standard deviation in the distance of the target can be derived to be $\sigma_{(normal)}$ = 13XRange in N.M (metres)
   Then $R_{68}$ (one plot) = $1.1 \times \{ (12)^2 + (13)^2 \}^{½} \times$ dist. = 19.5 X dist. (metres).
   If the target distance is close to the range in use which is always advisable.

$\sigma_{CTE}$ = 19.5 X Dist. / (2/3(n)$^{1/2}$) at point (A)

$\sigma_{CPA}$ = ((19.5 X Dist.)/ 1.155 X ((TCPA/plot int.) + 1 )

So $\sigma_{CPA}$ = 202.6 X 2.06 = 417.46 metres

= 0. 225 N.M

and the accuracy $M_{95}$ = 0.45 N.M which is much better, since the accuracy at point (A) will be affected, the accuracy of true course & speed of target will also be better.

### 3.1.3 Appraisal aids:

In a survey of collisions and from experience on board ships, it has been proved that in congested waters particularly during restricted visibility a great deal of time and expertise is demanded from the radar observer to evaluate the traffic situation correctly by plotting.
To reduce the load of work, the possibility of human error, and to give the observer more time to use his intelligence in appraising the situation and keeping it under review, radar engineers kept trying to develop the plotting devices and presented more advanced ones got the name appraisal aids which, in one way or another, produce information in the form needed.

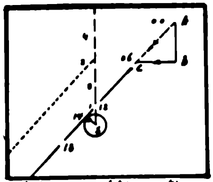
The concept of these devices is generally to adopt some available technology to enable a history of the target motion to be examined without the need for the observer to physically take ranges and bearings in the conventional way. This type of display is sometimes referred to as a history display. The following give a brief mention of some of the more commonly installed equipments.

3.1.3.1 <u>Raytheon TM / CA</u> :

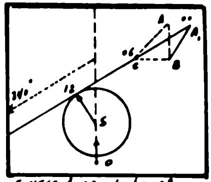
This device has an electronically aided manual plot. A small processor allows dual markers to be placed on echoes of the observer's choice one of the markers remains at the original position of the target while the other records own ships displacement. These two marks and the current position of the target provide the three corners of the vector traingle of manual plotting.

An electronic digital clock indicates the plot time for each echo separately when selected by the operator. To facilitate measurement, A more sophisticated electronic bearing line has a movable point of origin is made available to help in measuring true tracks or evaluate miss distance of the target. The equipment is able to deal with 8 targets in the same time. A trail course and speed shange can be carried out on the most dangerous target, and is automatically applied to the other 7 targets.

Although computation is facilitated in this way, the plot is basically manual and will suffer from the delays and discontinuities of a plot on a reflection plotter, there is no delivery of quantative information without the intervention of the operator.

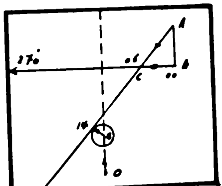


Plotting on relative motion



Course & speed change

Figure ( 56 )



plotting on true motion

3.1.3.2 <u>Anti-collision radar of Decca (66 AC)</u> :

The equipment provides five markers which can be placed individually on echoes whose movements need to be watched. Each marker is a bright line, one inch long, and having a bright spot at one end which is placed on the echo. The line points directly towards own ship, so if an echo diverges from the line, it shows that the target will pass either ahead or astern of own ship's centre, but if the echo remains on the marker, or very near to it, a collision risk then exist.
The line connecting the bright spot on the marker to the actual position of the echo portrays the relative motion line so that the predicted nearest approach can be estimated. The tail of the echo gives an indication of the true motion line. This information can now easily be collected and completed by means of reflection plotter.
With true motion mode the markers are moved in step with the picture origin to preserve the collision line integrity.

This way has a simplistic approach which permits the observer to behave in exactly the same way as he would in the use of conventional radar.
Since little computation is done, errors of the system are not significant, but it is necessary to maintain a careful watch on the echo track during the observation period to ensure that it is constant.

There will be discontinuities when the true motion resets and when scale or mode are changed. If own ship alters course or speed all the markers in use will have to be re-positioned on their echoes, also if a marked target alters, its marker will have to be reset.

In each case there has to be a hiatus while the echo moves away from the newly positioned origin, this will take between 1,5 to 3 minutes.

The figure shows the extra controls for anti-collision radar, above the display.


Figure( 57 )

3.1.3.3 K.H. Situation Display:

The purpose of this unusual radar is to provide enhanced true or relative echo trails. The radar picture is produced on a non-persistent 3-inch cathods ray tube and is projected on to a sensitive screen called Image Retaining panel (I.R.P.). The I.R.P. is scanned by a television camera and the picture thus obtained is shown on the bridge display, which is non-persistent.
This gives clearer daylight viewing, but does not use the signal processing adopted by the other systems previously mentioned.

Relative or true motion can be obtained, and the extending afterglow of the target´s history permit assessment of collision risk or true course of target respectively. The length of the trails give some indication of the target speed.

One advantage of this system is that any change in track, either relative or true, due to target´s manoeuvre is clearly-defined. Another is that when true motion is used own ship center remains at the picture centre.

Discontinuities are numerous due to IRP reset (the reset period is 3 minutes when the range scale is 3 miles or less and 6 minutes for 6 miles range or more). The discontinuity will last about two minutes while the trails build up sufficiently and the picture is again displaying a full track information. The IRP resets with similar effect when there is a change of mode or range scale.

The operator can draw a crude plot on the tube face as on a reflection plotter with all its time delays.

3.1.3.4 Marconi Predictor:

This is the most sophisticated of this group of systems. It is an automatic electronic plotting system, but not in the fully computerised sense.
The whole picture of the radar is stored on a videotape and then replayed in a cyclic fashion to give indication of the echo movement.
It displays a continually up-dated three position track for all echoes on the screen simultaneously. Using videotape means that all viewed targets will appear on the history display, this includes land, rain and sea clutter. The total duration of the track is 1.5,3, or 6 minutes.
Choice of these alternative speeds is under operator control to suit the range in use and the urgency of the situation.
The track are up-dated every 10 seconds.

The presentation is permanently centred and will show either true or relative tracks. There is no display of quantitative information and any needed values have to be measured by the operator.
Trial maneuver is possible, the relative tracks predicted as a result of a proposed change of course and speed can be displayed. Manual extrapolation will show the result of the trial manoeuvre in terms of achieved nearest approach.

The predictor display has a number of advantages above the conventional display:

1- Automatic solving of velocity triangles for past and future occasions for a determined time interval, enabling good continuous appreciation of the situation.

2- Bright echo track.

3- No re-setting has to be employed when using a true motion display.

This indeed, eliminates the danger of the frequent occurrance of late re-setting and makes the display also eminently suitable for fast moving vessels in clear weather.

4- The ability to move instantaneously to view either true or relative motion is much appreciated by the operator.

5- Information is represented in a form which is as easily simulated as possible.

Although, the system has some disadvantages:

1- No discrimination between targets and clutter echoes, these unwanted echoes appear on all pictures and hence, in relative motion particularly, make a considerable confusion on the screen.

2- Where traffic density is high, intersecting tracks of targets sometimes make possitive indentification difficult despite the cyclic brightening that occurs on the target train.

**COMMENT:**

However, electronically aided systems give some information more quickly than manual methods, but when using in a collision risk situation, one has to depend either upon visual interpretation unpunctuated by numerical facts, or on manual plotting to supplement it. Either way, the time scale will be, or will approach, that of 3 or 6 minute track duration, which may not be quick enough.

With predictor, velocity triangles are solved automatically saving time and reducing human blunders. Over, no resetting when using a true mode which eliminates the danger of the frequent occurrance of late resetting.
But since the appreciation of a change of target movement is dependent on visual discrimination of its computed track, the renewal rate will equal the plot interval in use 0.5, 1, or 2 minutes which still need to be removed.

## 3.2 Automatic Radar plotting Aids (ARPA):

Up to this stage, the extraction of the information required from marine radar in time and with adequate accuracy to aid decision-making, was still one of the prime problems which needed to be solved by the mariner. This is especially so in dense traffic and in confined waters under poor visibility condition.

There can be no doubt that man is unable to derive the amount of knowledge necessary to handle a complex situation from manual appreciation of the radar data. In low traffic density, with the aid of reflection plotters or other appraisal aids, there may be sufficient time available for an experienced and dedicated man to conduct a formal plot, analyse the data and implement an avoiding action. When the density of traffic and the complexity of the situation increases, manual appraisal is no longer adequate and the level of plotting must necessarily be reduced to accommodate the increasing number of threats until, ultimately, little more than a cursory tracking of supposed most dangerous targets is achieved.

The problem may be divided into five principal functions:

1- Determine which echoes are to be suppervised.

2- Keeping track of these echoes.

3- Analysing collision risk.

4- Determine escape manoeuvres.

5- Execute the escape manoeuvre and re-establish main course.

This demonstrable need has accelerated the application of technology in commercial marine radar to satisfy, accelerate and simplify, this task. Hence, more sophisticated equipment started to appear using computers and displays for automatic tracking and processing of data.

The designers faced many constrains, no least of which is the shipowners concern with cost benefits, problems of shipborne maintenance and the upgrading of training methods for proper and effective use of the system.

In 1965 the idea was conceived to establish an installation project for evaluating how computer technology could be used on board ship to increase safety at sea and reduce operational costs. Norcontrol was the project manager in this Norwegian research project which started in 1967 as a co-operation between the Norwegian Ship Research Institute, Det Norske Veritas and Norwegian shipowners.

Two years of extensive research and development began, and in 1969 the world's first shipborne computerized collision avoidance and integrated navigation system "Data Bridge" was installed on board of Wilhelmsen's M / S Taimyr.

The design goal was to obtain a system that:

1- Is accurate and easy to handle.

2- May follow a number of ships simultaneously.

3- Is easy to interprete.

4- Is up-dated automatically.

The more recently introduced computerized systems for collision avoidance promise not only a lighter work load for the navigator in times of stress and a more timely warning of impending danger, but a fuller and more up-to-date and objective presentation of the data on which he must make his decisions and a facility for assessing the outcome of any intended manoeuvre.

The computerized collision avoidance system was a radical innovation in the marine field, compared to unassisted radar. These systems represent a significant investment by the shipping industry.
In general, such systems can be described as automatic radar plotting devices which possess the ability to deal with denser traffic situations than could be accommodated by manual plotting alone. It can tirelessly produce correct data on a large number of selected targets and widening the appreciation of target behaviour.
User satisfaction has varied, much more has been said in its favour than against it. It may be danger to relinquish the tracking duty to the computer, since errors are always present in the radar system approach, but appreciation of these errors and their sources will permit a useful level of information to become available.

Typically the first comparative study by Liverpool Polytechnic of the princip al plotting systems, a practical examination by a group of 68 officers of widely different experience and nationality involving only very brief tuition and using simulated displays without the ergonomic advantages of the actual equipment, showed a very definite consensus in favour of the A.R.P.A.• A study by quite a different source carried out on the computer-aided operations research facility of the U.S.A. Maritime Administration reached a similar conclusion.

The trend towards the concept of using computers in a fully automatic radar plotting system was supported by extensive research projects. This provide that the need for such a system is essential to meet the contigencies which always arise due to the continuous increase in speed, size and number of ships.

Evidence in court cases indicate that the time which passed between the moment of realization that a high risk of collision existed and the collision was between five and fifteen minutes, with the average below ten. This time interval can be called "escape time" which may be divided into the time required for accurate observation, plotting (computation) and appraisal, (called planning time), and that available to manoeuvre clear. As the manoeuvre required will not be known until the planning is complete, it will be obvious that the planning time must be as short as possible.
In the interest of reducing the planning time to an absolute minimum, the information required by the observer is as follows:
Firstly, it should reach him at the earliest possible moment after the need for it is established.
Secondly, on arrival it should be as up-do-date as possible.
Thirdly, it should be renewed at the shortest possible intervals.

With an escape time of less than ten minutes, the paramount need after manoeuvring action is initiated, will be to watch closely and continously the behaviour of the other ship. Obviously, these can only be achieved by using computers with a very short renewal rate, in a full automatic radar plotting system with graphical and numerical displays. Moreover, this system could have the possibility of securing earlier recognition of high risk of collision and so increasing the escape time.

In December 1976 the Liberian registered tanker Argo Merchant ran aground on Nantucket shoals, producing a large oil slick which brought the threat of heavy pollution on the coast of Massachusetts and, although there was no appreciable damage to the environment, this casualty brought considerable pressure in the US for action to reduce the risk of similar accidents. In March 1977 th US president announced his intention to develop a series of regulations which would include a requirement that large tankers entering US waters be fitted with a collision avoidance system conforming to specified standards. The USCG requested the IMO Sub-Committee on Safety of Navigation to develop performance specifications and to prescribe carriage requirements for collision avoidance systems.
The US request was first considered by the IMO Sub-Committee in September 1977 but it was not until September 1979, after several meetings, that agreement was finally reached on performance standards and carriage requirement.

As a result of the IMO agreements, the regulations for the fitting of an ARPA are as follows:

i) Mandatory for all vessels of 10,000 tons gross upwards constructed on or after September 1 1984

ii) Tankers constructed before September 1 1984 shall be fitted with an ARPA as follows:

a) by January 1 1985 if of 40,000 tons gross and upwards

b) by January 1 1986 if of 10,000 tons gross and upwards but less than 40,000 tons gross

iii) Vessels constructed before September 1 1984 that are not tankers, shall be fitted with ARPA as follows:

a) by September 1 1986 if of 40,000 gross tons and upwards

b) by September 1 1987 if of 20,000 gross tons and upwards, but less than 40,000 gross tons

c) by September 1 1988 if of 15,000 gross tons and upwards, but less than 20,000 gross tons.

ARPAs fitted prior to September 1 1984 which do not conform to the performances standards adopted by IMO may be retained until January 1 1991. Also ships may be exempted from the ARPA requirements in cases where IMO considers it unreasonable or unnecessary for an ARPA to be carried, or when the ship will be taken permanently out of service within two years of appropriate implementation date.

The US Authorities were not satisfied with the progress at IMO, towards early implementation of ARPA carriage requirements. In October 1978, congress passed the port and tanker safety act which require tankers of over 10,000 gross tons entering American ports to be fitted with automatic plotting aids satisfying US specifications by July 1 1982.

To meet both specifications, collision avoidance systems must incorporate digital computers for radar data processing and display driving purposes. Synthetic predictive and time-history graphics are superimposed upon a slave radar display. Alpha-numeric readout of data for a selected target will be made available in addition.

By the end of 1979 the number of ships fitted with computerized plotting aids was approximately 900, indicating a rate of installation which has avereged about 100 per year. Under the pressure of IMO resolutions and US regulations on the fitting of ARPAs there is a potential market for some 10,000 at the rate of 1000 a year until 1990 or thereabouts after which it may decline but still exist for new buildings. This constitutes a very tempting cake around which manufacurers in various countries are each reaching out for a slice.

As considerable number of manufacturers became interested in this field of technology, this led to several types of such a system. All products must of course comply at least with the minimum preformance standard laid down in IMO resolution which forces the producers for a common identity in respect of main features. This could lead to a reduction in the cost of equipment to be available at a reasonable price, but for added attractions suppliers have tended to produce equipment surpassing the minimum requirements, which could lead to a complicated system not simple enough for proper use and could overwhelm a watchkeeping officer when he joins a diffirent ship fitted with such equipment.

Adequate training in the proper use of the principle types of ARPA systems and their display characteristics should be a requirement for all masters and officers serving on ships carrying such equipment. The IMO Sub-Committee on Safety of Navigation has recommended a training programme in the operational use of ARPA (Resolution A.482 XII adopted on Nov.1981). The Sub-Committee considered that training should, in addition to basic radar training, include the use of simulators capable of demonstrating the capabilities, limitations and possible errors of ARPA.
However, there is a doubt to achieve an adequate improvement in world-wide radar training standards in the near future. Some countries still do not have the ability to provide all masters and mates with an extensive radar simulator course. It seems probable that adequate improvements will not be made in time to satisfy training requirements which will result from the expected increased rate of installing ARPA to ships.

The automatic plotting aids offer advantages compared with basic radar which could result in a significant reduction in the incidence of collisions.
It remains to be seen whether, as happened when radar was introduced, such advantages could be lost due to improper use, lack of understanding, tendency to proceed at higher speed and over-confidence. To achive the full benefits it will be necessary that effective action has to be taken to implement the IMO recommendations on world-wide standards of training.

A look at ARPAs from some of the major suppliers may be interesting, though within confines of this thesis description must necessarily be brief and therefore superficial.

### 3.2.1 ARPA types:

ARPA's currently available are based on two different design philosophies.
One, which at the same time serves a need for a second radar, is a stand-alone single-screen system which is basically a navigational radar incorporating full ARPA facilities.
The other, aimed at ships that already have two radars, consists of a separate ARPA display unit deriving its video input from one of the existing navigational radar,or, if interswiching is provided, from either, whether s- band or x- band.
The latter configuration is in the majority and is adopted by among others.

- Radar Devices, Inc. of San Leandro, California; in devising their Radar Watch Series of add-on automatic plotting systems for interfacing with virtually any type of conventional radar on the screen of which it displays computer-generated graphic symbols.

- The Digiplot ARPA from the Iotron Corporation of Bedford, Mass.; is also an add-on system but has its own display unit separate from that of radar with which it is interfaced.
Iotron were recently acquired by Radar Devices, Inc., who have thus added the Digiplot to their armoury of plotting systems,

bolstering the Radar Watch which has only limited acceptance by the US authorities.
There are two Digiplot models, the RM and RR. Both analyse all echoes observed by the radar within a range of 17 miles and track and plot the 20 nearest to own ship in the case of the R.M and 40 in the R.R. The 16 in. PPI picture presents echoes in green with the synthetic display of alpha-numerics, plotted circles, and ship vectors superimposed in orange. Targets are acquired automatically on the computer's assessment of threat and tracking is also fully automatic. Alternatively, targets can be manually acquired by joystick control which can also be used to select targets on which information in the form of a display of range and bearing, course and speed, CPA and TCPA is required. A target selected by either means is indicated by a circle in orange around it on the PPI.
On the 3, 6, 12 and 24 miles ranges the display can be switched head-up or north-up, relative or true. Target positions are stored in the true motion mode in the computer and any outside an arc of 22.5 degrees on either bow and moving away are discarded. A trial manoeuvre facility as required by the specification is provided and fairway "charts" of harbours regularly visited can be programmed and stored in the computer memory for recall when required.

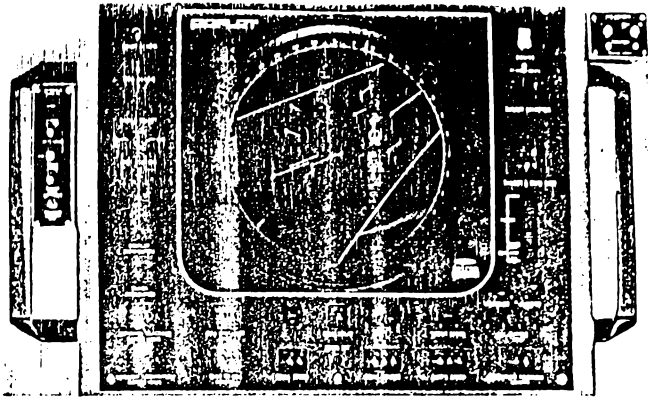
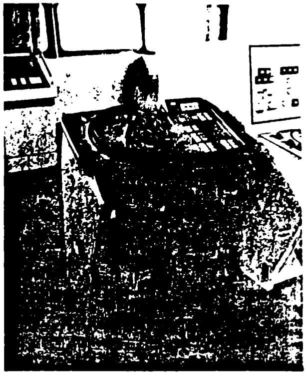


Figure ( 58 )

Another ARPA of American origin is Raytheon's Raycas. This too has a separate display interfaced with a standard radar and acquisition of targets for tracking is automatic on the ranges from 3 to 24 miles. Any target of potential hazzard is indicated by a flashing vector and when the system is operating in true motion a small circle on the screen ahead of its vector shows where collision could occur if own ship were to steer for it. A joystick is used for a manual acquisition. A guard zone within two adjustable boundaries can be placed around own ship anywhere between the 6 and 24 mile radii and the range and bearing of any target entering this zone, together with other necessary target data, will be presented in an alpha-numeric display.

To clarify a multi-target situation the screen can be cleared of all targets, save those presenting a positive threat and lines can be imposed on the PPI to represent safe navigation channels in restricted waters.

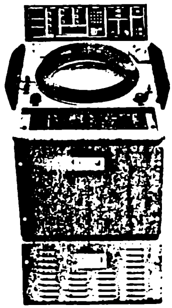


The Raycas collision avoidance system from Raytheon is seen here on the bridge of the giant French tanker "Prarial". This picture shows the unit interfaced with another Raytheon radar, but it can also be used in conjunction with other makes

Figure ( 59 )

In addition, Raytheon have recently introduced a lower-cost ARPA, the Raypath capable of acquiring and tracking up to 10 targets simultaneously within a range band between 1,5 and 12 n.m. Acquisition is manual by roller-ball and as new targets in excess of 10 are acquired earlier ones presenting least hazard are automatically erased. A guard zone may be set, target entry into which activates alarms, and the display can be switched between true and relative and between head-up and north-up while own ship's position can be offset in any direction.

Although only 10 targets can be simultaneously tracked the Raypath still complies with the IMO specification since acquisition is manual and the Performance Standard demands tracking of up to 20 only when acquisition is automatic.

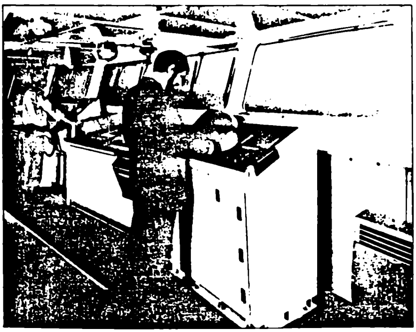


*The Raypath is Raytheon's lower-cost ARPA.*

Figure ( 60 )

- Sperry Marine Systems, a British American firm with European headquarters at Camberley in Surrey, have again opted for the separate-unit ARPA in their CASII. This provides for manual acquisition by joystick of up to 20 targets within the maximum search range of 36 n.m., with automatic acquisition as an option.

All targets are tracked and the microprocessor generates a hexagonal PAD (Predicted Area of Danger) for each and since these are not related to own ship the navigator needs only to steer clear of PADs displayed to avoid any possibility of collision. A PAD is computed and put on the screen after 30 radar scans of the target - about 90 seconds - from acquisition. Its appearance being preceded by a dashed line vector the targets ship's true course and, by its length her speed calculated on the basis of distance travelled in six minutes. The ARPA display is offset to show own ship head-up or north-up a quarter diameter from the rim of the screen and the user can erase any PADs clearly seen to pose no present or future threat. Alpha-numeric readouts of individual target data are shown on demand on a separate rectangular display to the right of the PPI.



*Sperry CAS II ARPA aboard a cross-Channel ferry. Raw Video is derived from either of the two radars.*

Figure ( 61 )

- The ARPA produced by the Italian company Selesmar, based in Florence, is again a separate unit capable of being interfaced with any navigational radar.
Designated the Prora Autotrack. Its PPI displays true or relative motion target vectors, targets being acquired manually at any range or automatically within a guard zone variable from 0.2 to 23.9 n.m. Any target penetrating this zone activates alarms and then projects a vector. Electronic plotting of target course and speed, CPA and TCPA, can be carried out automatically or manual selection, and channel tracks can be superimposed on the display.

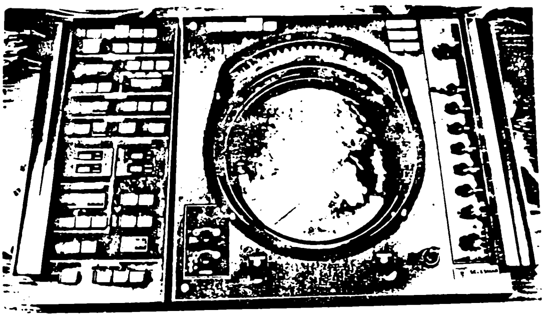
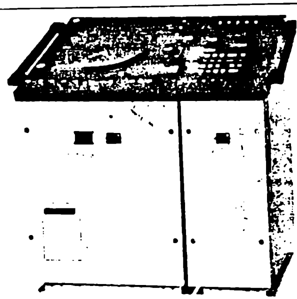


Figure ( 62 )

- Japan Radio Company's JAS-800 ARPA is again a separate unit system, with either manual or automatic acquisition of up to 20 targets which can be simultaneously displayed with course, speed and other data continually updated. A guard ring can be set at a selected range and audible and visual alarms also come into action if a target judged potentially dangerous by the user closes to a distance and time considered to present an active threat. Vectors can be displayed in relative or true modes with the picture stabilised head-up or north-up and the ARPA range scales are 1,5, 3, 6, 12 or 24 n.m. independent of the associated radar. A pair of navigation lines can be set up on the display to represent a navigable shannel or own ship's track.



*One of the Japanese ARPA's currently on the market is the Japan Radio Company's JAS-800 unit. A feature of this set is that the ARPA range scales are independent from those set on the associated radar.*

Figure ( 63 )

- Mitsubishi´s MARAC IIIA, is yet another separate ARPA display to be interfaced with a standard radar. This is capable of tracking as many as 60 targets simultaneously though no more than 30 appear on the screen at once, the remainder being displayed only so long as a call-up switch is pressed. Targets may be acquired automatically or manually by use of a roller-ball. With range scales of 3, 6, 12 and 24 n.m. the display can be presented north-up or head-up vectors indicating the course and speed of targets. A readout of required data on any particular target is obtained by pinpointing its echo using the roller-ball while if no one target is selected in this way the relevant data of that presenting the earliest and clearest threat remains on display. Marker lines can be brought up on the PPI to show the limits of any area of the screen deserving particular study.

- Krupp Atlas of Germany, produce their Type 8500 radar series in three versions, the AC / RM, AC / TM, and A / CAS, the last-named constituting a stand-alone ARPA in its own right although the others do have a more limited collision-avoidance capability. The 8500 A / CAS superimposes a synthetic computer-generated picture on the normal radar traces and acquisition of up to 20 targets can be achieved either automatically or manually by roller-ball manipulation.
Automatic tracking of targets acquired by either means is carried out while they are within 19 miles from own ship´s position which can be off-centred in the relative motion mode. A guard zone can be set and target vectors presented relative or true. Data concerning any target selected by using the

roller-ball is shown in a three-line LED readout and sectors of the display in which potentially hazardous situations exist are automatically computed and are marked by arcs of brightness round the circumference of the PPI.

*The Krupp-Atlas Elektronik 8500 microprocessor controlled radar system. The 16 in bright display units cover relative motion, true motion and automatic collision avoidance.*

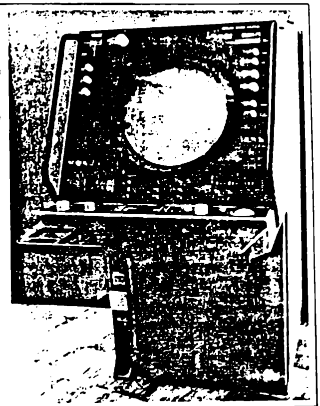
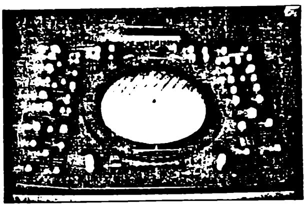


Figure ( 64 )

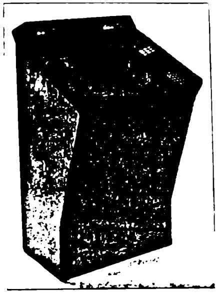
- In the U.K. Racal-Decca, have also opted for the stand-alone integrated radar / ARPA system. The radar uses the clearscan clutter-suppression technique and operates in true or relative motion with 10 range scales from 1/4 to 96 n.m. Up to 20 targets may be acquired either manually by joy-stick manipulation or semi-automatically on entering either of two adjustable guard zones, target data being stored in the true motion mode though the basic radar presentation may be in either true or relative. Vectors are drawn for all targets being tracked and an alpha-numeric display of data can be called up on the screen alongside the target to which it refers. Gain level is automatically reduced on large or close-to echoes so that all targets are optimised in viewing terms, and a feature of this ARPA is automatic stabilisation of the display relative to progress over the ground - a facility useful in providing anchor watch information on any movement of own ship or of other vessels.

*Racal-Decca ARPA display*



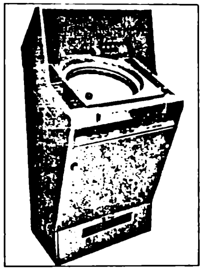
Figruer ( 65 )

- A joint design by Norcontrol of Norway and Kelvin Hughes in the U.K., has resulted in the ARPA designated the DB7 by the Norwegian firm and the Anticol by its British manufacturers. Based on the KH Radpak radar which is the commercial counterpart of the naval type 1006, this is a stand-alone single-screen radar-cum-ARPA capable of acquiring up to 20 targets by manual joystick control, or up to 50 automatically for tracking in true motion whitin a radius of 24 n.m. on a PPI which for radar purposes can be switched to nine ranges between 3/4 and 96 n.m. No more than 20 vectors are however displayed at any one time, each having a time-length of up to 30 minutes of travel. Information on individual targets of choice is shown alpha-numerically in a panel above the PPI.
The display can be switched to relative or true motion and the KH automatic clutter control system employed adjusts the amount of suppression to suit the general clutter level which under wind influence may be higher on one bearing than on others. A separate system controls the clutter return around each target by setting a threshold level based on the number and repetition rate of clutter echoes received. Adjustable safe limits for CPA and TCPA are incorporated and alarms warn of any intrusion on these. Warning of collision target loss is given by other alarms which also signal system or computer failure.
When navigating in restricted waters a fairway "chart" consisting of a set of parallel straight lines can be brought up on the PPI, channel length, width, and location relative to fixed objects being determined by the user. Ground stabilisation of the channel "chart" is by tracking from fixed land or seamarks or by DR derived from gyrocompass and speed log inputs.



( DB 7 )

Figure ( 66 )



Kelvin-Hughes/Norcentral Anticol Digital information appears in the panel above the PPI.

Figyure ( 67 )

On the other hand, the alternative systems can be divided into two main categories according to their method of data presentation:

1- Time based automatic plotter systems presenting time related vectors. These systems produce the same kind of plot as the mariner would manually generate. They display time related vectors which are terminated at the end of the selected time interval, drawing tracks from the immediate target position up to the point the target is supposed to reach in the time period. The track may either indicate the apparent motion and hence a means of evaluating the nearest approach, or the true motion of target. The latter, in comparison with the vector which is necessarily attached to own ship, also allows the true speed of the target ship to be evaluated.
As in the case of the history presentation the facility of being able to switch from relative to true motion continously is one of the greater advantages of the vector type of display.

However, in using these systems it is always necessary to be aware of the mode in which the system is operating before taking informations graphically from the display.
Errors arise when, for instance, observers attempt to establish distance of nearest approach by reference to true vectors.

Due to the fact that most computations of relative track are based on a number of positions which have been smothed into a best fit and the true motion is derived from this relative track by applying the immediate value of own ship´s course and

speed to it, the vectors portrayed during the period that own ship is altering course or speed may be in error.
Tracks made while targets are manoeuvring may also be in error and some delay in taking up the new direction may be apparent, particularly when the change in relative motion is small or the apparent rate is low.

Computer based vector systems offer a forecast role by a trial manoeuvre facility. The effect of different heading and speed trails are displayed by the computer to assist the mariner in arriving at a decision.
The ways of showing the forecast are, a simple presentation of numerical data on an alpha-numeric display, and the movement of echoes on the synthetic display in accelerated motion. Beyond these trial facilities no effort is made by the vector displays to assist in the decision making process.

2- Graphic situation display system which is a product of sperry Marine company using the concept of collision point and dangerous area which previously mentioned in the first section.

In this system the solution is independent of the time. It adopts a unique display which portrays the Probable Area of Danger (PAD) of each target entered into the computer and the total situation is displayed continously to assist in the decision making process.
The Sperry system approach outputs information in a manner which combines the separate steps of hazzard determination and safe manoeuvre identification, steps which are conducted sepera-

tely using vector techniques.

If own ship headings at present speed, which results in a pre-selected CPA distance, (the target can pass either a-head or astern of own ship), are computed, and their points of intersection with the target's track determined, the seg-ment of track between the intersection points becomes the longitudinal axis of a hexagonal PAD symbol, whose trans-verse axis is twice the selected CPA distance. Both axis are increased by a 300 yard allowance to represent a method of error compensation (sensor and system error).
The target track line, which is an extension of its unit 6-minute vector, is terminated conveniently in the centre of the PAD.

The PAD, therefore, represents an area into which own ship must not intrude if the pre-selected C.P.A. distance is not to be breached. This area is the only one in which own ship is capable of approaching the target closely and, in the lim-it, colliding with it. This fact is indisputable and is based on the realities of the relative motion of the encounter. When displayed on the P.P.I., the PAD has a location relative to own ship's present or planned direction and rate of pro-gress, (both the heading marker and the electronic bearing cursor are subdivided into 6-minute elements of own ship mo-tion determined from the speed inputs).

The most critical PAD is the one which intersects the head-ing marker and the relative motion on the P.P.I. of the echo of the target creating it will confirm the degree of hazard.

The PAD approach establishes a simple but correct manoeuvre convention for which time variable vector systems have no equivalent:
"Be prepared to take evasive action for PADs on the heading marker within the indicated time interval and in selecting an evasive manoeuvre avoid close encroachment on any other PAD". The directness and simplicity of this convention has a marked influence on familiarisation and training needs of Sperry CAS.

The PAD convention remains consistent, irrespective of target category. A target alters its course and / or speed; its vector will change in direction and / or length and the position of the PAD on the display will change (about 15 seconds for the corrected PAD to be drawn). A target stopped in the water will exhibit a zero vector when the speed input is water speed and will be enveloped by its PAD. A buoy, lightsvessel or ship at anchor will display a vector which is the negative of the tidal disturbance, a short track line and a PAD, (if own ship heads towards this PAD, the tide will carry her down on the target). A target whose speed is equivalent to own ship´s will place its PAD on the perpendicular bisector of its line of sight, which provides the basis for a pattern for PAD locations in respect to speed ratios. Faster targets exhibit more complex phenómena. With diminishing range, a faster target is likely to show a second PAD, reflecting the ambiguity in the velocity triangle, but as the encounter progresses and the target clears away, the two PADs merge and disappear as the target commences to recede from own ship. In this latter situation, the faster target is declared non-hazardous and shows a 6-minute vector only, which is a unique form and convenient economy in symbolism.

From this brief outline of the PAD approach, it will be obvious that the necessity for time-variable relative vectors to identify targets with critical C.P.A. distance is eliminated. (The PAD of the critical target appears inevitably under the heading marker without any specific operator-initiaated task). Likewise, it is unnecessary to provide any time variation with the target´s time tracks; they are terminated already in the PAD in exactly the same relative position on the P.P.I. as would be defined as a critical area if variable true vectors were cycled ahead in time until the close approach of the target was observed. PADs eliminate the necessity for a trial heading interrogation but preserve the facility for investigating the results of a trial speed change. It is not considered necessary, however, to apply dynamic time lags or manoeuvre delays.

The location of PADs provides a continuous representation of hazard which is obtained on an intermittent basis by vector manipulation:
The certain own ship headings and speed, (whether present or trial values), held for specific time intervals, result in inadequate C.P.A. distances.

When two different vessels produce PADs which are over lapping, special caution should be exercised, as one of the vessels shall have to take action even after own ship has taken avoiding action. In such a case one should keep well clear.

However, the following should be taken into consideration to avoid errors in interpretation:

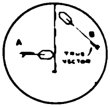
1- The line joining PAD to target is not a real vector, therefore it does not indicate speed. Short lines may be attached to fast targets and longer lines to slower targets.

2- The termination of this line when a PAD is drawn, is not the P.P.C. nor is the PAD symmetrical about the P.P.C.

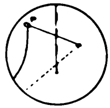
3- It must not be assumed that in cases where the heading marker intersects the PAD, reduction of speed before the vessel actually encounters the barrier will resolve the risk. Reduction in speed changes the outline of the PAD considerably and may in fact produce two PADs in cases where only one existed previously. If own heading marker cuts the PAD, reduction of speed may infact cause the boundary to move towards own ship.

4- The distance to the target is not necessarily the distance which own ship must run before the situation is resolved and own ship may resume course. For pass astern of targets this may be far less, and for pass ahead far more, than the time implied by the own ship heading marker.

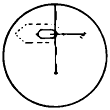
The distance to the PAD only indicate how far the danger could be.



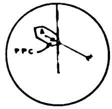

Errors of interpretation
Target A is faster and Target B is slower than own ship, despite appearances.
*Note* Vectors will show this



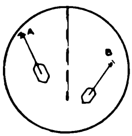

Errors of interpretation
Solid line shows track of PPC from P. Apparent track of echo which will occur is dotted.



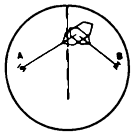
Errors of interpretation
Dotted PAD shown for two miles, solid PAD shown for one mile of CPA.




Errors of interpretation
PPC is not at A, the hexagon centre.

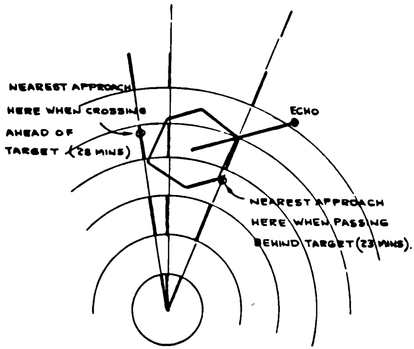



Errors of interpretation
Targets A and B will collide with each other, although not apparent from the display. PADs only constructed according to own ship movement.




Errors of interpretation
Targets A and B will not collide with each other although they may pass within the miss distance.

Figure ( 68 )




MISLEADING EFFECT OF USING BEARING MARKER
TO DETERMINE TIME TO RESUME

Figure ( 69 )

From this brief outline of both vector and PAD techniques, we may say that the fundamantal difference between the two approaches, is that PADs display the hazards in a graphical and complete manner which the human operator finds easy to assimilate, where as the time-variable vector system will generate hazard and manoeuvring information in many circumstances only if the navigator sees need to requice it. The time-variable vector systems indicate where and how fast each of the tracked targets are going, while sperry system indicates where own ship could not go. In other words, if own ship manoeuvres in such away that she can keep clear of the PADs, danger of collision is avoided.

To provide an indication of the impact of the PAD display, it is proposed to explore the PPI scenes in both vector and PAD format as seen by a number of ships engaged in a randomly selected multiple ship situation in a confluence region. This is illustrated in the following figures. The target density is representative of the level encountered normally in the Dover Straits. Three vessels are showing progressing in a SW-W´ly direction, with two vessels on approximately reciprocal headings. Two vessels are heading in a southerly direction, meeting three vessels coming in the opposite direction. With one exception, the vessels are heading into confluence region, with reducing separations.


Random multiple target distribution

Figure ( 70 )

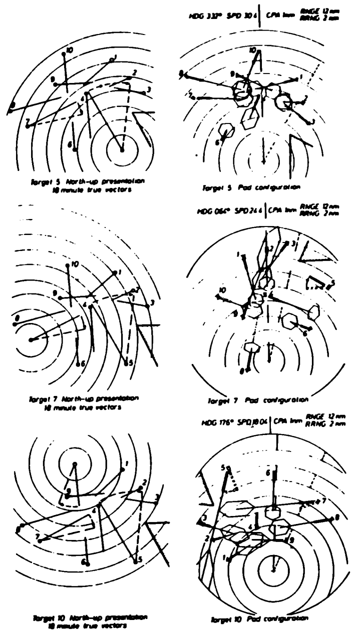

HDG 332° SPD 30.4 | CPA 1nm RNGE 12nm RRNG 2nm
Target 5 North-up presentation 18 minute true vectors
Target 5 Pad configuration
HDG 064° SPD 24.4 | CPA 1nm RNGE 12nm RRNG 2nm
Target 7 North-up presentation 18 minute true vectors
Target 7 Pad configuration
HDG 176° SPD 18.04 | CPA 1nm RNGE 12nm RRNG 2nm
Target 10 North-up presentation 18 minute true vectors
Target 10 Pad configuration

**Figure ( 71 )**

Figure (7/) shows the situation observed on the PPI's of the target numbers 5, 7 and 10, firstly in terms of 18-minute "true" vectors and secondly in the PAD format. The following interpretations suggest themselves:

Target 5 - The vector presentation shows the close approach of target pairs 1 and 9, 2 and 3 and 8 and 10 and Ownship proximity to targets 1 and 9. A suitable evasive heading change would result from rotating Ownship 18-minute vector 37 degrees to starboard to clear all hazard.

The PAD format provides an immediate and positive indication of the hazard distribution ahead. A heading alteration of 33 degrees to starboard is suggested. The cresent of PADS across either bow at roughly 18 to 20 minutes time interval indicates mutual hazard affecting these targets and high-lights their likelihood of manoeuvring.

Target 7 - In the vector format, allowing for the alteration of target 5, this vessel select an alteration of 15 degrees to starboard, bearing in mind that a broader alteration to clear target 6 would create problems with target 4 later.

In the PAD format, the alterations of target 5 would change its status to non-hazardous, leaving target 6 as the one of greatest concern. An alteration of 15 degrees to starboard is suggested, which avoids any problem with target 4. The future threat of target 9 is seen clearly and enters into the decision-making process.

Target 10 - The vector evaluation would suggest a heading alteration of 30 degrees to starboard; PADS show that 23 degrees is quite adequate to preserve the required CPA distance.

These examples are selected as an indication of the rapid and direct assessment of the total hazard situation against a single fixed time interval scale that is made possible by the PAD convention. In any given situation, the Navigator is presented with an unabiguius indication of the risks which attach to continuing his present line of progress and is made at a glance which is the optimum manoeuvre to alleviate the situation.

### 3.2.2 Errors and limitations:

Three sources of errors could affect the computerized systems:

1 - Sensor errors.

2 - ARPA errors.

3 - Interpretation errors.

1- Sensor errors:

These are already itemized in the IMO ARPA publications, and will be briefly mentioned again. Their errors and standard deviations are relatively small.

(i) Bearing Errors: These are due to:

(a) Target glint. It is not always known exactly which part of a target yields the strongest reflection. To a certain extent it depends on the aspect of the object.

(b) Some backlash in the aerial drive gear.

(c) Rolling and pitching. This gives rise to a quadrantal error, maximum on relative bearings of $45^o$, $135^o$, $225^o$ and $315^o$ with the minima in between. It is due to the angular tilting motion of the sanner. Superimposed on this quadrantal variation is a sinusoidal wave form caused by the lateral displacement of the scanner position.

(d) Beam shape in the horizontal plane.

(e) Quantification in azimuth.

(ii) Range Maeasurement Errors: These result from:

(a) Target glint.

(b) Rolling and pitching causing lateral displacement of the scanner position.

(c) Pulse-length echo-chape and strength (associated with pre-set threshold levels).

(d) Quantification in range.

(iii) Course Input Errors: These are caused by gyro-compass deviations and will affect tracking accuracy if their time constants equal those of the tracker filters.

(iv) Speed Input Errors: These are caused by log errors and can become important. They affect course and speed calculations of the target and display true motion vector errors and predicted relative motion vector errors when using the "Trial Manoeuvre" facility. Range, bearing, CPA and TCPA values are not affected.

2- <u>Errors generated in the ARPA itself:</u>

(i) Smoothing Errors: Especially, owing to rolling and pitching errors (a combined effect of scanner movement and gyro-compass errors) slight changes in vector quantities and digital read-outs are continously taking place for all targets in rough weather. It should, however, be remembered that a target´s velocity vector, even under ideal conditions, is always subject to slight changes, depending on type of steering facilities employed, weather and ship´s parameters.

When own ship or the target ship change their velocity vectors, smoothing will oppose the change and true velocity information of targets (vector and digital read-out) becomes unreliable. Some ARPAs stop tracking during these periods. The reason for this is that in most ARPAs, calculations are based on the relative motion velocity vector. In one particular ARPA, however, position and velocity of tracked targets are stored in true motion format, so that true motion vectors of targets do not need to be re-established after a change in relative motion. In case of fast manoeuvre the target may get out of the window if it was small and the tracker may lose the target.

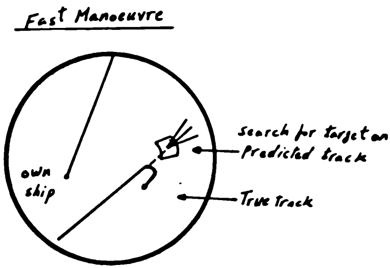



Figure ( 72 )

(ii) Computer calculation errors:

These are nearly always due to course and speed in-put errors.

(a) The influences on vectors:

Relative vectors will not be affected (except in case of trial manoeuvre), but true vectors will be affected leading to incorrect true course and speed of target.

incorrect speed

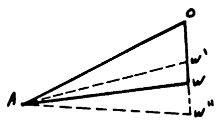



Figure ( 73 )

OW input speed correct

OW` input speed too low

OW`` input speed too high

In-correct course

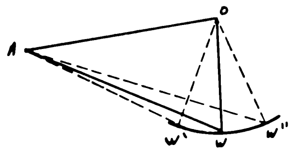



Figure ( 74 )

(b) <u>The influence on P.P.C.</u> :

In-correct speed

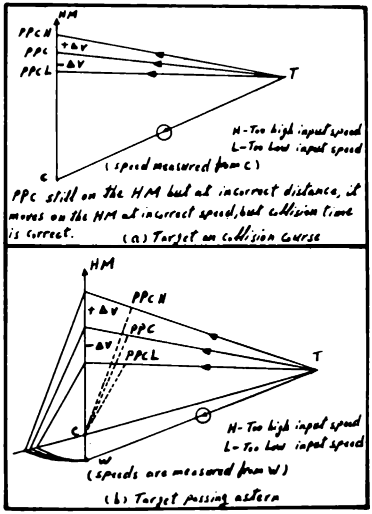



Figure ( 75 )

Incorrect course

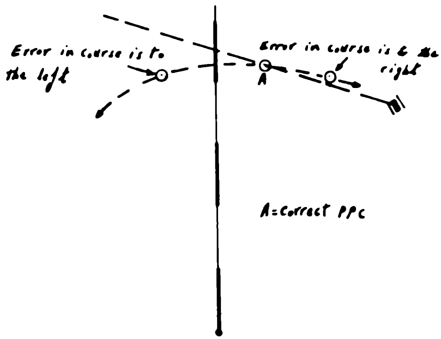



Figure ( 76 )

(c) <u>The influence on the PAD:</u>

Incorrect speed

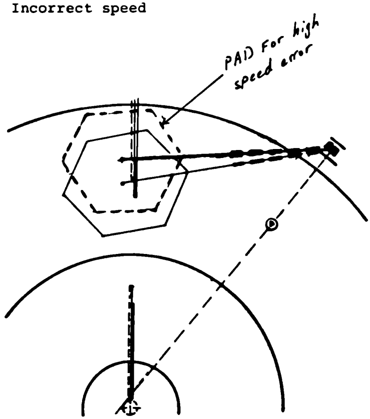
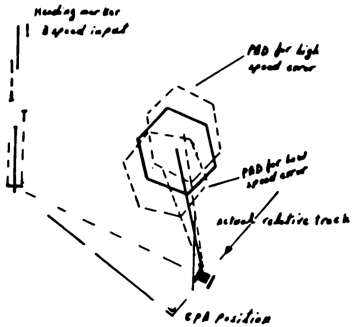



Figure ( 77 )




*Error influences PADs off the heading marker*

Figure ( 78 )

In correct course input will produce similar effect.
CPA data (distance and time) is independent of fixed errors in own ship speed and course inputs to the data processor, is always indicated correctly, but the result of specific manoeuvre such as adopting a heading tangential to the PAD may fall short of or exceed the navigator´s expectations.

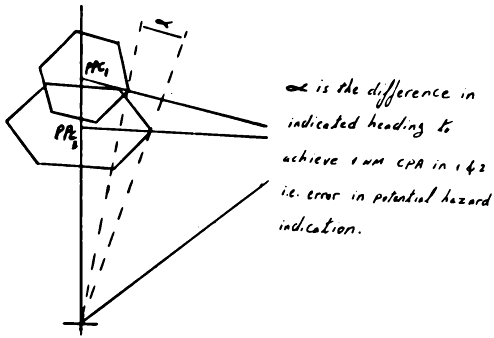



Figure ( 79 )

Note that, with ships on collision courses, speed input error will shift the P.P.C. but it will remain on the heading marker. On the assumption that the HM is correctly aligned, course input errors do not affect the P.P.C. positions with respect to the HM. However, picture and heading marker will be disorientated inside the tube, and correction has to be applied to obtain the true course to avoid a PAD.

(iii) Vector Jumping:

(a) This may occur when targets are close to each other and their two echoes are in the same tracking window. The two vectors may interchange and so will the digital information (target information swop) or sometimes they combine or, when in manual acquisition mode, one target may lose all its information while the other target may yield data for the first time, but they are the wrong data.

Target swop should be overcome by "rate-aiding" the forecast of the target(s) predicted position ahead of the echo during the next scan (so that the proper vector can be drawn if the position is later confirmed) and by making the tracking window as small as possible after the initial acquisition.

(b) It can also take place that while in automatic acquisition mode false echoes are received due to side-lobe effect or indirect reflection via superstuctures on own ship. The remedy is to switch over the manual acquisition mode or to put into action a minimum tracking and / or acquisition range.

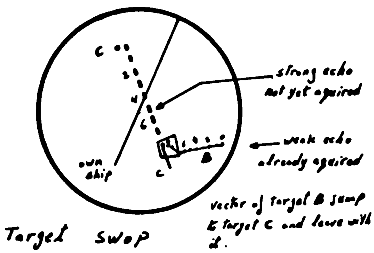



Figure ( 80 )

(iv) Spurious information owing to acquisitioning of rain and sea clutter echoes and to tracking information of land-based objects.

This can happen while using the automatic acquisition mode. Not only does the observer get far too much unwanted information, it will also make the radar picture confusing to look at.
Lastly it may saturate the tracking capacity of the computer and some of the targets may be dropped or ignored even though they are important to the observer.

In these cases one should go back to the manual acquisition mode or apply acquisition restriction for a minimum desired range and use the Area Rejection Boundaries or Zones (ARBs or ARZs).

Use of a 10 cm. ARPA display can be recommended to prevent computer saturation due to rain echoes (but keep on consulting a 3 cm. display if small targets can be expected nearby), although risk of target swop is increased as ship's echoes are "fatter".

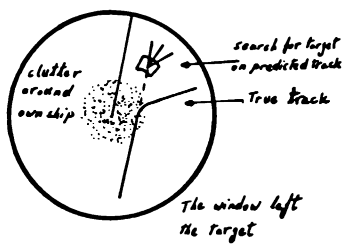



Figure ( 81 ) Effect of Sea clutter

(v) Interrupted tracking of targets, loss of targets or even nondetection of targets.

This will happen with low-level thresholds having been set too high. One may have to ask for technical advice, and in this connection it is wise to remember that with ARPA navigation consultation of a raw radar display should never be neglected.

3 - Errors in Interpretation:

(i) Misinterpretation of Display Presentation and Vector Mode.

The combination of different display and vector (plus eventual history tracks) are so many that mistakes are easily made in interpretation. Sometimes spring-loaded switches are provided for certain vector modes and this can be helpful.

In the True Motion vector mode, using a Relative Motion display, a vector will be attached to the point representing own ship although the point remains stationary on the radar screen. Note also that in some cases the past track does not coincide with the afterglow (for example TM past track on a RM display).

(ii) Misinterpretation of the Trial Manoeuvre (Simulation).

Here, also, the type of display presentation has to be appreciated. With static simulation, showing the predicted situation immediately after the manoeuvre, it seems best to use a Relative Motion Display with Relative Motion vectors of moderate length. With dynamic simulation, showing the predicted developing situation up to thirty minutes after the manoeuvre has been carried out, it will be better to have a True Motion Display, for good understanding, plus Relative Motion vectors (if possible). Although "Simulation" will give guidance for a predicted safe manoeuvre, the observer should keep the "Rule of the Road" in mind especially Rule 19, during poor visibility. The former prediction, which is based merely upon the other vessel keeping her course and speed, may clash with the latter requirement.

(iii) Misinterpretation of the Input speed (Velocity).

In open sea input speed to ARPA is generally manual sea speed or one-axis "water-locked" speed. In calm water-which is often the case during fog conditions-one can be reasonably certain from true motion vector what the target's aspect will be. Near the coast or in estuaries, it is often advisable to use "Auto-Track" or "Echo-Reference" facility, if these are available. The true motion vectors will then show the ground velocity giving a good idea where the ships are going to (this arrangement, under restricted visibility condi-

tions does not clash with Rule 19).
This facility can be used with a True Motion or a Relative Motion Display.

Whatever the speed input, one must make certain what the type is- sea or ground speed- one-axis; sea or ground speed dual axes (sea or ground velocity) - to appreciate the meaning of and to understand the interpretation of the true motion vectors. Also during rough weather, one should realise that some vessels will have wind drift (leeway) superimposed on their directed motion and their real aspect may differ from the one shown on the display or read out digitally. Error in the speed or velocity input does not affect the accuracy of range, bearing and RM past track.

(iv) Misinterpretation of Display Symbols.

It is a pity that symbols (and the same is true for display controls) are not standardized, and that different manufacturers use different symbols (circles, triangles, squares, diamonds etc.) for the same message. Putting it in a different way: the same symbol on different ARPA's often has different meanings. For example, depending on the ARPA make, a square symbol may indicate "acquired" or " Stationary Target" or "Passing within the set CPA distance".

(v) Misinterpretation of Data in Display which are using Points of Possible Collision (PPCs) and Predicted Areas of Danger (PADs). - This was previously mentioned.

Hidden limits to collision avoidance automation:

| | | |
|---|---|---|
| Equipment complexity | - | Ergonomics |
| Relia bility | - | Non-equipped vessels |

Equipment complexity:

Complexity is the prime contributor to reliability and ergonomic limitations. Many collision avoidance aids are still rather complex. For instance, one has fifty-one switches and other controls.

Is it no wonder that a new mate, fresh out of the hiring hall, is overhelmed to the point he is disinclined even to find out how to turn the thing on if it is one of the systems for wich he was not trained?

Further, he probably did not come on board until almost sailing time and is kept quite busy with other aspects of his job, so that even if he has the initiative, he is probably too busy to devote the time required to learn to operate the aid even if some-body was available to teach him.

Therefore, simplicity of equipment is very important, it enables the mariner to be easly familier with the equipment and to deal with it quickly, correctly and efficiently without fear and hence reducing the probability of human errors. Some companies started to produce ARPA sets which only fulfill IMO requirements to be simple and cheap.

## Ergonomics:

Ergonomics embraces the entire interaction between man and machine. The ergonomic limits in the use of collision avoidance aids go much deeper than a lack of training in how to push some switches and twist some knobs. The most serious limitation is the ability to understand the different presentations and the graphic display, the meaning of each of the different symbols and to interpret the encounter situation as presented. This is the same basic limitation that generated the phrase "radar assisted collisions", the failure to properly use the equipment and correctly interpret the display.

This limitation can only be ceased by offering an extensive planned training course which should be repeated after certain periods to provide sufficient training on the various types of ARPA and the different technique used, to ensure that the observer will be able to use each system properly to gain all the benefits, considering the accuracy, understand the limitations and know the possible errors and their effect.

## Reliability:

Computer-based collision avoidance aids are sophisticated electronic equipments. As such they do have failures. Therefore, watchkeeping officers must practice radar plotting frequently because who become accustomed to having solutions provided by automatic plotting aids may become less capable of making effective use of radar on occasions when the ARPA is defective.

Non-equipped vessels:

Several years are still needed before most ships will be fitted with ARPA, during which many ships will have to rely upon basic radar plotting. Then, in congested areas not all ships engaged in the traffic will be working with the same technique under the same tension. The performance of the watchkeeping officers will not be the same which could lead to inconsistent avoiding actions.

It was found that the use of radar induced watchofficers to operate a problem more deeply than they did with ARPA. Then, with less time remaining in which to make a decision, many watchofficers using radar chose to make unexpected manoeuvres which will confuse the watchofficers of nearby vessels and there by increase the probability of collision.

Therefore, shipping companies should be encouraged to fit their ships with ARPA even before IMO schedule, by making availabe simple, cheap sets easy to maintain and with longer time between failure, particularly those ships under flag of convenience.

3.2.3 Accuracy of ARPA plot:

1- Accuracy of CPA:

The standard deviation of the distance to the closest point of approach ( $\sigma_{CPA}$) for ARPA plot will obey to the same rules and procedures used for manual plot reflection plotter, e.g. final equation will be the same.

Therefore, $\sigma_{CPA} = \sigma_{CTE} \cdot ( ( TCPA / \text{plot interval} ) + 1 )$

$\therefore$ For one minute plotting interval

$$\sigma_{CPA} = \sigma_{CTE} \cdot (TCPA + 1)$$

and For three minute plotting interval

$$\sigma_{CPA} = \sigma_{CTE} \cdot (1/3 \; TCPA + 1)$$

Remembering that

$$\sigma_{CTE} = R_{68} \text{ (one plot) } / (2/3(n)^{1/2})$$

and $R_{68}$ (one plot)= 1.1 ( ( 12 distance of target)$^2$ + ( 13 range in use )$^2$ )$^{0.5}$

Hence, the accuracy (M95) in the CPA can be calculated.

A schedule which can be used for these calculations is shown next

| Range in use (M) | Distance target (M) | $\sigma_{tang.}$ (m) | $\sigma_{normal}$ (m) | $\sigma_{tot}$ (m) | MANUAL PLOT: n = 3, $\sigma_{CTE}$ (m) | MANUAL PLOT: M95 = 2·$\sigma_{CPA}$ (m) | ARPA PLOT (1 min): n = 30, $\sigma_{CTE}$ (m) | ARPA PLOT (1 min): M95 = 2·$\sigma_{CPA}$ (m) | ARPA PLOT (3 min): n = 60, $\sigma_{CTE}$ (m) | ARPA PLOT (3 min): M95 = 2·$\sigma_{CPA}$ (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| 12 | 12 | 144 | 156 | 234 | 202 | 404·(½TCPA+1) | 79 | 158·(TCPA + 1) | 45 | 89·(½TCPA+1) |
| 12 | 10 | 120 | 156 | 216 | 187 | 375·(½TCPA+1) | 73 | 146 (TCPA + 1) | 42 | 83·(½TCPA+1) |
| 12 | 8 | 96 | 156 | 201 | 174 | 348·(½TCPA+1) | 67 | 135·(TCPA + 1) | 39 | 77·(½TCPA+1) |
| 12 | 6 | 72 | 156 | 189 | 164 | 328·(½TCPA+1) | 63 | 126·(TCPA + 1) | 37 | 74·(½TCPA+1) |
| 6 | 6 | 72 | 78 | 116 | 102 | 203·(½TCPA+1) | 39 | 79·(TCPA + 1) | 22 | 45·(½TCPA+1) |
| 6 | 4 | 48 | 78 | 101 | 87 | 174·(½TCPA+1) | 34 | 67·(TCPA + 1) | 19 | 39·(½TCPA+1) |
| 6 | 3 | 36 | 78 | 94 | 82 | 164·(½TCPA+1) | 32 | 64·(TCPA + 1) | 18 | 36·(½TCPA+1) |

TCPA IS EXPRESSED IN MINUTES

Table ( 8 )

From the forgoing it will be clear that the number of variables which govern the value of M95 in the plotted Distance to CPA is large.

In order to attain a simplified but justified comparison between the accuracies of the various plotting methods on the 12-and 6 Mile ranges the maximum values of M95 with respect to the Distance of Target are pictured in the below graph.

From this graph it is concluded that:

- Accuracy from a 1-minute ARPA plot at the 12 Mile-range is the worst.

- Accuracies improve with a factor two when the 12-Mile-range is replaced by the 6 Mile-range.

- The best accuracy is obtained from a 3-minute ARPA Plot at the 6 Mile-range

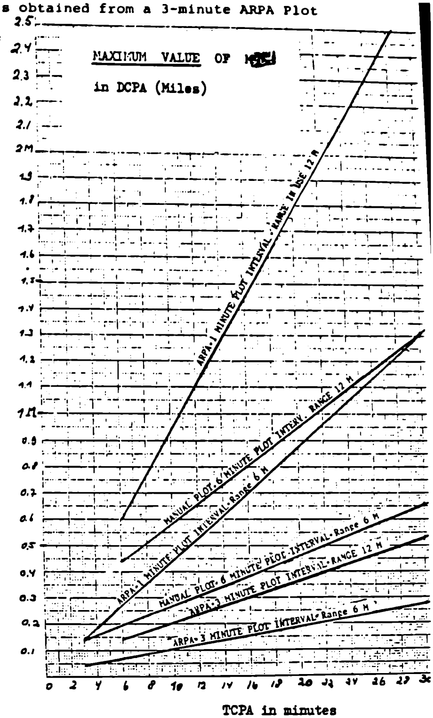



Figure ( 82 )

- By comparing these accuracies with IMO accuracy requirement, it does not differ much.

2- Accuracy of P.P.C. and PAD:

In the figure below these parametres are depicted for a certain close quarter situation, and in the following an analysis of the accuracy ($R_{95}$) of the PAD will be given for certain conditions

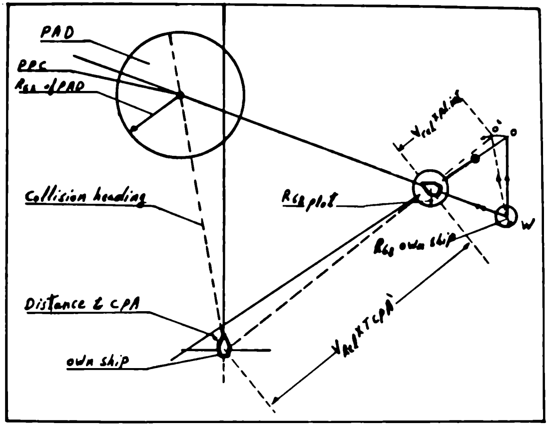



Figure ( 83 )

In the figure, the collision heading and the PPC are shown. It is remarked here that there is a second P.P.C. in this case which is not shown here.

The PPC is calculated by extending the speed vector of the other ship (WA) with a distance equal to $V_{other\ ship} \times TCPA$, Where TCP infact is the time to collision and this time interval differs actually from the TCPA in case no change in heading or speed is executed.

The $R_{68}$ of the PAD:

We will proceed as before when we dealt with manual plotting to show improvement due to avoiding some human errors.

The factors which will affect the accurarcy of the PAD are:

1- The accurarcy of own ship vector (WO) used in the velocity triangle which will depend on the accuracy of its direction and length.

a- The direction of the (WO) will be influenced only by wind drift and gyro alignement since the constructive error of the observer will not exist.

Error in wind drift can be considered using same equation used before

$$\sigma = C_W^o \frac{W}{V} \; ( AU / AL )^{1/2} \quad \sin\alpha$$

By using here a moderate wind speed and ship's velocity the variance ( $\sigma^2$ ) can be estimated to be $(1.5)^2$ instead of $(1.75)^2$ used before.

Error in gyro alignement will be estimated as before at $\sigma^2 = \frac{1^{oo}}{12}$.

Then the direction error can be estimated at

$$\sigma^2 = ( \;(1.5)^2 + (1/12) \;) = 2.33^{oo}$$

$$\therefore \sigma \simeq 1.5^o \quad \text{and the accuracy} = 3^o$$

It follows that the variance of cross track error will be

$$\sigma^2_{CT} = V^2 . \text{ (Plot interval)}^2 . \frac{2.33^\circ}{(57.3)^2}$$

b- The length of (WO) will also be influenced only by the log error, e.g. by the accuracy of the water speed (V). Assuming that the own ship's speed is greater than 10 knots, then the variance of the along-track error will be

$$\sigma^2_{AT} = (2\ \% \ . \ V \ . \ \text{Plot interval})^2$$

$$\therefore \ R_{68} \text{ of point } W = 1.1 \ (\sigma^2_{CT} + \sigma^2_{AT})^{1/2} \ / \sin 90^\circ$$

$$R^2_{68} = 1.21 \ (\sigma^2_{CT} + \sigma^2_{AT}) = \frac{1}{744} \ V^2 . \frac{(\text{Plot interval})^2}{60 \times 60} \text{ miles}$$

$$= \frac{(1852)^2}{744} . V^2 . \frac{(\text{Plot interval})^2}{60 \times 60} \quad \text{metres}$$

$$= 1.28 \ (V. \text{ plot interval})^2 \quad \text{metres}$$

Where V in knots and plot interval in minutes.

2- The accuracy of the target relative vector (OA) used:

As already explained in plotting using the aids as reffection plotter

$$R_{68} \text{ (one plot)} = 1.1 \ (\sigma^2_{Tangent} + \sigma^2_{Normal})^{1/2}$$

$$= 1.1 \ ((12.\text{target dist.})^2 + (13.\text{range in use})^2)^{1/2}$$

$$\therefore R^2_{68} \text{ (one plot)} = 1.21 ((12.\text{target dist.})^2 + (13.\text{range in use})^2)$$

$$= 175 \ (\text{Dist})^2 + 205 \ (\text{Range})^2$$

With (n) plots

$R^2_{68}$ of point (A) = ( $\frac{941}{n}$ (Dist in miles)$^2$ + $\frac{1104}{n}$ (Range in miles)$^2$ ) metres

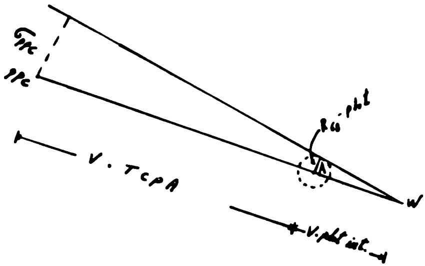


Figure ( 84 )

$\therefore$ $R^2_{68}$ - plot = ( $\frac{941}{n}$ (Dist in M)$^2$ + $\frac{1104}{n}$ (Range in M)$^2$

+ 1.28 (V. plot interval)$^2$) metres

Assuming that plotting interval is 3 minutes, scanning period 3 seconds the number of plots by ARPA equal 60

$\therefore R_{68}$ PPC=(15.7(Dist of target)$^2$+18.4(Range in use)$^2$+11.5 $V^2$)$^{1/2}$
X (1/3 TCPA + 1) metres

Accuracy $R_{95}$ = 5 / 3 $R_{68}$

The conditions for the formula are resumed again:

$\sigma_{Drift} = 1.5^{\circ}$

V more than 10 knots

Log obeying IMO Performance Specifications

Plot interval 3 minutes

Scanner period 3 seconds

TCPA in minutes

Range in use more than 2.5 miles

From the above formula some numerical values will be calculated and presented in the following tables for 12 M and 6 M ranges.

Range 12 M

| $R_{95}/(1/3\ TCPA + 1)$ | | | | |
|---|---|---|---|---|
| Speed \ Dist | 12 | 10 | 8 | 6 |
| 20 | 163 | 157 | 151 | 147 |
| 18 | 155 | 149 | 143 | 139 |
| 16 | 148 | 141 | 135 | 131 |
| 14 | 141 | 134 | 128 | 123 |
| 12 | 135 | 128 | 121 | 116 |
| 10 | 128 | 122 | 116 | 110 |

Range 6 M

| $R_{95}/(1/3\ TCPA + 1)$ | | | | |
|---|---|---|---|---|
| Speed \ Dist | 6 | 5 | 4 | 3 |
| 20 | 127 | 125 | 124 | 123 |
| 18 | 117 | 115 | 114 | 112 |
| 16 | 108 | 105 | 104 | 102 |
| 14 | 98 | 96 | 94 | 92 |
| 12 | 89 | 87 | 84 | 83 |
| 10 | 81 | 78 | 76 | 74 |

From the tables the graph which is pictured below is constructed.
As the influence of the Distance of the target is of minor importance to the tabular values, this argument is neglected in the graph.
Further it is emphasized that the value given is R95 of the PPC which means that in order to acquire R99.7, the R95 - values should be multiplied by 1.4.
Also attention is drawn to the fact that (TCPA) is different from TCPA on a clearing Heading and that (TCPA) in fact is TCPA on a collision heading.

This also explains that in "exact" PAD'S the PPC is not the centere of the PAD because (TCPA) differs from the TCPA's on the clearing headings on both sides of the PAD, the last two TCPA's also differing from each other.

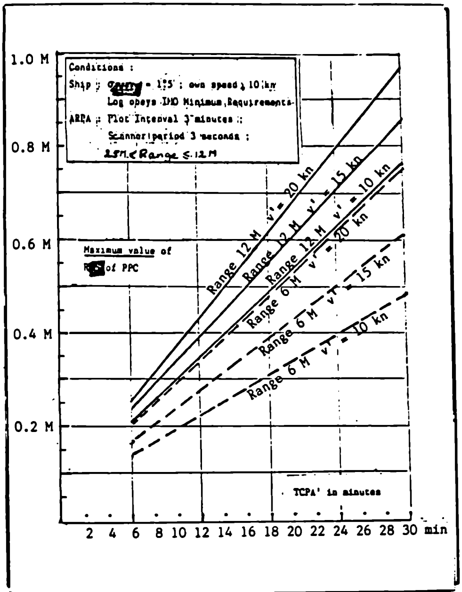



Figure ( 85 )

Advantages and disadvantages of ARPA system:

The potential advantages arising from these new developments, both for timely decision making and in relieving the work-load of the navigator, are evident.

The system provides a fuller and more up-to-date and objective presentation of the data on which the navigator must make his decisions and a facility for assessing the outcome of any intended manoeuvre.

Enumerating the advantages:

1- Raw data up-dated every scan (3 sec).

2- The selected echoes are vectored and displayed simultaneously.

3- There will be no discontinuities from re-setting processes or alterations in course or speed of own ship or target.

4- Elimination of human error in the mechanical task or plotting.

5- Collision Risk alarm based on C.P.A. distance selected by operator.

6- Information renewal rate about 15 secs.

7- Digital readout of target range and bearing, course and speed, C.P.A. distance and time for selected echo instantly on demand, i.e. continuous monitoring.

8- Trial manoeuvre presented dynamically and speeded up to 30 times.

9- Absence of discontinuities and renewal rate of 15 seconds permits plotting to continue during manoeuvring by own ship or targets.

The automatic systems, therefore, provide the mariner with a continuous supply of intelligence in the form in which he needs it and with a minimum of delay. It could enable the observer to study the effect on the situation of a projected alteration of course and/or speed, or several alternatives, within a few second.

Hence, it can readily be seen that with such equipment, time will be available to spend in studying up-to-date intelligence, rather than in the laborious production of much less timely and comprehensive information.

Although the system has all these advantages, it still has some limitations and disadvantages such as:

1- A confusion of vectors or PADs is possible in dense traffic.

2- Specialised training is required to be familiar with the correct use of the equipment to gain all its benefits.

3- Over-reliance on a system could lead to a false sense of security and hazardous encounters.

4- It's effectiveness remains closely dependent upon radar inputs and setting; the radar should be tuned correctly.

5- Still expensive.

6- Tendency for ARPA users to pay less attention to the visual look-out and to neglect other requirements of the collision regulations.

7- Mariners who became accustomed to having solutions provided by automatic plotting aids may become less capable of making effective use of basic radar on occasions when the ARPA is defective.

**Summary:**

In this section a wide range of plotting devices has been discussed. On the one side of the spectrum is the simple plotting sheet - still used by many observers, - and on the other side there is the ARPA, a sophisticated plotting aids, which, gradually, will be introduced on all ships of the medium and large tonnage class.

IMO has already adopted a Resolution on the "Minimum Requirements for Training in the use of Automatic Radar Plotting Aids (ARPA)" which starts with the paragraph:
Every master, chief mate and officer in charge of a navigational whatch on a ship fitted with an automatic radar plotting aid shall have completed an approved course of training in the use of automatic radar plotting aids.

The contents of this course is published in IMO ARPA Publication. Recently the Merchant Navy Training Board (U.K) has issued a booklet, entitled "Training in the Operational Use of Automatic Radar Plotting Aids", which contains a course specification which is based on the IMO specification.

It is worthwhile reading through the specification; two short sections are quoted blow.

1. The possible risks of exclusive reliance on ARPA.
Appreciation that ARPA is only a navigational aid and that its limitations including those of its sensors, make exclusive reliance on ARPA dangerous, in particular for keeping a look-

out; the need to comply at all times with the basic principles and operational guidance for officers in charge of a navigation watch.

2. Manual and automatic acquisition of targets and their respective limitations.

Knowledge of the limits imposed on both types of acquisition in multi-target scenarios, effects on acquisition of target fading and target swop.

Reading through these it seems that raw radar displays, including a 10 cm. set will remain as desirable and valuable aids.

## Conclusion

Shipping has always been more or less a hazardous enterprise and safety at sea has long been a preoccupation of the maritime community.
Collision in particular, has always been a prominent problem in maritime history and the rapid progress in all the aspects connected with the sea, specially in recent decades, led to the continuity of its occurrence with alarming regularity. This problem has resulted in the addition of a new and different dimension to safety equations and has led to changes in both the scope and difficulty of maritime safety work.

The simple and relatively similarly designed ships of earlier days have, to a large extent, been replaced by technically very sophisticated specialized ships. Increased size, speed of ships and cargo turnover, the growth in volume of traffic and the advent of a large amount of several types of hazardous cargoes transported by sea. Thus the situation became more and more complicated and led to an increase in the probability of collision risk with the seriousness of its results which have pushed strongly to give a greater concern to the safety at sea and the efficiency of shipping operations.

The increase in the number of ships together with the trend to spend less time in ports with more time at sea led to a large increase in the volume of traffic. As a result of the geographical distribution of trade, the traffic flow has been concentrated in certain areas creating high congested type of traffic proceeding in several different directions. Some of these waterways are restricted in width and hence reduce the latitude for manoeuvring decisions and the margin for errors.

Larger ships are less manoeuvrable and more difficult to stop, and they are also restricted in where they can go in safely, thus increasing the encounter rate in some areas, and constitute a considerable collision hazard.

The sophisticated specialized ships have complicated operating conditions and demand higher organizational and operational qualities in the interaction between man and materials.

The commercial world demands that the sea voyages should be completed as efficiently as possible, usually with respect of time. Therefore, modern ships are of high speed and masters of these ships normally proceed with full speed in congested areas even in restricted visibility which increase collision risk tremendously.

Several shipowners have been using the so-called flags of convenience to keep their ships at a lower standard level (sub-standard ships). Some of these shipowners have no hesitation in sending old,ill-equipped ships to sea with poorly qualified and trained officers in charge.These ships may cause disastrous consequences and often not only to themselves.

This situation has led to an increase in the number of collisions involving the probable loss of property, life and or pollution. If the hazardous nature of cargoes is taken into consideration, such casualties will need a huge amount of money, considerable period of time and concerted effort to remove its effect.

The importance of reducing the shipping losses, environmental damage and loss of lives that are often associated with marine collisions is well recognized and has tended to persuade the maritime community to explore ways to enhance and promote the safety, accuracy and increased effectiveness of collision avoidance and navigation practices on board ships to improve the situation.

In response to the persistent need of active preventive measures, strenuous efforts and comprehensive work have been conducted, and are still going on, by the international organizations, national administrations, classification societies, firms, research centres and various institutions to eliminate this risk and put it under control.
As a result of extensive studies, investigations, research work and experiments, several measures have been taken and developed, the major of which are:

- The Rules of the Nautical Roads, to direct the actions taken by mariners so that a safe conduct results.
- Ship-to-ship communication, to make clear the intentions and exchange anti-collision advice.
- Optimal bridge design and arrangement, seeking for the most efficient navigational operations.
- Suitable well defined bridge routines and procedures, to ensure that the necessary tasks are carried out correctly at the right time.
- Vessel traffic services, to regulate the traffic in the congested areas and provide invaluable advice to prevent accidents within those areas.
- Reliable ship's control systems, for better ship handling

and more effective manoeuvres.

- Organized education and training systems, for upgrading mariner's qualifications, promoting their practical experience and improving the navigators skills to handle effectively their ships and avoid collision risks.
- Marine casualty investigation techniques, to check the effectiveness of the preventive measures and explore new adequate ideas for successful safety work.
- Developed bridge equipment to improve both navigation accuracy reducing the work load, and threat assessment avoiding ambiguity.

Some adjustment is still needed to gain the full benefit of these measures to improve the situation and increase the safety level.

The Rules of the Nautical Roads, as one of the principal means for preventing collisions, must be well arranged, very clear and simple.
The verbiage of the rules should be in a better form to give the correct meaning; more restrictions on the behaviour of ships in collision avoidance situations in poor visibility are required, the cooperation between the give way vessel and the stand-on vessel still need better arrangement and more effort is still needed to make the rules simpler to be used easily and correctly without hesitation.

Communications are very important for the safe conduct of shipping and therefore additional steps should be taken to ensure its effectiveness.

More strict regulations are needed to ensure greater circuit discipline. Communication facilities should be more recognized in the 1972 International Rules which should specifically acknowledge the existence of the V.H.F. equipment. An "anti-collision message" section has to be included in the International Code (INTERCO) and its content should be closely aligned with the International Regulations. The adoption of a separate worldwide V.H.F. channel is necessary to be used during ship encounters in international waters to ensure that the passing of vital navigational and anti-collision informations are not prejudiced.

Shore-to-ship communication still needs to be promoted by setting a better arrangement of procedures and adequate equipments to increase its range, so ships can ask for an advice when needed and can be continuously informed with the necessary intelligence of the traffic and local environment through which they pass. This will be quite useful in areas of heavy shipping traffic, particularly when bad visibility is likely to occur.

Bridge design and arrangement has been recognized as an important measure. A concern for ergonomics has become a necessity in today's maritime industry.

More careful work is still needed to ensure the most efficient navigational operations.

A serious continuous contact between ship designers, owners and operators is essential to have a wheelhouse which suits the ship's function and route and enables the officers to discharge their duties correctly and in time. Classification societies should contribute to help in finding out the best suitable design and arrangement taking into account the forthcoming international regulations. The societies should also advice the owners of existing vessels for the necessary, not much costly, modifications needed to improve the working conditions on the bridge by having a sensible layout of instruments and equipment, enough area of visibility, etc.

Well defined bridge routines and procedures are very important and can be considered as a necessary measure needed to increase the safety at sea. The reason for the existing higher safety standards in air navigation is actually due to the successful extensive routines and procedures.
More effort is still needed to formalize adequate bridge routines and practices on board ships and not leaving it up to the individual navigator. The traditional attitudes should be changed and the work on the bridge must be regulated and organized to stop the widespread improvisation which often leads to accidents.
Bridge teamwork training should also be included in the nautical colleges curriculum.

Vessel Traffic Services (V.T.S.) can provide a higher level of safety and efficiency when tailored to meet the needs of the specific areas serviced.
Traffic Separation Schemes have been found very effective in reducing the incidence of collisions especially meeting and fine crossing collisions in poor visibility.
More IMO approved T.S.S. are still needed in some congested areas such as some coastal regions off Japan and Korea.
Extension of shore based radar surveillance and improving

identification methods might be necessary, perhaps compulsory fitting of transponders is a good idea. Better arrangement techniques and equipment are also needed for successful accurate communication and reporting procedures.

The sudden failure of some ship's systems could lead to an accident particularly in close quarter situations.Therefore careful structures, maintenance and repair under the classification societies supervision is always necessary.
More attention is required to ensure a good rudder effectiveness, an active back up or parallel system is necessary to increase the reliability of the steering gear. An extensive well established engine room routine is essential, and more serious check by the chief engineer is needed to always have a well maintained machinery. There is a need for a greater use of fault-diagnosis and control systems, and strict state of readiness procedures.

It has been found from marine casualties analysis that the factor of human error predominates. In a lion's share of cases, human factors were cited as causes of collision. Accordingly, upgrading the education and training of ship personnel can be considered as a direct preventive measure.Education and training must be sufficient and efficient to fulfil the needs.
There is a need to agree internationally on entrance qualifications for maritime colleges which have to be high enough. "Hose pipe" systems must be stopped and I personally believe that officers following that system never receive sufficient amount of education and training.

Naval officers who like to join merchant ships must attend a certain course of education and training to adapt their knowledge and skills to suit the working conditions on board merchant ships and not considering them automatically holding a master certificate of competency on reaching a certain rank which is the case in many countries.
There is still a need for more serious training on procedures aimed at the avoidance of collisions, and how to deal correctly with the emergency cases. Radar simulators are quite useful for such courses which should be compulsory. Some countries such as Panama and Liberia still believe that it is not necessary. Within this courses marine casualty statistics should be analyzed and the navigators have to study special cases with the aim of finding causes and recommend measures. Such courses ought to be made available in the education program of the navigational colleges as many lives and ships are lost each year simply because the lessons learned from accident investigations do not reach those who are most concerned, the mariners.
Cooperation between maritime colleges is essential to exchange knowledge and experience to reach a high international standard of education and training.

Investigation of marine casualties is necessary to improve the existing measures to suit the modern situation and to initiate extra adequate preventive actions to avoid the recurrence of similar accidents. Reduction of collision probability can not be achieved to any significant extent unless a serious investigation of collision cases is carried out. The investigation should be based on correct informations, therefore recording devices should be installed on board ships to be as the black box on the airplanes in order to preserve the vital information prior to the accident and at the instant of its occurrence.

Development of an international system for collecting, analyzing and presenting marine casualty data (data bank) is required to recognize where and how they occurred to arrive at a quantitative and qualitative description of the causal factors to determine the correct recommendations for increasing the safety at sea.

The role of IMO should be increased; efforts made by the various maritime countries and their achievements in improving safety as a result of casualty investigations are still, with very few exceptions, not communicated to other countries.

In the past 50 years there has been a vast development in bridge equipment to increase the safety and improve the efficiency of ship's operation. The advanced electronic navigation aids have improved the situation to a considerable degree. The equipment used to determine the ship's position are now providing accurate enough position fixes. The accuracy will further improve with the introduction of Navstar (GPS) which is expected to have extremely far reaching effects not only on position fixing but also on the whole spectrum of navigation.

This type of equipment plays a principle role in reducing the work load of watchkeeping officers, leaving more time for them to evaluate the traffic situation and taking the correct action in time. Any navigator, in confined and congested waters, will have his attention divided between pure navigation and collision avoidance. Therefore, any step done to simplify the navigation will leave him with more freedom to attend shipping in the vicinity and hence safety of navigation will increase.

There is still a need to recognize a good enough training course for the proper use of these equipment to analyze correctly the informations available taking into account their limitations. This course should be repeated at certain periods to clear any ambiguity and ensure that the navigator is capable to deal with them perfectly, particularly with the new generation.

Radar and ARPA are, perhaps, the most useful aids that have been given to the navigator. They have a direct contribution to collision avoidance procedure. Collision avoidance is an important task facing the navigator and any mechanical assistance which improves the information flow, accelerates decision making, and reduces stress and indecision, is performing a worthwhile service to the mariner.

The introduction of radar to merchant ships has brought benefit in terms of collision avoidance. When used properly, it can greatly benefit the navigator in determining the risk of collision, but if it is not used and interpreted correctly it can do more harm than good.

Probably the most famous case of misuse of radar was on 26th. July 1956, when the Andrea Doria and Stockholm collided off Nantucket lightvessel. Although the radar pips of the other vessel were detected by the Andrea Doria at 17 miles and the Stockholm at 12 miles, neither vessel made proper use of the available information.

So, there can be no doubt that almost every collision has been caused by a human aberration of some kind which led to failure to recognize early enough that action was going to be called for, the time left to get clear has been too short to permit coherent planning with the means available plus the actual manoeuvre performing. Possibly the knowledge of this constraint prompted the irrational behavior which followed.

The object of any kind of marine plot is to give an explanation for the radar picture, producing a plan of the area around own ship with the vessels moving on it. The plot will be expected to show the current position of each target vessel, the expected forward movement of each and the risk of collision, if any, then guide the observer to determine the manoeuvre required to avoid that collision taking into consideration other vessels in the area.

Some excuse may be offered for the manual plotting deficiency since the work load of manual data extraction, and the difficulties of situation analysis on a conventional radar display are considerable. They are both time consuming and tedious. It is not surprising that in high traffic densities formal attempt to extract data is often abandoned.

The principal deficiencies of the manual transferred plot lie within the observer/PPI combination; they are of poor accuracy, slow delivery, they have low maximum capacity , and produce fatigue. The PPI is a poor discriminator of small changes of bearing and the observer can only deal with one problem at a time concerning one echo at a time. If there is more than one target to study, the delay in providing the required intelligence accummulates in proportion.

However, the only effective and reliable method of getting the necessary information from radar observations is to compute them. It is quite feasible for this to be done automatically, or to have some of the process automated . A very great deal has been done in efforts to make the work of computation easier, faster, accurate enough, and accommodate several targets simultaneously.
A variety of manual plotting aids has been produced, perhaps the most generally useful device is the reflection plotter, some semi-automatic plots are introduced, but none of them have come into major use; also some attempts have been made to produce electronic computation on the face of the PPI, but to obtain a complete computed data it is still necessary to do a certain amount of manual plotting. Al - though it is reasonable to suppose that the use of mechano/ electronic devices reduce the work load and the possibility of human error to some extent, each system has a limited capacity in terms of the number of targets which can be dealt with and the quantity and quality of intelligence which can be provided.

The introduction of collision avoidance systems has improved and sustained the performance by eliminating many of the known limitations of radar plotting. It is a considerable step forward in the constant battle against collision.
The system provides the mariner with a continuous supply of updated information in the form he needs it with a minimum delay. It also enables the observer to study the effect on the situation of a projected alteration of course and/or speed, or several alternatives, within a few seconds, to recognize the effective manoeuvre.

Do the ARPA systems really make the navigation safer and reduce the probability of collision?
A series of experiments have been run on the simulator at CAORF (USA) from early 1976 to the spring of 1979 to analyze the performance of navigators utilizing visual techniques compared to radar and a collision avoidance system.
The collision avoidance program had initially ascertained that the overall watch officer performance while using a collision threat assessment system was superior to his radar aided performance or his performance using only visual clues. These results were then extended and it was found that the superiority of a threat assessment system over radar was also evidenced when more than one ship in a potential close quarters situation had collision threat assessment aiding compared with radar aiding. This supports the argument that fitting more ships with ARPA systems would result in safer vessel operation.

In an attempt to verify the results of the CAORF study and overcome some criticisms of an earlier study (1974-1975), the Liverpool Polytechnic Maritime Operations Research Unit conducted further research and the overall conclusion indicates that the results align closely with CAORF.

Then an attempt was made to locate comparisons with the effectiveness of the stored history devices. The following table summarizes the results which are drawn from the analysis of 23 Offshore Vessel Traffic Management Casualties.

| Casualty | Computerized CAS cases helped | Stored history cases helped |
|---|---|---|
| Collisions (17) | 14 | 9 |
| Rammings (6) | 4 | 0 |
| Collisions and Rammings | 18 | 9 |

Table (9)

Later CAORF had the following results from a further study :

| Measure | visual | radar | S.H. without digital display | S.H. with digital display | PAD | vector |
|---|---|---|---|---|---|---|
| CPA (n.m.) | 0.57 | 0.61 | 0.96 | 0.77 | 0.8 | 1.14 |
| TCPA (min.) | 8.7 | 7.4 | 11.4 | 10.8 | 10.8 | 12.7 |
| Manoeuvre (deg.) | 24 | 24 | 38 | 39 | 35 | 47 |
| Near Misses $\leq$ 0.3n.m. | 13 | 10 | 9 | 7 | 2 | 2 |
| Collision | 0 | 1 | 1 | 1 | 0 | 0 |

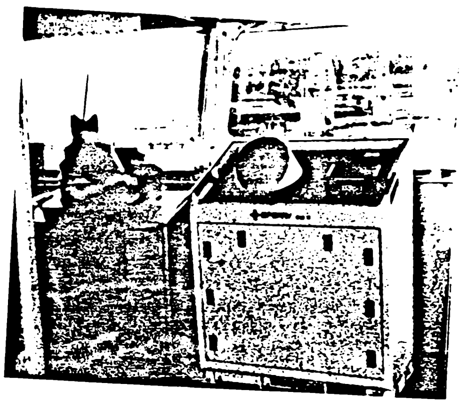
Table (10)

CPA = closest point of approach

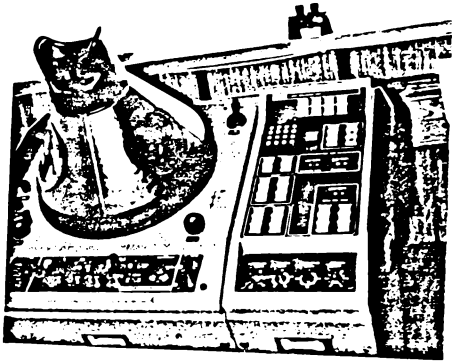
TCPA= time of closest point of approach

In a field visit, I have done three voyages on three ferries each of which is equipped with a different type of collision avoidance system.

1. 14th. of July 1980, Sea-Link Ferries - Vortigers Ferry , from Folkestone to Boulogne and back (1410 to 1900). The ferry was equipped with Digiplot of Iotron.
2. 15th. of July. Sea-Link, Hengist Ferry, from Dover to Calais and back to Folkestone. The ferry was equipped with CAS II, Sperry.



3. 28th. of July, P & O Ferries, N.F. Panther, from Dover to Boulogne and back. The ferry was equipped with Raycas , Raytheon.



The captain and officers on each ferry were quite happy and satisfied with the equipment they had got on board saying it makes life easier, reducing the load quite a lot and increasing their confidence in complex situations, which helps them to act quickly and correctly. Most of the officers where not familiar with the other types of ARPA so believing that the one they had got on board is one of the best, always pre - ferring to deal with the same type. Maybe they gave this answer because a representative from the company was with me each time, but I think that the point is that they succeed to be familiar with the equipment they have on board and are able to use most of its benefits, if not all,which helped them to successfully avoid dangerous situations, so they prefer to keep going with the same type. The reason for this,of course is due to the lack of training courses which should soon be covered.

The visit indicated that the navigator really needs such equipment to be on the bridge and an adequate training should be available for the different types and to be compulsory.

An ARPA should, in order to improve the standard of collision avoidance at sea, reduce the work load of the observer.

Therefore, simplicity of equipment is very important; the companies should produce ARPA sets which fulfil IMO requirements with an emphasis on compactness, simplicity and reliability . This will also be beneficial in avoiding an excessive training requirement and expensive sets.

Controls should be arranged in a way that their functions can be recognized from the first glance and that can be achieved by appointing only one function to each control, not different functions to the same one.

The meaning of the symbols used in the different types should be standardized to avoid ambiguity and its number should be reduced to avoid the possibility of masking small targets.

Positive steps should be taken on board ships to avoid over-relience of navigators on an ARPA set, perhaps by not using it in areas where few traffic of ships is expected,keeping it on stand-by and insisting in carrying out a manual plotting in case of meeting any. The tendency of ARPA users to give less attention to the visual look-out, neglect other collision avoidance requirements and be less capable of making effective use of basic radar could lead to a false sense of security and thus to hazardous encounters causing an "ARPA assisted collision".

## Recommendations

1. Strengthening the training and examination methods related to International Regulations for Preventing Collisions at Sea to ensure that all officers are well prepared to abide by them intelligently and correctly in time without hesitation. International unification of these methods will give better results.
2. Testing and analyzing the application of the rules experimentaly and adjusting them when necessary to keep them abreast of development in marine technology . The rules should always be suitable for the infinite variety of maritime circumstances; any amendment must come into force as quickly as possible for faster improvement of the situation.
3. Greater emphasis on the use of communication, ship-to-ship communication should be promoted and regulated in a better way to increase its effectiveness,cooperation between ships is very important particularly in heavy traffic portions.
4. The bridge design should be evaluated in relation to the requirements of functional analysis and forthcoming international regulations. It should allow the housing of new technology without affecting negatively existing functions and routines.
5. Ergonomical approach to bridge arrangement. It is better to group equipment according to function, which means having regard to inter alia usage, circumstances, presentation and back-up facilities. Only equipment which is actually required for the navigation of the ship

should be placed in front of the navigator, and all other equipment relegated to the back of the bridge.

6. Continuous contact between ship designers, builders,owners and operators is necessary to ensure that the bridge will suit the user providing all the needs for most efficient operation of the particular ship and trade.
7. Well defined job requirements on board ships is very important, extensive bridge routine and procedures are essential and strict watch rules and orders are necessary, followed by consecutive checks and serious control by the master to ensure adequate coverage of the watch,executing properly the vital tasks.
8. Regular and frequent check of the performance of bridge equipment by officers and never allow them to completely rely upon a single device, therefore certain back - up systems are necessary to increase the safety of operation
9. Owners who fit their ships with an ARPA system have a duty to ensure that their staff are clearly aware of both the virtues and the vices of the system chosen, as well as their own fallibility. It could be better to standardize on one system as that staff could be confused by the subtle differences between marks when they have to be transferred to another ship.
10. It is better not to use ARPA when few traffic is expected (to be on stand-by) to keep the officers aware of the importance of the visual look-out, practicing manual plotting and developing their manoeuvring skills, and not to become accustomed to have all the solutions provided by ARPA. It must be completely understood at all times that ARPA is just an aid rather than an automatic control.

11. The safety advantage of ARPA actually increases substantially when the two interacting ships are both equipped with threat assessment systems. Therefore, shipping companies should be encouraged to fit their ships with ARPA even before IMO schedule by making available simple and cheap sets, easy to maintain and with longer times between failure.

12. Improvement of performance of aids interfaced with ARPAs such as radar, gyro and log.
Development of two-component logs measuring speed through the water in two directions ( X and Y axis of the ship ).
Development of ARPA in combination of radar picture and navigation maps (electronic maps). In addition, it is necessary to have a rate of turn measuring device which can be connected to the ARPA computer.

13. Vessel Traffic Service (VTS) is a very effective preventive measure in congested areas, and an international survey is needed to determine the location of the necessary ones where the risk of collision is greatest and where collision effects are the most serious.

14. Extension of the areas which require a compulsory pilotage in heavy traffic portions.

15. There is a need to identify, in connection with the licensing and certification programs, the general emergency ship handling procedures expected to be followed that will reduce ship collisions caused by vital control system failure. A model simulator training program related to this matter should be developed.

16. Well established engine room procedures and maintenance programs are important; main engine and steering gear

must always be kept in good order and seriously checked on approaching congested areas.

17. Using standardized formats for presenting clear concise ship manoeuvring data such as the rate of turn, the advance distance and the stopping distance under different ship conditions.

18. Marine college courses, educational tools,training techniques and test materials must be well arranged and developed so as to be always suitable for the requirements and cope with the developments that so frequently occur in the maritime field.

19. Renewal of certificates and training at certain periods is very important and should be done according to STCW requirements.

20. The appreciation of collision avoidance problems by seafarers, must be widened beyond knowledge of the collision regulations and the recognition of risk, to encompass a knowledge of the limitations imposed by self and other ships manoeuvrability and equipment.

21. Further objective study should be undertaken to understand better how officers use the data presented to them and how they percieve the overall collision avoidance problem to find out why human factors have a large contribution in marine casualties. It is not sufficient to just indicate that the cause of the accident is due to human error, it is necessary to find out why the officer acted in such a way which led to the accident.

22. Ship owners must not fit their ships with any new piece of equipment before they are sure that the staff is able to use it properly and effectively, as the incorrect use of equipment could cause more harm than good.

23. Reducing the officer's work load to an adequate level;this could be achieved by changing the framework condition governing the running of the ship, the manning arrangement, hours of work and watchkeeping plan.
Ship manning must never be reduced before adjusting the ship to suit the limited number of personnel, otherwise a gap will exist in the bridge organization.

24. The social climate on board ships should be improved to get the officers best effort.

25. No pressure should exist to complete the voyage in a certain period of time. Masters of ships must consider safety as the major goal and not proceed with a speed more than that permitted by the circumstances; the higher the speed the faster the situation will develop and the less the time available for decision making.

26. Passage planning must be well prepared and discussed in advance taking into account the needs of each phase of the voyage for safe passage.

27. Introduction of automatic registry of operational data on board ships for the purpose of obtaining more relevant and correct data for casualty investigation.

28. More contribution by IMO to regulate investigation of casualties and establishment of a well structured and active international system for investigating, analyzing and reporting marine accidents as that organized by ICAO.
A modest start has been made by the Maritime Safety Committee of IMO, which has begun to issue statistics of serious accidents, but the reports are not complete and detailed enough to be of much practical value.

29. Fairways must be adjusted to suit the development occurred

in marine industry, the increase in ship's size and draft and the increase in the amount and types of hazardous materials.

30. The overall responsibility for the control of maritime safety must be held by the national administrations. In the light of this, a system must be developed that enables work on safety to be arranged in such a way that the overall responsibility held by the national administration is effective in practice, at the same time as services of the classification societies are utilized to the extent considered justifiable and appropiate. The national administration must keep abreast of developments in the field of maritime safety in all aspects as regards shipping in general. It is necessary to examine its future ability to perform both current and future duties taking into account all convention requirements.

31. The national administration must play a central role in cooperation with education and training centres, owners and ship masters to ensure that ships staff have an adequate competency. The administration should make a record for each officer containing a detailed information about him, particularly his acts on board ships according to which the officer may have to repeat a certain training course or to sail as an extra officer or officer of lower rank for a certain period of time.
The administration must take over the entire responsibility for reformed signing-on activities for this purpose.

32. Increase the cooperation between national administrations and the classification societies to ensure that a ship, when it is being operated, is actually seaworthy, adequately

crewed, equiped and maintained in such a way that it provides adequate safety in order to prevent marine casualties, with regard to the ship's operation and the trade in which it is operated. To-day's technically advanced shipping requires the coordination of the technical, structural and operational aspects.

33. The classification societies must, in spite of the competition between them, collaborate in the work of international maritime safety, exchange experience and detailed information, carry out research work and objective studies to explore ideas which could improve the operational safety. They must cooperate on a mutual basis to be able to offer relevant professional assistance and guidance in this field. Det Norske Veritas Research Division has carried out a project in the period 1977 - 80 on cause relationships of collisions and groundings to evaluate its classification rules for ships and proposed a voluntary class for nautical safety. The data used was based upon the collisions and groundings involving norwegian ships. If same work could be done in cooperation with the other classification societies, the data would be wider, the experience greater and the work more extensive, which surely would lead to more comprehensive and accurate results for greater benefit.

34. Cooperation between the national administrations of various countries must be extended for better control of ship's standards, to prevent owners of sub-standard ships to continue and keep them operating in this condition. Ships not complying with internationally agreed standards must be stopped.

It is of greatest importance to ensure that IMO operational and technical standards are maintained on ships. In the North Sea area, the national administrations of the North Sea states, i.e. Belgium, Denmark, France, West Germany, The Netherlands, Norway, England and Sweden, as well as Greece, cooperate in port inspection of all ships to ensure the maintenance of certain standards. This cooperation is based on the so-called Memorandum of Understanding between certain maritime authorities.

Similar cooperation should be organized in other regions.

35. The assistance provided by the International Maritime Organization (IMO) for maritime countries, particularly the developing ones, should continue and to be increased when necessary to develop their maritime industry and to be able to implement the requirements of the STCW convention as quickly as possible in the near future. The establishment of the World Maritime University (WMU) under the auspices of IMO is a magnificent work and correct positive step towards a better future.

I BELIEVE THAT, IF THE MENTIONED SHORTCOMINGS ARE OVERCOME AND THESE RECOMMENDATIONS ARE REASONABLY SATISFIED, THEN WE WILL BE ABLE TO GAIN THE FULL BENEFITS OF THE PREVENTATIVE MEASURES AND REACH A REASONABLE SOLUTION FOR THE COLLISION PROBLEM, HENCE INCREASE THE SAFETY OF NAVIGATION.

WORLD MARITIME UNIVERSITY MALMÖ - SWEDEN

# AN INVESTIGATION INTO MARINE COLLISIONS AND INTO METHODS FOR THEIR REDUCTION WITH AN EMPHASIS ON RADAR AND ARPA

Volume II (Appendices and References)

BY

SALAH AHMED MOHAMED SALEH
Egypt

A paper submitted to the Faculty of the WORLD MARITIME UNIVERSITY in partial satisfaction of the requirements of the MARITIME EDUCATION (NAUTICAL) COURSE.

The contents of this paper reflect my own personnal views and are not necessarily endorsed by the UNIVERSITY.

Signature:
01 July 1985

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Appendix 1

VERNMENTAL MARITIME
ATIVE ORGANIZATION

OMMITTEE ON SAFETY OF
ATION - 26th session
item 4

NAV 26/4/1
15 September 1981
Original: ENGLISH

IMCO

MATTERS RELATED TO THE 1972 COLLISION REGULATIONS

COLLISION STATISTICS AND ANALYSIS OF THE
CAUSES OF COLLISIONS

Note by the International Association of Institutes
of Navigation (IAIN)

The attached report "Collision statistics and analysis of the causes of collisions", compiled by A.N. Cockroft, is brought to the attention of the Sub-Committee for any action it deems appropriate.

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# ANNEX

## COLLISION STATISTICS AND ANALYSIS OF THE CAUSES OF COLLISIONS

### INTRODUCTION

OBJECTIVES The investigation is related to collisions which have occurred outside port areas, in coastal waters or in the open sea. Statistics of all known collisions have been used to determine trends according to regions and to investigate the effects of other factors such as darkness and visibility. From the data bank of known collisions it has been possible to seek out further details of the circumstances of the accidents from various sources for the purpose of analysis of the causes of collisions.

SCOPE OF THE INVESTIGATION The survey has been restricted to collisions between vessels of over 100 tons gross under way and proceeding on passage and not engaged in special activities such as fishing, replenishment or naval exercises. It applies to collisions occurring world-wide in coastal waters or the open sea but does not apply to accidents in harbours, rivers, canals or inland waters. Narrow straits such as the Sound, the Bosporus and the Straits of Messina have been excluded from consideration but collisions in the Straits of Gibraltar and Singapore have been included. Data has been obtained for collisions which have occurred since the 1st January 1956. The data bank will continue to be up-dated in the immediate future.

SOURCES OF DATA The initial data relating to the incidence and location of collisions for statistical purposes has been obtained from Lloyd's Weekly Casualty Reports published by the Corporation of Lloyds. Data on collisions in the Dover Strait area has been checked by comparison with the reports of the National Maritime Institute of the United Kingdom and supplemented by information received from the Channel Navigation Information Service.

More detailed information about the circumstances of collisions has been received from various national administrations and from other sources. Data based on Japanese investigations has been provided by Professor Kandori of the Shimonoseki University of Fisheries.

### BACKGROUND

NUMBER OF SHIPS IN SERVICE This report is concerned with collisions between ships proceeding on passage, which are almost invariably merchant ships engaged on commercial voyages. When considering trends in the incidence of collisions account must be taken of the number of trading ships in service, which has increased considerably over the period covered by the investigation. Estimates of the number of trading ships in service at ten yearly intervals are shown in Table 1 for different size categories. The figures are based on the Statistical Tables of Lloyd's Register of Shipping and on data published by the General Council of British Shipping.

Table 1 Numbers of trading ships in service according to size category (g.r.t.)

| Year | 100-999 | 1000-9999 | 10000 over | Total |
|---|---|---|---|---|
| 1950 | 5100 | 11200 | 1100 | 17400 |
| 1960 | 7400 | 12300 | 3000 | 22700 |
| 1970 | 11400 | 13000 | 6200 | 30600 |
| 1980 | 11800 | 13600 | 9500 | 34900 |

REGIONAL TRAFFIC DENSITIES During the first part of the period covered by the survey the density of marine traffic was highest in the coastal region off north west Europe, particularly on the route from Ushant to the Elbe. (Traffic surveys made in 1972 and 1977 indicated that the volume of through traffic was of the order of 300-400 ships per day in the Dover Strait, with 150-200 crossing ships per day in the peak summer months.)

Traffic off N.W. Europe may have been slightly higher in earlier years when there was a larger number of small coastal ships operating in the area. In 1962 the number of through ships on the Borkum-Terschelling swept route was estimated to be about 350 per day.

The volume of traffic in Japanese coastal waters has increased considerably during the period covered by this investigation and traffic density off some sections of the coast is now higher than in the Dover Strait and all other coastal regions. The high traffic density is due to the large number of small coastal ships trading in this region, apart from the considerable number of fishing vessels.

Other coastal regions with a high traffic density are the Malacca and Singapore Straits, the southern part of the Baltic Sea and the Strait of Gibraltar. In 1978 the flow of traffic through the Strait of Gibraltar was found to be of the order of 100-150 ships per day.

## RESULTS OF THE INVESTIGATION

### 1. STATISTICS OF WORLD-WIDE COLLISIONS

It is difficult to obtain complete statistics of world-wide casualties, especially with respect to the numerous minor accidents which occur in port areas. A very high proportion of collisions which occur in coastal regions or the open sea will be reported by Lloyd's as at least one of the ships involved is likely to suffer appreciable damage. However, it has been found that some collisions between small ships in Japanese coastal waters have not been included in Lloyd's Casualty Reports and the data bank has been supplemented by additional information received from Japan.

INCIDENCE OF COLLISIONS The annual incidence of world-wide collisions is shown in Table 2. Despite the considerable increase in the number of ships in service the incidence of sea collisions, as reported by Lloyd's, has remained relatively constant.

Table 2 Annual Incidence of Reported Collisions

| | 1956-60 | 1961-65 | 1966-70 | 1971-75 | 1976-80 | 1956-80 |
|---|---|---|---|---|---|---|
| Both ships | 46 | 51 | 48 | 41 | 34 | |
| over 1000 tons | 46 | 41 | 36 | 45 | 36 | |
| | 41 | 48 | 45 | 34 | 46 | |
| | 45 | 51 | 55 | 40 | 43 | |
| | 50 | 41 | 52 | 57 | 35 | |
| Totals | 228 | 232 | 236 | 217 | 194 | 1107 |
| Both ships | 80 | 77 | 87 | 105 | 79 | |
| over 100 tons | 68 | 57 | 73 | 85 | 81 | |
| | 65 | 87 | 87 | 77 | 79 | |
| | 76 | 83 | 105 | 93 | 76 | |
| | 70 | 94 | 100 | 94 | 66 | |
| Totals | 359 | 398 | 452 | 454 | 381 | 2044 |

RATIO TO NUMBER AT RISK The total number of ships of different size categories which are known to have been involved in a sea collision are given for each five year period in Table 3. The ratio of the mean annual rate to the number of ships in service is also shown. The ratio of ships in collision to ships at risk was appreciably higher for larger ships before 1970, but has decreased in recent years to be about the same as for small ships.

Table 3 Numbers of ships involved in collision and annual ratios to the numbers in service, for different size categories

| Period | | Size Category in g.r.t. 100-999 | 1000-9999 | 10000 & over |
|---|---|---|---|---|
| 1956-60 | No of ships in collision | 141 | 450 | 110 |
| | Ratio to number in service | .0043 | .0074 | .0088 |
| 1961-65 | Ships in collision | 171 | 435 | 140 |
| | Ratio | .0041 | .0070 | .0081 |
| 1966-70 | Ships in collision | 261 | 384 | 212 |
| | Ratio | .0049 | .0060 | .0081 |
| 1971-75 | Ships in collision | 298 | 347 | 239 |
| | Ratio | .0051 | .0053 | .0069 |
| 1976-80 | Ships in collision | 220 | 319 | 189 |
| | Ratio | .0039 | .0047 | .0045 |

REGIONAL INCIDENCE The regional totals of collisions for five year periods are shown in Table 4. The figures for Japan and Korea are likely to be incomplete, especially for the earlier years. Collisions in the bays of Japan and in restricted waters of the Inland Sea have not been included.

Table 4 Regional totals of collisions for five year periods, 1956 to 1980

| Region | 1958-60 | 1961-65 | 1966-70 | 1971-75 | 1976-80 | TOTALS |
|---|---|---|---|---|---|---|
| Baltic Sea | 37 | 42 | 39 | 33 | 21 | 172 |
| Southern North Sea | 82 | 80 | 71 | 32 | 22 | 287 |
| Dover Strait | 60 | 69 | 45 | 19 | 16 | 209 |
| English Channel | 25 | 29 | 23 | 22 | 15 | 113 |
| E Coast UK | 34 | 19 | 17 | 12 | 10 | 92 |
| W Coast Spain-Portugal | 13 | 29 | 17 | 15 | 12 | 86 |
| Gibraltar Strait | 10 | 13 | 13 | 3 | 17 | 56 |
| Mediterranean | 22 | 19 | 15 | 29 | 31 | 116 |
| E Coast N America | 27 | 22 | 20 | 18 | 11 | 98 |
| Malacca & Singapore Straits | 2 | 5 | 13 | 26 | 20 | 66 |
| Coasts of Japan and Korea | 5 | 29 | 114 | 163 | 125 | 436 |
| S.W. Pacific | 2 | 6 | 11 | 24 | 17 | 60 |
| Other regions | 40 | 34 | 55 | 58 | 52 | 239 |

There has been a considerable decrease in the number of collisions occurring off north west Europe in recent years which cannot be accounted for by the possible slight decrease in traffic density. The coastal region from Ushant to the Elbe will be considered in more detail in the next section of this report.

The increase of collisions occurring off Japan during the period of the survey can be attributed to the growth of international and coastal trade and the considerable increase in the number of Japanese ships. There are no IMCO approved traffic separation schemes in the coastal regions off Japan and Korea.

EFFECT OF RESTRICTED VISIBILITY It is not possible to determine the exact proportion of collisions occurring in restricted visibility for all regions as the extent of the visibility is not always indicated in Lloyd's Casualty Reports. Restricted visibility (less than 2 miles) was reported in 505 of the 742 collisions (68%) for which details have been received.

During the 10 year period 1956-1965 over 80% of collisions in the Dover Strait area occurred in restricted visibility, but during the last 10 years this proportion has been reduced to less than 50%.

The proportion of collisions in restricted visibility has been of the order of 60% or more in the coastal regions of N.W. Europe, Japan, N.E. America and in the Gibraltar Strait. Less than 30% of collisions in the Malacca and Singapore Straits have occurred in restricted visibility, due mainly to heavy rainfall.

EFFECT OF DARKNESS The effect of darkness on the incidence of collisions, for which information relating to time and visibility was available, is shown in Table 5. For collisions known to have occurred in clear visibility the number of collisions occurring in darkness is approximately three times the number occurring in daylight. In restricted visibility collisions occur as frequently in daylight as in darkness.

Table 5 Effect of darkness on the incidence of collisions

| | Daylight | Darkness |
|---|---|---|
| Collisions in clear visibility | 60 | 184 |
| Collisions in restricted visibility | 427 | 405 |

In conditions of clear visibility the higher incidence of collisions was found to apply evenly throughout the period of darkness. The incidence during the period of twilight does not appear to be greater than during the period of darkness.

## 2. COLLISIONS OFF NORTH WEST EUROPE

The coastal region of north west Europe between Ushant and the Elbe merits special consideration. During the period 1956-65 over 40% of reported world-wide collisions occurred in this region but during the last 10 years the proportion has reduced to less than 20% of the world total. Traffic separation schemes were first established in this region in 1967-68, and have subsequently been revised and extended. The effect of traffic separation in this area will be investigated.

The coastal region can conveniently be divided into three sections: the English Channel west of the Greenwich Meridian, the Dover Strait and the southern part of the North Sea. The three sections will be considered separately.

THE DOVER STRAIT For the purpose of this investigation the Dover Strait area is considered to extend from latitude 50°15'N to latitude 51°15'N and from the Greenwich meridian to longitude 2° 00'E. A traffic separation scheme now extends entirely through the area so that all navigable water lies within the scheme or the adjacent inshore zones.

Traffic separation was first introduced on a voluntary basis in September 1967. A radar surveillance scheme was brought into operation in July 1972 and has since been extended to cover the full width of the Strait in the narrow section. Compliance with the principles of traffic separation was made compulsory for some ships during the period 1972 to 1977. In July 1977 the new Collision Regulations came into force requiring all ships to comply with the principles of traffic separation.

Voyage data has been obtained for almost all ships involved in collision in this area and in many cases information about courses steered has also been received. Table 6 shows the number of collisions according to the category of encounter situation for five year periods between 1st July 1956 and 30th June 1981. The number of collisions in clear and restricted visibility are also given for each period.

Table 6 Numbers of collisions in the Dover Strait according to encounter situation and visibility, for five year periods.

| Encounter Situation | 1956-61 | 1961-66 | 1966-71 | 1971-76 | 1976-81 |
|---|---|---|---|---|---|
| Opposite directions | 43 | 52 | 25 | 7 | 4 |
| Broad crossing | 0 | 0 | 0 | 0 | 1 |
| Same direction | 7 | 7 | 8 | 6 | 6 |
| Not known | 1 | 2 | 1 | 1 | 0 |
| Totals | 51 | 62 | 34 | 14 | 11 |
| Restricted visibility | 49 | 52 | 26 | 10 | 7 |
| Clear visibility | 2 | 9 | 8 | 4 | 4 |

In recent years the number of collisions between vessels proceeding in opposite directions has been reduced to approximately 10% of the incidence before traffic separation was introduced. There have been no collisions between vessels proceeding in opposite directions within the traffic lanes of this area since 1972. The last 10 collisions between vessels proceeding in opposite directions have occurred within the inshore zones.

Since traffic separation was introduced in 1967 there have been 20 collisions between vessels proceeding in the opposite directions in the inshore zones of the Dover Strait and 18 of these have involved at least one ship which was neither calling at a port or pilot station within the zone nor proceeding to or from a nearby port on the adjacent coast.

Despite the considerable volume of both through and crossing traffic and the relatively high incidence of fog there is no record of any collision involving ships crossing at a broad angle during the 21 years before the 1972 Collision Regulations came into force.

The number of collisions between vessels proceeding in the same direction has remained relatively constant throughout the 25 year period of the survey. The majority of collisions between vessels going in the same direction (22 out of a total of 34) occurred in restricted visibility.

The incidence of collisions in clear visibility in the Dover Strait has also remained relatively constant. The introduction of traffic separation does not appear to have affected the low incidence of collisions between vessels proceeding in opposite directions in conditions of clear visibility.

SOUTHERN NORTH SEA This area is considered to extend from the eastern boundary of the Dover Strait area to the Elbe estuary, and to include the traffic separation schemes and deep water route off the European coast. The region off the east coast of England has been considered separately.

During the first half of the 25 year period of this survey channels swept clear of mines were established as NEMEDRI routes. Centre line buoys provided a form of traffic separation but in periods of restricted visibility vessels tended to move into the wrong side of the channel and there were numerous collisions. The swept channels were relatively narrow causing vessels to overtake at close distances.

Traffic separation schemes were introduced in parts of this coastal region in 1968. There is no radar surveillance of the schemes and no procedure for identifying ships which are contravening Rule 10 of the Collision Regulations.

Table 7 shows the numbers of collisions related to encounter situations for five year periods between mid 1956 and mid 1981. The number of collisions between vessels proceeding in opposite directions has decreased to less than 20% of the incidence before traffic separation was introduced. During the last 5 years there have been 10 collisions between vessels proceeding in opposite directions within the region, but 5 of these occurred in areas well clear of the traffic separation schemes.

Table 7 Numbers of collisions in the southern North Sea according to encounter situation

| | 1956-61 | 1961-66 | 1966-71 | 1971-76 | 1976-81 |
|---|---|---|---|---|---|
| Opposite directions | 56 | 60 | 47 | 12 | 10 |
| Broad crossing | 7 | 6 | 6 | 9 | 4 |
| Same direction | 10 | 10 | 6 | 6 | 4 |
| Not known | 10 | 10 | 7 | 3 | 2 |
| Totals | 83 | 84 | 66 | 30 | 20 |

The number of collisions resulting from broad crossing situations has remained relatively constant. The majority of broad crossing collisions occurred in restricted visibility and involved a small ship.

There has been a decrease in the incidence of collisions between vessels proceeding in the same direction. This was to be expected as the traffic lanes are wider than the swept channels of the NEMEDRI routes.

ENGLISH CHANNEL This area is considered to extend from the western boundary of the Dover Strait area to longitude 7°W and to include the southern approaches to the traffic separation scheme off Ushant.

Traffic separation schemes were established off Ushant and Casquets, and off south west England in 1968 but most of the area is not covered by separation schemes. Extensive changes to the separation schemes off Ushant and Casquets came into force in January 1979.

Table 8 shows the number of collisions according to type of encounter situations for 5 year periods since 1st July 1956. The decrease in the number of collisions between vessels proceeding in opposite directions is less pronounced than in the other coastal regions of north west Europe but in the vicinity of the traffic separation schemes established in 1968 the number decreased from 18 in the period 1956-66 to 6 in the period 1971-81.

There have been very few collisions between vessels in broad crossing situations in this region. The incidence of collisions between vessels proceeding in the same direction is relatively low and there is no apparent trend.

Table 8 Numbers of collisions in the English Channel according to encounter situation

| | 1956-61 | 1961-66 | 1966-71 | 1971-76 | 1976-81 |
|---|---|---|---|---|---|
| Opposite directions | 19 | 27 | 17 | 16 | 11 |
| Broad crossing | 0 | 1 | 1 | 0 | 1 |
| Same direction | 2 | 2 | 4 | 3 | 2 |
| Not known | 1 | 1 | 0 | 1 | 0 |
| Totals | 22 | 31 | 22 | 20 | 14 |

<u>SUMMARY</u> Table 9 shows the totals for 5 year periods for the entire coastal region, and the totals of collisions which have occurred in areas where traffic separation schemes have been established. There has been a considerable reduction in the incidence of collisions between vessels proceeding in opposite directions in restricted visibility through areas where traffic separation schemes have been established. The incidence of collisions involving vessels crossing or proceeding in the same direction within those areas, and of all types of collisions outside those areas has remained relatively constant.

Table 9 Numbers of collisions in the coastal region off North West Europe for five year periods

| Area | 1956-61 | 1961-66 | 1966-71 | 1971-76 | 1976-81 |
|---|---|---|---|---|---|
| Dover Strait | 51 | 62 | 34 | 14 | 11 |
| Southern North Sea | 83 | 84 | 66 | 30 | 20 |
| English Channel | 22 | 31 | 22 | 20 | 14 |
| Totals | 156 | 176 | 122 | 64 | 45 |
| Vicinity of TSS | 128 | 140 | 89 | 34 | 24 |
| Away from TSS | 28 | 36 | 29 | 30 | 21 |

## 3. ANALYSIS OF COLLISION CASES

Information about the circumstances preceding collisions in the open sea or coastal waters has been received for approximately 750 cases. For the years 1968 to 1977 inclusive it has been possible to obtain data relating to at least one ship in 50% or more of known sea collisions. Some initial results of the analysis will be summarised in this section of the report.

Table 10 shows a breakdown of reported collisions with respect to category of encounter situation and condition of visibility. The categories of encounter referred to in the table are defined as follows:

<u>Meeting end-on</u> Each vessel initially subtending less than $5^\circ$ on the bow of the other ship.

<u>Fine crossing</u> Each vessel initially subtending less than $30^\circ$ on the bow from the other ship. One or both subtending more than $5^\circ$.

<u>Broad crossing</u> Each vessel initially subtending less than $112\frac{1}{2}^\circ$ on the bow from the other ship. One or both subtending more than $30^\circ$.

<u>Overtaking</u> One vessel subtending more than $112\frac{1}{2}^\circ$ on the bow from the other ship.

The figures should only be regarded as close approximations, owing to the imprecise nature of the evidence available.

Table 10 Numbers of collisions according to encounter situation and visibility for different regions

| | Meeting end-on | Fine Crossing | Broad Crossing | Overtaking |
|---|---|---|---|---|
| **Clear visibility** | | | | |
| N.W. Europe | 8 | 18 | 23 | 23 |
| Japan | 3 | 24 | 40 | 24 |
| Other areas | 7 | 26 | 21 | 14 |
| **Totals** | 18 | 68 | 84 | 61 |

**Restricted Visibility**

COLLISIONS IN CLEAR VISIBILITY

MEETING END-ON Only 18 cases have been considered to be in this category, less than 3% of the total for which information about the circumstances has been received. For most of these cases the angle on the bow was of the order of 3° to 5° on the bow for one or both ships so that the Crossing Rule would probably have been applicable.

Some of the collisions in this group could be attributed mainly to poor look-out on one or both ships - usually in cases involving small vessels. In a few cases the close presence of a third vessel was a contributory factor. A third cause, in several collisions of this type, was a late starboard turn by one ship in what was initially a starboard to starboard passing situation.

CROSSING SITUATIONS The Crossing Rule would have been applicable in approximately 70% of the collisions which occurred in clear visibility. The predominant cause in almost every case was poor look-out by the watch officer of the give-way ship. In a very high proportion of collisions of this type action was not taken by either ship until very close range.

The Stand-on Rule of the 1972 Regulations, which came into force in July 1977, permits the stand-on vessel to take action at an earlier stage than was permitted under previous regulations.

Information has not been received for sufficient casualties which have occurred since July 1977 to assess the effectiveness of the change but it will be possible to make a comparison at a later date.

Some collisions have occurred as a result of a crossing situation in which a change of course was made on rounding a headland. Traffic separation is believed to have been effective in reducing the incidence of collision of this type.

Although the majority of collisions which occurred in clear visibility have been classed as broad crossings only about 15% (27 collisions) involved vessels crossing with an initial course difference within 30° of a right angle. Collisions between vessels crossing at a very broad angle tend to occur in areas of low traffic density where less vigilance is maintained. Several accidents of this type have occurred in the central Mediterranean and the open oceans. Broad crossing collisions are relatively frequent in Japanese waters, where small vessels are usually involved.

OVERTAKING CASES As in the case of crossing situations the principal cause of collisions between vessels involved in overtaking in clear visibility is poor look-out on one or both ships. At least 8 collisions have resulted from a sudden change of heading by one vessel due to failure of the steering system when overtaking at close distance. Several others involved the close presence of a third vessel or other special circumstances.

## COLLISIONS IN RESTRICTED VISIBILITY

MEETING OR FINE CROSSING SITUATIONS Before the introduction of traffic separation collisions between vessels on nearly opposite courses, each subtending less than 30° on the bow of the other ship, represented over 90% of collision in restricted visibility. Traffic separation is reducing the incidence of this type of collision but there have been numerous instances in recent years, some involving very large ships.

The frequency of meeting or fine crossing collisions in restricted visibility is mainly due to improper use of radar and faulty interpretation of radar data, associated with a relatively high speed of approach. Many collisions of this type featured starboard helm action by one ship and port helm action by the other, usually at a late stage.

The 1972 Regulations have placed more emphasis on starboard helm action but it is too soon to assess the effectiveness of this change. Several meeting/fine crossing collisions in restricted visibility have resulted from starboard helm action by one ship in a starboard to starboard passing situation.

It should be possible to reduce the incidence of this type of collision by introducing further traffic separation schemes, especially off the coast of Japan, and by additional routeing measures - such as those agreed for the English Channel. Some of the existing traffic separation schemes are relatively ineffective.

BROAD CROSSINGS There are relatively few collisions between vessels crossing at a broad angle in restricted visibility. This type of situation can be more readily interpreted from the radar display and the rate of approach is less than for fine crossings.

Most of the reported cases have involved a small vessel and/or a ship without operational radar so that detection was made at a late stage. In each of the 27 cases involving vessels crossing within 30° of a right angle detection was made by one or both vessels at a range of less than 5 miles, and in 25 of the 27 cases one vessel was less than 3000 tons gross.

OVERTAKING CASES Overtaking collisions account for less than 5% of the total occurring in restricted visibility. The annual incidence of this type of collision is less in restricted visibility than in clear visibility.

As in the case of broad crossing situations the majority of cases are associated with a low detection range. Several collisions of this type have occurred as a result of action to avoid a third ship, particularly in the traffic lanes of traffic separation schemes.

CONCLUSIONS

1) The incidence of world-wide collisions in the open sea and coastal waters has remained relatively constant over the last 25 years despite the considerable increase in the number of ships in service.

2) There has been a decrease of over 50% in the incidence of collisions off north west Europe during the second half of the 25 year period whereas the incidence of collisions in the coastal regions of eastern Asia has greatly increased.

3) Before the introduction of traffic separation schemes the proportion of collisions in restricted visibility was about 70% of the total. This proportion is now decreasing. In the Dover Strait the proportion occurring in restricted visibility was over 80% before traffic separation was introduced, it is now less than 50%.

4) In conditions of clear visibility the incidence of collisions in darkness is three times greater than the incidence in daylight.

5) Off the coast of north west Europe collisions between vessels proceeding in opposite, or nearly opposite, directions constituted approximately 80% of the total before traffic separation was introduced. The incidence of this type of collision has been very much reduced in this region and is now almost negligible within the limits of the separation schemes.

6) Traffic separation has not appreciably affected the incidence of collisions between vessels proceeding in the same direction, or crossing at a broad angle, off the coast of north west Europe.

7) The incidence of collisions in clear visibility has not been appreciably affected by the introduction of traffic separation schemes.

8) Almost all collisions which have occurred within the inshore zones of the Dover Strait since traffic separation was introduced have involved at least one ship which was not calling at a port or pilot station within the zone, nor proceeding to or from a nearby port on the adjacent coast.

9) In clear visibility the Crossing Rule would have been applicable in approximately 70% of collisions. The predominant cause of this type of collision is poor look out.

10) Collisions between vessels crossing at a broad angle in clear visibility tend to occur in areas of low traffic density or to involve small vessels.

11) In clear visibility overtaking collisions are usually attributable to poor look out and/or a sudden change of heading when passing at a close distance.

12) In restricted visibility approximately 90% of collisions involve vessels proceeding in opposite or nearly opposite directions. The predominant cause is improper use of radar and faulty interpretation of radar data, associated with a high speed of approach.

13) There are relatively few collisions between vessels crossing at a broad angle in restricted visibility. Such cases usually involve a small vessel and/or vessels without operational radar.

14) Overtaking collisions account for less than 5% of the total occurring in restricted visibility. Collisions of this type are usually associated with low detection range or action to avoid a third ship.

IMO

MODEL TRAINING COURSES

Note by the Secretariat

## Introduction

1 To develop frameworks of model courses in response to recommendations made by the Joint ESCAP/IMO Regional Meeting of Experts in Maritime Training and Certification (Bangkok, April/May 1980), the IMO Secretariat prepared terms of reference for the guidance of consultants contributing to the project.

## Terms of Reference

2 The main points of these terms of reference are set out in the Annex and subject to the advice and comments of the Sub-Committee, will be used as guidance for any further model courses prepared under or associated with IMO technical co-operation projects.

## Material developed to date

3 Model course material for the following has been developed to date:

.1 Certificate as Officer in Charge of a Navigational Watch on ships of 200 GT or more;

.2 Certificate as Engineer Officer in Charge of a Watch in a traditionally manned engine room as a sea-going ship powered by propulsion machinery of 750 kW propulsion power or more;

.3 Model frameworks and teaching syllabuses for safety training for masters, officers and ratings of oil tankers, chemical tankers and liquefied gas tankers.

4 Preliminary drafts of other material have been prepared by IMO consultants on an ad hoc basis in response to project demands.

...

ANNEX

**Terms of Reference**

**on the Development of Detailed Teaching Syllabuses, Frameworks of Model Courses and Specimen Examination Papers based on the 1978 STCW Convention and associated 1978 STW Conference Resolution1/**

rt 1 - Project Development and Co-ordination

1 Parts 2 and 3 of the project dealing with basic courses shall be co-ordinated three project co-ordinators, one for deck department, one for engine partment and one for radio department matters.2/

2 The work is to be distributed by the co-ordinators in such a manner that e institution will take full responsibility for the production of the detailed aching syllabuses, the frameworks of courses and the specimen examinations for complete subject at all basic course levels, and so that the resultant work presents the combined efforts of as many countries as practicable.

3 Drafts of the detailed teaching syllabuses, frameworks of model courses d specimen examinations shall be validated by a small group of experts and O consultants.

rt 2 - Requirements for "Unrestricted Certificates" (Basic Courses)

1 General

1.1 The general objective is to develop detailed syllabuses, frameworks of del courses and specimen examination papers in the English language3/ imarily reflecting:

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Only the Parties to the 1978 STCW Convention may authoritatively pronounce on its meaning and application. The detailed syllabuses, frameworks of model courses and specimen examination questions developed under this technical co-operation project are only to be regarded as an effort to provide and harmonize technical assistance in maritime training.

To be developed in consultation with ITU.

Subsequent to validation of the English versions, all material will be translated into appropriate languages.

.1 the mandatory minimum requirements for the 1978 STCW Convention grades or classes of certificates and authorizations which are valid for voyages which are more extensive than near-coastal voyages and those certificates issued under the Radio Regulations that are required to be held under the provisions of the 1978 STCW Convention or recommended as a minimum requirement by the 1978 STW Conference Resolution 7; and

.2 the minimum requirements for ratings made mandatory by the STCW Convention or recommended by the 1978 STW Conference Resolution 9; and

.3 the mandatory minimum requirements for certificates of proficiency in survival craft.

2.1.2 The complete list of certificates and qualifications concerned is as follows:

Chapter II - Master - Deck Department

Master of ships of 1600 GT or more (unrestricted).

Chief Mate of ships of 1600 GT or more (unrestricted).

Master of ships of 200 - 1600 GT (unrestricted).

Chief Mate c ships of 200 - 1600 GT (unrestricted).

Officer in Charge of a Navigational Watch on ships of 200 GT or more (unrestricted).

Mandatory Minimum Requirements for a Rating forming part of a Navigational Watch.

Chapter III - Engine Department

Chief Engineer Officer of ships powered by main propulsion machinery of 3000 kW or more (unrestricted).

Second Engineer Officer of ships powered by main propulsion machinery of 3000 kW or more (unrestricted).[1]

Engineer Officer in Charge of a Watch on ships powered by main propulsion machinery of 750 kW or more.

Chief Engineer Officer of ships powered by main propulsion machinery between 750 and 3000 kW (unrestricted).

Second Engineer Officer of ships powered by main propulsion machinery between 750 and 3000 kW (unrestricted).

Mandatory Minimum Requirements for a rating forming part of an Engine Room Watch.

Minimum Requirements for a Rating nominated as the Assistant to the Engineer Officer in Charge of the Watch.

## Chapter IV - Radio Department

Radiocommunication Operator's General Certificate for the Maritime Mobile Service including the additional knowledge required by the 1978 STCW Convention

First Class Radio Telgraph Operator's Certificate including the additional knowledge required by the 1978 STCW Convention.

Second Class Radiotelegraph Operator's Certificate including the additional knowledge required by the 1978 STCW Convention.

Radiotelephone Operator's General Certificate including the additional knowledge required by the 1978 STCW Convention.

Restricted Radiotelephone Operator's Certificate including the additional knowledge required by the 1978 STCW Convention.

Radiotelegraph Operator's Special Certificate including the additional knowledge recommended by the STW Conference Resolution 7.[2]

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1/ An authorization to serve as Chief Engineer Officer of ships powered by main propulsion machinery of less than 3000 kW (unrestricted) may be endorsed on the Second Engineer Officer Certificate but no separate course for this is necessary.

2/ Chapter V requirements are being dealt with as specialized courses.

2.1.3 The detailed teaching syllabuses, frameworks of basic model courses and specimen examination papers are intended to provide information on minimum levels for use by technical advisers, consultants and experts implementing technical assistance projects for developing countries in the field of the training and certification of seafarers so that their approach and the minimum standards implemented may be as uniform as possible. The work must not be regarded as an official interpretation of the Convention. The following note is therefore to be inserted immediately below the title of each detailed syllabus, model course framework and specimen examination paper:

> "N.B. Only Parties to the 1978 STCW Convention may authoritatively pronounce on the meaning and application of the Convention and the information contained in this document must be regarded as reflecting only the consensus of opinion of the contributing consultants."

2.1.4 Since levels of development vary from country to country and progressively improve, the entry requirements identified with the course frameworks for 'first' certificates may in some countries necessitate augmentation of the academic knowledge of students who possess the most suitable general education qualifications, by preparatory upgrading courses or by academic enrichment of the technical courses at entry levels.

2.1.5 In other countries the level of development may permit the implementation of a more ambitious training programme which exceeds the basic requirements of the 1978 STCW Convention. In such cases the COMMON CORE CURRICULA reflected in the model courses would be enriched to the extent appropriate by the consultant or expert concerned as part of the technical assistance being provided.

2.2 Detailed Teaching Syllabuses

2.2.1 A detailed teaching syllabus shall be drawn up for each master - deck department and engine department certificate and qualification listed in paragraph 2.1.2, based on the general objectives listed in the 1978 STCW Convention regulation concerned and its appendix, if any, taking into account the permitted variations in the level of knowledge, the relevant resolutions adopted by the 1978 STW Conference and relevant IMO recommendations.

2.2.2 A detailed teaching syllabus shall be drawn up for each radio department certificate listed in paragraph 2.1.2, based on the provisions of the Radio Regulations, the general objectives listed in the 1978 STCW Convention regulation concerned and its appendix, the provisions of the 1974 SOLAS Convention, Chapter IV, the relevant resolutions adopted by the 1978 STW Conference and relevant IMO recommendations. It shall be assumed that the additional knowledge specified in the 1978 STCW Convention and STW Conference Resolution 7 is included in the examination for the Radio Regulations Certificate.

2.2.3 A detailed teaching syllabus shall be drawn up for the certificate of proficiency in survival craft based on the provisions of the 1978 STCW Convention, V/1, the provisions of the 1974 SOLAS Convention, Chapter III, the 1978 STW Conference, Resolution 19 and relevant IMO recommendations.

2.2.4 Each detailed teaching syllabus shall:

.1 be drawn up in an appropriate subject order;

.2 primarily reflect the basic minimum requirements but incorporate where appropriate any supplementary provisions recommended in the related documents as identified above, indicating their recommendatory nature;

.3 clearly identify the source of each subject element incorporated in the syllabus by paranthetic inclusion or marginal notation of appropriate cross references to the paragraph or sub-paragraph of the convention, resolution or recommendation concerned.

2.3 Post-Sea Service Course Frameworks

2.3.1 Each course framework shall be specific to the certificate or requirement concerned and shall:

.1 not assume that any maritime training has been undergone by the course participants other than the minimum training specified for the certificate or qualification concerned;[1/]

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1/ Where options are provided, the option requiring the least formal training is to be assumed.

.2 identify the minimum entry requirements appropriate to the qualification and knowledge requirements of the appropriate regulations and the academic knowledge presupposed in designing the course framework in each subject;1/

.3 primarily reflect in appropriate subject order and sequence only the basic or mandatory requirements;2/

.4 incorporate where appropriate any supplementary provisions recommended in the relevant documents identified in paragraphs 2.2.1 to 2.2.3 in an appropriate sequence but clearly indicate their recommendatory nature;

.5 clearly identify the source of each subject element incorporated in the course by parenthetic inclusion or marginal notation of appropriate cross-references to the paragraph or sub-paragraph of the Convention, its annex or resolution adopted by the 1978 STW Conference or by IMO;

.6 indicate the amount of lecture and laboratory time allotted each main subject element;

.7 identify the personnel, accommodation, laboratory, teaching aid, equipment, consumables and other resource inputs that are:

- essential, and
- desirable;3/

.8 indicate the order of priority of those resource inputs identified as being desirable;

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Since no uniform academic structure exists, the presupposed academic knowledge must be specifically identified.

This involves judgement of the minimal reasonable interpretation of the convention requirements bearing in mind the needs and difficulties experienced by developing countries as well as the needs of safety. Where possible the course outline should be provided in learning objective format. Appropriate explanatory material drawn from a number of sources can be made available.

An intake of 20-25 students is to be assumed for resource input estimates. Appropriate guidance should be provided re: scaling up.

.9 be supported by appropriate performance specifications[1] and approximate costs in US dollars for the specific teaching aids and equipment and indicating the estimate year;

.10 be supported by layout plans or diagrams where necessary;

.11 indicate any applicable course loading or teacher/student ratio limitation;

.12 indicate siting or location requirements, limitations or considerations where requisite and any support or outside services necessary;

.13 indicate the number of teaching staff required and their minimum academic and professional qualifications, industrial experience and pedagogical training which are appropriate to the level of the course;

.14 utilize when possible course modules that are common to more than one department and level of certificate, the commonality of such modules being identified.

2.4 Specimen Examination Questions

2.4.1 Two separate sets of specimen examination questions shall be drawn up in the selected subject order (see paragraph 2.3.1.3) for each subject for which a written examination is appropriate, one illustrating the use of traditional (subjective) type questions and the other illustrating the use of objective (preferably multiple choice) type questions.

2.4.2 The advantages and disadvantages of the two examination techniques and the effect this may have on training are to be briefly summarized to assist officials in maritime training administrations to choose whichever examination system or mix of systems is best suited to their needs

Part 3 - Detailed syllabuses and frameworks of courses regarded as equivalent to sea-going service (Approved education and training, pre-sea or sandwich type courses, etc.

3.1 In addition to the basic material specified in Part 2, detailed syllabuses, model course frameworks and specimen examination questions shall be drawn up for the deck, marine engineering and radio disciplines so as to

1/ Reference should be made to applicable IMO operating requirements and performance specifications.

vide a broader based career oriented maritime education primarily for new rants to the industry.[1]

In the case of officer trainees, the above material shall be drawn up the basis of a career pattern that allows the trainees to obtain the highest ropriate certificate in their discipline in the shortest permitted time ing full advantage of examination exemption and similar provisions. The ic provisions shall be enriched to the extent necessary to provide a sound cational basis for easy assimilation of all specialized training identified the 1978 STCW Convention, the associated Conference resolutions and IMO ommendations (see Part 4 for a sample list of specialized courses).

In the case of rating trainees the detailed syllabuses, model course meworks and specimen examination questions should be sufficiently comprehensive to provide a sound basis for both safety and career purposes and for such sequent training as may be required to fill key rating positions.

Except as provided in paragraphs 3.2 and 3.3, the frameworks of these el courses shall take full account of the provisions of Part 2.

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Experienced seafarers may in some circumstances enter such courses.

## Part 4 - List of Model Specialized Courses for Selective Offering

| Subject | Participants | Course Level | Priority | Remarks |
|---|---|---|---|---|
| Dangerous and Hazardous Cargoes (Other than Special Requirements, oil, chemical and liquefied gas tankers) | Officers and Key Ratings | Advanced | 2 | STW Conference Resolution 13 Assembly resolutions A.537(13) (and A.437(XI)) |
| Bridge Team Training and Passage Planning | Masters and Senior Deck Officers | Advanced | 2 | STCW Regulation II/1, 6(a) (STW Conference Resolutions 17, 18 and 20) |
| Specialized oil, chemical and liquefied gas tanker courses | Officers and Ratings | Familiarization | 1 | STCW Convention Chapter V Resolutions 10, 11 and 12 (Resolution 16) (Assembly resolutions A.286(VIII) and A.437(XI)) |
| | Masters, Senior Officers and Key Personnel | Specialized Training Programme (Advanced) | 1 | |
| Human Relationships | Supervisor Personnel | Advanced | 3 | STW Conference Resolution 22 |
| Shiphandling Simulator | Masters and Senior Deck Officers | Advanced | 2 | STW Conference Resolution 17 |
| Radar Simulator Training | Masters and Deck Officers | Advanced | 1 | STW Conference Resolutions 1 and 18 (Assembly resolution A.483(XII) |
| Automatic Radar Plotting Aids (ARPA) | Masters and All Deck Officers in Ships fitted with ARPA | Practical Use and Limitations (Advanced) | 1 | STW Conference Resolution 20 (Assembly resolution A.482(XII) Use of simulator included |

| Subject | Participants | Course Level | Priority | Remarks |
|---|---|---|---|---|
| Radio/Electronic Equipment Maintenance | Primarily Radio Officers | Supplementary or Updating (Advanced) | 2 | STW Conference Resolution 14, Part II. Course may include use of simulator |
| Medical Care | Persons in charge of Medical Care Aboard Ships on Certain Voyages | Advanced | 2 | IMO resolution A.438(XI) |
| Electronics | Engineer Officers and Electrical Officers | Advanced | 1 | Course may include use of simulator |
| Control Engineering and Automation | Senior Engineer Officers | Advanced | 1 | Course may include use of simulator |
| Fuel Combustion and Plant Efficiency | Senior Engineer Officers | Advanced | 2 | |
| Planned Maintenance for Machinery Installations | Senior Engineer Officers | Advanced | 2 | |
| Engineering Department Financial, Technical and Personnel Management | Senior Engineer Officers | Advanced | 2 | |

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Appendix 3

ARPA

# NEWSLETTER

## No.7 March 1984

**International**

**Maritime**

**Lecturers**

**Association**

## Practical Use of an ARPA

In this paper I will try to give an impression of the practical use of an ARPA as it is usually applied on board ships and hydrofoils (jetfoils) today.

My experience of the practical use of ARPA's dates from the early sixties, when the first prototype of ARPA, the "Philips El-plot" was experimentally installed on board some Dutch ships.
This experience was among other things gained on board ships and hydrofoils from constantly observing the proceedings on different makes of ARPA's. Further I may add my experience gained in the use of a Raytheon ARPA "Raycas" linked up with the radar simulator of the Amsterdam Nautical College. Further I sailed on the training vessel "Prinses Margriet" equipped with the Racal-Decca ARPA.

Particular attention was paid to utilizing and testing what was possible and impossible on ARPA:

1. The interpretation of the vectors of targets which were only recently acquired.
2. The interpretation of the "Target Window".
3. The use of the "Trial Manoeuvre".
4. The false safety feeling when using "Guard Zones" for automatic acquisition.
5. Judging "Target Trails" (equally time-spaced history spots).
6. Realising what log the ARPA is linked to.
7. Using the various "Navigation Lines" and "Navigation Marks".
8. The false safety feeling when using the "Potential Collision Points (PCP's)" of the Raytheon Raycas.
9. Using the "Sytem Clear" on the Raytheon Raycas.
10. Having a reflex plotter at one's disposal on the ARPA display.
11. The incompleteness of ARPA manuals.

### sub 1. The interpretation of the vectors of targets which were only recently acquired.

There are ARPA's which after the acquisition of a target only show the relevant vector when it has been found to be reliable by the microprocessor. Or in any case show a figure round the target to show the more or less reliability of the vector shown.
In the Raytheon Raycas the calculation of the ARPA is as it were shown by the development of the vector from zero to a reliable vector. By expressing the vector into readable digits it can be checked whether the vector has become stable.
With this method the user should be careful not to draw premature conclusions on the basis of too early shown vectors.

### sub 2. The interpretation of the "Target Window".

After the acquisition some systems do not show the "Target Window" or only show it after typing-in the relative code figure.

I am convinced that this search window should be visible at all times, for only then does the user know that the target is accepted by the microprocessor. If in the case of Raycas the aforementioned code figure is not used and consequently the window is not shown, then after the acquisition of targets of, say a fishing fleet when the windows, if visible, would overlap each other, these targets are not accepted by the microprocessor and therefore never get a vector either! They would not even activate the signal of a lost target!
Moreover if the windows of various acquired targets are shown on the same bearing, the process of time sharing would also be clearly visible, through which it is understandable that the result of eventually reliable vectors will be slow in coming.

sub 3. The use of the "Trial Manoeuvre".

It is a good system when in the case of the "Trial Manoeuvre" mode one automatically proceeds from the present heading and speed. However, in the trial mode many systems still show the previous "Trial Course" and "Trial Speed". And in most cases the safe distances to surrounding ships are found with the "Trial Course", but the "Trial Speed" is not on the present right speed. Already many times these manipulations have led to dangerous close-quarters situations.

There are systems with a dynamic vector presentation in the "Trial Manoeuvre", in which the vectors leave the present positions of the targets to show thus, say ten to thirty times as quickly as in reality the relative or true future movements of the echoes on the radar screen. The advantage of this system is that the manoeuvring characteristics of the own ship are more or less included in the "Trial Manoeuvre". This is of course splendid provided the user knows what the starting points of the programmed manoeuvring characteristics are. Such as: for what rudder angle or rate of turn has a trial course-change been programmed or, say a stopping manoeuvre?
A disadvantage may be that because in the "Trial Manoeuvre" the vectors on the radar screen leave the echoes, it may sometimes be difficult to check what vector proceeds from what echo. Especially if many echoes are plotted.
It may also happen that in the "Trial Manoeuvre" new echoes are added which are not immediately noticed as such.

Other systems have a static vector presentation in the "Trial Manoeuvre" in which the vectors remain in the present position of the targets on the radar screen to immediately show the result of the "Trial Manoeuvre" as if the own ship is already at once heading on the simulated course or immediately running the simulated speed. In this case the effective result of a trial manoeuvre can only be checked correctly when the relative vectors are used.
In view of the delay in the movements of the own ship the user himself should then determine a safety margin as to the future shortest approach and this again in connection with the safe distance.

Moreover it should be noticed that the "Trial Manoeuvre" possibility has found very little application on board. One simply changes course and/or

speed and then looks for the result as to the safe distance at the relative vectors.
Corrections are subsequently made then by means of course and/or speed changes to obtain the safe distance as yet.

sub 4. The false safety feeling when using "Guard Zones" for automatic acquisition.

In contrast to the earlier system of Iotron with the Digiplot the system with "Guard Zones" may be called semi-automatic. And in this semi-automatic system a target must cut these "Guard Zones" before it is automatically presented to the microprocessor for calculation and then gives a signal of "Target in Guard Zone".
If a target comes within radar view between the "Guard Zones", it may be a considerable time before the signal "Target in Guard Zone" can be heard and the target is acquired. Meanwhile the object may have arrived at too short a distance.
In some cases when the echo is too weak or comes within radar view within the innermost "Guard Zone", the target is not acquired at all and not any warning signal is heard.
Racal-Decca gives very justly the following warning in its ARPA manual:

"The (semi-)automatic detection and acquisition facility must always be considered as an aid but never as a substitute for proper watchkeeping".

Even the fully automatic target acquisition of the earlier system of Iotron is not infallible. Especially not in the case of weak echoes which are not at all "automatically acquired" and therefore do not give an alarm. Consequently the following statement in the Digiplot manual should be read with great reserve:

"Fully automatic target acquisition provides unattended radar watch-keeping on both open sea and in restricted waters.........".

sub 5. Judging "Target Trails" (equally time-spaced history spots).

With these history spots one should realize that the distance and the direction between the first two dots (the two last shown dots after the target echo) in the beginning of the tracking do not give reliable indications about the movement of the echo. As was already described sub 1, the vector is still unreliable in the beginning of the tracking and consequently the distance and the direction between the first two dots shown after the acquisition are not correct.

sub 6. Realising what log the ARPA is linked to.

The important speed information of the own ship can be introduced into some ARPA microprocessors by means of:

a. Manual adjustment of the speed in the direction of the heading (single axis stabilised).

This introduction of the dead reckoning speed through the water is applied if there is no other possibility. However, if this dead reckoning speed through the water is practically correct, the practically correct true vectors through the water are also obtained and therefore they can serve for anti-collision.

b. A log showing the speed through the water in the direction of the heading (single axis water stabilised, for example a pitot log or an electromagnetic log).
This method also gives the practically correct true vectors through the water and is therefore correct for anti-collision.
"Practically correct true vectors": because when course is altered with a large rate of turn, the vectors become unreliable during the process of turning. This because the athwartships component is not recorded by the above logs.

c. An electromagnetic log or doppler log showing the speed in the heading and athwartships direction through the water (double axes water stabilised).
This method would, if the radar is suitable for this, be very good for anti-collision.

d. A doppler log showing the speed in the heading course over the ground (single axis ground stabilised).
This method should in any case be discouraged both for anti-collision and for radar navigation!

e. A doppler log showing the speed in the heading course and in the athwartships direction over the ground (double axes ground stabilised).
This method gives true vectors over the ground and is therefore correct for radar navigation, but is no good for anti-collision!

f. A geographic "fixed target" (double axes ground stabilised, with the "Echo Reference" of Racal-Decca and with the "Autodrift" of Raycas).
This system also shows the true movements over the ground and is as such very good for radar navigation, but again unsuitable for anti-collision!

<u>sub 7. Using the various "Navigation Lines" and "Navigation Marks".</u>

Very often there is a possibility to make electronic dots and/or lines visible on the ARPA display. For example the "Nav. Lines" of the Digiplot of Iotron, the "Nav. Lines" and "True Marks" of the Raycas of Raytheon and in the case of the Racal-Decca ARPA the so-called "Elements" ("Straight Lines" and/or "Dots").

The user should be thoroughly aware of:

a. What lines are suitable for the Parallel Index method (PI method) and
b. what lines and dots are suitable for the True Tracking method (TT method).

<u>Lines suitable for the PI method</u> should be "fixed" with regard to the own ship. As it were sail with the own ship. Thus the "Nav. Lines" of the

Digiplot are exclusively suitable for PI.
The "Nav. Lines" of Raycas and the "Straight Lines" of Racal-Decca are unsuitable for PI, as these lines are fixed with regard to the water.
All lines of the Raycas and Racal-Decca ARPA are therefore unsuitable for PI and also the "EBL-free" of the two makes, but also the "Acquisition Exclusion Lines" of Raycas (if not in the 42 mode).
The "Acquisition Exclusion Lines" (two) of Raycas are in the 42 mode, though not intended as such, suitable for PI, as these are "fixed" in the 42 mode with regard to the own ship.

Lines and dots suitable for the TT method should be geographically "fixed" with regard to the ground. The "Nav. Lines" and the "True Marks" of Raycas and the "Straight Lines" and "Dots" of Racal-Decca can be ground stabilised. In the case of Raycas by means of the resulting input of a dual axes ground stabilised doppler log or with "Autodrift" on a geographically "fixed" and suitable object on the radar (buoy, vessel riding at anchor, an isolated tower or a very small island etc.).
In this way the "Straight Lines" and "Dots" of Racal-Decca can be ground stabilised by means of the "Echo Reference" on a geographically "fixed" and suitable object on the radar.

In the standard type of the Racal-Decca ARPA the straight lines and dots can be shifted by means of the "X-Y shifts", so that the position of the true tracks (straight lines) and the conspicuous points such as capes, buoys and lightvessels (dots) in a fairway can be previously prepared on the radar display.
Once arrived in that fairway, they can, simply by means of the "X-Y shifts", be made to cover the corresponding conspicuous radar points after the "Echo Reference" has been applied.

On the standard type of the Raycas an "X-Y shift" of the "Nav. Lines" and "True Marks" is impossible. Consequently the planned tracks should be prepared on the spot by means of these "Nav. Lines" and "True Marks" and at the same time one should be carefully on one's guard that the used "Nav. Lines" and "True Marks" are not geographically replaced on the radar screen meanwhile, in consequence of possible current and/or wind drift. Therefore one should first find a conspicuous point for the "Autodrift" and then construct the planned tracks on the radar screen by means of the "Nav. Lines" and "True Marks". However, if for some reason the autodrift object should become a lost target, the "Nav. Lines" and "True Marks" may drift with regard to the ground (current and/or wind drift) and should then again be introduced one by one.
All this is time-consuming and is consequently not applied on board.
In the case of Raycas one is for the PI method dependent on the two "Acquisition Exclusion Lines" in the 42 mode ("fixed" with regard to the own ship).

sub 8. The false safety feeling when using the "Potential Collision Points (PCP's)" of the Raytheon Raycas.

The PCP facility provides the user with a visual indication on what courses a collision might take place. Assuming that the target retains its present course and speed and that the own ship also maintains its

speed.
This last remark is very important. The position of the PCP is greatly dependent on the log input of the own ship and the time-lag of the microprocessor system.
An ample margin of safety should therefore be taken round this PCP, which is difficult to determine by the user by showing the PCP only. One of the first ARPA assisted collision affords a good example:

"On August 14th 1981 at 07.52 a jetfoil equipped with a conventional radar and an ARPA connected to an electromagnetic log was on its way from Ostend to Dover.
And while crossing at right angles the traffic separation scheme of the Dover Strait, collided in a position 2.5 miles east-south-east of the MPC buoy with a cargo ship in the north-east lane of the above-mentioned scheme on its way to Rotterdam.
The jetfoil entered a fogbank 2 minutes prior to the casualty.
The jetfoil is normally travelling at a speed of about 42 knots. This speed can be reduced to 35 knots leaving the craft's hull lifted out of the water. If the speed is reduced under this norm the jetfoil drops down and becomes water-borne, enabling it to proceed at only 8 knots.
The cargo ship, automatically plotted, was showing a north-east true vector (through the water).
At 07.50 course was altered from 270° to 310° in order to cross the TSS at right angles. The jetfoil was still "on foils" .
The ARPA plot gave a PCP information of the cargo ship just free to starboard. The echo of the cargo ship being just fine to port of the course line.
When finally the echo of the cargo ship remained ahead instead of shifting to starboard (according tot the PCP), at close range a hard port rudder was executed in an attempt to pass astern.
Unfortunately this occurred a few seconds too late".

From the foregoing report it appears that the use of a PCP only is dangerous. Even if the momentary position of the PCP should be accurate, it does not give the user any information about the shortest approach with regard to the safe distance.
In this case the PAD system of Sperry is better. If the navigator stays outside a PAD, he is sure that he stays outside the safe distance chosen by him.
To this PAD a certain safety factor has been applied by Sperry to keep the target absolutely outside the preset safe distance in spite of any inaccuracies of the system.

sub 9. Using the "System Clear" on the Raytheon Raycas.

"System Clear" resets the Raycas V to the initial turn on state, i.e. all ongoing target information and processing is cancelled.
However, there may be the danger that together with "System Clear" the log input is automatically changed into "Manual Log".
If the "Manual Log" was not set at the present speed, the plotted targets get wrong true vectors and a wrong impression about the surrounding ships is obtained and moreover a wrong "Trial Manoeuvre". This may contribute to a decision for a dangerous manoeuvre.

## sub 10. Reflex Plotter on the ARPA display?

It is well-known that ARPA systems experience difficulties with "clutter" in general and "sea-clutter" in particular.
As soon as targets get into seaclutter the vectors belonging to them are influenced by this seaclutter and the vectors become unreliable or even leave the targets at great speeds.
Very often the target echo can still be distinguished from the radar screen with the eye and a manual plot could offer a solution for this circumstance.
For this purpose a reflex plotter on the ARPA display could be necessary. The reaction to this is of course that the reflex plotter on the nearest conventional radar will serve the purpose. But in practice this is hardly ever done. One prefers trying to get the target echo into the processor again for one wants to keep informed of the targets with the correct vectors outside the seaclutter. Therefore it would be recommendable to have a reflex plotter on the ARPA display for this purpose alone.
However, such a reflex plotter is hostile to "daylight display", it removes a large percentage of the light intensity and provides additional annoying reflections.
However, first things should come first!

## sub 11. The incompleteness of the ARPA manuals.

The completeness of the ARPA manuals occasionally leaves much to be desired. When a certain ARPA-make is purchased this may lead to disappointments when demonstrations are made and the (incomplete) manuals are perused again.

Examples of the omissions are:

a. Not mentioning the maximum rate of turn when automatic tracking is still reliable.

b. Can the "Nav. Lines" be used for the PI method or for the TT method?

c. No mention is made that a ground stabilised display is right for radar navigation, but is no good for anti-collision.

d. Further omissions are closely related to what was discussed sub 1 up to and including sub 10.

## General

Although on the one hand the user is warned of dangers which may occur by implicitly relying on an ARPA, it should be noted that on the other hand the manufacturer adds "novel features" which often give the user a false appearance of accuracy and safety.
Moreover too many ARPA proceedings can still be done wrongly by the user, which may give rise to the risk of collision and/or stranding.
It is true that the ARPA user should be trained in everything that is possible and impossible for ARPA, but many wrong ARPA proceedings should be made impossible by the maker!

Hans Klerk.

# PERFORMANCE STANDARDS FOR NAVIGATIONAL EQUIPMENT

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Appendix 4

## PERFORMANCE STANDARDS FOR NAVIGATIONAL RADAR EQUIPMENT

(Installed before 1.9.1984)

### 1 INTRODUCTION

1.1 The radar equipment should provide an indication, in relation to the ship of the position of other surface craft and obstructions and of buoys, shorelines and navigational marks in a manner which will assist in avoiding collision and in navigation.

1.2 In addition to the general requirements contained in Chapter 1.1 of this publication, the radar equipment should comply with the following minimum performance requirements.

### 2 RANGE PERFORMANCE

2.1 The operational requirement under normal propagation conditions, when the radar aerial is mounted at a height of 15 metres above sea level, is that the equipment should give a clear indication of:

2.2 Coastlines

At 20 nautical miles when the ground rises to 60 metres.

At 7 nautical miles when the ground rises to 6 metres.

2.3 Surface objects

At 7 nautical miles a ship of 5,000 tons gross tonnage, whatever her aspect

At 3 nautical miles a small ship of length 10 metres.

At 2 nautical miles an object such as a navigational buoy having an effective echoing area of approximately 10 square metres.

### 3 MINIMUM RANGE

The surface objects specified in paragraph 2.2 should be clearly displayed from a minimum range of 50 metres up to a range of one nautical mile, without adjustment of controls other than the range selector.

### 4 DISPLAY

4.1 The equipment should provide a relative plan display of not less than 180 mm effective diameter.

4.2 The equipment should be provided with at least five ranges, the smallest of which is not more than 1 nautical mile and the greatest of which is not less than 24 nautical miles. The scales should be preferably of 1 : 2 ratio. Additional ranges may be provided.

4.3 Positive indication should be given of the range of view displayed and the interval between range rings.

## 5 RANGE MEASUREMENT

5.1 The primary means provided for range measurement should be fixed electronic range rings. There should be at least 4 range rings displayed on each of the ranges mentioned in paragraph 4.2, except that on ranges below 1 nautical mile range rings should be displayed at intervals of ¼ nautical mile.

5.2 Fixed range rings should enable the range of an object, whose echo lies on a range ring, to be measured with an error not exceeding 1.5 per cent of the maximum range of the scale in use, or 70 metres, whichever is the greater.

5.3 Any additional means of measuring range should have an error not exceeding 2.5 per cent of the maximum range of the displayed scale in use, or 120 metres, whichever is the greater.

## 6 HEADING INDICATOR

6.1 The heading of the ship should be indicated by a line on the display with a maximum error not greater than $\pm 1^\circ$. The thickness of the display heading line should not be greater than $½^\circ$.

6.2 Provision should be made to switch off the heading indicator by a device which cannot be left in the "heading marker off" position.

## 7 BEARING MEASUREMENT

7.1 Provision should be made to obtain quickly the bearing of any object whose echo appears on the display.

7.2 The means provided for obtaining bearings should enable the bearing of a target whose echo appears at the edge of the display to be measured with an accuracy of $\pm 1^\circ$ or better.

## 8 DISCRIMINATION

8.1 The equipment should display as separate indications, on the shortest range scale provided, two objects on the same azimuth separated by not more than 50 metres in range.

8.2 The equipment should display as separate indications two objects at the same range separated by not more than $2.5^\circ$ in azimuth.

8.3 The equipment should be designed to avoid, as far as is practicable, the display of spurious echoes.

## 9 ROLL

The performance of the equipment should be such that when the ship is rolling $\pm 10^\circ$ the echoes of targets remain visible on the display.

## 10 SCAN

The scan should be continuous and automatic through $360^\circ$ of azimuth. The target data rate should be at least 12 per minute. The equipment should operate satisfactorily in relative wind speeds of up to 100 knots.

## 11 AZIMUTH STABILIZATION

11.1 Means should be provided to enable the display to be stabilized in azimuth by a transmitting compass. The accuracy of alignment with the compass transmission should be within $½^\circ$ with a compass rotation rate of 2 r.p.m.

11.2 The equipment should operate satisfactorily for relative bearings when the compass control is inoperative or not fitted.

## 12 PERFORMANCE CHECK

Means should be available, while the equipment is used operationally, to determine readily a significant drop in performance relative to a calibration standard established at the time of installation.

## 13 ANTI-CLUTTER DEVICES

Means should be provided to minimize the display of unwanted responses from precipitation and the sea.

## 14 OPERATION

14.1 The equipment should be capable of being switched on and operated from the main display position.

14.2 After switching on from cold, the equipment should become fully operational within 4 minutes.

14.3 A standby condition should be provided from which the equipment can be brought to a fully operational condition within one minute.

## 15 INTERFERENCE

After installation and adjustment on board, the bearing accuracy should be maintained without further adjustment irrespective of the variation of external magnetic fields.

## 16 SEA OR GROUND STABILIZATION

Sea or ground stabilization, if provided, should not degrade the accuracy of the display below the requirements of these performance standards and the view ahead on the display should not be unduly restricted by the use of this facility.

## 17 SITING OF THE AERIAL

The aerial system should be installed in such a manner that the efficiency of the display is not impaired by the close proximity of the aerial to other objects. In particular, blind sectors in the forward direction should be avoided.

# PERFORMANCE STANDARDS FOR NAVIGATIONAL RADAR EQUIPMENT

(Installed on or after 1.9.1984)

## 1 INTRODUCTION

In addition to the general requirements contained in Chapter 1.1 of this publication, the radar equipment should comply with the following minimum performance requirements.

## 2 APPLICATION

2.1 These performance standards apply to all ships' radar equipment installed on or after 1 September 1984.

2.2 Radar equipment installed before 1 September 1984 should comply at least with the performance standards given in the first part of this Chapter.

## 3 GENERAL

The radar equipment should provide an indication, in relation to the ship of the position of other surface craft and obstructions and of buoys, shorelines and navigational marks in a manner which will assist in navigation and in avoiding

## 4 RANGE PERFORMANCE

The operational requirement under normal propagation conditions, when the radar antenna is mounted at a height of 15 metres above sea level, is that the equipment should in the absence of clutter give a clear indication of:

4.1 **Coastlines**

At 20 nautical miles when the ground rises to 60 metres.

At 7 nautical miles when the ground rises to 6 metres.

4.2 **Surface objects**

At 7 nautical miles a ship of 5,000 tons gross tonnage, whatever her aspect.

At 3 nautical miles a small ship of 10 metres in length.

At 2 nautical miles an object such as a navigational buoy having an effective echoing area of approximately 10 square metres.

## 5 MINIMUM RANGE

The surface objects specified in paragraph 4.2 should be clearly displayed from a minimum range of 50 metres up to a range of one nautical mile, without changing the setting of controls other than the range selector.

## 6 DISPLAY

6.1 The equipment should without external magnification provide a relative plan display in the head-up unstabilized mode with an effective diameter of not less than:

.1 180 millimetres* on ships of 500 tons gross tonnage and more but less than 1,600 tons gross tonnage;

.2 250 millimetres* on ships of 1,600 tons gross tonnage and more but less than 10,000 tons gross tonnage.

.3 340 millimetres* in the case of one display and 250 millimetres in the case of the other on ships of 10,000 tons gross tonnage and upwards

6.2 The equipment should provide one of the two following sets of range scales of display:

.1 1.5, 3, 6, 12 and 24 nautical miles and one range scale of not less than 0.5 and not greater than 0.8 nautical miles, or

.2 1, 2, 4, 8, 16 and 32 nautical miles.

6.3 Additional range scales may be provided.

6.4 The range scale displayed and the distance between range rings should be clearly indicated at all times.

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## 7 RANGE MEASUREMENT

7.1 Fixed electronic range rings should be provided for range measurements as follows:

.1 where range scales are provided in accordance with paragraph 6.2.1, on the range scale of between 0.5 and 0.8 nautical miles at least two range rings should be provided and on each of the other range scales six range rings should be provided, or

.2 where range scales are provided in accordance with paragraph 6.2.2 four range rings should be provided on each of the range scales.

7.2 A variable electronic range marker should be provided with a numeric readout of range.

7.3 The fixed range rings and the variable range marker should enable the range of an object to be measured with an error not exceeding 1.5 per cent of the maximum range of the scale in use, or 70 metres, whichever is the greater.

7.4 It should be possible to vary the brilliance of the fixed range rings and the variable range marker and to remove them completely from the display.

## 8 HEADING INDICATOR

8.1 The heading of the ship should be indicated by a line on the display with a maximum error not greater than plus or minus 1 degree. The thickness of the displayed heading line should not be greater than 0.5 degrees.

8.2 Provision should be made to switch off the heading indicator by a device which cannot be left in the "heading marker off" position.

## 9 BEARING MEASUREMENT

9.1 Provision should be made to obtain quickly the bearing of any object whose echo appears on the display.

9.2 The means provided for obtaining bearing should enable the bearing of a target whose echo appears at the edge of the display to be measured with an accuracy of plus or minus 1 degree or better.

## 10 DISCRIMINATION

10.1 The equipment should be capable of displaying as separate indications on a range scale of 2 nautical miles or less, two small similar targets at a range of between 50 per cent and 100 per cent of the range scale in use, and on the same azimuth, separated by not more than 50 metres in range.

10.2 The equipment should be capable of displaying as separate indications two small similar targets both situated at the same range between 50 per cent and 100 per cent of the 1.5 or 2 mile range scales, and separated by not more than 2.5 degrees in azimuth.

## 11 ROLL OR PITCH

The performance of the equipment should be such that when the ship is rolling or pitching up to plus or minus 10 degrees the range performance requirements of paragraphs 4 and 5 continue to be met.

## 12 SCAN

The scan should be clockwise, continuous and automatic through 360 degrees of azimuth. The scan rate should be not less than 12 revolutions per minute. The equipment should operate satisfactorily in relative wind speeds of up to 100 knots.

## 13 AZIMUTH STABILIZATION

13.1 Means should be provided to enable the display to be stabilized in azimuth by a transmitting compass. The equipment should be provided with a compass input to enable it to be stabilized in azimuth. The accuracy of alignment with the compass transmission should be within 0.5 degrees with a compass rotation rate of 2 revolutions per minute.

13.2 The equipment should operate satisfactorily in the unstabilized mode when the compass control is inoperative.

## 14 PERFORMANCE CHECK

Means should be available, while the equipment is used operationally, to determine readily a significant drop in performance relative to a calibration standard established at the time of installation, and that the equipment is correctly tuned in the absence of targets.

## 15 ANTI-CLUTTER DEVICES

Suitable means should be provided for the suppression of unwanted echoes from sea clutter, rain and other forms of precipitation, clouds and sandstorms. It should be possible to adjust manually and continuously the anti-clutter controls. Anti-clutter controls should be inoperative in the fully anti-clockwise positions. In addition, automatic anti-clutter controls may be provided, however, they must be capable of being switched off.

## 16 OPERATION

16.1 The equipment should be capable of being switched on and operated from the display position.

16.2 Operational controls should be accessible and easy to identify and use. Where symbols are used they should comply with the recommendations of the Organization on symbols for controls on marine navigational radar equipment.

16.3 After switching on from cold the equipment should become fully operational within 4 minutes.

16.4 A standby condition should be provided from which the equipment can be brought to an operational condition within 15 seconds.

## 17 INTERFERENCE

After installation and adjustment on board, the bearing accuracy as prescribed in these performance standards should be maintained without further adjustment irrespective of the movement of the ship in the earth's magnetic field.

## 18 SEA OR GROUND STABILIZATION (TRUE MOTION DISPLAY)

18.1 Where sea or ground stabilization is provided the accuracy and discrimination of the display should be at least equivalent to that required by these performance standards.

18.2 The motion of the trace origin should not, except under manual override conditions, continue to a point beyond 75 per cent of the radius of the display. Automatic resetting may be provided.

## 19 ANTENNA SYSTEM

The antenna system should be installed in such a manner that the design efficiency of the radar system is not substantially impaired

## 20 OPERATION WITH RADAR BEACONS

20.1 All radars operating in the 3 centimetres band should be capable of operating in a horizontally polarized mode.

20.2 It should be possible to switch off those signal processing facilities which might prevent a radar beacon from being shown on the radar display.

## 21 MULTIPLE RADAR INSTALLATIONS

21.1 Where two radars are required to be carried they should be so installed that each radar can be operated individually and both can be operated simultaneously without being dependent upon one another. When an emergency source of electrical power is provided in accordance with the appropriate requirements of Chapter II-1 of the 1974 SOLAS Convention, both radars should be capable of being operated from this source.

21.2 Where two radars are fitted, interswitching facilities may be provided to improve the flexibility and availability of the overall radar installation. They should be so installed that failure of either radar would not cause the supply of electrical energy to the other radar to be interrupted or adversely affected.

# PERFORMANCE STANDARDS

# FOR

# NAVIGATIONAL EQUIPMENT

LONDON 1982

## 1 INTRODUCTION

1.1 Automatic radar plotting aids (ARPA) should, in order to improve the standard of collision avoidance at sea:

.1 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;

.2 provide continuous, accurate and rapid situation evaluation.

1.2 In addition to the general requirements contained in Chapter 1.1 of this publication, ARPA should comply with the following minimum performance standards.

## 2 DEFINITIONS

2.1 Definitions of terms used in these performance standards are given in Annex 1.

## 3 PERFORMANCE STANDARDS

### 3.1 Detection

3.1.1 Where a separate facility is provided for detection of targets, other than by the radar observer, it should have a performance not inferior to that which could be obtained by the use of the radar display.

### 3.2 Acquisition

3.2.1 Target acquisition may be manual or automatic. However, there should always be a facility to provide for manual acquisition and cancellation: ARPA with automatic acquisition should have a facility to suppress acquisition in certain areas. On any range scale where acquisition is suppressed over a certain area, the area of acquisition should be indicated on the display.

3.2.2 Automatic or manual acquisition should have a performance not inferior to that which could be obtained by the user of the radar display.

### 3.3 Tracking

3.3.1 The ARPA should be able to automatically track, process, simultaneously display and continuously update the information on at least:

.1 20 targets, if automatic acquisition is provided, whether automatically or manually acquired;

.2 10 targets, if only manual acquisition is provided.

3.3.2 If automatic acquisition is provided, description of the criteria of selection of targets for tracking should be provided to the user. If the ARPA does not track all targets visible on the display, targets which are being tracked should be clearly indicated on the display. The reliability of tracking should not be less than that obtainable using manual recordings of successive target positions obtained from the radar display.

3.3.3 Provided the target is not subject to target swop, the ARPA should continue to track an acquired target which is clearly distinguishable on the display for 5 out of 10 consecutive scans.

3.3.4 The possibility of tracking errors, including target swop, should be minimized by ARPA design. A qualitative description of the effects of error sources on the automatic tracking and corresponding errors should be provided to the user, including the effects of low signal-to-noise and low signal-to-clutter ratios caused by sea returns, rain, snow, low clouds and non-synchronous emissions.

3.3.5 The ARPA should be able to display on request at least four equally time-spaced past positions of any targets being tracked over a period of at least eight minutes.

### 3.4 Display

3.4.1 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.

3.4.2 The design should be such that any malfunction of ARPA parts producing data additional to information to be produced by the radar as required by the performance standards for navigational equipment should not affect the integrity of the basic radar presentation.

3.4.3 The display on which ARPA information is presented should have an effective diameter of at least 340 mm.

3.4.4 The ARPA facilities should be available on at least the following range scales:

.1 12 or 16 miles;

.2 3 or 4 miles.

3.4.5 There should be a positive indication of the range scale in use.

3.4.6 The ARPA should be capable of operating with a relative motion display with "north-up" and either "head-up" or "course-up" azimuth stabilization. In addition, the ARPA may also provide for a true motion display. If true motion is provided, the operator should be able to select for his display either true or relative motion. There should be a positive indication of the display mode and orientation in use.

3.4.7 The course and speed information generated by the ARPA for acquired targets should be displayed in a vector or graphic form which clearly indicates the target's predicted motion. In this regard:

.1 ARPA presenting predicted information in vector form only should have the option of both true and relative vectors;

.2 an ARPA which is capable of presenting target course and speed information in graphic form should also, on request, provide the target's true and/or relative vector;

.3 vectors displayed should either be time-adjustable or have a fixed time-scale;

.4 a positive indication of the time-scale of the vector in use should be given.

3.4.8 The ARPA information should not obscure radar information in such a manner as to degrade the process of detecting targets. The display of ARPA data should be under the control of the radar observer. It should be possible to cancel the display of unwanted ARPA data.

3.4.9 Means should be provided to adjust independently the brilliance of the ARPA data and radar data, including complete elimination of the ARPA data.

3.4.10 The method of presentation should ensure that the ARPA data are clearly visible in general to more than one observer in the conditions of light normally experienced on the bridge of a ship by day and by night. Screening may be provided to shade the display from sunlight but not to the extent that it will impair the observer's ability to maintain a proper lookout. Facilities to adjust the brightness should be provided.

3.4.11 Provisions should be made to obtain quickly the range and bearing of any object which appears on the ARPA display.

3.4.12 When a target appears on the radar display and, in the case of automatic acquisition, enters within the acquisition area chosen by the observer or, in the case of manual acquisition, has been acquired by the observer, the ARPA should present in a period of not more than one minute an indication of the target's motion trend and display within three minutes the target's predicted motion in accordance with paragraphs 3.4.7, 3.6, 3.8.2 and 3.8.3.

3.4.13 After changing range scales on which the ARPA facilities are available or resetting the display, full plotting information should be displayed within a period of time not exceeding four scans.

### 3.5 Operational warnings

3.5.1 The ARPA should have the capability to warn the observer with a visual and/or audible signal of any distinguishable target which closes to a range or transits a zone chosen by the observer. The target causing the warning should be clearly indicated on the display.

3.5.3 The ARPA should clearly indicate if a tracked target is lost, other than out of range, and the target's last tracked position should be clearly indicated on the display.

3.5.4 It should be possible to activate or de-activate the operational warnings.

### 3.6 Data requirements

3.6.1 At the request of the observer the following information should be immediately available from the ARPA in alphanumeric form in regard to any tracked target:

.1 present range to the target;

.2 present bearing of the target;

.3 predicted target range at the closest point of approach (CPA);

.4 predicted time to CPA (TCPA);

.5 calculated true course of target;

.6 calculated true speed of target.

### 3.7 Trial manoeuvre

3.7.1 The ARPA should be capable of simulating the effect on all tracked targets of an own ship manoeuvre without interrupting the updating of target information. The simulation should be initiated by the depression either of a spring-loaded switch, or of a function key, with a positive identification on the display.

### 3.8 Accuracy

3.8.1 The ARPA should provide accuracies not less than those given in paragraphs 3.8.2 and 3.8.3 for the four scenarios defined in Annex 2. With the sensor errors specified in Annex 3, the values given relate to the best possible manual plotting performance under environmental conditions of plus and minus ten degrees of roll.

3.8.2 An ARPA should present within one minute of steady state tracking the relative motion trend of a target with the following accuracy values (95 per cent probability values).

| | | | |
|---|---|---|---|
| 2 | 7 | 0.6 | X |
| 3 | 14 | 2.2 | 1.8 |
| 4 | 15 | 1.5 | 2.0 |

3.8.3 An ARPA should present within three minutes of steady state tracking the motion of a target with the following accuracy values (95 per cent probability values).

| Scenario \ Data | Relative course (degrees) | Relative speed (knots) | CPA (nautical miles) | TCPA (mins) | True course (degrees) | True speed (knots) |
|---|---|---|---|---|---|---|
| 1 | 3.0 | 0.8 | 0.5 | 1.0 | 7.4 | 1.2 |
| 2 | 2.3 | 0.3 | X | X | 2.8 | 0.8 |
| 3 | 4.4 | 0.9 | 0.7 | 1.0 | 3.3 | 1.0 |
| 4 | 4.6 | 0.8 | 0.7 | 1.0 | 2.6 | 1.2 |

3.8.4 When a tracked target, or own ship, has completed a manoeuvre, the system should present in a period of not more than one minute an indication of the target's motion trend, and display within three minutes the target's predicted motion, in accordance with paragraphs 3.4.7, 3.6, 3.8.2 and 3.8.3.

3.8.5 The ARPA should be designed in such a manner that under the most favourable conditions of own ship motion the error contribution from the ARPA should remain insignificant compared to the errors associated with the input sensors, for the scenarios of Annex 2.

### 3.9 Connexions with other equipment

3.9.1 The ARPA should not degrade the performance of any equipment providing sensor inputs. The connexion of the ARPA to any other equipment should not degrade the performance of that equipment.

3.10.1 The ARPA should provide suitable warnings of ARPA malfunction to enable the observer to monitor the proper operation of the system. Additionally, test programmes should be available so that the overall performance of ARPA can be assessed periodically against a known solution.

3.11 Equipment used with ARPA

3.11.1 Log and speed indicators providing inputs to ARPA equipment should be capable of providing the ship's speed through the water.

## ANNEX 1

## DEFINITIONS OF TERMS TO BE USED ONLY IN CONNEXION WITH ARPA PERFORMANCE STANDARDS

| | |
|---|---|
| Relative course | – The direction of motion of a target related to own ship as deduced from a number of measurements of its range and bearing on the radar, expressed as an angular distance from north. |
| Relative speed | – The speed of a target related to own ship, as deduced from a number of measurements of its range and bearing on the radar. |
| True course | – The apparent heading of a target obtained by the vectorial combination of the target's relative motion and own ship's motion*, expressed as an angular distance from north. |
| True speed | – The speed of a target obtained by the vectorial combination of its relative motion and own ship's motion*. |
| Bearing | – The direction of one terrestrial point from another, expressed as an angular distance from north. |
| Relative motion display | – The position of own ship on such a display remains fixed. |
| True motion display | – The position of own ship on such a display moves in accordance with its own motion. |
| stabilization | – Own ship's compass information is fed to the display so that echoes of targets on the display will not be caused to smear by changes of own ship's heading. |
| – north-up | – The line connecting the centre with the top of the display is north. |
| – head-up | – The line connecting the centre with the top of the display is own ship's heading. |
| – course-up | – An intended course can be set to the line connecting the centre with the top of the display. |
| Heading | – The direction in which the bows of a ship are pointing, expressed as an angular distance from north. |
| Target's predicted motion | – The indication on the display of a linear extrapolation into the future of a target's motion, based on measurements of the target's range and bearing on the radar in the recent past. |
| Target's motion trend | – An early indication of the target's predicted motion. |
| Radar plotting | – The whole process of target detection, tracking, calculation of parameters and display of information. |
| Detection | – The recognition of the presence of a target. |
| Acquisition | – The selection of those targets requiring a tracking procedure and the initiation of their tracking. |
| Tracking | – The process of observing the sequential changes in the position of a target, to establish its motion. |
| Display | – The plan position presentation of ARPA data with radar data. |
| Manual | – Relating to an activity which a radar observer performs, possibly with assistance from a machine. |
| Automatic | – Relating to an activity which is performed wholly by a machine. |

* For the purpose of these definitions there is no need to distinguish between sea and ground stabilization.

For each of the following scenarios predictions are made at the target position defined after previously tracking for the appropriate time of one or three minutes:

**Scenario 1**

| | |
|---|---|
| Own ship course | 000° |
| Own ship speed | 10 knots |
| Target range | 8 nautical miles |
| Bearing of target | 000° |
| Relative course of target | 180° |
| Relative speed of target | 20 knots |

**Scenario 2**

| | |
|---|---|
| Own ship course | 000° |
| Own ship speed | 10 knots |
| Target range | 1 nautical mile |
| Bearing of target | 000° |
| Relative course of target | 090° |
| Relative speed of target | 10 knots |

**Scenario 3**

| | |
|---|---|
| Own ship course | 000° |
| Own ship speed | 5 knots |
| Target range | 8 nautical miles |
| Bearing of target | 045° |
| Relative course of target | 225° |
| Relative speed of target | 20 knots |

**Scenario 4**

| | |
|---|---|
| Own ship course | 000° |
| Own ship speed | 25 knots |
| Target range | 8 nautical miles |
| Bearing of target | 045° |
| Relative course of target | 225° |
| Relative speed of target | 20 knots |

The accuracy figures quoted in paragraph 3.8 are based upon the following sensor errors and are appropriate to equipment complying with the performance standards for shipborne navigational equipment.

***Note:*** *$\sigma$ means "standard deviation".*

**Radar**

**Target glint (scintillation) (for 200 m length target)**

Along length of target $\sigma$ = 30 metres (normal distribution)

Across beam of target $\sigma$ = 1 metre (normal distribution).

**Roll-pitch bearing** The bearing error will peak in each of the four quadrants around own ship for targets on relative bearings of 045°, 135°, 225° and 315° and will be zero at relative bearings of 0°, 90°, 180° and 270°. This error has a sinusoidal variation at twice the roll frequency.

For a 10° roll the mean error is

0.22° with a 0.22° peak sine wave superimposed.

**Beam shape** — assumed normal distribution giving bearing error with $\sigma$ = 0.05°.

**Pulse shape** — assumed normal distribution giving range error with $\sigma$ = 20 metres.

**Antenna backlash** — assumed rectangular distribution giving bearing error ± 0.5° maximum.

**Quantization**

Bearing — rectangular distribution ± 0.01° maximum.

Range — rectangular distribution ± 0.01° nautical miles maximum.

Bearing encoder assumed to be running from a remote synchro giving bearing errors with a normal distribution $\sigma$ = 0.03°.

**Gyro-compass**

Calibration error 0.5°.

Normal distribution about this with $\sigma$ = 0.12°.

**Log**

Calibration error 0.5 knots.

Normal distribution about this, $3\sigma$ = 0.2 knots.

## MINIMUM TRAINING REQUIREMENT IN THE OPERATIONAL USE OF AUTOMATIC RADAR PLOTTING AIDS (ARPA)

1. In addition to the minimum knowledge of radar equipment, the masters, chief mates and officers in charge of a navigational watch on ships carrying ARPA shall be trained in the fundamentals and operation of ARPA equipment and the interpretation and analysis of information obtained from this equipment.

2. The training shall ensure that the master, chief mate and officers in charge of a navigational watch has:—

(*a*) Knowledge of:

(i) the possible risks of exclusive reliance on ARPA;

(ii) the principal types of ARPA systems and their display characteristics;

(iii) the IMO performance standards for ARPA;

(iv) factors affecting system performance and accuracy;

(v) tracking capabilities and limitations of ARPA;

(vi) processing delays.

(*b*) Knowledge and ability to demonstrate in conjunction with the use of an ARPA simulator or other effective means approved by the administration:

(i) setting up and maintaining ARPA displays;

(ii) when and how to use the operational warnings, their benefits and limitations;

(iii) the system operational tests;

(iv) when and how to obtain information in both relative and true motion modes of display, including:
—identification of critical echoes;
—speed and direction of targets relative movement;
—time to and predicted range at targets closest point of approach;
—course and speed of targets;
—detecting course and speed changes of targets and the limitations of such information;
—effect of changes in own ship's course or speed or both;
—operation of the trial manoeuvre;

(v) manual and automatic acquisition of targets and their respective limitations;

(vi) when and how to use true and relative vectors and typical graphic representation of target information and danger areas;

(vii) when and how to use information on past positions of targets being tracked;

(viii) application of the International Regulations for Preventing Collisions at Sea.

## RECOMMENDED TRAINING PROGRAMME IN THE OPERATIONAL USE OF AUTOMATIC RADAR PLOTTING AIDS (ARPA)

1. *General*

(*a*) In addition to the minimum knowledge of radar equipment, masters, chief mates and officers in charge of a navigational watch on ships carrying ARPA should be capable of demonstrating a knowledge of the fundamentals and operation of ARPA equipment and the interpretation and analysis of information obtained from this equipment.

(*b*) Training facilities should include the use of simulators or other effective means capable of demonstrating the capabilities, limitations and possible errors of ARPA.

(*c*) The simulation facilities mentioned above should provide a capability such that trainees undergo a series of real-time exercises where the displayed radar information, at the choice of the trainee or as required by the instructor, is either in the ARPA format or in the basic radar format. Such flexibility of presentation will enable realistic exercises to be undertaken, providing for each group of trainees the widest range of displayed information available to the user and thus consolidating his ability to use effectively either basic radar or ARPA systems.

(*d*) The ARPA training programme should include all items listed in paragraphs 3 and 4 below.

2. *Training programme development*

Where ARPA training is provided as part of the general training requirements, masters, chief mates and officers in charge of a navigational watch should understand the factors involved in decision making based on the information supplied by ARPA in association with other navigational data inputs, having a similar appreciation of the operational aspects and of system errors of modern electronic navigational systems. This training should be progressive in nature commensurate with responsibilities of the individual and the certificate issued.

3. *Theory and demonstration*

3.1 *The possible risks of exclusive reliance on ARPA*

Appreciation that ARPA is only a navigational aid and that its limitations including those of its sensors make exclusive reliance on ARPA dangerous, in particular for keeping a look-out; the need to comply at all times with the basic principles and operational guidance for officers in charge of a navigational watch.

3.2 *The principal types of ARPA systems and their display characteristics*

Knowledge of the principal types of ARPA systems in use; their various display characteristics and an understanding of when to use ground or sea stabilised modes and north up, course up or head up presentations.

3.3 *IMO performance standards for ARPA*

An appreciation of the IMO performance standards for ARPA, in particular the standards relating to accuracy.

3.4 *Factors affecting system performance and accuracy*

(*a*) Knowledge of ARPA sensor input performance parameters—radar, compass and speed inputs; effects of sensor malfunction on the accuracy of ARPA data.

(*b*) Effects of the limitations of radar range and bearing discrimination and accuracy; the limitations of compass and speed input accuracies on the accuracy of ARPA data.

(*c*) Knowledge of factors which influence vector accuracy.

3.5 *Tracking capabilities and limitations*

(*a*) Knowledge of the criteria for the selection of targets by automatic acquisition.

(*b*) Factors leading to the correct choice of targets for manual acquisition.

(*c*) Effects on tracking of "lost" targets and target fading.

(*d*) Circumstances causing "target swop" and its effects on displayed data.

3.6 *Processing delays*

The delays inherent in the display of processed ARPA information, particularly on acquisition and re-acquisition or when a tracked target manoeuvres.

3.7 *When and how to use the operational warnings, their benefits and limitations*

Appreciation of the uses, benefits and limitations of ARPA operational warnings; correct setting, where applicable, to avoid spurious interference.

3.8 *System operational tests*

(*a*) Methods for testing for malfunctions of ARPA systems, including functional self testing.

(*b*) Precautions to be taken after a malfunction occurs.

3.9 *Manual and automatic acquisition of targets and their respective limitations*

Knowledge of the limits imposed on both types of acquisition in multi-target scenarios, effects on acquisition of target fading and target swop.

3.10 *When and how to use true and relative vectors and typical graphic representation of target information and danger areas*

(*a*) Thorough knowledge of true and relative vectors; derivation of targets true courses and speeds.

(*b*) Threat assessment; derivation of predicted closest point of approach and predicted time to closest point of approach from forward extrapolation of vectors, the use of graphic representation of danger areas.

(*c*) Effects of alterations of courses and/or speeds of own ship and/or targets on predicted closest point of approach and predicted time to closest point of approach and danger areas.

(*d*) Effects of incorrect vectors and danger areas.

(*e*) Benefit of switching between true and relative vectors.

3.11 *When and how to use information on past position of targets being tracked*

Knowledge of the derivation of past positions of targets being tracked, recognition of historic data as a means of indicating recent manoeuvring of targets and as a method of checking the validity of the ARPA's tracking.

4. *Practice*

4.1 *Setting up and maintaining displays*

(*a*) The correct starting procedure to obtain the optimum display of ARPA information.

(*b*) Choice of display presentation; stabilised relative motion displays and true motion displays.

(*c*) Correct adjustment of all variable radar display controls for optimum display of data.

(*d*) Selection, as appropriate, of required speed input to ARPA.

(*e*) Selection of ARPA plotting controls, manual/automatic acquisition, vector/graphic display of data.

(*f*) Selection of the time scale of vectors/graphics.

(*g*) Use of exclusion areas when automatic acquisition is employed by ARPA.

(*h*) Performance checks of radar, compass, speed input sensors and ARPA.

4.2 *System operational tests*

System checks and determining data accuracy of ARPA including the trial manoeuvre facility by checking against basic radar plot.

4.3 *When and how to obtain information from ARPA display*

Demonstrate ability to obtain information in both relative and true motion modes of display, including:

—identification of critical echoes;
—speed and direction of targets relative movement;
—time to and predicted range at target's closest point of approach;
—course and speed of targets;
—detecting course and speed changes of targets and the limitations of such information;
—effect of changes in own ship's course or speed or both;
—operation of the trial manoeuvre.

4.4 *Application of the International Regulations for Preventing Collisions at Sea*

Analysis of potential collision situations from displayed information, determination and execution of action to avoid close quarter situations in accordance with International Regulations for Prevention of Collisions at Sea.

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