FUTURE MARINE NAVIGATION SYSTEMS

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Summary

New technology is beginning to provide electronic navigation systems offering high accuracies of position fixing over wide areas, together with a range of associated sophisticated information services. Most shipping is however still reliant on traditional aids to navigation.

Visual aids, radar aids and radio navigation systems are three of the main types of navigation systems and services used for marine navigation. Visual aids have traditionally been the predominant type of aid provided in Australia for coastal navigation. Radar aids, specifically racons, are a relatively new type of aid, and have become increasingly popular. Although radio navigation systems are widely used in many developed countries, they have only ever been provided on a very minor scale in Australia.

AMSA provides an extensive network of visual aids in the Great Barrier Reef and Torres Strait regions, supplemented by a few racons. No radio navigation systems have ever been provided for the Great Barrier Reef region.

The Global Positioning System (GPS) operated by the US Department of Defense will provide, to all civil users throughout the world, a horizontal position fixing accuracy of 100 metres. GPS will be widely used for marine navigation, and will most likely be the major worldwide radio navigation system for many years. Although 100 metre accuracy is acceptable for many navigational situations, it does not meet the requirements for some of the more demanding requirements, such as navigation through much of the Great Barrier Reef. A Differential GPS service can enable the accuracy of position fixing to be improved to better than 10 metres.

The paper describes the main features of a DGPS service for marine navigation, and the implications for users. The status of DGPS services provided by maritime authorities in other countries is mentioned. The AMSA strategy for the provision of DGPS services, which includes the first trial DGPS service planned for installation in Victoria, is discussed. Indicative details of a possible DGPS network for the Great Barrier Reef, Torres Strait and Great North East Channel are outlined.

The role which DGPS could play in shipboard integrated navigation systems, and in vessel reporting systems, is briefly mentioned.

Introduction

New technology is providing the opportunity for dramatically changing the process of navigation on the sea, on land, and in the air. Satellite navigation systems are enabling the achievement of high accuracies of position fixing throughout the world, in all weather conditions and at all times. The new technology will not only provide the mariner with accurate position fixes. Other information available from satellite navigation systems includes, for example, speed, heading, distance to waypoints, and cross track errors with respect to a preplanned route. Because all this information is available in electronic form, it can be employed in association with electronic charts, and integrated shipboard navigation systems. The information can also be automatically relayed to shore installations, say to the shipowner's office, to a vessel traffic monitoring centre, or to a search and rescue centre.

Most shipping is still heavily reliant on traditional aids to navigation, with navigation by visual means being predominant. The aim of this paper is to look at the features and

benefits of satellite navigation, and especially at a new system known as Differential GPS. It is not the intention of this paper to argue the case for the establishment of any new system. The intention is merely to describe new technologies which are already available, and which appear to offer considerable benefits to vessel operators and other parties concerned with navigational safety. The possible application of these new technologies in the Great Barrier Reef and surrounding areas would need to be examined in more detail before any firm proposals could be drawn up.

Marine Navigation Systems and Services

The International Association of Lighthouse Authorities' publication "Navguide" lists seven different types of systems and services available to the user for position fixing and navigation. These are astronomical position fixing, charts (and other nautical documents), pilotage, vessel traffic services, visual aids to navigation, radar aids to navigation and radio navigation systems.

Astronomical position fixing has little relevance to navigating the Inner Route of the Great Barrier Reef. Charting and pilotage are the subject of other papers at this Workshop. Towards the end of this paper, brief mention will be made of vessel traffic services. All the position fixing services provided by AMSA in the Great Barrier Reef region are either visual aids or radar aids. The numbers of existing aids in the Great Barrier Reef and surrounding areas are listed in **Attachment 1**. Visual aids predominate. This is because navigation in the region has principally been by visual means, with reliance on pilotage services.

The visual aids are conventional lights, now almost all solar powered. Most of the structures housing these aids also serve a useful function as daymarks for navigation during daylight. For many years the Commonwealth has provided a very extensive network of visual aids in this region, particularly in the northern section of the Great Barrier Reef and the Torres Strait. AMSA, and its predecessor Commonwealth organisations, has consulted closely with the shipping industry and the Queensland Coast and Torres Strait Pilot Service in planning the various changes made to the network of aids. One major change currently being planned is the replacement of all floating aids in this region, most by fixed structures.

AMSA operates a small number of radar aids. All these are racons, or radar transponder beacons. Five were installed in the Great Barrier Reef, and another four in surrounding areas, all over the period 1985 to 1992. The purpose of the racon is to provide positive identification, on a ship's radar display, of a known point, typically a lighthouse tower. Thus the range and bearing to this point from the ship can be determined.

AMSA operates four radio reporting tide gauges in the Torres Strait, which broadcast real time tide height over VHF radio. The data is also accessible over the public telephone system.

Unlike many developed countries in the Northern Hemisphere, Australia has only ventured into marine radio navigation systems in a very small way. The Commonwealth operated up to ten radio direction finding beacons, and the last of these will be discontinued later this year. Only one was in Queensland, at Booby Island. The era of the usefulness of this aid has passed. The Commonwealth established two Decca Navigator Chains in Western Australia just over twenty years ago. One was closed in 1986 and the other last year. AMSA continues to operate the Australian Omega station, under an agreement between the Australian and U.S. Governments. The station is one of a network of eight stations in the world comprising the Omega Navigation System. Omega has an accuracy of 2 to 4 miles, and no longer serves any useful purpose for marine navigation in the Australian area.

Global Positioning System

The radio navigation system which is on the verge of revolutionising navigation is the NAVSTAR Global Positioning System, usually referred to simply as GPS. Although developed by the United States Department of Defense, the US Government has declared that the Standard Positioning Service of GPS will be available to all civil users around the world with an accuracy of 100 metres at the 95% probability level. GPS is due to be declared as achieving its "Interim Operational Capability" in August this year, and its "Full Operational Capability" next year.

The space segment of GPS consists of 24 orbiting satellites. A user's GPS receiver determines its position by making range measurements to satellites which are in view. For a three dimensional fix, measurements must be made to four or more satellites. For a two dimensional fix, measurements must be made to three or more satellites.

In providing the Standard Positioning Service of GPS, the US Department of Defence has deliberately degraded the achievable accuracy, by a process known as Selective Availability. If Selective Availability were not imposed, then the two dimensional position fixing accuracy would be about 30 metres instead of the specified 100 metres.

DGPS Basics

Although GPS provides sufficient accuracy for most navigational situations, it does not meet the requirements for some of the more demanding applications, such as navigation in channels, ports and confined waterways. Differential GPS services have been developed to provide considerable improvement in position fixing using GPS. For the type of DGPS service discussed in this paper, the achievable accuracy is better than 10 metres.

A Differential GPS (DGPS) service is based on the principle that if a GPS receiver is located at an accurately known ("reference station") location, it can continuously measure the errors in ranges to all the satellites in view, and relay these errors to users within a distance of up to some hundreds of miles away. The user's receiving equipment will apply these errors to improve the accuracy of position fixing. DGPS cancels out the effects of Selective Availability, as well as correcting for some other factors which contribute to the errors of GPS measurements.

The principle of DGPS is illustrated in **Attachment 2**. If the ship is equipped with only a GPS receiver, then the ship's position is determined by range measurements to the three satellites in view, that is R1, R2 and R3. The GPS receiver at the DGPS reference station makes range measurements to the satellites, and its computer calculates the corrections applicable to these range measurements, that is R1, R2 and R3. These corrections are then broadcast over a radio transmitter. If the ship is equipped with the appropriate equipment to receive these broadcast corrections, it will apply the corrections to its range measurements, and thereby improve its accuracy of position fixing to better than 10 metres.

In addition to improving the accuracy of position determination and other data, DGPS performs an important function in monitoring the integrity of GPS itself. The US Department of Defence operates a sophisticated network of monitoring and control stations as part of GPS. When a satellite is detected as "unhealthy", the satellite is commanded to transmit a message to that effect, so that user GPS receivers are made aware. Although GPS is expected to achieve very high standards of performance, it is possible for a satellite to transmit an unhealthy signal before users can be warned not to use the signal. A recent International Association of Lighthouse Authorities' discussion paper states that "the disposition of the Ground Segment of the system is such that a satellite can malfunction, broadcasting erroneous data for up to 2 hours before any warning can be issued or the satellite can be commanded to broadcast its faulty state". A

recent U.S. Coast Guard paper states that "a satellite can be transmitting an unhealthy signal for 2 to 6 hours before it can be detected and corrected by the Master Control Station or before users can be warned not to use the signal". With DGPS messages, a direction can be given not to use a particular satellite (which may or may not be marked as unhealthy), or an unhealthy satellite may still be used in certain circumstances.

DGPS Benefits

The benefits to mariners of public broadcast DGPS services are:

- improves accuracy of position fixing using GPS
- improves accuracy of other GPS derived information
- provides information to other shipborne systems
- provides real time integrity monitoring of GPS
- requires only modest amount of additional shipborne equipment
- shipborne equipment useable in many countries
- reception of data is "free".

DGPS in other countries

Several countries are already operating DGPS services for marine navigation purposes, and more services are planned. The services known to AMSA are listed in **Attachment 3.** In all cases except the U.K., the broadcast data is free at the point of use. The data broadcast from the U.K. stations is encrypted, and access requires users to pay.

All countries providing these services are following the same standards for the broadcast data, as recommended by the International Association of Lighthouse Authorities. The IALA standard is based on the RTCM (Radio Technical Commission for Maritime Services, U.S.A.) Special Committee No. 104 "Recommended Standards for Differential Navstar GPS Service (Version 2.0.)". All countries are using Medium Frequency radio transmitters to broadcast the data, operating in the band allocated for maritime radionavigation.

If a ship is already fitted with a GPS receiver having the capability to process differential corrections to the RTCM recommended standards, then the additional shipborne equipment required is a single unit consisting of a Medium Frequency radio receiver, demodulator, and a processor which converts the data into the prescribed form suitable for transfer to the GPS receiver. Several companies are producing these units.

AMSA strategy for DGPS

AMSA has a strategy for the provision of DGPS services in Australia for marine navigation. The key elements of this strategy are:

- establish one or two pilot installations
- examine the establishment of further installations
- consult with maritime organisations in developing plans
- keep abreast of developments in Australia and overseas
- contribute to the development of standards
- follow international standards for data transmission
- evaluate the services provided
- promote the use of the services established
- provide advisory service to users and receiver suppliers.

The first pilot installation will be in Victoria, with the broadcasting station located at Cape Schanck, the site of an existing radio beacon. Tenders for the supply of equipment were called in December 1992, and it is expected that a contract will be placed in the very near future. The current program is for broadcasts to commence on a trial basis in December 1993.

If the first one or two installations perform satisfactorily, and if it is considered that there would be substantial benefits to navigational safety from installing additional stations, then a program could be drawn up for a network of stations. The Great Barrier Reef, Torres Strait and Great North East Channel are areas which could potentially benefit from the provision of DGPS services.

An indicative DGPS network for these areas is depicted in **Attachment 4.** This possible network comprises six broadcasting stations, each transmitting data on a different frequency in the Medium Frequency marine radionavigation band. It is stressed that the number and locations of these stations is at this stage indicative only. Further examination would be required before a firm proposal could be drawn up, and cost estimates prepared. Present indications are that the cost of establishing a six station network may be around $2 million. One major determinant of cost would be the extent to which AMSA might be able to install its equipment at existing facilities operated by other organisations.

Integrated Navigation Systems

Highly sophisticated integrated navigation systems are available to the mariner. The electronic chart will be a key element of future integrated navigation systems. For the full potential of electronic charts to be realised, there must be accurate real time position information available in electronic form. DGPS is a highly suitable means of meeting this need.

An integrated navigation system is illustrated in **Attachment 5.** This is the system used in the Norwegian Seatrans Project, which assessed the use of ECDIS, as described in the February 1991 report by the Norwegian Marine Technology Research Institute. The prime role of DGPS was to feed accurate position data to the electronic chart display. The Inmarsat service was used to provide chart updates from the Hydrographic Service to the ship, and also to relay position information (as determined by GPS/DGPS) on request to the shipowner or maritime authorities.

Vessel Reporting Systems

In the aftermath of the Exxon Valdez grounding in Alaska in 1989, various measures were taken with the view to minimising the possibility of future such disasters. One measure is the introduction of a vessel traffic system in Prince William Sound. All tankers will be required to carry equipment which will continuously and automatically report their position, and other data. The prescribed vessel position reporting sensor will be DGPS, using DGPS signals provided by U.S. Coast Guard DGPS broadcasting stations.

The provision of some form of vessel reporting system in the Torres Strait and Great Barrier Reef, and how such a system could contribute to safety, appears to be worth examining. A vessel reporting system could take various possible forms. At one extreme is the type being introduced in Alaska, that is a compulsory system with automatic highly accurate position sensing, and with rigid controls. At the other extreme is a voluntary system with manual reporting of approximate positions at prescribed times. It would be most desirable however for any planned system to have the capability of not only feeding ship position information to a "central station", but also of enabling each participating ship to receive position reports from all other participating ships. The technology is already here to meet any type of system within these two extremes. The prime determinant should be the resultant contribution which the system would make to navigational safety, and to minimising the probability of environmental damage due to collisions or groundings.

Conclusions

Satellite navigation, and specifically GPS, will be used extensively for marine navigation throughout the world. The accuracy of GPS is adequate for many situations, but not for

navigation in confined waterways. DGPS services provide considerably enhanced accuracies, and carry out integrity monitoring of GPS, at modest cost to shipowners. AMSA is planning one or two pilot DGPS services, and may consider the establishment of further services.

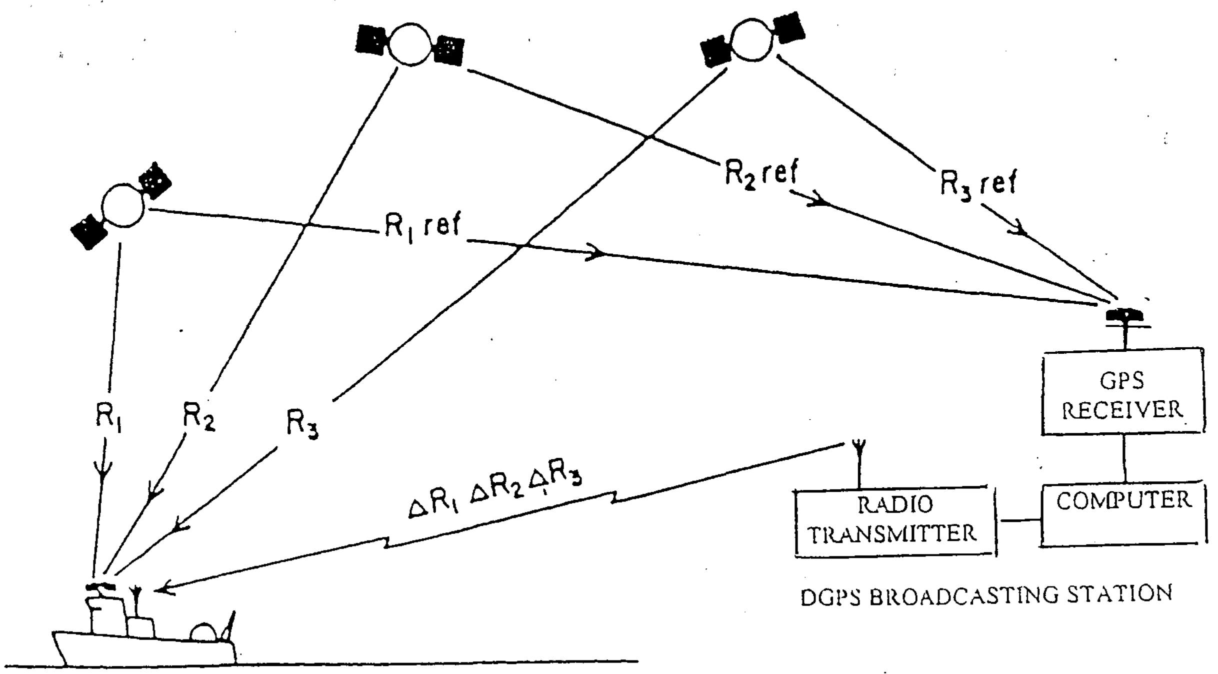
The establishment of a network of DGPS broadcasting stations to cover the Great Barrier Reef, Torres Strait and Great North East Channel would appear to be worth examining, in view of the contribution that such a network could conceivably make to improving navigational safety. It would also seem desirable for an examination to be carried out into the provision of some form of vessel reporting system for this region.

ATTACHMENT 1

AMSA AIDS TO NAVIGATION IN THE GREAT BARRIER REEF MARINE PARK AND ADJOINING AREAS

Type	Great Barrier Reef Marine Park	Torres Strait	Great North East Channel	Coral Sea
Light (on structure)	77	11	6	4
Light (floating aid)	2	6	0	0
Unlit Aid	7	1	0	0
Racon	5	0	1	3
Tide Gauge	0	4	0	0
Total	91	22	7	7

ATTACHMENT 2



DGPS - SCHEMATIC

ATTACHMENT 3

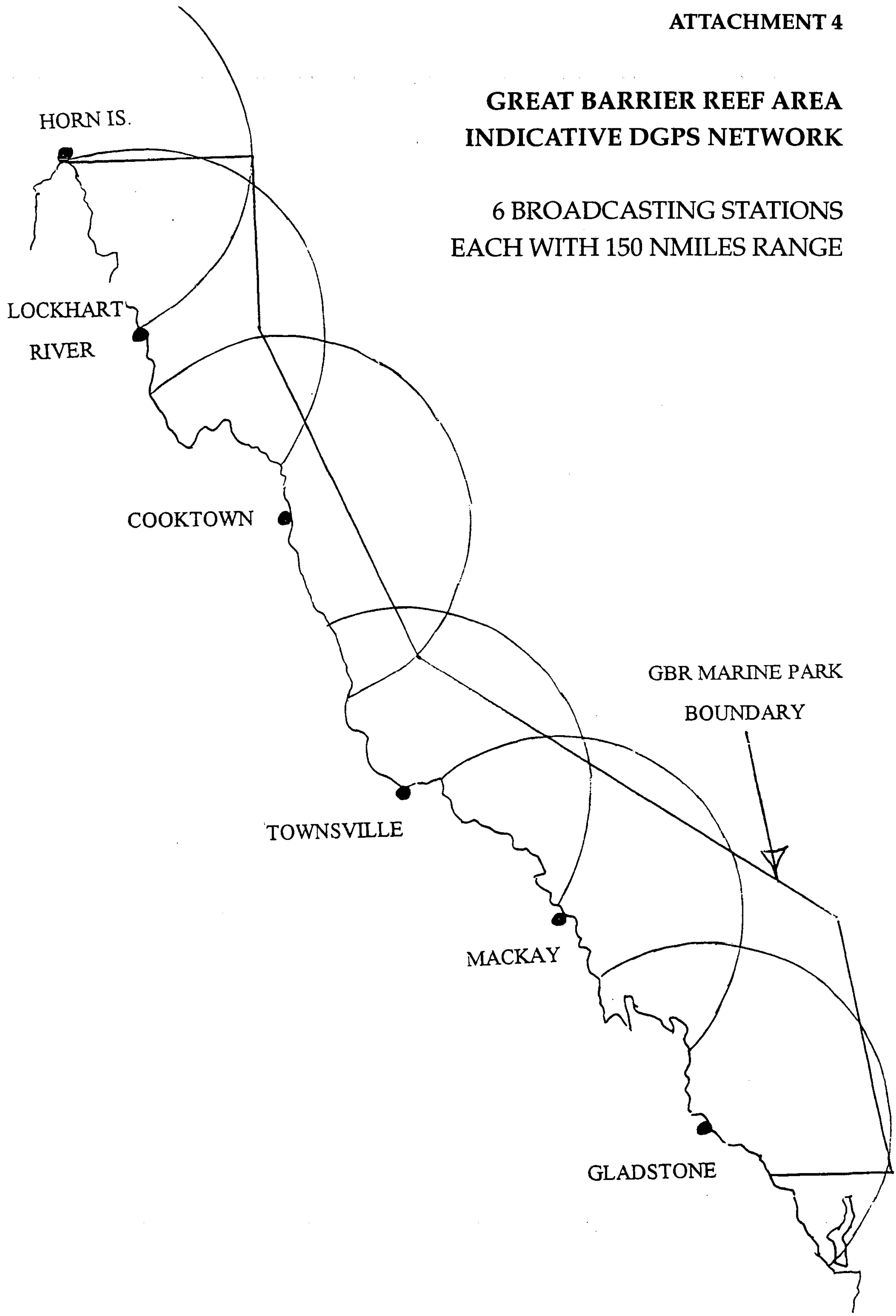
MARITIME DGPS SERVICES PROVIDED IN OTHER COUNTRIES

	Stations Operating as at Feb. 1993	Total Number of Stations Planned
USA	9	52 (by 1996)
NORWAY	4	12 (by 1995)
SWEDEN	3	6
FINLAND	3	5
DENMARK	1	4
GERMANY	0	2
NETHERLANDS	1	2
UK and IRELAND	7	11

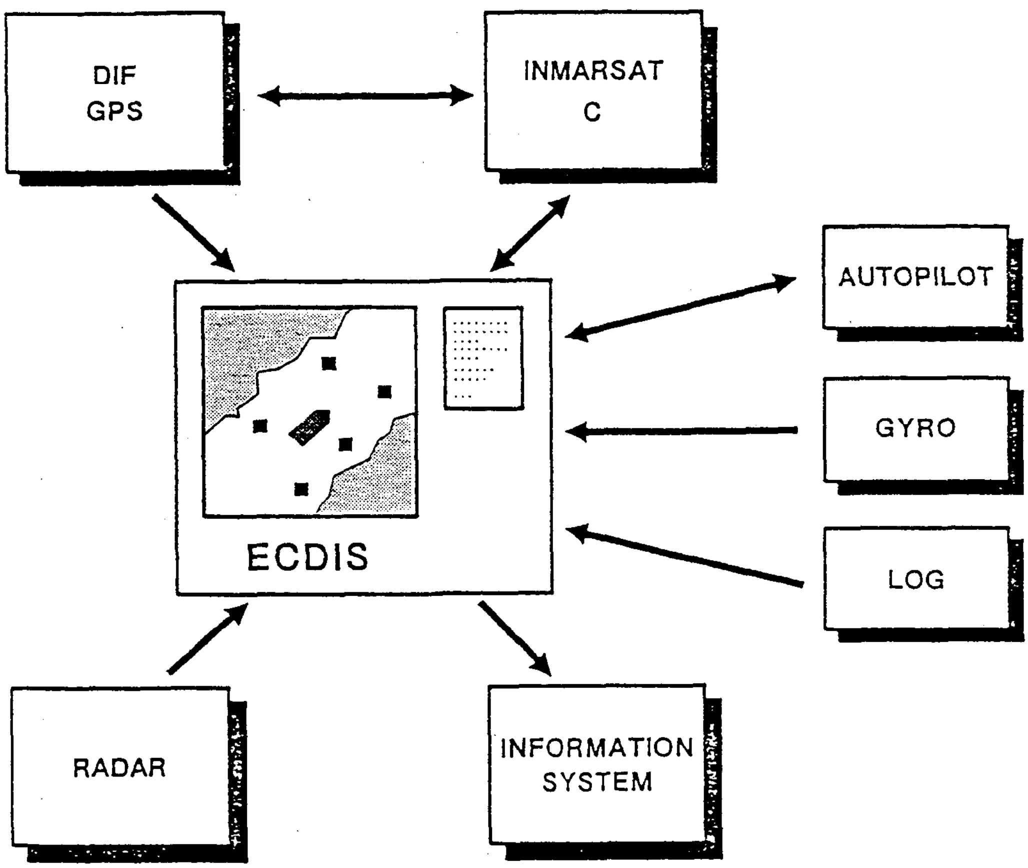
ATTACHMENT 4

GREAT BARRIER REEF AREA INDICATIVE DGPS NETWORK

6 BROADCASTING STATIONS
EACH WITH 150 NMILES RANGE



ATTACHMENT 5



INTEGRATED NAVIGATION SYSTEM
SYSTEM CONFIGURATION USED FOR SEATRANS PROJECT

QUESTIONS AND ANSWERS*

David Langford's presentation

Question
The two million dollar figure you mentioned was for the construction of six stations in the GBR region?

Answer
Yes, it's an indicative cost for six stations. The unit cost would, including the MF transmitting aerial, be probably be about $200,000 with an allowance of $100,000 for building. The main factor would be the building cost.

Question
You said that at the moment, the accuracy with a differential GPS system is roughly ten metres and this is not adequate. On land we are getting down to accuracies of centimetres. Is there any technological reason why, through accommodation of the integrated systems we're talking about and using the inertial systems, we can't get that kind of accuracy.

Answer
I think the accuracy that's achievable from the differential GPS service that I've been talking about is 6 or 7 metres which I think is adequate for almost every navigational situation. I do not think the centimetre accuracy is really needed for marine navigation. It is achievable but requires a lot of expensive equipment. For surveys, they use two or three sets of equipment that they move around to do a precise survey in a certain area. For an accuracy of 6-7 metres, and assuming that a ship already has a GPS receiver, the additional cost of the ship owner providing a unit which will access and process the differential information is at the moment about $2,000. I'm sure that this will come down, because there's already a lot of competition.

Comment from the floor.
The centimetre precision is really derived from a static observation, where you can have an enormous number of observations, so you can reduce your root-mean-square error. Of course in a dynamic situation, you've only got one observation and you're not there anymore, so the machine will only therefore reduce your root-mean-square error to something to the order of 10 metres. There's a lot of interest in the use of ECDIS and DGPS in north America where they suffer very badly from fog and ice, and particularly the St Lawrence Seaway and these things are being used on a daily basis in ferries in the St Lawrence Seaway to put ships along-side wharves. There it's not a problem. Centimetre accuracy is certainly achievable, but it requires a lot more sophisticated equipment.

Question
On your slide you seem to be using MF for passing information of DGPS to ships. What consideration has been given to using either VHF or INMARSAT?

Answer
Well, at the moment, we've decided to follow the standard which has been laid down by the International Association of Lighthouse Authorities (IALA). They've looked a range of options to transmit the differential corrections to the ship. There are advantages and disadvantages with the various systems. I suppose the main advantage of the INMARSAT service is that it can cover a very wide geographical area, but it comes at a considerably higher cost to the ship owner. I think the aviation community may well in future years have a system that does use INMARSAT and there's a certain amount of development in that area at the moment. The main thing about the MF transmission is

that it is being implemented now. It is a system that has been agreed upon by a lot of countries, it's very easy and very economical to install on the ship. The INMARSAT approach, would be considerably more expensive to implement. I think at the end of the day, it may not be producing any great advantages. The main problem with VHF is it has a much smaller area of coverage. In order to cover the GBR area, you'd probably need 6 stations of medium frequency; if you went to VHF, it might be 2 or 3 times that number of stations. With VHF, you really get the signal by line of sight, from the transmitter to the ship. With MF it is essentially ground wave propagation and there is no line of sight requirement.

* Note: This text is not a verbatim record of the questions and answers. To assist with comprehension, the Editor has deleted some text and made modifications to highlight key points. Speakers are not identified.