1994

Satellite technology in the maritime world : applications and implications

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SATELLITE TECHNOLOGY IN THE MARITIME WORLD - APPLICATIONS AND IMPLICATIONS

By

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

MASTER OF SCIENCE

in

MARITIME EDUCATION AND TRAINING
(Nautical)

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

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

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Dedicated to

my dear colleagues at the Vietnam Maritime University

ACKNOWLEDGEMENTS

This dissertation was developed during my two years of study at the World Maritime University through the kind support and selfless assistance of various people and organizations. I would like to take this opportunity to thank them all for their valuable contribution to this study.

My special thanks go to Prof. Le Duc Toan, Rector of the Vietnam Maritime University, for nominating me to study at the World Maritime University. His notable support and encouragement has greatly contributed to my successful completion of this course.

I wish to express my profound gratitude and sincere thanks to Prof. Peter Muirhead, my Course Professor, for his sagacious guidance and counselling as well as his patient supervision of my work. His forbearance and generous assistance during my whole two-year course, particularly in the process of my dissertation writing, were the most important factors that made this study possible.

My deepest gratitude is given to Dr. Bernard Berking, Professor at the Hamburg Fachhochschule, for his perceptive comments and constructive advice in making this dissertation better. During our meetings in Malmo as well as in Lisbon, he gave me guidance essential for developing the structure and contents of my study.

I am extremely grateful to Captain Lars Brodje, Senior Maritime Advisor of INMARSAT, for constantly providing assistance and encouragement throughout my research. Without his support, the success of this study could not have been achieved.

My sincere gratitude is extended to the following organizations for providing me with valuable information and materials: INMARSAT, COSPAS-SARSAT, Norwegian Telecom (Norway), Trimble Navigation (US), Posseidon AS (Norway), Sercel (France) and the Meteorology Office (UK).

I would like to take this opportunity to acknowledge the contribution of the WMU staff to my study. In particular, my special thanks go to Ms. Susan Wangeci Boidhie for providing me with valuable materials on the topic, Mr. Alan Rudderham and Mr. Clive Cole for carefully reviewing the draft of my dissertation.

I am especially appreciative of the patience, help and encouragement given by my MET(N)-94 friends. I am also indebted to my dear colleagues at the Vietnam Maritime University for their tireless support. It is to them that this dissertation is wholeheartedly dedicated.

Last but not least, special thanks are given to my family, my beloved parents and brothers, for providing me with uninterrupted moral support and encouragement.

ABSTRACT

This dissertation is a study of the widespread utilization of satellite technology in the maritime world, with particular reference to the applications and implications of communication, navigation and remote sensing satellites to shipping and other maritime related fields.

A brief look is taken at the general background of satellite technology, including the growth and development and basic techniques as well as categorization of applications. This is followed by a more detailed view of the three different areas of the applications of satellite technology, namely maritime communications, marine navigation and maritime meteorology and oceanography.

The two well-known satellite-based systems, the INMARSAT System and the Global Positioning System, are both widely used by the maritime community and thus emphasized in this study. Apart from a brief description of those two systems, their applications are examined, their impact on the marine industry is discussed and their future development is investigated in order to obtain an appreciation of their role in the present maritime world. The applications of remote sensing satellites in marine meteorology and oceanography are also discussed. In addition to the above , the impact of the increasing use of satellite technology on maritime education and training is investigated.

The concluding chapter is a summary of the main points discussed in the core chapters, which reflect the author's view point.

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GLOSSARY

CES	Coast Earth Station
COSPAS-SARSAT	A joint international satellite-aided search and rescue system operated by Canada, CIS, France and US
DGPS	Differential Global Positioning System
DOD	US Department of Defence
DOT	US Department of Transportation
drms	distance root mean square
DSC	Digital Selective Calling
ECDIS	Electronic Chart Display and Information System
EDI	Electronic Data Change
EGC	Enhanced Group Call
EIRP	Effective Isotropic Radiated Power
E-mail	Electronic Mail
ESA	European Space Agency
EPIRB	Satellite Emergency Position Indicating Radio Beacon
FOC	Full Operational Capability (of the GPS system)

GEO	Geostationary orbit
GIB	GPS Integrity Broadcast
GIC	GPS Integrity Channel
GLONASS	Russian-owned Global Navigation Satellite System
GMDSS	Global Maritime Distress and Safety System
GNSS	Global Navigation Satellite System
GOC	General Operator's Certificate
GPS	American-owned Global Positioning System
HDOP	Horizontal Dilution Of Precision
HF	High Frequency, in between 3 Mhz and 30 MHz
HSD	High Speed Data
kbps	Kilobit per second
IALA	International Association of Lighthouse Authorities
ICAO	International Civil Aviation Organization
ICO	Intermediate Circular Orbit
IMO	International Maritime Organization
INMARSAT	International Maritime Satellite Organization
IOC	Initial Operational Capability (of the GPS system)

ISDN	Integrated Switch Digital Network
ITU	International Telecommunication Union
LEO	Low Earth Orbit
LES	Land Earth Station
LUT	Local User Terminal
MCC	Mission Co-ordination Centre
MF	Medium Frequency, in between 300 KHz and 3 MHz
MRCC	Maritime Rescue Co-ordination Centre
MSI	Maritime Safety Information
NAVTEXT	Narrow-band direct printing telegraphy system for transmission and reception of maritime safety information
NBDP	Narrow Band Direct Printing
NOAA	National Oceanic and Atmospheric Administration (US)
PPS	Precise Positioning Service
PRN	Pseudo-Random Noise
RAIM	Receiver Autonomous Integrity Monitoring
RDSS	Radiodetermination Satellite System

RTCM -SC	Radio Technical Commission for Maritime Service - Special Committee
SA	Selective Availability
SAR	Search and Rescue
SART	Search and Rescue Transponder
Satcom	Satellite Communication
Satnav	Satellite Navigation
SES	Ship Earth Station, operating with the INMARSAT space segment
SOLAS	International Convention on Safety of Life at Sea
SPS	Standard Positioning Service
STCW	International Convention on Standards of Training , Certification and Watchkeeping for Seafarers
USCG	US Coast Guard
VHF	Very High Frequency, in between 30 MHz and 300 MHz
VSAT	Very Small Aperture Terminal
VTS	Vessel Traffic Services
WADGPS	Wide-area Differential GPS

INTRODUCTION

There has been a lot of research and many studies which have discussed satellite communications, satellite navigation or satellite remote sensing techniques separately. However, it is the author's intention to provide readers with a holistic view of the utilization of satellite technology in the maritime world. In order to achieve this pre-determined idea, a general approach was set up and has been pursued throughout the process of this study.

The main objectives of this study are, inte alia:

- to provide a general understanding of satellite technology being utilized in the maritime world
- to investigate the current use as well as future potential of satellite technology in the maritime world
- to investigate the impact of the increasing use of satellite technology on the maritime world, with particular reference to the shipping industry and maritime education and training.

In addition, this study can be considered as a modest contribution to the author's institution, the Vietnam Maritime University, as a reference source in the areas of certain subjects investigated by this study such as the Global Positioning System and the Global Maritime Distress and Safety System.

The research methodology adopted for this study includes learning through lectures and seminars during course time at the World Maritime University; exposure during field studies; material search from various sources, particularly from the library of the World Maritime University and from various organizations; discussions with the course professor and visiting professors; as well as consultation from experts in the field.

Much effort has been made to construct the dissertation in a simple, systematic, and balanced manner. Emphasis has been placed on highlighting the critical areas within the general picture of the increasing use of satellite technology in the maritime world. Since it is not the objective of this study to go into greater depth, the details of the technical aspects are avoided.

Nevertheless, there are certain unavoidable limitations which have been encountered in the process of conducting this study such as the unavailability of some relevant materials and the problems of communication with some related organizations. It is hoped that this study will benefit those interested in the subject, especially my colleagues at the Vietnam Maritime University.

CHAPTER I

SATELLITE TECHNOLOGY - AN OVERVIEW

1.1. Early Growth and Development

It is often said that the dream of satellites is as old as astronomy. Since the very beginning of history, man has dreamed of machines that would take him to other celestial worlds. The dream had not become true until 1957, when SPUTNIK, the first man-made satellite, was successfully rocketed by the Russians, marking the beginning of the space era. Following the Russians, the Americans launched their first Satellite EXPLORER in 1958 and the space race was born between the two leading countries in the field of Space Exploration. Since then, the number of satellites launched into orbit has been continuously increasing, influencing many fields of human life. Table 1.1 shows examples of the most important launches of satellites.

At present, there are a large number of satellites in orbit around the earth. Although most of them were launched by the US and the former USSR, recent years have seen a considerable increase in the number of countries capable of designing, building and launching satellites such as China, Japan, India, France and UK. According to a recent statistical study by Chien (1994, p32), over 22,900 items have been put into orbit by ten nations since 1957 when the space age began. Of those, only 4,486 were useful satellites.

Satellite technology is an expensive industry which needs dozens of billions of dollars' budget. However, recognizing its vital role in enriching life on earth, a number of countries, both developed and developing, have spent a great amount of money to enhance the satellite industry.

Table 1.1 - Selected Unmanned Artificial Satellites

Satellite	Launched	Launcher	Remarks
SPUTNIK 1	1957	USSR	first artificial satellite
SPUTNIK 2	1957	USSR	first inhabited space capsule
SCORE	1958	US	first transmission of voice messages
LUNA2	1959	USSR	first spacecraft on Moon
TIROS 1	1960	US	first weather satellite
TRANSIT 1B	1960	US	first navigation satellite
ECHO 1	1960	US	passive communication satellite
TELSTAR 1	1962	US	first transatlantic relay of TV signals
INTELSAT 1	1965	US	first communication satellite
A-1 ASTERISX	1965	France	first French satellite
LUNA 9	1966	USSR	first successful lunar soft landing
OSUMI	1970	Japan	first Japanese satellite
CHINA 1	1970	China	first Chinese satellite
PROSPERO	1971	UK	first British satellite
ERTS 1	1972	US	first earth resource technology satellite
ARYABHATA	1975	India	first Indian satellite
MARISAT-F1	1976	US	first maritime communication satellite
GPS-SVN1	1978	US	first Block I GPS satellite
INMARSAT 2-F1	1990	US	first INMARSAT-owned satellite

(source: Encyclopedia Britanica)

1.2. Basic Knowledge about Satellites

1.2.1. Overview

A satellite is defined as a space craft that is in orbit about a planet, usually the earth, and is intended for observation, research or communication in space. The behaviour of a satellite is described by the laws of celestial mechanics discovered by Keppler and Newton. The path of an earth-orbiting satellite might be a circle or an ellipse, but the center of the earth must be at its center or focal point. In order to get into orbit, a satellite must reach an escape velocity where the centrifugal force overcomes the force of gravity. For example, the escape velocity to get into a circular orbit around the earth is about 7.5 km per second. A satellite is placed into orbit by a rocket, which generates an enormous amount of energy to bring the satellite up to the required velocity and leave it in the orbit.

1.2.2. Types of Earth Orbit

Regarding the motion of satellites around the earth, there are four main types of orbit of satellites, as below.

Geostationary Orbit: Geostationary orbit is a unique eastward circular orbit on the equatorial plane, 35,686 km above the earth surface. A satellite in this orbit will move synchronously with the earth's rotation so that it can be seen as a fixed point from the earth. Since the altitude of the orbit is high, global coverage can be achieved by employing only three geostationary satellites. Most communication satellites are in the geostationary orbit, e.g. INTELSAT and INMARSAT satellites.

Inclined Circular Geosynchronous Orbits: Satellites in this type of orbit follow an identical ground track to some previous orbit after a certain period of time. Examples are Navstar GPS satellites.

Inclined Eccentric Geosynchronous Orbits: They are of varying inclination eccentricity and period. Molniya satellites are examples.

Non-Synchronous Orbits: Satellites in these orbits do not move synchronously with the earth's period of rotation. They are mostly used for research and military purposes.

The altitude of a satellite is also very important because it governs the time period, speed and time in line of sight of the satellite. Therefore, satellite orbits are sometimes categorized by the altitude.

- low orbit: lower than 500 km

- medium orbit : from 500 - 25,000 km
- high orbit: higher than 25,000 km.

1.2.3. Launch Vehicle and Launching

The rocket which brings a satellite to its orbit is called a launch vehicle or launcher. The major part of a launcher is used to carry fuel and re-agents. Efficient launching, weight lifting and velocity capacity of launchers are improved by employing multi-staged rockets and multi-injection techniques.

1.2.4. Structure

Space craft structure is required to be compatible with the launch vehicle and to provide a stable strong platform for the pay loads, subsystems and instruments. It is made from light weight and strong materials such as aluminum, magnesium and, more advanced, beryllium and plastic. Its weight represents only 5 to 20% of the weight of the satellite. A satellite typically comprises a payload, which is a set of experiments to perform the mission of the satellite, and a number of subsystems and instruments such as altitude control, thermal control, adapter.

1.2.5. Power

The primary source of power is the solar cell arrays oriented continuously perpendicular to the sun. Besides this, storage batteries are used during eclipse periods or when lacking solar power.

1.2.6. Control and Monitoring of Satellite Operations

Satellites send data to and receive commands from control stations on the earth through the telemetry, tracking command and communication subsystem. Measurements collected by satellites are transmitted to earth stations where the motion of satellites is tracked and plotted. Commands are sent back to the satellites in order to maintain the control over satellite operations.

1.3. The Impact of Satellite Technology

1.3.1. General Impact

Satellite technology development has an ever-increasing impact on our daily lives. Satellite technology makes valuable contributions to the knowledge of mankind about the earth itself, the solar system, as well as outer space. Various applications of satellite technology can be seen in many fields, such as in communications, weather forecasting, navigation, education, agriculture, earth resource monitoring and exploration, and even military reconnaissance. The potential of satellite technology is so great that it can change human life. In general, the applications of satellites can break down into three main areas, namely satellite communications, satellite remote sensing and satellite navigation.

Satellite Communications

The entire globe, including the ocean regions, can be covered by satellite communications. Satellites provide reliable communications to areas where conventional communication methods cannot reach. Satellite communication is the most important segment of today's commercial space market. At present, satellites provide over half of all international communications, including telephone, television and data communications. Applications of satellite communications can be seen in a large number of fields such as news reports, business, education, entertainment, health care.

Satellite Remote Sensing

Through the use of satellite technology, the earth can be monitored on a global scale. Remote sensing satellites have been used for meteorology and climatology, ocean and polar ice physics, surveying and mapping, earth resource exploration, monitoring of natural disaster and environmental impact of human activities. Satellite remote sensing makes it possible to obtain a global picture for the study of meteorology, oceanography, geology, seismic location, crop conditions and soil association assessment, etc.

Satellite Navigation

For navigators, surveyors and those who need to know accurately their position on earth, satellite technology has opened new horizons. Navigation satellites can provide them with unimaginably precise position data. The applications of satellite navigation are almost limitless. Navigators, aviators, surveyors and drivers are the primary beneficiaries of satellite navigation. Ships and aircraft can know exactly their position, whilst automobiles can pinpoint their destinations wherever they go. Applications of satellite navigation can also be seen in precision map making, construction projects, agriculture, etc.

1.3.2. Impact on the Maritime World

In the maritime world, the application of satellite communications and satellite navigation is clearly visible. Satellite communication is one of the main factors contributing to the safety and efficiency of modern shipping. With satellite communication, ships are capable of keeping in touch with shore at any time and any where. Information regarding ship operation, including commercial instructions, technical support as well as ship performance reports, can be exchanged via communication satellites. Apart from managerial functions, satellite communication has proven to be the best choice for distress and safety communications. The Global Maritime Distress and Safety System was developed on the basis of advanced technology in satellite communications and electronic devices.

Satellite navigation, particularly with the advent of the Global Positioning System, has brought about a new perspective to mariners. Navigators can now have access to a highly accurate, all weather, global positioning system. With the level of accuracy provided by satellite navigation, the distinctions among ocean navigation, coastal navigation and harbour navigation will gradually disappear. Navigation tasks are simplified, and hence the workload of navigators is reduced. Obviously, satellite navigation has greatly improved the safety and efficiency of shipping.

Mariners can also benefit from the applications of satellite remote sensing in the fields of meteorology and oceanography. Valuable data from satellites will be collected by meteorological and hydrographic offices before being sent to mariners in the forms of weather forecasts, storm warnings, routeing services, etc.

Undoubtedly, the increasing use of satellite technology in the maritime world needs to be reflected in the curriculum for maritime education. Training in satellite communications and satellite navigation has drawn much attention in maritime institutions. In addition, there is a growing interest in utilizing satellite technology to facilitate and enhance education and training onboard for seafarers.

In the following chapters, the application and implication of satellite communications, satellite navigation and satellite remote sensing, as well as their impact on maritime education and training will be discussed in depth.

CHAPTER II

SATELLITE TECHNOLOGY AND MARITIME COMMUNICATION

2.1. Introduction to Satellite Communications

More than a decade before the first successful launch of a satellite, the idea of using satellites for communications had been introduced. Scientists pointed out that radio signals could be relayed around the earth via satellites. Since then great developments have been made, both in theory and in experiments. The first transatlantic relay of TV signals was successfully transmitted via the telecommunication satellite named TELSTAR in 1962. However, until 1965, the era of commercial satellite communications was inaugurated by INTELSAT with the launch of INTELSAT I. The following years have seen great advances in the development of satellite communications such as the quantity and quality of satellites, the capability of communication systems, the services available. In addition, the number of agencies and organizations - national and international - dealing with satellite communications is increasing on a global scale.

Basically, a satellite communication system comprises three major components, which are the space segment, ground segment and user segment.

2.1.1. Space Segment

Most of the satellite communication systems employ satellites in geostationary orbit. Theoretically, three geostationary satellites can provide a global coverage. The main advantages of using geostationary satellites in communications are uninterrupted transmissions and unsophisticated tracking equipment. However, the disadvantages are that high latitude areas on earth cannot be covered and the received signals are weak due to free space loss of energy. Inclined eccentric geosynchronous satellites can also be deployed in the satellite communication systems, e.g. the Molnyvia satellite communication system in Russia.

2.1.2. Ground Segment

The operation of satellites in orbit and the activities of the communication network are monitored by a number of ground stations, which make up the ground segment of the system. The duties of the ground segment are:

- to monitor the operational activities of satellites in orbit.
- to control and assign communication traffic.
- to provide the link between the space segment and terrestrial communication networks.

Typically, a ground segment consists of:

- a Network Co-ordination Centre.
- Network Co-ordination Stations.
- Land Earth Stations.

2.1.3. User Segment

Users can access the satellite communication network through their terminals. Each terminal consists of antenna equipment and control and communication electronics, that provide the communication link between the users and the network.

In the maritime field, satellite communications have met the need to improve the communication links between ships and between ships and shore. Satellite communications have made a great impact on the shipping industry. Especially with the establishment of the International Maritime Satellite Organization, more and more satellite communication services are available to ships all over the world.

2.2. INMARSAT and Maritime Services

2.2.1. The Organization

The International Maritime Satellite Organization (INMARSAT) was founded and has been in operation since 1982. The primary purpose of INMARSAT is to improve communications for safety of life at sea and efficient fleet management. However, INMARSAT has been working constantly to improve and expand the range of its services. Jai Singh, Executive Vice President of INMARSAT, noted in one of his papers presented at the INMARSAT 1993 Conference that:

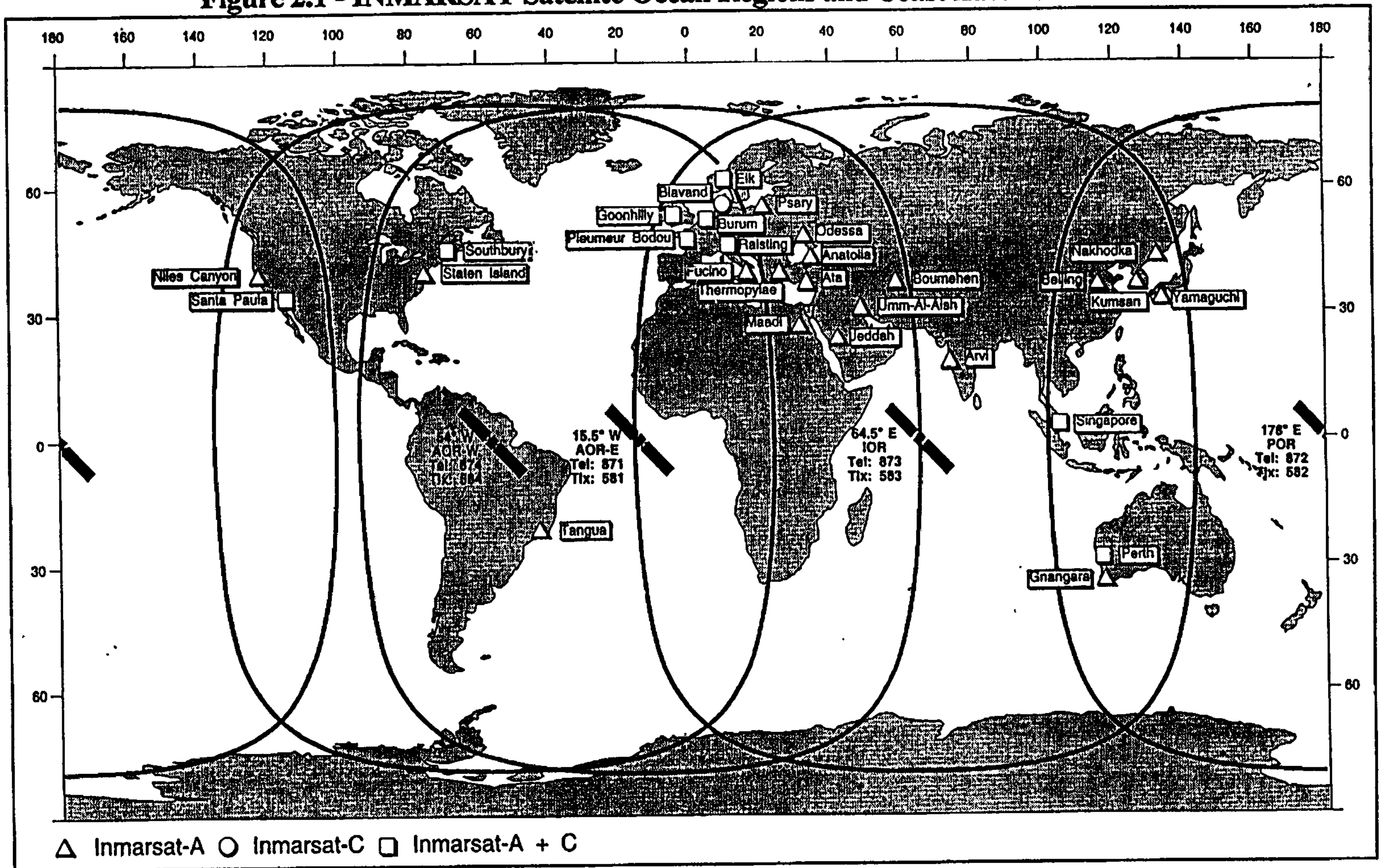
> It [INMARSAT] has evolved from a single market, single service system into a full service, global mobile-satellite system for all mobile user communities - maritime, aeronautical and land - with multi services (Jai Singh, 1993, p2).

INMARSAT is owned by telecommunication organizations known as its signatories. Currently, there are seventy two signatories, representing seventy two member states, with investment shares allocated in proportion to traffic carried. INMARSAT comprises three bodies which are Assembly, Council and Directorate. The Assembly consists of representatives from all member states. The Council is the policy-making body of the organization, comprising twenty two signatories of major member states. The Directorate is responsible for day-to-day operation of the system in the headquarters in London.

2.2.2. INMARSAT System

At the beginning, INMARSAT took over the Marisat Systems from COMSAT GENERAL (USA) and leased the other first generation satellites from the International Telecommunication Satellite Organization and the European Space Agency. During 1990 - 1992, INMARSAT launched its own second generation satellites and took over full control and operation of the communication system. All INMARSAT satellites are in geostationary orbit. Currently, there are four operational satellites located in four ocean regions: Pacific Ocean Region (POR), India Ocean Region (IOR), Atlantic Ocean Region - East (AOR-E) and Atlantic Ocean Region - West (AOR-W) (see Figure 2.1). There are also other fully ready

Figure 2.1 - INMARSAT Satellite Ocean Regions and Coast Earth Stations



(source: INMARSAT)

back-up satellites in each region to ensure continuity of service. In geostationary orbit, INMARSAT satellites provide communication coverage of all areas of the globe except the extreme polar regions.

The control centre of the INMARSAT system, which coordinates all operational activities of the network, is the Network Coordination Centre (NCC). The NCC is directly connected with all Land Earth Stations (LES) around the world, providing the link to the terrestrial communication network. It is also connected to the Network Coordination Stations (NCS) which manage and control communications traffic within each separate ocean region.

In the user segment, INMARSAT terminals installed on board ships are called Ship Earth Stations (SES). INMARSAT offers four different types of SES in compliance with four services: INMARSAT A, C, M and B (see Figure 2.2).

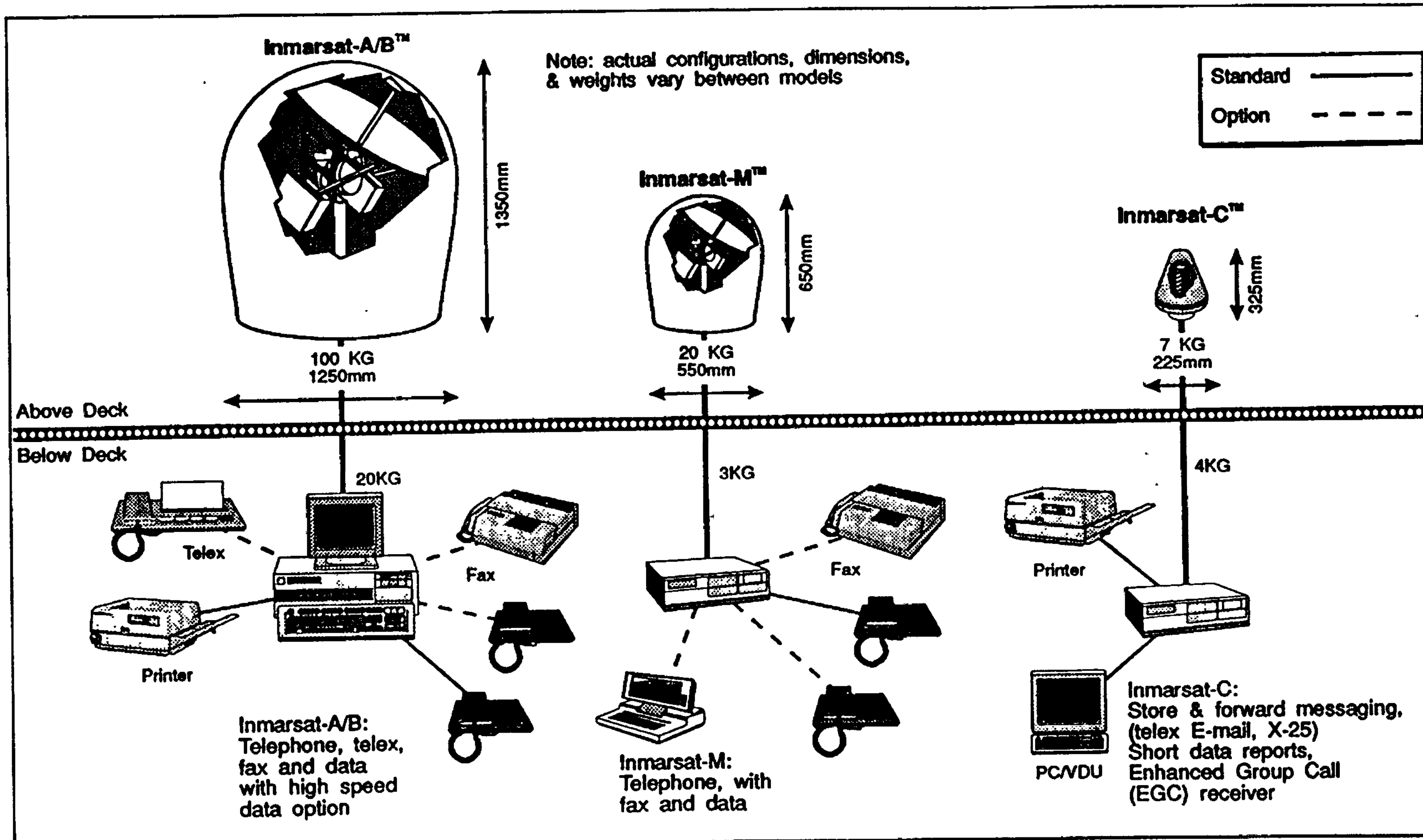
2.2.3. Maritime Services

The INMARSAT system provides a wide range of communication services with global coverage to a high degree of operational reliability. In general, users can access the following services, among other things:

- Distress communications
- Voice communications
- Telex
- Facsimile
- Data communications (low, medium and high speed)
- Data reporting
- Electronic data interchange
- Enhanced Group Call Broadcasting.

The communication services depend on the types and installation of SESs and the support from LESs. Table 2.1 and Figure 2.2 provide a short description of different SESs and their respective services.

Figure 2.2 - INMARSAT Ship Earth Stations: Size, Weight and Main Services



(source: INMARSAT)

Table 2.1 - INMARSAT Ship Earth Stations and Services

INMARSAT SES	System Description	Year of Introduction	Services Available
A	Real-time, Analogue system	1982	Voice, Telex, Fax, E-mail, Data communications, Distress alerting
C	Digital, Store and forward system	1991	Fax, Telex, E-mail, Data reporting, Distress alerting
M	Real-time, Digital system	1993	Voice, Fax, Telex, E-mail, Data Communications
B	Real-time, Digital system	1993	Voice, Fax, Telex, E-mail, Data communications Distress alerting

(source: INMARSAT)

2.3. Satellite Communications for the Global Maritime Distress and Safety System

2.3.1. Basic Concept of the Global Maritime Distress and Safety System

2.3.1.1. Introduction

Since the invention of radio at the turn of the last century, distress and safety communications at sea have been dependent on the radio-based terrestrial communications. However, there are a number of limitations in the existing distress and safety system which restrict its efficiency and reliability. For example, the range of the existing system is limited to around 150 nautical miles, the messages can be affected by atmospheric disturbances and ionospheric interference. These deficiencies of the existing system have led to the need of developing a new system, which can take advantage of modern technology in communications to overcome the problem.

The Global Maritime Distress and Safety System (GMDSS), which was adopted in 1988 in the form of amendments to the International Convention on Safety of Life at Sea (SOLAS), has entered into force since February 1992. Its introduction is a great effort by IMO to implement the objective of improving the existing distress and safety system by using satellite technology and advanced electronic devices.

2.3.1.2. Communication Functions in the GMDSS

In the GMDSS, search and rescue forces ashore and all ships in the vicinity of a ship in distress will be rapidly alerted and can assist search and rescue operations with a minimum delay (see Figure 2.3). Urgency and safety communications as well as promulgation of Maritime Safety Information are also provided. All ships subject to GMDSS will be able to perform, throughout any voyage, all of the following communication functions:

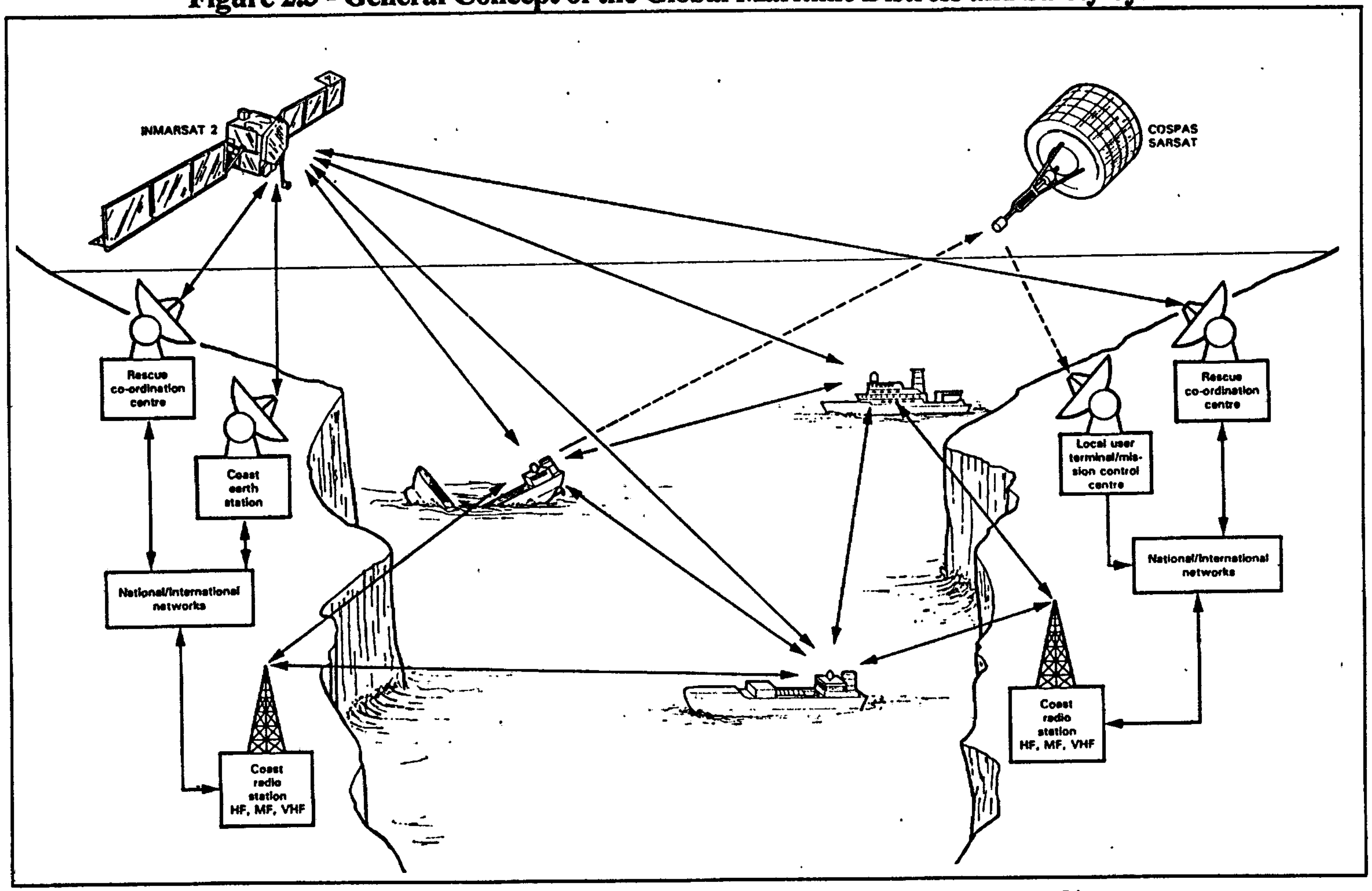
- Ship-to-shore distress alerting
- Shore-to-ship distress alerting
- Ship-to-ship distress alerting
- Search and rescue coordinating communications
- On-sense communications
- Locating signals
- Promulgation of Maritime Safety Information (MSI)
- General radio communications
- Bridge-to-bridge communications.

2.3.1.3. Sea Areas and Equipment Carriage Requirements

In order to be capable of performing the above-mentioned communication functions, ships need to be installed with the necessary equipment. Carriage requirements of equipment are based not on the ship's size but on the sea area where the ship operates. The GMDSS divides the oceans into four Sea Areas:

- Sea Area A1 - within the range of a VHF coast station with continuous Digital Selective Calling (DSC).
- Sea Area A2 - within the range of an MF coast station with continuous DSC (excluding Sea Area A1).

Figure 2.3 - General Concept of the Global Maritime Distress and Safety System



(source: IMO)

- Sea Area A3 - within the coverage of an INMARSAT satellite (excluding Sea Areas A1, A2).
- Sea Area A4 - the remaining sea areas outside Sea Areas A1, A2, A3.

Minimum carriage requirements for all ships subject to GMDSS can be summarized as below:

- VHF equipment with DSC
- Search and rescue radar transponder (9GHz)
- Equipment for receiving MSI broadcasts (NAVTEX or INMARSAT SES with Enhanced Group Call)
- Satellite Emergency Position Indicating Radio Beacon (EPIRB). VHF EPIRB can be an option for Sea Area A1 ships.

In addition to the minimum carriage requirements, ships will have to carry other radio equipment depending on operating sea area:

- ships in Sea Area A2 will have to carry MF equipment
- ships in Sea Area A3 will have to carry MF and either HF or Satellite equipment
- ships in Sea Area A4 will have to carry MF and HF equipment.

2.3.1.4. Time Frame for Introducing GMDSS

The GMDSS has been phased in gradually since February 1992 and will be fully implemented in February 1999, with the schedule as below:

- Ships constructed after 1st February 1992 to be fitted with radar transponders and two-way VHF apparatus for survival craft
- All ships to be fitted with NAVTEX receivers and a satellite EPIRBs by 1st August 1993
- All ships constructed before 1st February 1992 to be fitted with radar transponders and two-way VHF apparatus for survival craft
- All ships constructed after 1st February 1995 to comply with all requirements of GMDSS
- All ships to be fitted with radars capable of operating in the 9GHz band by 1st February 1995
- All ships to comply with GMDSS requirements by 1st February 1999.

2.3.2. The Role of Satellite Communications in GMDSS

Depending on the ship's operating sea area, the cost of equipment and services, and the need for total communications, shipowners and operators have a wide range of choice in equipment and operating system complying with GMDSS. Satellite communications have proved to be the best choice for medium and long-range requirements of GMDSS.

2.3.2.1. The Role of INMARSAT in GMDSS

The INMARSAT system plays a vital role in the GMDSS because it offers a simple and effective means to meet the requirements of the GMDSS. Under GMDSS, ships operating within INMARSAT coverage but outside the range of VHF and MF Coast Stations are allowed to dispense with HF radio equipment by using satellite equipment, i.e. INMARSAT SESs.

The INMARSAT system - with four satellites covering almost the entire globe, except the extreme polar regions - provides the services to most parts of the oceans. Distress alerting services via the INMARSAT system are constant and reliable. According to a recent operations report of INMARSAT on GMDSS communication services, the availability of space segment was maintained at a level of 100%, Network operation availability nearly 99.99%, and Network coordination stations availability 99.90% (IMO, COM 39/INF.6). Distress messages in the INMARSAT system automatically get the highest level of priority. They are immediately allocated a communication channel and routed to a Rescue Coordination Centre.

Most of GMDSS medium and long-range communications are offered by the INMARSAT system. Ship-to-shore distress alerting is provided by INMARSAT terminals or by INMARSAT satellite EPIRBs. Shore-to-ship distress alerting is transmitted through SafetyNET services of the Enhanced Group Call capabilities. INMARSAT terminals are also provided with SAR coordination communications, General radio communications and Promulgation of MSI.

In fact, the MSI can be provided by the NAVTEX service in coastal areas. However, a number of coastal states, due to many reasons, do not establish NAVTEX transmitting stations. In this case, INMARSAT terminals with EGC equipment are required to receive the promulgation of MSI through the International SafetyNET services.

The design of sea areas should also be taken into account. It is the governments who decide their own sea areas after establishing the radio coast stations network. Some coastal states have declared that their coastal waters are considered to be sea area A3 since they cannot afford the cost of building radio coast stations all along their coast. Therefore, satellite equipment installation is the best choice for ships to comply with GMDSS requirements.

2.3.2.2. The Role of COSPAS-SARSAT in GMDSS

COSPAS-SARSAT, a joint international satellite-aided search and rescue system, has been fully operational since 1985. Today, there are a total of 27 participating countries in the COSPAS-SARSAT system, including four party countries to the COSPAS-SARSAT agreement namely Canada, France, Russia and The United States.

The COSPAS-SARSAT system consists of three main components, which are:

- the space segment with four polar orbiting satellites
- the ground segment with a number of Local User Terminals (LUTs) and Mission Control Centres (MCCs)
- the user segment with three different types of beacons for aviation, land and maritime users.

The system operates on the following principle: COSPAS-SARSAT satellites detect the distress signals transmitted from beacons in distress and then relay them to LUTs, where the signals are processed to determine the beacon location. Messages are then forwarded to Rescue Coordination Centres through the MCC communications network.

Since the COSPAS-SARSAT system provides global coverage service with 100% availability, it has been adopted by IMO as a key element of the GMDSS. The number of 406 MHz COSPAS-SARSAT EPIRBs is continuously growing in the shipping industry due to the introduction of the GMDSS. According to the time frame of introducing GMDSS, all ships have had to carry satellite EPIRBs since 1st August 1993. At present, COSPAS-SARSAT EPIRBs have proved to be the best choice to comply with the requirements.

2.4. Impact of Satellite Communications on Shipping

2.4.1. Fitting of INMARSAT Terminals in the World Fleet

Since the introduction of INMARSAT-A in 1982 , the number of ships fitted with INMARSAT ship earth stations has been constantly increasing. According to the latest statistics from INMARSAT, INMARSAT-A still remains the mainstay for the satellite communication needs of ocean-going vessels, with more than 16,000 ships fitted with INMARSAT-A SESs. Despite the introduction of INMARSAT-C, and later on of INMARSAT-M and INMARSAT-B, the fitting rate of INMARSAT-A SESs is still consistent at about 100 terminals per month. However, the INMARSAT-C fitting rate is more impressive, about 200 per month, due to its suitability for GMDSS, small size and cost-effectiveness. Currently, more than 6,000 ships are equipped with INMARSAT-C SESs. The introduction of two new satellite communication systems in 1993, INMARSAT-M and INMARSAT-B, presents an opportunity for usage by more vessels. During the first introductory year, more than 100 INMARSAT-M and INMARSAT-B terminals have been installed on board ships. In addition, a small number of INMARSAT-E type approved EPIRBs are fitted on board ships.

The main categories of ships which have the highest number of INMARSAT SES fittings are general cargo and container ships, oil tankers, bulk carriers, fishing vessels and pleasure yachts. A large number of INMARSAT terminals are also installed in gas and chemical carriers, passenger ships and offshore vessels, including seismic vessels, drilling platforms and offshore support craft.

In terms of flag states, the highest SESs fitters are those countries who have the largest fleet such as Panama, Liberia, Japan, USA, UK, Norway, Russia.

2.4.2. Satellite Communications and Safety of Shipping

For a long time, mariners relied on a terrestrial ship-to-ship distress and safety communication system, which is limited by range, efficiency and reliability. The development of satellite communications (satcoms), together with that of advanced electronic technology has led to the introduction of the Global Maritime Distress and Safety System. As mentioned earlier, satcoms play a vital role in the GMDSS, providing an effective means to meet its requirements. Satcoms have proven to be of great advantage in alerting and locating the ship in distress, in assisting search and rescue operations, and in transmitting urgent messages as well as safety information. Needless to say, satcoms have vastly improved the safety of shipping.

Distress alerts can be relayed simply by pressing a distress button on the satellite communication terminal, by manually or automatically activating the satellite EPIRB. Distress communications are free of charge and automatically get the top priority. They are immediately allocated a communication channel and routed to the appropriate search and rescue centres as well as the ships in the vicinity. With satcoms, there is no danger that a ship will disappear without any trace.

Besides distress communications, shipping nowadays benefits from a large number of safety communication services. Maritime Safety Information broadcasts will enable mariners to avoid hazards, meanwhile weather routing services will provide the ship with the safest route, eliminating dangers during the voyage. Satcoms can also facilitate the search and rescue service by providing means to communicate essential information about the ship in distress. Furthermore, in any case of accident, immediate technical support from shore and the ships in the vicinity can be provided if necessary. Medical advice and assistance are also available through satcoms.

Using satcoms for broadcasting of chart corrections, GPS integrity and differential corrections will improve the safety of navigation. Vessel traffic can be properly monitored and controlled so that no regretful casualties will take place. In addition, satcoms are also used to eliminate unlawful acts such as piracy. Reports on the movement of pirates can be broadcast from the anti-piracy centre to all ships in the region over the SafetyNET. Casualties investigators and classification society surveyors can also benefit from the utilization of satcoms.

2.4.3. Satellite Communications and Efficiency of Shipping

Shipowners nowadays consider communications as a vital management tool to optimise ship operation, and they tend to move towards relying on satcoms for their communication needs. Reliability, clarity and flexibility of satcoms have made it the cost effective choice, compared with terrestrial communications. In fact, satcoms has significantly contributed to the improvement of efficiency of shipping, both for on-shore operation and for shipboard operations.

From the ship managers' viewpoint, progressive development of satcoms leads to the fact that the shore-based head office can play a much greater role in the day-to-day running of a ship. The exchange of information via satcoms provides a constant link between the ship and the head office, thus more and more of the ship's decision making and general management functions can be undertaken ashore. In the head office, there is a wide range of information about the chartering market, the freight, the bunker prices, etc., and a close connection with every ship in the fleet as well as all concerned parties such as insurers, brokers and agents, customs, suppliers. Commercial instructions from the head office, will be very helpful for the ship to reduce the turn-around time, to save bunkers, to eliminate time delays and to maximize the efficient use of transport facilities. Technical support, e.g. providing maintenance, cargo handling and voyage plans, will minimize maintenance costs, optimize loading and discharging procedures and assist the ship in finding out the best route to save time and bunker. In general, satcoms provide the ship operator with a reliable tool for management of the ship, its cargoes and crew, and hence enables him/her to respond well to the competitive market.

From the ship side, satcoms will provide the ship master with more information and support from the shore to assist him/her in making the right decisions and conduct the ship in a profitable and safe manner. Optimal routes can be chosen after a thorough analysis of all the information available such as weather forecast, navigational warnings, recommended routes, charter party requirements. Workload on board ship will be reduced since part of the management, such as maintenance plans, cargo bay plans and cargo handling, is carried out on shore. Crew performance can be encouraged due to regular connections with home and with the office. Technical support can be obtained from the experts and manufacturers on shore. Furthermore, satcoms is a main component of advanced technology used on board to support automation and reduction of crew manning.

In short, the ever-increasing use of satcoms terminal fittings as well as satcoms traffic has proved the necessity of satcoms in shipping nowadays.

2.5. Future Development of Satellite Communications

2.5.1. Lines of Development of INMARSAT

Mobile satellite communications is rapidly being developed to match the ever-increasing needs of world-wide mobile users. INMARSAT is continually working to improve and expand the range of services, on the basis of an advanced and efficient communication system of its own. In brief, lines of development of INMARSAT will take place in all aspects of technology enhancement, services and applications expansion, and legally binding amendments.

2.5.1.1. Enhancement of the Communication System

- Space Segment: The expansion of mobile communication satellite services and applications is much dependent on the capacity and flexibility of the satellites. Larger investment in the space segment is required to achieve the goals of smaller and cheaper mobile terminals for users. INMARSAT is introducing its third generation satellites, INMARSAT 3, with higher radiated power, larger capacity, increased sensibility and incorporated navigational payload. Further study for the introduction of a new INMARSAT-P system is also being conducted.

- Ground Segment: INMARSAT, in active cooperation with its signatories, is speeding up the deployment of Land Earth Stations all over the world in order to provide its services to all mobile users. Services and applications of each individual LES is also being expanded and improved.

- User Segment: With the introduction of INMARSAT 3 satellites, INMARSAT can urge Mobile Earth Stations manufacturers through the type approval procedure to develop smaller and less expensive mobile equipment and to increase the attractiveness to the customers. INMARSAT will also look for the improvement of the compatibility between terminals and the capability of integration with the terrestrial network.

2.5.1.2. Development of New Services and Applications

Based on the development of the communication system, particularly the space segment, the range of INMARSAT services and applications will be expanded to reach more and more customers. The existing and future services provided by INMARSAT are described in the INMARSAT Development Programme named Project 21 which was announced in 1991. The programme reflects INMARSAT strategy for the development of personal mobile satellite communication systems. The first stages of the programme have already taken place with the introduction of four different services namely INMARSAT-A, INMARSAT-C, INMARSAT-M and INMARSAT-B. The next stages will lead to the introduction of a global paging service and a global handheld telephone service.

In addition to the communications services, INMARSAT will also exploit the possibility of providing navigational services by geostationary satellites. Such concepts like geostationary overlay, global satellite navigation integrity broadcast and wide-area differential GPS are being developed and introduced to enhance the integration of communications and navigation by satellites.

INMARSAT will also have to take into consideration not only the improvement of existing satcoms applications but also the development of new applications such as multimedia conferencing, remote control and monitoring. Due to the increase of communication needs, there is no limit to the development of new applications in all areas of shipping, aviation and land mobile transportation.

2.5.1.3. Amendment to the INMARSAT Convention

Although INMARSAT was initially established for the purpose of improving maritime communications, it has expanded its services to the whole mobile users' community including maritime, aeronautical and land users. According to Jai Singh (1993, p2), land mobile services currently represent over a third of the organisation revenues. The INMARSAT Convention therefore has been amended twice; the aeronautical amendment in 1985 and the land mobile amendment in 1989. However, there are still some arguments on this issue such as the inequality of the three service areas, the name of the organisation. The question therefore arises of whether INMARSAT should change its name (as IMO did in 1982) and whether the INMARSAT Convention should be revised as a whole. Currently, there are no official statements but it may happen that there will be the so-called International Mobile Satellite (INMOSAT) Organisation instead of INMARSAT.

2.5.2. High Speed Data and Multimedia Conferencing

To meet the growing need of data communications, INMARSAT now offers high speed data (HSD) services, in which data is transmitted through INMARSAT satellites at the rate of 56 or 64 kbits per second. The HSD services, including simplex (one way ship-to-shore) HSD and duplex (two way) HSD, allow the fast transmission of computer data, still and moving pictures, high quality voice and video conferencing. It can also be connected with the public switch digital network, such as Integrated Switch Digital Network ISDN, providing users with high rate data connection to the final destination.

Taking the advantage of HSD communications and shipboard computer-based equipment, much effort has been done to develop the applications of multimedia conferencing between a specially equipped ship and several shore-based organizations. For instance, in most cases of serious technical problems, the experience of the ship's crew is insufficient, and thus technical support from the shore is necessary. A ship equipped with an INMARSAT-A terminal and a multimedia communication system including a local broadband network will then benefit from the multimedia communications with on-shore organisations. Experts from the shipping company, shipyards, engine and equipment manufacturers, etc., can use multimedia conferencing for remote inspection, problem diagnosis and solving, as well as for supervision of the repairing procedure.

A number of researches were conducted from 1989 to 1992 within the MARIN-ABC (Marine Industry Applications of Broadband Communications) Project, where positive results were found. Further development is now being studied under the MOEBIUS (Mobile Experimental Broadband Interconnection Using Satellites) Project. The project aims at the commercialisation of the results found by the MARINE-ABC Project.

Looking forward to the future, the applications of multimedia conferencing will be not only applicable to the maintenance and repair of ships but expanded to medical aids, vessel safety and administration, cruise floating conferences, etc. Further consideration needs to be taken in order to bring it from the theoretical experiments and demonstrations to commercial reality. It is also worth bearing in mind that 64 kbps is the lower edge for multimedia provision. Hence, much effort needs to be done in order to increase the data rate of the satellite channel and to refine the data compression algorithms.

2.5.3. Third Generation of INMARSAT Satellites

During 1994-1995, INMARSAT will deploy its third generation mobile communication system INMARSAT 3. Each of the four INMARSAT 3 satellites will provide a global beam and six spot beams. The power and band width can be dynamically reallocated among those beams so that the satellites can respond more rapidly to variations in traffic demand. Both the Effective Isotropic Radiated Power (EIRP) and the capacity of INMARSAT 3 satellites are much higher than that of the current second generation satellites. Each INMARSAT 3 satellite has an L-band EIRP of 49 dBW and capacity of 2500 two-way voice circuits, while the figures of INMARSAT 2 satellites are 39 dBW and 250 circuits. Using the latest technology in mobile communication satellites, i.e. spot beams, increased sensibility, higher capacity and power, INMARSAT 3 satellites will make it possible for users to communicate via smaller and less expensive mobile terminals. In addition, INMARSAT 3 satellites will also carry navigation payloads and mobile-to-mobile links.

2.5.4. INMARSAT Navigational Services

Differential GPS transmission

Differential GPS corrections can be disseminated through INMARSAT satellites to help users to improve accuracy to a few metres. Currently, INMARSAT is developing a Wide-Area Differential GPS system which collects the GPS signals from a number of reference points, processes these signals at a central processing centre and then relays the differential correction factors to users.

INMARSAT overlay to GPS

INMARSAT 3 satellites will carry on board navigation payloads designed to broadcast L1 GPS/GLONASS look-alike signals. Studies have shown that if INMARSAT satellites transmit Coarse/Acquisition coded signals, there is no significant impact interference with the GPS signals. GPS receivers will need only minor modifications to receive such signals. GPS and GLONASS users will benefit from geostationary overlay because it can provide:

- additional ranging signal sources to enhance the availability of the GPS/GLONASS system(s).
- real-time GPS/GLONASS Integrity Broadcast (GIB) to alert users when any of the navigation satellites is out of tolerance.
- differential correction broadcast to improve the accuracy of positioning.

In addition, the overlay of INMARSAT satellites will provide civilian administrations participation in GPS and GLONASS navigation systems which are not under their control.

2.5.5. INMARSAT Global Paging Service

Regional radio paging services have been operational for almost 20 years, providing one-way message delivery services to users in limited areas via the terrestrial communication networks. The growing interest of travelers in mobile vehicles in the applications of paging services has led to the need of a global paging service. INMARSAT is currently studying the possibility of extending the existing radio paging services using satellite communications. The INMARSAT Land Earth Stations can be connected to the terrestrial radio paging services through the message originators and paging terminals. Special equipment and facilities in the LESs will encode and format the messages and then relay to receivers mounted on mobile vehicles via the INMARSAT satellites. It is hoped that the Global Paging Service will be introduced by INMARSAT during the next few years.

2.5.6. INMARSAT-P Handheld Telephone Service

INMARSAT-P is the final stage of the project 21, which INMARSAT has been working along, in order to achieve the objective of introducing increasingly smaller and less expensive global personal mobile satellite communication services. INMARSAT-P is a dual mode satellite-cellular handheld terminal, offering line-of-sign satellite voice service to mobile users all over the world. INMARSAT-P is aimed at about 30 times the third generation capacities with EIRP of 64 dBW and over a hundred beams. INMARSAT is intensively working so that INMARSAT-P can be introduced at the end of the decade (1998-2000). According to Jai Singh (1993, p10), INMARSAT has conducted a comprehensive study on the potential market for INMARSAT-P user needs and preferences, as well as technical and economic evaluation of various satellite configurations for such a system.

To introduce INMARSAT-P service, INMARSAT will deploy a new satellite system of higher cost, greater complexity and larger capacity. Three options have been proposed by various telecommunications contractors, which are summarised by Jai Singh (1993, p9) as below:

- An enhanced geostationary (GEO) satellite system, comprising 4 to 6 more powerful satellites which are incorporated with a large number of small spot beams.
- An intermediate circular orbit (ICO) satellite system, comprising of 9 to 15 satellites orbiting at about 10,000 Km.
- A low earth orbit (LEO) satellite system, comprising 54 operational satellites orbiting at about 1,800 Km.

INMARSAT has decided to focus on GEO and ICO constellations, but not LEO, to minimize the cost and complexity. The final architecture of the system will be decided this year. After this decision, INMARSAT will have to conduct further studies such as to examine the service commercialization issues, to initiate the Technology Validation Programmes, to prepare for the launches of new satellites, etc., before deploying the system (Jai Singh, 1993, p10). Hopefully, INMARSAT-P system will be operational at the start of the next century, providing mobile users with access to a global handheld telephone service anywhere on the globe.

CHAPTER III

SATELLITE TECHNOLOGY AND MARINE NAVIGATION

3.1. Introduction to Satellite Navigation

Conventional ground-based radio navigation systems have been in use for many years, providing reliable position data with sufficient accuracy for navigators. They are of many types, with different operational principles, range, coverage and accuracy. The most common and widely used ground-based radio navigation systems are, inte alia:

- *Decca:* a low frequency hyperbolic system using phase-differencing measurement techniques, short range (440 NM by day, 240 NM by night), accuracy of 50 to 200 m.
- *Loran C:* a low frequency hyperbolic system using time-differencing measurement techniques, medium to long-range (1000 NM), accuracy of 100 to 500 m.
- *Chayka:* the Russian equivalent to Loran C.
- *Omega:* an ultra low frequency hyperbolic system using phase-differencing measurement techniques, providing global coverage with eight stations and accuracy of 2 to 3 NM.
- *Alpha:* the Russian equivalent to Omega.
- *HyperFix:* a medium frequency, hyperbolic system with short range (less than 150 NM) and accuracy of 10 to 50 m

The above ground-based radio navigation systems are suffered from a number of shortcomings, inte alia:

- Restricted range and coverage; apart from Omega and Alpha, the other systems are limited by range and coverage.

- Inaccuracy; generally, the accuracy cannot meet the needs of precise navigation, except within a very limited range.
- Weather dependence; accuracy is strongly affected by weather conditions such as snow and precipitation.
- Propagation variability; received signals may come from unwanted sources such as sky waves.

The inherent deficiencies of the ground-based positioning systems have led to the growing interest in utilizing satellite technology for the purpose of positioning. Since the advent of satellite technology, a number of satellite-based positioning systems have been deployed, contributing a significant element in the improvement of safety and efficiency of navigation. Those satellite-based systems, which are used solely for navigation and positioning purposes on a global basis, are called 'satellite navigation' or 'satnav' systems. In addition, a number of satellite communication systems can also provide location services as a secondary function and normally on a regional scale.

3.1.1. Satellite-based Radio Location systems

Deploying geostationary satellites, these systems can be considered as Radio Determination Satellite Systems, which enhance communication satellites by navigation payloads. Like other ground-based radio navigation systems, they are designed to provide services to cover only high demand navigation areas such as North America and Europe. However, they do make competition with other position fixing systems by offering positioning services of high accuracy for fleet management.

Starfix

Operated by John E. Chance and Associates Inc. (US), Starfix is a regional satellite positioning system in the US and the Gulf of Mexico. It can offer a real-time, 24 hour a day positioning service with accuracy of two to five metres. Starfix employs geostationary satellites in the equator plane. Positioning techniques to some extent are similar to the GPS system with the use of pseudo-random codes. Starfix has been incorporated with the differential GPS system to provide its clients with additional redundancy and three dimensional positioning service.

Euteltracs

Euteltracs is a regional satellite-based mobile communication system operated by EUTELSAT. It has been in commercial operation since 1991, primarily for European transport industry. Euteltracs provides real-time, two-way message exchange and position reporting for transport operations. Position determination is obtained by the transmission signals to mobile terminal via two separated EUTELSAT satellites in the geostationary orbit. Time difference between the two wave forms is measured by the mobile terminals and then transmitted to a central hub station, where the position is calculated with an accuracy of about 300 m.

Omnitracs

The Omnitracs system is based on the same technology as used in the Euteltracs system. Owned and operated by Qualcom company in the US, the system has been commercially operated since 1989. Like Euteltracs, it is primarily used by the road transport industry.

Argos

Argos is a satellite processing and location system in the US. Operated by Service Argos Inc., Argos utilized the TIROS-series polar orbiting satellites of the US National Oceanic and Atmospheric Administration to provide marine users with near real-time environmental data collection and location processing. The accuracy of the Argos location service is 150 m.

In addition, it is also worth mentioning that two other satellite-based radio location systems in North America and Europe, Geostar and Locstar have been recently defunct.

All of the regional satellite-based radio navigation systems have provided a very good tool for positioning requirements in some areas. However, there are still a number of limitations, inter alia:

- Global coverage cannot be achieved.
- Only two dimensional position information can be provided.
- Geometry around the equator is not good.

3.1.2. Satellite-based Radio Navigation Systems

The idea of using polar orbiting navigation satellites to achieve global coverage was considered immediately after the successful launch of the first man-made satellite. In the early 1960s, the United States deployed the first global navigation satellite system, Transit. Since then great efforts have been made in this field, both by the Americans and the Russians. Currently, there are four global satellite navigation systems which have been operational or are under development. They are Transit, Tsicada, Navstar GPS and GLONASS.

Transit

Established by the US Navy since the early 1960s, Transit was the first global satellite navigation system in the world. The system exploits six low polar orbiting satellites which transmit radio signals in two carrier frequencies of 400 MHz and 150 MHz. The position is calculated from Doppler shift in the frequencies of satellite transmissions. In order to compute the position, a receiver needs to get signals from one or more satellites within its sight at an acceptable elevation (from 10 to 75°). This causes the main shortcoming of the system because six satellites in polar orbits cannot provide continuous position fixing. The time between acceptable fixes will increase from the poles to the equator, taking an average of 1.5 hours. Even a ten-hour interval time between two fixes has been recorded. Despite this, the system has been highly appreciated by navigators due to its global coverage and high accuracy of position fixing. With the introduction of the GPS system, Transit is scheduled to be switched off, ending a quarter of a century serving navigators.

Tsikada

A Russian equivalent system to Transit is the Tsicada system which deploys four polar orbiting satellites. Similar to Transit, it provides for discontinuous position fixing with accuracy of 80 to 120 metres. The system will be utilized until the full deployment of the GLONASS system.

Navstar GPS

Developed by the US Department of Defense since the early 1970s , Navstar GPS is a worldwide satnav system designed primarily for military use. Civil users can access the system through the Standard Positioning Service. The US Government has invested US$ 12 billion to establish the system. However, its incredible performance and potential have proved that the money has been well spent. The system employs some of the most advanced techniques to provide high accuracy three dimensional positioning data with an update rate of less than one second. Navstar GPS will be dealt with in more detail later on in this chapter.

GLONASS

GLONASS is a Russian system which offers many features in common with the Navstar GPS system. Its design consists of 24 satellites at the altitude of 19,100 km, with eight satellites in each of the three orbital planes. Currently, the system is still in the pre-operational phase, with 14 satellites in operation. Due to the economic difficulties currently facing the Russian Government, there is doubt about the full deployment of the system. However, Russian officials are still insisting that the system will be fully operational in a couple of years' time. There is also some support in Europe for employing GLONASS, either integrated with Navstar GPS or standalone, in the proposed Civil Global Navigation Satellite System.

Satellite technology has brought about a new perspective to navigation in general and marine navigation in particular. Obviously, satellite navigation (satnav) systems play a critical role. They are gradually replacing the outdated ground-based systems, as Hugh Young (1993, p10) pointed out:

> Positioning systems are in a transitional stage between radio systems and satnav systems. Although the former are in current use, there is little incentive to develop them further, and they are being displaced by satnav systems, mainly the Global Positioning Systems.

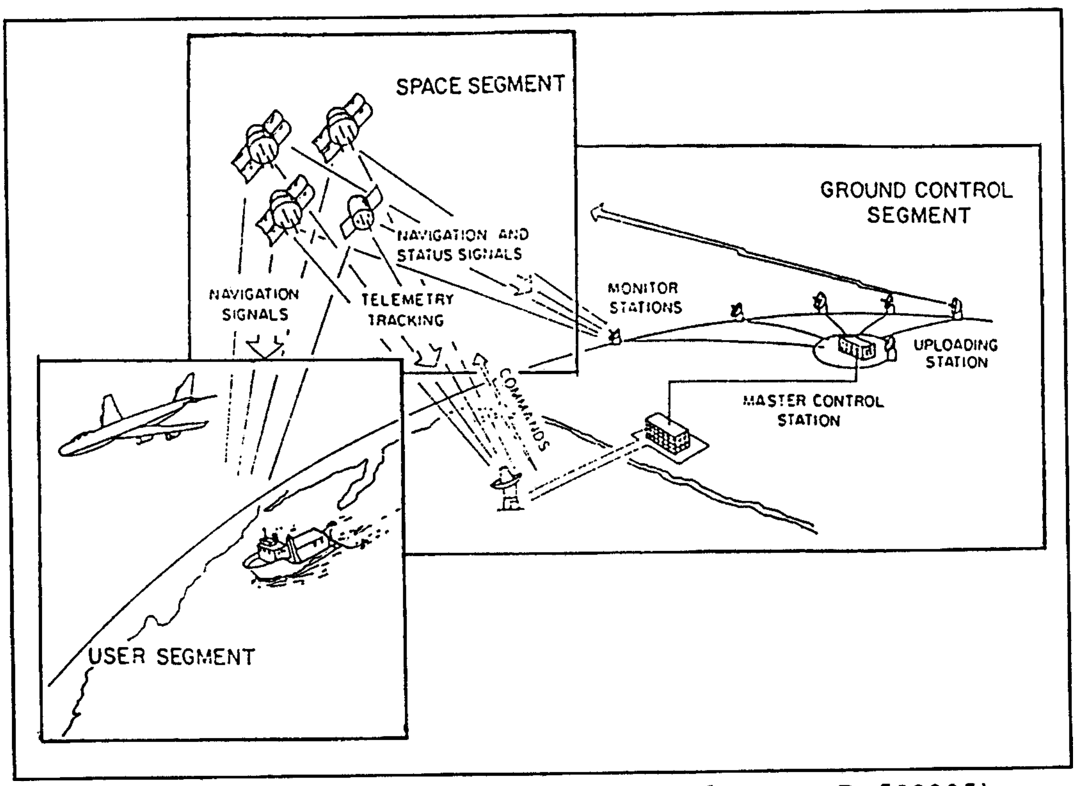
Since Transit and Tsicada are going to complete their historic role and GLONASS is currently in the operational phase, the GPS system will be emphasized in this study.

3.2. Short Description of Navstar GPS

3.2.1. The System Design

The Navstar GPS system, or simply GPS, is composed of three main parts, which are the space segment, the ground segment and the user segment (see Figure 3.1).

Figure 3.1- Configuration of the Global Positioning System



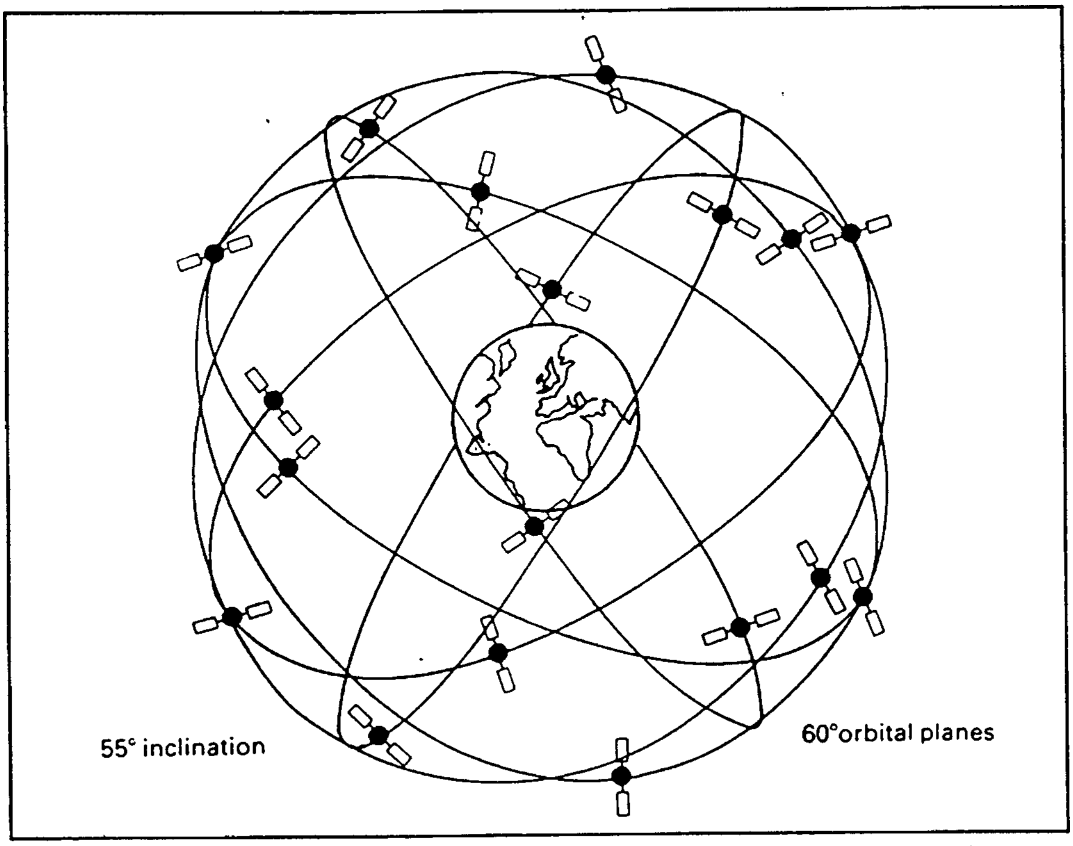
(source: Ackroyd N. and Lorimer R. [1990])

3.2.1.1. Space Segment

The fully operational system consists of 21 operational plus 3 active spare satellites for a total of 24 satellites orbiting the earth at an altitude of 20,200 km.

Four satellites are deployed in each of six near-circular orbital planes which are inclined at 55° to the equator and phasing 120° to each other (see Fig. 3.2). With this design, any point on the earth's surface can view at least six satellites at any given time.

Figure 3.2 - GPS Satellite Coverage



(source: Tetley L. and Calcutt D. [1991])

According to the GPS programme, five blocks of GPS satellites have been developed, namely:

- Block I (Navigation Development Satellites): Eleven Block I satellites were launched during the 1978-1985 period (including one failure). Three of them are still functioning well beyond their designed lifetime.
- Block II (Operational Satellites): Nine Block II satellites, which were launched during 1989-1990, continue to function successfully.

- Block IIA (Operational Satellites): Fifteen Block IIA satellites were launched during the last four years.
- Block IIR (Replacement Satellites): There will be 20 Block IIR satellites available for launch from 1996 onwards.

The Initial Operational Capability (IOC) was announced in 1993, when there were twenty one Block II and three Block I satellites in orbit. At the time of writing, the operational constellation has been brought up to 27 satellites, including 24 Block II and IIR satellites and three usable Block I satellites. Full Operational Capability (FOC) will likely take place in the very near future.

3.2.1.2. Ground Segment

The ground segment is responsible for daily control of the system, i.e. tracking and updating satellites to keep them accurate. It consists of three main types of operational facility:

- Master Control Station: controlling the satellites, estimating the navigation performance and producing the ephemeris.
- Monitoring Stations: tracking the satellites and collecting range data.
- Uplink/Downlink antennas: transmitting navigation data and commands to satellites.

3.2.1.3. User Segment

The essential part of the user segment is the GPS receivers which receive the signals from the satellites to process and determine the position. They can be of three main types:

- Parallel/multi-channel receivers: one dedicated channel to each satellite.
- Slow and fast sequencing receivers: single or dual channels only.
- Multiplexing receivers: capable of switching between all tracked satellites in very short time (less than 20 milliseconds).

In addition, the user segment includes other elements such as Differential GPS and integrity monitoring systems.

3.2.2. Pseudo-Ranging for Position

GPS is based on satellite ranging. In other words, the position is calculated from distance measurement to satellites. Theoretically, with three satellite positions as precise reference points and their corresponding distance measurements, the three-dimensional position of the receiver can be triangulated or computed. However, due to the time difference between satellite and receiver clocks, four, not three, measurements are required. In order to determine the position of a receiver, the range measurements must be accurately calculated and the position of satellites in the space must be identified. In the GPS system, a number of advanced techniques are applied to obtain these goals.

3.2.2.1. Pseudo-random Noise Codes

In the GPS system, both satellites and receivers generate very complicated pre-designed sets of digital codes of 1s and 0s, which look like a long string of random pulses (hence the name pseudo-random). There are two different types of pseudo-random noise (PRN) codes, P code and C/A code, used for two positioning services of the GPS system, respectively Precise Positioning Service and Standard Positioning Service. Each satellite is allotted its own individual PRN codes so that the receivers can distinguish it from others. The codes are also carefully chosen so that they can be compared easily and unambiguously at any time. This is an advantage of code signals over the conventional radio waves.

3.2.2.2. Pseudo-range

The GPS system works by timing how long the radio signals travel and then calculates the distance from that time. The satellite sends PRN codes, meanwhile the receiver generates replica satellite codes and then compares with the codes received from the satellite to get the time difference and hence range measurement. Due to the satellite clock and the receiver clock not being synchronized, the measurement is not the true range but pseudo-range.

3.2.2.3. GPS Clocks and Timing

Accurate timing is the key to measuring distance to satellites. GPS satellites have atomic clocks on board, which provide extremely accurate time and frequency. The receiver clock bias, i.e. the difference between satellite clocks and receiver clocks, is then considered as another unknown in the process of computing the position. This can be solved by taking the fourth satellite range measurement.

3.2.2.4. Satellite's Position

The GPS satellites continuously transmit 1500-bit-long navigation messages, which contain the information about satellite ephemeris, satellite clock corrections, almanac and system status. Based on this information, the receivers have knowledge of the satellites positions at all times.

3.2.2.5. Position Determination

Because the receiver's position is calculated in a three dimensional coordination system, there are three unknowns which are latitude, longitude and height, or more generally x, y, z. In addition, the clock error t is the fourth unknown. After the receiver has performed range measurements to four satellites, a series of four simultaneous equations can be established with the above mentioned four unknowns. The position and clock error are then easily calculated by the receiver processor.

If additional information about height and/or clock error is provided , one or two unknowns can be determined independently. Therefore, the number of simultaneous equations and the number of range measurements can be reduced. This approach is called position aiding. In the case of only height aiding or only clock aiding, three range measurements are needed. If both of them are available, only two range measurements are required to determine the position.

3.2.3. GPS Parameters

3.2.3.1. GPS Signals and Frequencies

All satellite operations are synchronized with the satellite atomic clocks operating at the fundamental frequency (f_o) of 10.23 MHz (In fact, f_o is increased by 0.00455 Hz to counteract the effect of relativity). GPS satellite signals are transmitted on two carrier frequencies in the L band: L_1 = 1575.42 MHz (154 f_o) and L_2 = 1227.60 MHz (120 f_o). The PRN codes and navigation messages are modulated on the carriers using spread spectrum and phase quadrature techniques. L_1 carrier carries the navigation messages and both P code and C/A code, while on the L_2 carrier, navigation messages and only P code are available.

- Satellite navigation message: consists of a data frame of 1500 bits and transmitted with a rate of 50 baud.
- C/A code: has a bit frequency of 1.023 (f_o/10) and a code length of 1023 bits or 1 millisecond.
- P code: has a bit frequency of 10.23 (f_o) and a code length of 6.05×10^{12} bits or 267 days.

3.2.3.2. Error Sources and Accuracy

The accuracy of the GPS system is degraded by various error sources, depending on the atmospheric and equipment condition. In addition, the US Department of Defense has intentionally, for the military needs, implemented Selective Availability (SA) mode which contributes the largest component of GPS error. Typical GPS error budget, in term of range errors with two standard deviations, is provided in Table 3.1.

Satellites geometry or geometrical constellation of satellites can also be considered as another error source that degrades the accuracy of the GPS position. It is expressed by a multiple factor called Dilution Of Precision. For maritime users, Horizontal Dilution Of Precision (HDOP) is normally used. The two dimensional position accuracy is the product of the total range error and the HDOP. When the GPS system is fully deployed, HDOP is expected to be less than 3.0. It means that,

Table 3.1. GPS Error Budget

Sources	Error (2drms)
Satellite clock error	1.5 m
Ionospheric and tropospheric delay	5.5 m
Emphemeris error	2.5 m
Multipath	0.6 m
Receiver noise	0.3 m
Selective Availability	30.0 m

(source: Trimble Navigation)

even with the worst case of the SA, the accuracy is still within 100 meters (2drms).

Military users have access both to the Precise Positioning Service (PPS) and the Standard Positioning Service (SPS) and can remove the effect of SA. Meanwhile, civilian users can only access to the SPS. PPS has a two dimensional accuracy of better than 18 m (2drms). SPS provides a two dimensional accuracy of better than 35 m (2drms) without SA and 100 m (2drms) in case of SA.

3.3. Differential GPS

3.3.1. The Need for Differential GPS

Although the GPS system provides remarkable accuracy, it still does not meet the needs of harbour and harbour approaches navigation as well as some other maritime applications in coastal water. For instance in the US, the accuracy for coastal navigation are provided in the 1990 Federal Radio Navigation Plan as in Table 3.2 below.

Both services offered by the GPS system, i.e. the SPS (with or without SA) and PPS, cannot reach this level of accuracy. However, differential technique can provide a method to make the system more accurate. Differential GPS (DGPS) can improve the navigational accuracy to better than 10 metres and therefore it can cover all the navigator's needs except berthing. Differential GPS can also meet all the requirements of integrated navigation systems, including the Electronic Chart and Display Information System.

Table 3.2 - Required Accuracy for Maritime Applications in Coastal Water

Harbour and harbour approaches	10 m (2drms)
Aids to navigation Positioning	10 m (2drms)
Vessel traffic services	10 m (2drms)
Near-shore surveying	15 m (2drms)

(source: US Federal Radio Navigation Plan - 1990)

In addition to this, DGPS also provides a mean of continuous integrity check on the satellites' health. In fact, there is a danger that users' receivers may use erroneous signals from an unhealthy satellite because those signals cannot, within a certain period of time up to six hours, be detected and corrected by the Master Control Station. DGPS with continuous and real-time transmission can immediately detect, alert and instruct the users' receivers not to use the erroneous signals.

DGPS has been under study since 1983, when the GPS system was announced to be available to the world. It has been thoroughly tested, providing the accuracy of less than 10 metres for moving vehicles and even better for stationary objects. Currently, DGPS is deployed, or planned to be deployed, on a global scale.

3.3.2. Differential GPS Fundamentals

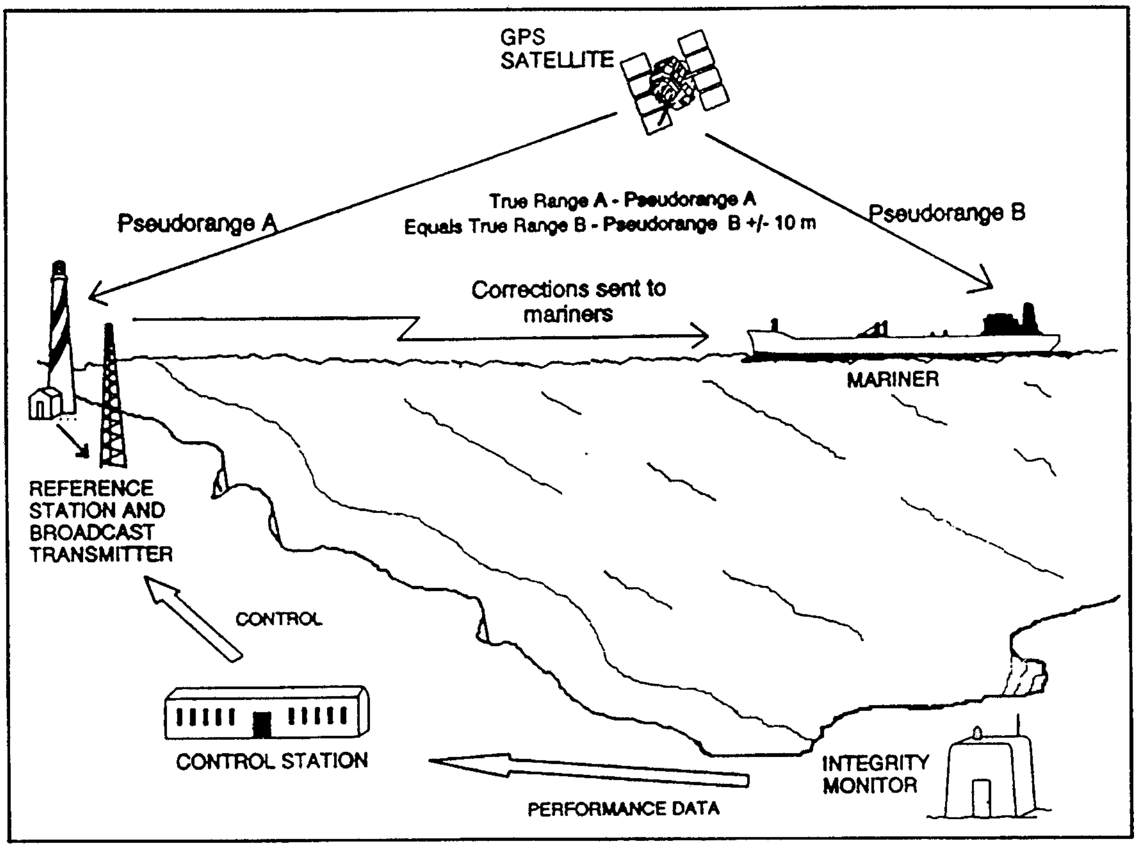
3.3.2.1. Operational Principles

DGPS techniques make the GPS system more accurate by canceling out most of the natural and man-made errors in normal GPS measurements. A reference station, of which the geographic location is precisely surveyed, is used to compute corrections to GPS parameters and error sources. All correction information is then transmitted to GPS users' receivers within the coverage of the reference station to correct their position calculation. Theoretically, there are two basic methods of transmitting the corrections in DGPS as below:

- Transmitting position corrections in three dimensional co-ordinates
- Transmitting pseudo-range corrections to each satellite.

Transmission of position corrections messages requires less data to broadcast but the accuracy of the corrections depends on the distance from the reference station to the receivers. In addition, the reference station and the receivers must use the same set of satellites. Pseudo-range correction methods can overcome such limitations and is used for the DGPS services.

Figure 3.3 - DGPS System Concept



(source: Alsip D. H. et al [1993])

3.3.2.2. Configuration

Typically, a DGPS system consists of the following major elements, among other things:

- The Reference Station: computing the pseudo-range corrections from the GPS observations and generating messages in the required format.
- The Data Link: relaying the correction messages received from the reference station to the mobile stations.
- The mobile station: computing a position solution from the received raw GPS data and the corrections.

3.3.2.3. Transmission of DGPS Correction Data

There are a number of choices for the radio link to relay the corrections from the reference station to the mobile station. MF and HF bands have been chosen for transmitting the DGPS messages. For instance, Sercel (France) uses HF frequencies between 1.6 - 3.5 MHz, and the USCG chooses the MF radiobeacon frequencies between 285 -325 KHz. Satellite-based data link is also taken into consideration.

Typically, the DGPS messages are transmitted at the rate of 50 baud, with an update rate of once every ten seconds. Experience has shown that an update rate of once every five seconds is much better, especially when SA is implemented.

There is an international standard for sending and receiving DGPS messages called RTCM-SC104. The RTCM-SC104 format version 2.0 was introduced by the US Radio Technical Commission for Maritime Service - Special Committee 104 and supported by the International Association of Lighthouse Authorities (IALA). It is now being used by all GPS manufacturers. A new version of RTCM-SC104 is also under study by the IALA. A number of different types of DGPS messages have been defined. The most significant ones are:

- Type 1: Standard DGPS Corrections
- Type 2: Delta DGPS Corrections
- Type 3: Reference Station Information
- Type 5: Constellation Health

- Type 9: High Rate DGPS Corrections
- Type 16: Special Text Messages.

Type 1 DGPS messages contain the pseudo-range corrections and their rate of change for all satellites in view of the reference station. Type 9 messages are similar to type 1 but they are transmitted at a higher update rate, providing greater accuracy, improved integrity and reliability over type 1. Therefore, type 1 is supposed to be superseded by type 9.

3.4. Impact of GPS on the Marine Industry

3.4.1. Impact of GPS on Marine Navigation

The GPS system is considered to be the world's most dramatic navigation achievement. For the first time, all of the navigator's tasks can be covered by an all-weather, highly accurate and worldwide positioning system. With the introduction of GPS, marine navigation is shifting to a new era of precise navigation, as Nijjer (1993, p3) pointed out: 'It [GPS] will enable port-to-port navigation using a single navigation aid with an accuracy and precision unimaginable even a decade ago'. Only the GPS system can provide consistent accuracy of better than 100 metres in all weather, any where in the world and at any time for general navigation. Different techniques can also be applied to offer accuracy of several metres or even at sub-metre levels for the purposes of coastal and harbour navigation.

In general, there is no doubt that GPS will greatly improve the safety and efficiency of navigation. Overall errors in determining the distance between a vessel and the closest danger can be substantially reduced. The danger of accident due to inaccurately positioning can be eliminated. Ships can be efficiently guided to follow the planned tracks to save time and bunkers. Ship officers' workloads will be reduced regarding to the duties of positioning and evaluating the reliability of position fixes. In addition, GPS can also be the most reliable and consistent positioning data input to any integrated navigation system.

On the other hand, it is worth paying attention to the negative impact of the GPS system to navigation, particularly to the man-machine-environment relationship.

Ship officers might be over dependent on GPS and fail to try to obtain information from various sources. Another danger is the reliance on the accuracy of GPS without considering the effects of the navigational environment. For example, if the accuracy of the surrounding chart data is not as good as the accuracy of GPS position, to some extent GPS has created a higher potential for danger.

The increasing use of GPS will also improve the existing problem regarding the co-ordination and datum of sea charts. GPS corresponds to the World Geodetic System WGS-84 while sea charts have been produced according to a large number of different geodetic datums. GPS fixes can be transformed to some of them but the accuracy will be degraded. A number of sea charts cannot be used for plotting GPS fixes because they are of unknown datums. For example, approximately half of the 3,300 British Admiralty Charts are referenced to various known datums, whilst the remaining half are not referenced to a stated datum. Thus there is a need for an international adoption of a single worldwide datum for sea charts.

3.4.2. Effects of GPS on Other Navigation Systems

The applications of the GPS system, which are spreading into the marine industry, will have great impact on the operation and development of other radio navigation systems. GPS is much more attractive to navigators than the others for a number of reasons listed below.

- GPS has proven its superiority over the other positioning systems such as weather-independence, high accuracy, real-time and worldwide coverage.
- Currently, GPS is offered to the civilian users free of charge (at least for ten years).
- In the GPS system, the complexity is built into the satellites so that the GPS receivers are simple and small, with low power, and hence relatively low cost.
- GPS can provide numerous applications in all aspects of the marine industry.
- GPS is the most suitable positioning sensor in an integrated navigation system.

Technological achievement and applications of GPS will ensure that GPS is a standard navigation system. The superiority of GPS not only attracts the maritime users but will affect the maritime policy-makers as well. Eventually, it would lead to the suppression of the other conventional positioning systems by a single highly reliable satellite navigation system such as GPS.

In the US, Transit is planned to be switched off. Omega is going to be phased out and Loran-C will no longer be required after full deployment of the GPS system. Meanwhile, carrying GPS/DGPS receivers is likely to be compulsory.

Reactions to this issue in the rest of the world are much more cautious because navigators cannot rely solely upon a system under the control of the US and principally used for military purposes. Therefore, another back-up system selected from the conventional navigation systems should be chosen to anticipate the redundancy of GPS. In fact, only Loran-C can become a partner to GPS into the 21st century. Recently, a number of agreements among the US, Russia and European countries have been signed either to upgrade and expand Loran-C chains in North West Europe, the North Atlantic and the Mediterranean or to combine Loran-C with Chayka. The other navigation systems seem to have an uncertain future. Decca is only paid attention to in the UK, principally to meet the need of the fishing industry in the British Isles. There is no statement about further development of Omega after being phased out by the US.

Meanwhile, the number of GPS users is rapidly growing and the DGPS services are deployed worldwide. This proves the fact that GPS will gradually replace the other navigation systems to become the dominant positioning system. It is also worth noting that the introduction of GPS, to some extent, will speed up the development of other deploying or planned satellite navigation systems such as GLONASS or a future civil Global Navigation Satellite System.

3.4.3. Worldwide Deployment of DGPS

Realizing the benefit of DGPS to the safety and efficiency of navigation as well as to other fields, many countries in the world have deployed DGPS systems, although the GPS system is still not yet fully operational. The introduction of DGPS has been greatly supported by international organizations and agencies such as IMO, ICAO, IALA. Offshore and hydrographic survey industries also play an important role in the development of DGPS systems. Currently, there are a number of different types of DGPS services being deployed all over the world:

DGPS Radiobeacons: Marine radiobeacons, which operate in the medium frequency are being used as a cost-effective means to broadcast DGPS corrections. The US Coast Guard is the pioneer both in study trials and in the development of DGPS radiobeacons services. A number of DGPS stations are currently operational. According to the plan of the US Coast Guard, up to 1996, the entire US sea coast will be covered by 50 DGPS stations. The Canadian Coast Guard is planning a 25-station DGPS network compatible with the US system. Scandinavian countries are also very active in the field with an increasing number of operational DGPS stations in Norway, Denmark, Sweden and Finland. In the UK, Scorpio Marine has provided DGPS services all over the coast line and a part of the North Sea. Many other operational and experimental DGPS stations are being conducted in Germany, Australia, France, CIS, Japan, etc.

Long Range DGPS: Sercel France has developed its product of long range DGPS stations which operates in the HF band of 1.6 - 3.5 MHz. Currently, there are 48 Sercel-based DGPS stations covering the European Shelf, Gulf of Mexico, West Coast of Africa, South China Sea, Timor Sea, etc. An example is the Veripos DGPS Network with seven stations covering the whole North West European Continental Shelf. Apart from Sercel, some other companies have also launched Long range DGPS services, e.g. Racal Positioning Systems Ltd. with the DeltaFix LR system.

DGPS Broadcast over FM frequency: The idea of broadcasting DGPS corrections over FM radio stations has been exploited by Magnavox Electronic Systems Co. and CUE Network Corporation (US). The system, named Acc-Q-Point Positioning and Location Service, can provide DGPS service via FM subcarrier (88 - 108 MHz) up to 65 - 80 km offshore. Currently, it is usable in most coastal areas of the US.

Multi-site DGPS system: John E. Chance Inc. (US) has recently developed a multi-site DGPS system utilizing the geostationary satellite data link. The system, which exploits the StarFix system in conjunction with the StarFix positioning system, has been in use since 1992. A total of 55 StarFix reference stations are covering almost half of the earth surface with DGPS service. Geoteam AS (Norway) and Wimpol Ltd. (UK) also provide DGPS networks (GeoRef and Orion DGPS services) which use the similar method to Starfix.

3.4.4. DGPS and Conventional Aids

Research and experimental trials have shown that radiobeacons provide a cost-effective means for broadcast of DGPS corrections for range up to 200 NM. Enge et all (1993; p363) listed a number of reasons for this:

- DGPS correction message can be broadcast in the frequency of radiobeacon bands without interfering with direction finding functions.
- Broadcasting DGPS data from existing radiobeacons requires only the addition of some inexpensive equipment.
- Range of radiobeacon signals is suitable for DGPS data transmission requirements.
- Marine radiobeacons have been widespread and well located for critical navigation functions.

IMO and IALA policy is to encourage members to support the transmission of DGPS by radiobeacons as one means of providing a high accuracy radio navigation system. This will lead to the incorporation or suppression of radiobeacons by DGPS reference stations. In addition, the applications of DGPS services will eventually permit the decommissioning of thousands of ground-based navigational aids. Visual aids, for example, will be phased out or sharply reduced. Part of the funds saved from operating and maintenance expenditures of those navigational aids can be used to set up DGPS reference stations. Conversely, DGPS can be used as the best means for accurately positioning buoys, marks and other conventional aids.

3.5. Legal Aspect of GPS

GPS was principally developed to meet the US military needs. Up to the present time, there has been a number of controversies about the ownership, the control and management of the system and the liability in the system operation. Future arguments can be focused on three main issues as below.

3.5.1. GPS Ownership - National or International?

GPS is a worldwide utility with enormous potential for many civil application areas. The global characteristics and high costs of the system have led to the question of whether the system should be organized on an international contractual basis like COSPAS-SARSAT and INMARSAT or not. Although the US Government has committed itself to provide SPS to the world without any direct charge for the foreseeable future, the current status of GPS cannot meet the requirements of international civil users because:

- The international community cannot rely on a nation-owned system
- Authorities other than the US cannot take responsibility for certifying a system that is officially declared unreliable under certain political circumstances by the system owner.
- GPS provide substantial benefits to the whole world but only the US tax payers have to bear the charges.

This leads to the fact that a civil GNSS is better than a nation owned system (except for national security needs). However, Beukers (1994, p58) noted the main roadblocks to accept GPS as an international system are: the national interest of the US, the extremely high costs of GPS and the time needed for international negotiation.

3.5.2. GPS Control and Management - Military or Civilian Jurisdiction?

GPS is intended for military applications so it is under the control of DOD. However, under the pressure of the US Congress, it has been introduced to the civil community. The two policies from the US Government are :

- *SPS policy:* available to all users on continuous worldwide basis with no direct charge
- *PPS policy:* available to users authorized by DOD, in the US and its allies, with special agreements with DOD.

According to Senator Jim Exxon (1993, p44), the US government should review its policy regarding the military or civilian jurisdiction, for a number of reasons, inte alia:

- DOD is already a minority user of the GPS system. Civil and commercial user will dwarf that of DOD.
- Selective Availability security feature is now meaningless through the march of technology.
- Shifting GPS control out of DOD will ease international concerns about civil and commercial applications.
- Civilian beneficiaries should share the deployment and maintenance costs of the system.

Civil control could be the best solution for the future of the GPS system. Currently, the role of the Department of Transport and the Federal Aviation Administration is increasing in the control and management of GPS.

3.5.3. Liability - Lawsuits in Negligence?

The third contentious issue is the question of lawsuits in the case of any negligence in the operation of GPS. Ferrier (1993, p11) argues that it is difficult not only to prove a failure in the GPS operation but also to sue the wrong-doers, in terms of where to sue, how to sue and who to compensate for negligence. As a general rule, a claim against the US Government and its military will fail. In addition, civilian users can assess GPS free of charge so it is a true "user risk" system (Ferrier, 1993, p12). To some extent, this issue will lead to the need for the GPS system to be of both an international and civil nature.

3.6. Future Development of GPS and Satellite Navigation

3.6.1. Lines of GPS Development

When the GPS system is complete, questions will be raised on its future, both on the management of the system and on the development of its applications. In the author's viewpoint, lines of development of GPS would be as below (some of them will be discussed in more detail in the following sections).

3.6.1.1. GPS Control and Management

- Internationalization: The international civil community is looking for a civil Global Navigation Satellite System (GNSS), for which GPS is the most realistic and closest contender. Is there any possibility of negotiating for an international status of GPS? Should a combination of GPS with GLONASS be taken into consideration?

- Civilization: The pressure from the US Congress and civil users will speed up the process of civilization of GPS. The US Department of Transportation and Federal Aviation Administration will have more and more power in the control and management of GPS so that, eventually, they would take it over from DOD.

- User charges: Once GPS becomes an international civil satellite navigation system, civilian beneficiaries of GPS technology will have to share the deployment and maintenance costs of the system through modest and acceptable user charges.

- Successor: What will be the next generation of satellite navigation? Probably, a civil GNSS is the answer, depending on actual circumstances.

3.6.1.2. Future Applications of GPS

- Wide-Area Differential GPS (WADGPS): users will be able achieve DGPS accuracy level, not only in limited sea areas but in the open sea as well, through a WADGPS system using communication satellites for broadcasting DGPS corrections.

- Phase carrier measurements: Recent developments in processing GPS carrier phase and ambiguity resolution techniques have been made for surveying industry. The aviation industry is also studying this techniques to apply for precise landing purposes. In the maritime industry, navigators can benefit from the centimetre level accuracy for positioning in a number of precise navigation tasks such as:

+ to guide heavily loaded vessels in dredged channel
+ to maintain waterway and to position buoys and marks
+ to calculate tidal information from vertical component of position data.

- Pseudolites: Ground based pseudo-satellites sending signals identical to GPS satellites will be used as:

+ a data-link for local DGPS
+ an additional ranging sources for GPS augmentation
+ aids for determination of carrier phase integer ambiguities.

Pseudolites can be applied for precise navigation tasks such as berthing large ships.

- Other applications: More and more applications of GPS technology will be developed in the future, including the utilization of GPS for automatic berthing, tidal calculation, true course determination and calculation of trim, draft, bending, stress, rolling and pitching.

3.6.3. Combination of GPS and GLONASS

Much effort has been done to develop the inter-operability of GPS and GLONASS. US and Russian scientists started studying the capability of incorporating GPS/GLONASS receivers in 1990. Such receivers have been designed and tested at Lincoln Laboratories (US). In Japan, examinations of the integrated use of GPS and GLONASS started in 1991 in a three-year project of Japan Civil Aviation Promotion and Japan Radio Company Ltd. The project includes studies on the operational requirements and basic design, manufacturing of experimental GPS/GLONASS integrated receivers, and evaluating tests. Currently, the Russian Institute of Radio Navigation and Time (CIS) together with Deutche Aerospace (Germany) are also developing combined GPS/GLONASS receivers. Tests will be likely to take place in the near future.

The idea of incorporating GPS and GLONASS receivers is based on the fact that neither GPS nor GLONASS can satisfy the requirements of sole means integrity and reliability for navigators, especially in air navigation. Combined GPS/GLONASS receivers will benefit the navigators due to the following reasons, inter alia:

- reduced error component, better accuracy and coverage, eliminated zone of high PDOP
- improved integrity by Receiver Autonomous Integrity Monitoring (RAIM)

- higher redundancy factor and reliability with at least eight satellites being available at any given point in the world when both systems are fully operational
- not solely reliant on a single system but having choices.

GPS and GLONASS receiver requirements are very similar, due to the similarity of space segment, signal structure, operating frequencies and positioning principle. However, designers and producers have to contend with a number of incompatibility problems regarding the differences in time and coordinate systems and tracking methods. Integrated receivers must be capable of tracking the signals from both GPS and GLONASS satellites and of converting coordination and time. Hopefully, integrated GPS/GLONASS receivers will be available in the near future, with the complexity and costs not much higher than that of the single ones.

3.6.4. The Future Civil Global Navigation Satellite System

The development of satellite technology, particularly the deployment of GPS and GLONASS, has urged the international civil community to think of a future civil Global Navigation Satellite System (GNSS). Although GPS and GLONASS are global systems, they are state-owned properties and under military control. For that reason, civilian users cannot solely rely on them, and hence need to have a satellite navigation system owned, operated and controlled by an international civil authority.

Such a GNSS system should meet the following requirements:

- under international civil control in terms of ownership, participation, funding, cost sharing and liability
- guaranteed performance and availability
- enhanced integrity and accuracy assurance
- cost-effective.

Analyzing the current situation, the Future Air Navigation Systems (FANS) Committee of ICAO proposed five various options for a civil GNSS (O'Keeffe, 1993, p14).

1. GPS or GLONASS with further development in integrity and accuracy assurance
2. Combination of GPS and GLONASS
3. GPS/GLONASS and an overlay such as INMARSAT satellites
4. GPS/GLONASS and civil GNSS satellites
5. Civil GNSS.

Much effort has been made in studying and discussing the issue. A number of international organizations and agencies such as IMO, ICAO, INMARSAT, ESA (European Space Agency), have paid attention to the development of GNSS. From the viewpoint of the European countries, there are three ways that a GNSS can be established:

- negotiation with the US and Russian governments for an international status of GPS and GLONASS
- cooperation with Russians to invest, both finance and technology from the West, in the GLONASS system which has some advantages for Europe
- investment in a civil GNSS system (worst case).

The US is not much concerned about GNSS, except some arguments that such a GNSS system should be compatible with GPS or based on GPS. Similarly, Russia is only looking forward to the support to overcome the financial difficulties in deploying GLONASS. It is the duty of European countries and international civil organizations to look for the best answer to this question. Probably, a combination of GPS, GLONASS and INMARSAT, in which INMARSAT plays the major central role of an international civil authority, is the most realistic and effective way. In the worst case, a cost-effective satellite navigation such as ECONOSAT should be taken into consideration (McDonald, 1993, p14).

3.6.5. Wide-Area Differential GPS

Conventional DGPS systems can only be exploited in coastal or restricted busy shipping areas because the range, over which the differential corrections are valid, is limited. It is very difficult to deploy a conventional DGPS system over an area as large as an ocean for a number of reasons, as below:

- extremely large number of reference stations are required
- geodetic coordinates of reference stations may vary from country to country
- it is difficult and costly to place reference stations in the mid-ocean.

To remove these limitations of conventional DGPS techniques, researches and studies are being conducted to develop and design a Wide-Area Differential GPS (WADGPS) system. The WADGPS system can extend the range of DGPS service to a greater area of the globe, while the number of reference stations and total transmission data rate are minimized. Research has shown that only a network of 10 to 12 reference stations is needed to cover the whole Atlantic Ocean. The medium for transmitting DGPS corrections is communication satellites. Signal error data from reference stations will be relayed via a communication satellite to a central processing station where it is processed and separated into three fundamental groupings: satellite positioning, propagation delay and clock deviation. The differential correction message with three respective components is then transmitted to users via the satellite. All users within the footprint of the communication satellite can achieve the DGPS accuracy.

INMARSAT is sponsoring studies on the development of WADGPS using INMARSAT geostationary satellites. A study carried out by the Institute of Engineering Surveying and Space Geodesy together with British Aerospace Ltd. (UK) has shown that accuracy of two to five metres can be achieved through WADGPS (Ashkenazi et al, 1993b, p297). ICAO has also tested the capability of using WADGPS via INMARSAT satellites for precision landing. In June 1994, the Federal Aviation Administration (US) released a Request for Proposals for a GPS Wide-area augmentation system, which is scheduled to implement by 1997. Hopefully, WADGPS will be available in the next few years, when the third generation of INMARSAT satellites is launched.

CHAPTER IV

APPLICATIONS OF SATELLITE COMMUNICATIONS AND SATELLITE NAVIGATION FOR THE MARITIME WORLD

4.1. Overview

As mentioned earlier, the two main areas of applications of satellite technology in the maritime world are in communications and navigation. The applications of satcom and satnav are widespread and in continuous development. They can be seen in many areas of both shipboard and shore-based operations in the maritime industry. With particular reference to INMARSAT and GPS, a general picture of the wide range of applications and a closer look in some applications of satcom and satnav are provided in this chapter.

4.1.1. Maritime Services and Applications of Satellite Communications

Needless to say, satellite communication nowadays appears everywhere in the maritime industry, from routine communications to distress alerts, from commercial needs to technical supports, from ship management to cargo monitoring, from crew satisfaction to passenger communication needs, etc. With the various services offered by INMARSAT, a countless number of satcoms applications have been developed. In general, they can be categorized into the following main areas, inte alia.

Distress and Safety Communications

- Distress communications: Distress alerts can be relayed through priority satellite communication channels, instantaneously addressing the appropriate shore-based search and rescue authorities as well as the shipping in the vicinity.
- Search and rescue communications: Satellite communication provides a real-time, world-wide and reliable means for search and rescue communications.
- Safety information broadcast: Utilizing the Enhanced Group Call technique, all maritime safety information such as weather forecast, gale warnings, navigational warnings, notice to mariners, can be broadcast via satellite communication SafetyNET service.

Fleet Management

- The FleetNET service incorporated with a ship reporting system will enable the shipping company to keep in touch with every vessel in its fleet. Ship operation can be more effectively monitored from the shore-based head office, meanwhile the ships are provided with all necessary and in time information regarding voyage planning, ports of call, bunker prices, estimated time of arrival, etc.
- Maintenance planning: Plans of maintenance and replacement can be conducted from the head office.
- Crew management: All information on the sea staff such as payroll and holidays can be exchanged between the ships and their head office.
- Other communications between ships, head office and third parties such as port authorities, pilotage, ship chandlers and suppliers, will be enhanced by the use of satcoms.

Crew and Passenger Services

- Crew services: Crew's communication needs can be satisfied with satcoms. In addition, satcoms can also provide a number of services such as medical advice, medical assistance, news service with daily news letters, still photo transmission.
- Passenger services: The communication needs for business and transactions will be met by the satcoms services available on board cruises and passenger ships such as multi-channel direct-dialing telephone, fax, telex, E-mail and data communication. Credit card and video telephones are also provided. New applications of cruise and ferry conferencing is being developed.

Cargo Monitoring

- Cargo tracking: Containers, hazardous and highly valuable cargoes, etc. can be tracked from the shipping company.
- Cargo handling: Cargo plans, ballast data, cargo bay plans and other information relating to cargo handling can be exchanged between ships and their head office.

Technical Support from the Shore

- Ship's crew can get support from on-shore experts in any case of damage to the ship's engine and equipment. Video pictures of damage surveys and machinery diagnosis are sent through high speed data service to the shore, meanwhile detailed instructions for repairing are sent back to the ship.

Navigation

- A number of computerized weather routing systems have been developed, where satcoms is the medium to connect on board computers with the data platform on shore.
- Satcoms can be used for broadcasting differential GPS corrections, GPS integrity, chart corrections, etc., to enhance the safety of navigation.

Miscellaneous

Applications of satcoms are also available in a number of other areas, including:

- Electronic Data Interchange: Through satcoms, a ship may have assess to various electronic database systems such as Electronic Data Interchange of Maritime Documents (EDIMAR), Electronic Data Interchange of Dangerous Goods (EDIDA), European Water Traffic Information System (EWTIS), Freight Management in Europe (FRAM).
- Maritime Education and Training: Satcoms provide the most effective two-way communication means to support onboard education and training for seafarers.
- Disaster Management: Oil spill response plans and pollution monitoring using satcoms.
- Fishery Surveillance and Monitoring: Fishing activities will be monitored by fishery authorities using satcoms and vessel tracking systems, e.g. the system established by Australia Fisheries Management Authority.
- Offshore Seismic Survey: seismic survey information can be transferred from a seismic vessel to the processing centre on shore, through the data communication channels.

- Vessel Traffic Management.
- Maritime Security and Anti-piracy Mission.
- Remote monitoring of Navigational Aids, e.g. unmanned lighthouses.
- Ice Navigation Information.

4.1.2. Applications of Satellites Navigation

The applications and products of GPS are growing exponentially. Worldwide sales of GPS receivers were half billion US dollars in 1993 and are expected to reach five to six billions at the end of the decade. GPS has generated an ever-increasing interest not only from the military users, as it was preliminary intended to serve, but also from a number of civilian fields such as marine, land and air navigation, surveying and mapping industry, resource exploration.

The marine industry benefits tremendously from GPS. The numerous applications of GPS, both when stand-alone and when integrated with other modern technology, can be summarized as below.

Navigation: GPS receivers enhance the safety and efficiency of navigation through harbour entrance, crowded waterways and on the open sea. This may include the positioning fixing, automatic track keeping, anchor watch, man-over-board and other functions.

Fleet Management: The head office of a shipping company can continuously keep in touch and know exactly the location of each individual ship, through an automatic tracking system.

Electronic Chart and Integrated Systems: GPS is the best means to provide the continuously updating and accurate position data to ECDIS and other integrated navigation systems.

Traffic Management: GPS can provide accurate positions for ship surveillance and identification in VTS systems.

Distress and Safety at Sea: All the GMDSS equipment on board can be connected with GPS receivers for updating the accurate position for distress alerting. GPS also can assist Search and Rescue units in their mission to search for ships in distress.

Cargo Tracking: GPS can be used for tracking hazardous cargo in containers or chemical tankers. Similarly, any type of precious cargo can be tracked from the shore.

Waterway Maintenance: GPS has been used for dredging vessels, as well as for positioning and monitoring aids to navigation.
Offshore Exploration: GPS is widely used for precisely positioning oil-rigs and platforms, for mapping and offshore surveying.

Marine Geodesy: GPS is used for hydrographic surveys, seabed mapping, sea surface and movement determination.

Other areas of GPS applications may include:
- Fishery surveillance
- Oil spill tracking
- Pipe and cable laying operation
- Ice-breaking activities.

4.2. Fleet Management

4.2.1. The Need for Fleet Management

It is often said that there would be no quality ship management without a close working relationship between the head office and the fleet. Ship managers nowadays are looking for effective management tools to exploit their vessels efficiently and safely in a competitive environment. The commercial success of ship operations is much dependent on the communications between the shore office and each individual ship in the fleet. There are a number of reasons for this. First, the reduction of manning on board leads to an increase of workload for ship's officers. It is a good idea to transfer some of the managerial tasks on board to the shore office where necessary information is available. Ship officers can concentrate on navigational tasks. Secondly, successful ship operations need much support from many shore-based organizations such as cargo owners, port authorities, bunker suppliers. Thirdly, there is also a need for the fast turnaround of ships. Last but not least, the development of technology today, particularly in the field of satellite communications and satellite navigation, has made it feasible to have remote fleet management systems.

4.2.2. Satellite Technology and Fleet Management

Satellite communications play an essential role in the fleet management systems. From the ship, the satellite terminals collect all necessary data relating to ship operations from the shipboard computer network and transmit to the shore office via satellite link. Meanwhile, advice and instructions as well as necessary data from the shore side are sent back to the ship. The data exchanged between the ship and its shore office may, inte alia, include:

- ship performance data, i.e. position, course, speed, engine and equipment status, stress and stability.
- fuel consumption
- cargo loading and ballast calculations
- crew records such as payrolls, holiday schedules,.
- maintenance plan
- spare parts inventory
- consumable orders
- voyage and passage planning
- ship repair specifications
- technical requirements from classification societies.

As mentioned earlier, INMARSAT provides a number of services to meet the needs of communication between ships and shore, including voice, telex, facsimile, data communications. In particular, the Enhanced Group Call capability of the INMARSAT-C system provides the FleetNET service for commercial use. Messages sent via the FleetNET can only be received by vessels with a pre-determined identification code. This allows the shipping company to disseminate confidential and sensitive information throughout its fleet or to a number of ships without any fear of interception.

A ship reporting service is also available from INMARSAT where ship position reports can be sent to the shore office. The position reports can be automatically transmitted at regular intervals or polled by the shore office at any time. An accurate and reliable positioning system is then needed to connect with the communication system. The satellite navigation system GPS has proved to be most suitable for such a vessel reporting system. With a combination of satcom and satnav, ships can be automatically and precisely tracked from wherever they are.

4.3. Integrated Bridge Systems

4.3.1. The Need for Integrated Bridge Systems

Shipping is always a competitive industry where there is a constant need for the modernization of ships and reduction of manning. Recent years have seen great changes from the traditional shipboard operation with a number of crew to the sophisticated monitoring and control systems with only one watch-keeper on the bridge. Nowadays, the concepts of integrated navigation, integrated bridge, intelligent ship, one man bridge operation, etc., are a familiar sight. The development of technology has made it possible to gain full control of all aspects of ship operations from a single monitoring centre, the bridge, which is suitable for one man bridge operation. Both navigational and managerial tasks can be performed from the bridge. An integrated bridge system with high level of automation is the answer for modernizing ships. Optimum manning can be achieved while the operational safety is maintained.

4.3.2. Satellite Technology and Integrated Bridge Systems

A typical integrated bridge consists of the following elements, inte alia, a navigation unit, an engine unit, a cargo and ballast unit, a communications and weather unit and a ship and voyage management unit. Obviously, satellite technology, i.e. satellite communications and satellite navigation, has been of utmost important in the navigation and communication units. Other elements of the integrated bridge system can also benefit from the advent of satellite technology.

Satnav and Integrated Bridge Systems

GPS with global, highly accurate, real-time positioning services would be the most important navigation sensor in an integrated navigation system. GPS has proved its superiority over other positioning systems in general and its suitability for integrated bridge and for integrated navigation in particular.

The heart of an integrated bridge system is the Electronic Chart Display and Information System (ECDIS), where continuous, highly accurate ship positioning data are required. Recent years have seen the growing interest in the utilization of ECDIS. A large number of projects and test-beds are being conducted by US, Canada, Norway, Germany, UK, Japan and Australia. Most of the studies and researches have shown that DGPS, with the accuracy of better than 10 metres, is the most suitable position fixing system for the ECDIS system. With the ship position being continuously displayed, position fixing, manoeuvring and anti-collision information can be combined on the same screen. A reliable real-time position fixing system like DGPS will make the navigator confident in monitoring the ship track on a pre-planned route, controlling the ship's manoeuvres, as well as avoiding collision.

In addition, computerized route planing and automatic track keeping, in which satnav is one of the main components, will reduce the workload of navigators when carrying out navigational tasks.

Satcom and Integrated Bridge Systems

Satcom is the best choice for the communication unit in the integrated bridge system because it can offer long range, real-time and uninterrupted communications with high data flow and short access time. For an integrated bridge system which requires fast communications and large amount of data, satellite communications are also a cost-effective means. With satcom, the two-way communication link between the ships and the shore office is provided. Radio communications are simplified and speeded up so that navigators' workloads can be reduced.

Satcom sensors can collect all the environmental information for navigational tasks, e.g. weather forecasts and maritime safety information, passage planning from the shore office, routeing services from meteorological offices, advice and instructions from the VTS Centre, etc. They can also be used for managerial tasks, e.g. instructions from head office, technical assistance from experts ashore, access to on-shore electronic database, etc.

For the ECDIS, satcom provides an excellent tool for automatic chart updating. Studies within the Norwegian SEATRANS Project have shown that chart corrections originated from specialized offices can be automatically sent to ships via satellite link, using the SafetyNET broadcast. Automatic chart updating via satellites will reduce the workload for ships officers as well as eliminate human error that may take place in manual chart updating. Many other researches are being conducted to study this possibility of automatic chart updating via communication satellites.

4.4. Vessel Traffic Management

4.4.1. The Need for Vessel Traffic Management

To keep in pace with developing trends in modern shipping, particularly the increasing number and size of ships, the concentration of shipping in ports and conventional routes, the flow of hazardous cargo carried by sea, etc., a large number of Vessel Traffic Services have been operational throughout the world. A Vessel Traffic Service (VTS), as defined by IMO and IALA, is a service designed to improve safety and efficiency of vessel traffic and to protect the environment (IALA, 1993, 15). The service may vary from simple navigational information broadcasting to highly complicated traffic management, depending on the facilities provided. Statistics have shown that the number of maritime accidents, such as collision and grounding, has dramatically dropped in the areas where VTS systems are implemented. Recognizing the important role of VTS for improvement of safety and efficiency of shipping as well as protection of marine environment, IMO encourages its member states to establish VTS systems. Proposals of mandatory routeing of ships have been made in IMO meetings.

4.4.2. Satellite Technology and Vessel Traffic Management

Modern technology, such as computerization, sensing and communicating techniques, has a great impact on the evolution of VTS technology. In particular, the development of satellite technology has brought about a new perspective to VTS in two main operational aspects, namely communications and position reporting.

Satcoms and VTS

Communication is the key element in a VTS system. It may consist of transmission and reception of voice as well as processed data and information by all means of conventional telecommunication methods. Obviously, VHF communication is essential for the VTS systems. However, satellite links can facilitate and enhance the communication procedure, and hence increase the reliability and efficiency of the VTS system. With satcom, navigators and VTS operators can benefit from a reduced workload and better data flow. Position data and vessel identification messages can be sent automatically at pre-designed intervals. Warning information as well as advice about the traffic conditions and other relevant safety matters can be sent directly to ships by all means of satellite communications including video text. Satcom can be an excellent media for a ship reporting system. Communications using satellite is real-time and uninterrupted. Furthermore, satcom will overcome the range limit of VHF communications, in case the VTS area is expanded. In the future, the possibility of using direct satellite communication services with Very Small Aperture Terminal networks (VSAT) provided by INTELSAT, Iridium, INMARSAT, etc., for the VTS services is viable.

Satnav and VTS

Most of the currently operational VTS systems utilize radar to provide independent surveillance of the traffic. Although radar-based VTS systems have served shipping well for many years, they suffered from a number of limitations. Establishing a radar site is so expensive that the expansion of VTS coverage may be cost-prohibitive. In some cases such as in rivers with many bends and objects, the capability of radar surveillance is limited. Radar-based VTS systems also require specially trained and experienced operators capable of identifying radar targets.

Those limitations can be overcome by automatic dependent surveillance systems, where participating vessels automatically transmit their position to the VTS centre. Satellite navigation plays a key role in such systems. Currently, a number of studies are being conducted to introduce the GPS-based VTS system concept. In a GPS-based VTS system, the ship position as well as related data such as course, speed, will be incorporated with identification information in pre-designed simple messages. The VTS centre receives such messages, processes them and displays them on the screen for monitoring the traffic.

The disadvantages of a GPS-based system is that it cannot detect all the traffic in the VTS area. However, its advantage over the radar-based VTS system is that it is cheaper, and not affected by weather and geographical characteristics of the VTS area. Currently, USCG is going to establish a GPS-based system in Alaska. Similar systems are undergoing trials in Sweden and Holland.

In a radar-based VTS system, there can be also some potential for applications of GPS/DGPS. For example, the possibility to use GPS/DGPS as the position sensors for shipborn transponders, which can be identified by VTS radars, is currently under study to enhance the VTS system.

4.5. Satellite Emergency Position Indicating Radio Beacons

An Emergency Position Indicating Radio Beacon (EPIRB) is a device capable of transmitting distress signals to alert the search and rescue authorities and to enable the rescue units to locate the position of the accident. The satellite-based EPIRB has been adopted by IMO as a key element of the GMDSS system because satellite technology allows precise navigation and highly reliable communications to be achieved under the most severe conditions. Two types of satellite EPIRB complying with the GMDSS requirements are provided by COSPAS-SARSAT and INMARSAT.

4.5.1. COSPAS-SARSAT 406 MHz EPIRBs

As mentioned earlier, COSPAS-SARSAT is a radio location search and rescue system utilizing the polar orbiting satellites. For maritime users, COSPAS-SARSAT provides an EPIRB service on the frequency of 406 MHz. The position of a COSPAS-SARSAT EPIRB is determined by measuring the Doppler shift between the signal transmitted by the EPIRB in distress and the signal received by the satellites. Resulting data is stored in the satellite memory and instantly relayed on the satellite down link in a global mode coverage. Local User Terminals, the ground segment of the system to receive distress data from the satellites, will then distribute alert data to an appropriate rescue co-ordination centre for conducting the search and rescue mission.

Advantages of the COSPAS-SARSAT system

- The system provides a full global coverage with 100% availability
- The position of the EPIRB is calculated by itself so that it is independent from other positioning systems.
- The EPIRBs are relatively small and cheap.

Disadvantages of the COSPAS-SARSAT system

- The use of a polar-orbiting satellite configuration cannot provide permanent coverage. According to experiments conducted by COSPAS-SARSAT, the mean alert-handling time is about 71 minutes. The maximum delay time is 90 minutes including 44 minutes waiting time and 27 minutes satellite storage time.
- The accuracy of position fixing is low.

Currently, COSPAS-SARSAT EPIRBs are a good choice to comply with the requirement of the GMDSS. An increasingly growing number of EPIRBs has been installed on board ships.

4.5.2. INMARSAT L-band EPIRBs

INMARSAT provides EPIRB service operating on the 1.6 GHz frequency (L-band). In case of accident, INMARSAT geostationary satellites receive the distress alert from the EPIRB, including the latest positioning data extracted from the connected navigation systems and then relay to the appropriate rescues co-ordination centre.

Advantages of INMARSAT EPIRBs

- rapid alert, typically less than two minutes
- world-wide coverage by INMARSAT satellites (the coverage reaches to 80 latitude North and South with 99.9% of all possible users).

Disadvantages of INMARSAT EPIRBs

- Polar regions are not covered
- EPIRBs are needed connecting with another navigation system to get the position data at constant updated periods.
- INMARSAT EPIRBs are relatively expensive in comparison with COSPAS-SARSAT EPIRBs.

The development of miniaturised GPS receivers has brought about the possibility of building a GPS receiver into the EPIRB. Recently, a study has been conducted to incorporate the GPS receivers into the INMARSAT-E type approved EPIRBs. In addition to the advantages of the INMARSAT-E system, maritime users will also benefit from such EPIRBs because they can provide:

- accurate position by GPS receivers which is typically better than 100 metres
- constantly updated position reports

Furthermore, a GPS/INMARSAT-E EPIRB can be considered as a backup navigation system for the primary position fixing systems. Although the number of ships currently equipped with INMARSAT L-band EPIRBs is small, an integration with GPS receivers will bring about a promising market in the near future.

4.6. Marine Environmental Protection

Tanker accidents such as those which involved the Torrey Canyon and the Exxon Valdez, have drawn public attention to the prevention of marine environmental pollution. On the one hand, various measures such as double hull requirements, vessel traffic management establishment, have been, or are going to be, applied in order to prevent such regretful accidents taking place. On the other hand, much attention is also concentrated on the monitoring and combating of any disaster.

Satellite technology is also very useful for monitoring the disasters. Information about the movement and location of oil spills is essential in deploying clean-up equipment and personnel. Environmental emergency response centres can benefit from satellite-aided oil spill tracking buoys that stick to the oil and float with the spill. The buoy system relies on the GPS satellites to provide precise and continuous positioning information. A communication link is designed between the buoy system and a command centre to allow the oil spill response team to track the movement of the spill even in darkness and bad weather.

The time factor is crucial in the response to an oil spill disaster. In case of an accident, the ship master is required to report the incident in detail without any delay to the nearest coastal states, utilizing the fastest communication link available. Satellite communication has proven to be the most effective means for such disaster reports. Using satellite communications, pre-designed reports can be sent immediately to the spill response centre and other related parties such as the shipowner, rescue coordination centre, port state control, P&I Club. Immediate action can be taken to eliminate the scope and effects of the disaster.

4.7. Offshore Exploration

Although the offshore industry operates a very limited number of vessels, compared with that of the merchant fleet, fishing vessels and yachts, it has pioneered the development of new technologies. Hundreds of Differential GPS services have been developed to meet the needs of offshore operation. Most of the offshore vessels are equipped with GPS/DGPS receivers and INMARSAT terminals.

The accuracy of positioning is of utmost importance in various offshore operations including installation of offshore structures, rig moves, seismic surveys, positioning of underwater robots and diving. For example, the three dimensional seismic survey requires that the vessel, source, air guns and streamers must be located with an accuracy equal to or better than five metres. The advances in satellite navigation, i.e. the development of GPS/DGPS, have fulfilled such stringent accuracy requirements. GPS/DGPS is now considered as the primary positioning system in offshore operations.

In a three dimensional seismic survey, there is a huge amount of navigation data that needs to be processed. Typically, a three dimensional seismic survey may involve the acquisition and processing of two to three gigabits. In order to reduce the time taken to process the navigation data, two methods have been exploited:

- conducting the navigation data processing on board.
- sending the navigation data to the ashore processing centre.

The former method is faced with the problem of manning. Experts are needed to be on board the seismic vessel all the time during the survey. The latter method is more promising, using the INMARSAT High Speed Data communications link between the seismic vessel and the on-shore processing centre. Normally, with the transmission speed of 56 or 64 kilobits per second via INMARSAT HSD service, it needs only about 10 minutes to transmit all navigation data generated by a seismic survey per day. Therefore the new data can be processed ashore within a very short time. In fact, transmitting seismic navigation data to an on-shore centre has proven to be more cost-effective than the on board data processing method.

4.8. Integration of Satcom and Satnav Terminals

There has been a demand for an integrated terminal which can provide both communications and position reporting capabilities on a global scale. Study has shown that it is possible to combine the INMARSAT-C package with the GPS receiver into a single unit. Theoretically, both the INMARSAT-C system and the GPS system have:

- similar system description with global coverage and the division of three distinct segments namely space, ground and user segment.

- common base-band frequency so that they can share the common antenna and the signal processing circuitry.
- common receiver architecture, including antenna diplexer and subsystem components.

A lot of research and experiment has been carried out to develop this possibility. Trimble Navigation is the first company to be successful with its product of Galaxy INMARSAT-C/GPS. The key elements of the integrated terminal are an INMARSAT-C/GPS transceiver, a multipurpose antenna, a computer with advanced software and a printer.

Maritime users can benefit from the integrated system in the following applications:

- Remote position reporting: the integrated unit can be programmed to deliver regular and automatic positioning reports. Central office can also poll for the reports at any time.
- Automatic monitoring of secure cargo: highly dangerous or valuable cargo can be tracked during the international transport.
- Automated geographical addressing: maritime safety messages sent via SafetyNET can be accurately addressed to all ships within a designated geographical area.

Integrated INMARSAT-C/GPS terminals will likely become popular with more and more maritime customers, especially in the field of ship reporting systems and fishery surveillance and monitoring. Although all of the current ship reporting systems such as AUSREP (Australia), AMVER (US) and JASREP (Japan) are now on a voluntary basis, IMO is now moving toward mandatory vessel reporting schemes in the future to enhance the safety for shipping. Similar systems for surveillance and monitoring of fishing vessels have been studied and conducted in Australia, Japan, Iceland and the US. The ability to poll certain vessels is useful for enforcement officials in monitoring suspected violations of fishery conservation and management measures.

4.9. Concept of Radio Determination Satellite Services

Radio determination is a generic term covering both radio navigation and radio location activities and services. The radio navigation service utilises the properties of the radio waves for the purpose of navigation and is considered as a safety service. Meanwhile, the radio location service is used to locate the position of an object or to determine its movement and speed but not for the purpose of navigation.

However, the concept of radio determination in satellite technology is somewhat different. A Radio Determination Satellite Service (RDSS) is generally conceived as ancillary navigational payloads loaded on board communication satellites. Thus, an RDSS provides services capable of both positioning and communications. This makes it distinct from the navigation satellite system which is solely used for the purpose of positioning.

Satellite navigation systems have wide geographical coverage, which is normally global, and utilize non-geostationary satellite configurations. Transit and NavstarGPS, as described earlier, are typical examples of the satellite-based navigation systems.

RDSS systems, on the other hand, normally utilize geostationary satellites to provide regional coverage. Geostationary-based systems are usually of continental size, providing communications and positioning services to high demand areas such as North America, Europe. Examples of such services are SkyFix and Omnitracs (US), and Euteltracs (France). They are now serving well the needs of fleet management, such as intelligent vehicle/highway systems and vessel tracking systems. Currently, they are used primarily for land mobile vehicles' control and monitoring.

The main drawback of the geostationary-based RDSS systems is the coverage limit. However, the possibility of expanding their service to a global scale by using non-geostationary satellites or a combination of geostationary satellites with those in other orbits has been studied. Much effort has been made by the European Space Agency and INMARSAT in the development of RDSS services. The concept of unifying the geostationary satellites with the high earth orbiting satellites has been under study by the NAVSAT Project conducted by the European Space Agency. Meanwhile, INMARSAT is aiming at integrating navigation with communication services in the development of a global personal communication system.

Investment in an RDSS service is rather risky nowadays. The recent demise of Geostar (in the US) and Locstar (in Europe) to some extent has discouraged the development of RDSS. However, Kinal (1993, p1) argued that 'RDSS was not successful in the market place but did enhance the public awareness of the relationship between the two distinct functions.'

Looking forward to the future, there is always a promising perspective for RDSS systems due to a number of reasons, inte alia:

- Many users require both navigation and communication services and very often the two functions are used simultaneously.
- Users can benefit from the advantages of common equipment for both communication and positioning services over two separated sets of equipment.
- RDSS is a cost-effective means to meet the needs of both communication and navigation markets. The cost of providing the services would be greatly reduced.
- The development of future satellite systems will blur the distinction between navigation and communication satellite systems.

Talking about the possibility of integration of satellite navigation and satellite communications, Oleg Lundberg (1991, p5), Director General of INMARSAT pointed out:

> Although satellite communications and satellite navigation have evolved along somewhat different paths, it is not inconceivable that they will become more integrated at the system level in the future.

CHAPTER V

REMOTE SENSING SATELLITES AND THEIR APPLICATIONS FOR THE MARITIME WORLD

5.1. Introduction to Satellite Remote Sensing Techniques

In the maritime world, the applications of satellite communications and satellite navigation are clearly visible. However, navigators seem to be not so familiar with remote sensing satellites, which are also very important for improving safety and efficiency of shipping. Remote sensing satellites are utilized to observe, measure and monitor the atmosphere and the earth surface. From space, remote sensing satellites collect all necessary information for meteorological and oceanographic studies. Information collected by the satellite is transmitted to the ground stations via communication links. Normally, data provided from the remote sensing satellites are processed at the specialized offices, i.e. hydrographic and meteorological offices, before they are sent to ships and other marine users.

To observe the Earth from space, remote sensing satellites employ various types of sensors. Sensors onboard remote sensing satellites are sensitive to a particular range of wavelengths within the electromagnetic spectrum. There are two types of sensors, namely passive and active sensors. Passive sensors record the energy reflected or emitted from the earth, whilst active sensors generate pulses and record the returned echoes. Examples of the most widely used satellite sensors includes, inte alia:

Active sensors

- Altimeter
- Synthetic Aperture Radar
- Scatterometer

Passive sensors

- Advanced Very High Resolution Radiometer
- Scanning Multifrequency Microwave Radiometer
- Visible and Infrared Spin-scan Radiometer.

Based on their primary applications, remote sensing satellites can be divided into two categories, which are meteorological satellites or earth resources satellites. In the maritime world, their applications are in the fields of either marine meteorology or oceanography which are very related to each other. Remote sensing satellites can be of any orbit type. Normally, they are in near-polar or geostationary orbits.

Since the launch of the first weather satellite TIROS-1 in 1960, a large number of remote sensing satellites have been put into orbit. Most of them have been launched by the United States and the former Soviet Union. The other have been launched by the European Space Agency and some other countries such as Japan, India, France.

The most important remote sensing satellites are listed as below.

- Remote sensing satellites launched by the US: TIROS series (including the first weather satellite TIROS-1), ESSA (former TOS) series, NOAA (former ITOS) series, GOES series, Landsat series, Seasat (the first oceanographic satellite), Nimbus series.
- Remote sensing satellites launched by the former Soviet Union: Cosmos series, and Meteor series.
- Remote sensing satellites launched by the European Space Agency: Meteosat series, ERS series.
- Others: GMS series and JERS series launched by Japan, Insat series by India, SPOT series by France in co-operation with Belgium and Sweden, etc.

Although the applications of remote sensing satellites are extensive, for the purpose of this research, only those related to the maritime world will be discussed.

5.2. Applications of Remote Sensing Satellites for Marine Meteorology

Operational meteorological satellites can observe and photograph every portion of the world, providing meteorologists and scientists with comprehensive information in a large scale that none of the other meteorological observing systems can do. Fundamental parameters for determining the weather such as atmospheric pressure, temperature, humidity, wind, sea surface temperature, can be achieved from the satellite observations. Satellite imagery can be viewed at short intervals, which allows meteorologists to forecast the weather development.

The meteorological information interpreted from the satellite imagery and data may include, inte alia:

Storms

From remote sensing satellites, continuous assessment of a large portion of the earth can be done. Storms can be immediately detected by remote sensing satellites, normally two or three days earlier than by other means. Remote sensing satellites are especially helpful in tracking storms forming over tropical seas, where weather data is sparse or non-existent. The actual route of a storm can also be accurately plotted.

Atmospheric conditions

Data, regarding the condition of the atmosphere that is useful for weather forecasts, can be collected from the remote sensing satellites. It includes the distribution of air pressure, the amount of moisture, temperature, vapour content, snow and rain rate, and the earth's radiation and energy balance.

Clouds

Data about clouds from the satellite observations is normally in the form of colour photographs of clouds and cloud maps. The altitude of the observed clouds can also be estimated.

Wind

Tracking the movements of the clouds from one visible satellite image to the next, wind speed and direction information can be obtained.

Sea surface characteristics

Sea surface temperature, waves and current, ice conditions and other data necessary for determining the weather can be provided from the meteorological satellites. Sea surface temperature strongly influences the rate of evaporation into weather systems and the location of early development of tropical cyclones.

The meteorological data from the remote sensing satellites is processed by meteorologists before being broadcast to users. Marine users benefit from various weather services available from the meteorological offices around the world. In the form of weather forecasts, storm warnings, routeing services, etc., they can strongly affect the safety and efficiency of shipping.

A number of meteorological satellite image mapping systems also have been developed for marine and mobile use. Users of such systems will benefit from direct meteorological images from the satellites. An example is the computer-based system METMAP from DARTCOM (UK). The system enables maritime users to receive the weather images from NOAA remote sensing satellites of the US National Oceanic and Atmospheric Administration. The images generated by NOAA satellites are accurately registered and fed to the orthographic map projections.

5.3. Applications of Remote Sensing Satellites for Oceanography

Today, with the development of remote sensing satellites, oceanographers can have access to the total coverage of the world's oceans. Data generated by the remote sensing satellites is useful not only for general understanding of the ocean but also for a number of applications such as ship routeing, marine environmental monitoring, fisheries management.

Marine users benefit from remote sensing satellites since they can provide them with invaluable information for safe and efficient navigation. Applications of the remote sensing satellites can be seen in the following areas.

Ice monitoring

Using data from the observing satellites, significant improvements in the field of sea ice monitoring and ship routeing through icy waters have been made. Synthetic Aperture Radar images from the satellites are sent to the to specialized centres to integrate and process in order to get a detailed ice map of the region. The maps are then faxed to the vessels within less than three hours of the initial observation. Utilising the service, vessels are able to get out of the area where there is a danger of ice movement against them. In addition, remote sensing satellites can also track drifting icebergs and provide advance warning so that ships can find safer routes.

Sea level observation

Tide gauges have been utilised to provide precise records of the sea level and its changes. However, it is very difficult to study the sea level changes in a large areas and in a long period of time because most tide gauge sites are located in coastal areas. Oceanographers need data from observations over the entire globe. Remote sensing satellites, using satellite altimetry technique, provide an excellent tool for access tidal data in remote locations. Both the sea surface height and sea level changes can be detected from the satellites with an accuracy of a few centimetres.

Ocean current information

Measuring the ocean surface current has been a difficult problem. Since reliable measurements of the surface current are not very easy to acquire, the remote sensing techniques such as satellite feature-tracking are crucial. Satellite feature-tracking is based on comparison of successive satellite images to determine the changes in feature locations. It offers the potential for providing the information on surface currents over large ocean areas on a regular basis. This information, together with other weather observations, is very useful for determining the optimum ships' routes. In addition, ocean current information is also important to the offshore industry when designing offshore structures like oil rigs.

Wave form information

Imaging of the ocean waves can be done by the satellite-based synthetic aperture radar. The radar can provide invaluable information of the wave spectrum such as significant wave lengths, heights and directions, surface elevator and roughness.

Environmental monitoring

Remote sensing satellites provide necessary information not only for managing living resources and coastal ecosystems but also for monitoring marine pollution as well. Large oil spills can be detected from the satellite observations. Regions of oil pollution can be monitored by satellites.

Sea charts mapping

The possibility of using satellite images as a reliable source of information for mapping sea charts, especially the electronic charts, is being studied in some countries, such as Germany, Canada and Australia. As a matter of fact, the sea coast features generated by remote sensing satellites are very important to improve the accuracy of the sea charts. In addition, the data generated by the satellites is in the digital form which can be use directly for the electronic sea charts.

CHAPTER VI

IMPACT OF SATELLITE TECHNOLOGY ON MARITIME EDUCATION AND TRAINING

6.1. Impact of Satellite Navigation on Maritime Education and Training.

6.1.1. GPS and Navigation Teaching

The advances in satellite navigation have opened a new era to navigation. The introduction of GPS has had a great impact on shipboard operations, where conventional position fixing equipment are gradually being replaced by GPS. Consequently, improvements in the curriculum of teaching navigation for ship's officers are needed to match up the crew qualifications with the emergence of new technologies. In brief, the impact of the increasing use of GPS on Maritime Education and Training can be clearly visible in both the quantity, i.e. the teaching time allocation, and the quality, i.e. the teaching content, of navigation teaching.

Quantitative Impact

As discussed earlier in chapter III, the introduction of GPS has strongly affected the future development of other positioning and navigation systems. Modern ships tend to carry on board GPS receivers, either as stand-alone units or as a part of integrated systems, and hence, the use of other means of positioning is significantly decreasing. This fact is obviously reflected by changes in the teaching of navigation in various maritime education and training institutions. In terms of teaching time allocation, some parts of the navigation subject have been cut down or gradually reduced whilst the role of GPS becomes more significant.

Reduction of teaching time allocation can be seen in a number of areas such as celestial navigation and conventional electronic aids to navigation. Currently, there is no need to teach Transit and Omega, since they are going to be phased out very soon. The decreasing use of Decca and direction finding systems will also lead to the fact that teaching time allocated for these topics is shortened. Although Loran-C is currently considered the most suitable back-up system for GPS, its role is no longer as important as before. If there is any intention to deploy another satellite navigation system or to enhance GPS as a sole-means navigation system the future of Loran-C may become uncertain. Therefore, time allocation for teaching Loran-C may also be cut down. Discussion about whether celestial navigation should be phased out or not is also taking place. However, it is generally accepted that teaching of celestial navigation should be reduced.

Obviously, part of the time saved from the above-mentioned topics will be used to enhance the teaching of GPS and other related topics such as integrated navigation systems and electronic charts where GPS is a major component.

Qualitative Impact

The increasing use of GPS, and consequently the increasing use of electronic charts and integrated navigation systems, will basically change the teaching content in the navigation subject. A new approach to navigation teaching is required in order to provide students with the full knowledge of the efficient use of GPS and integrated systems in shipboard operations and the awareness of any risks or dangers facing them due to the increasing use of GPS. When looking for the new approach, a number of factors should be borne in mind.

The first factor is the change in the nature of navigation due to developments in technology, including the increasing use of GPS and modern navigational equipment in shipboard operations. Conventional navigation relies on the extensive use of various means to produce navigational data, to plot the ship's position on the chart and to keep the ship on track. In modern navigation, the ship's position is continuously displayed in the form of latitude and longitude on a GPS receiver. Furthermore, the ship's position is automatically transferred to the electronic chart and the pre-designed route can be accurately tracked. In other words, the increasing use of GPS and other modern navigational equipment is a synonym for simplification, automation and integration of navigation.

The second factor can be considered as a result of the first one. The increasing use of GPS and other modern equipment has basically changed the man-machine-environment relationship, where the role of ship's officers is no longer the same as in traditional navigation. Ship officers tend to be more passive and the dangers of over-confidence and over-reliance on equipment are obvious. To some extent, the increasing use of GPS will bring about higher risks to safe navigation.

As a matter of fact, it is the responsibility of maritime lectures and instructors to take into consideration both the benefits and shortcomings of the increasing use of GPS when teaching navigation. Necessary modifications should be added to the curriculum of the navigation subject to address the impact of new technology .

6.1.2. Required Knowledge of GPS

Ship's officers need to be fully knowledgeable of GPS so that they can use it efficiently for the purpose of safe navigation. The required knowledge for ship's officers should cover the basic knowledge of the system itself. Additionally, a broader knowledge is necessary to enhance the efficient use of GPS.

6.1.2.1. Basic Knowledge of GPS

At this level, all the technical aspects of GPS should be explored, including the system design and operational principles, error and accuracy, as well as differential techniques. Further considerations should be taken of the potential and limitations of GPS, its applications in shipboard operations and its future development. Below is a proposed syllabus for teaching the GPS topic.

Table 6.1 - Syllabus for a GPS Module

Contents	Time allocation (hours)
1. Introduction...	1 h
- Satellite navigation evolution (including GPS counterparts)	
- GPS system design	
2. Operational principles..	4 h
- Pseudo-range and PRN codes	
- Clock and timing	
- Frequencies	
- Navigational messages	
- Computation of position	
- Position aidings	
- Position reference frame	
3. Errors and accuracy..	1 h
- Error sources	
- Accuracy	
- System integrity	
4. Differential GPS...	2 h
- Need for DGPS	
- Configuration and operational principles	
- DGPS messages	
- Worldwide development of DGPS	
5. Potential of GPS/DGPS..	0.5 h
- Applications positioning	
- Impact on other positioning systems	
6. Legal aspects of GPS..	0.5 h
- Control and management	
- Positioning services and selection availability	

Contents	Time allocation (hours)
7. GPS and shipboard operations..	2 h
- GPS receivers	
- GPS and electronic chart and integrated navigation system	
- Impact of GPS on navigation	
- Charting aspects of GPS	
- Man-machine-environment relationship	
8. Future developments..	1 h
- Phase carrier measurement	
- Pseudolites	
- Future applications	
- Wide-area DGPS	
- Combination of GPS/GLONASS	
- INMARSAT navigational services	
- Future civil Global Navigation Satellite System	

(source: author)

Remarks:

1. With particular reference to the current situation at the Vietnam Maritime University, this proposed syllabus is only a brief outline for teaching GPS within the subject of Electronic Aids to Navigation.
2. The total time allocated for this module is 12 teaching hours (one teaching hour is equal to 45 minutes)

6.1.2.2. GPS in a Larger Context

As discussed earlier, the increasing use of GPS has strongly affected the nature of navigation and basically changed the man-machine-environment relationship in shipboard operations. Therefore, apart from the basic knowledge about the system itself, GPS should be considered in a broader context so that a full understanding of GPS and its impact on shipboard operations can be achieved. This context, according to Berking (1994, p2), consists of the following three main areas:

- GPS and navigation
- GPS and data processing
- GPS and the human element.

• GPS and Navigation:

There are two aspects of the impact of GPS on navigation of which ship's officers should be aware of. On the one hand, mariners greatly benefit from the use of GPS in navigation. From the navigator's point of view, GPS is an ideal tool for navigation, providing global coverage and high accuracy. The differentiation of ocean navigation, coastal navigation and harbour navigation will disappear with the high level of accuracy provided by GPS/DGPS. GPS can also be used for effectively optimizing the route and speed and automatic track keeping. With a GPS receiver on board, navigational tasks are obviously much simpler and easier than without it, and hence the workload can be significantly reduced. Furthermore, many other applications of GPS can be seen in shipboard operations such as man-over-board and anchor-watch functions. GPS can also be used as positioning sensors for distress and safety equipment and even the "black-box". Further applications such as calculation of draft, trim and bending, will be developed in the foreseeable future. Undoubtedly, GPS has greatly contributed to the improvement of safety and efficiency of navigation.

On the other hand, GPS also brings some dangers to navigation. When using GPS, safe margins to the nearest dangers are often reduced by navigators. Although GPS is extremely accurate, it does not necessarily mean that it fits with other navigational facilities and equipment, e.g. the sea charts. With regard to safe navigation, the accuracy of GPS is meaningless if the accuracy of the charts is not at the same level. Difference in the GPS reference system and the chart datums will significantly reduce the accuracy of GPS fixes. To some extent, GPS brings higher risks if these limitations are not taken into account.

• GPS and Data Processing

In fact, the GPS receiver is a product of computing technology, which provides navigators with positioning data. According to Berking (1994, p19), GPS users are free from producing the position data, unlike when using conventional means.

Instead, they are responsible for accessing and evaluating the data as well as for providing adequate judgement on the reliability of data. The fast processing of data is therefore needed.

In addition, it is worth bearing in mind that GPS is normally used as the positioning sensor of the bridge integrated system based on computer technology. The complexity of the interface between the system and the navigator will obviously affect the capability of accessing and processing data. For example, it is very hard to distinguish unreliable data from the huge amount of data provided by the system, as well as to find out the origin of the mistakes.

• GPS and the Human Element

It is generally perceived that the human element is the main factor that contributes to marine casualties. As mentioned earlier, the increasing use of GPS has basically changed the man-machine-environment relationship in which the human factor is of utmost importance. For example, the use of GPS in shipboard operations may bring about some dangers such as lack of critical thinking, lack of attention, passive response, inability to access information, difficulty of finding mistakes when things go wrong and psychomotoric problems. In addition to this, there are two common mistakes which are normally made by GPS users, namely over-confidence and over-reliance.

- Over-confidence: The habit of being suspicious of any danger may disappear. GPS users tend to reduce safety margins due to the high level of accuracy of GPS, and to forget to cross-check with other positioning systems.
- Over-reliance: GPS users tend to be dependent on the GPS receivers and disregard obtaining information from various sources.

In conclusion, efficient use of GPS can only be achieved if all limitations of GPS are acknowledged. Consideration should be taken when deciding what to teach and how to teach GPS.

6.2. Satellite Communications and Training of GMDSS

6.2.1. The Need to Train GMDSS for Ship's Officers

As mentioned earlier, the Global Maritime Distress and Safety System is being phased in between 1992 - 1999. The implementation of GMDSS has had great impact on the training of maritime radio personnel. Before the introduction of GMDSS, ships had to carry specialized radio personnel who were capable of operating radiotelephony and radiotelegraphy equipment. The requirement was provided in a number of IMO and ITU instruments such as SOLAS 74, STCW 78, Radio Regulations. Radio personnel were required to be equipped with specialist skills in order to be able to use radio equipment, including Morse telegraph, to carry out distress and safety communications.

The trend in enhancing safety and efficiency at sea has led to the demise of Morse telegraphy and the utilization of modern radio communication technology in shipboard operations. The GMDSS system was adopted in the 1988 amendments to the SOLAS convention, in which ships are required to carry 'personnel qualified for distress and safety radio communication purposes to the satisfaction of the Administration' (SOLAS, Reg. V/16). With the new requirement, the role of radio officers has changed. Radio personnel on board ships can now be considered as GMDSS operators who are capable of utilizing all the GMDSS equipment. Based on the latest automated technology in both terrestrial and satellite communications, easy-to-use GMDSS equipment has been promoted. This allows non-specialists to become GMDSS operators after taking short GMDSS courses. In other words, all ship's officers can be trained to become GMDSS operators. A ship can have several GMDSS operators on board, and hence the safety of the ship will be much improved.

However, the introduction of the GMDSS does not necessarily mean that there is no need for specialized radio personnel. Since the equipment is becoming sophisticated, specialized radio personnel can be maintained on board for repair and maintenance of the radio equipment, apart from operating the GMDSS equipment.

Although a large number of ships are now being equipped with GMDSS equipment, ship's officers are not provided with adequate training to operate the facilities. A number of Search and Rescue authorities have warned about the problem of false alarms. In 1992, only 12 of 662 GMDSS alerts handled by the UK Maritime Co-ordination Centre were genuine. During the same period of time, the Dutch Coast Guard were called out 179 times but only one of the calls was a real emergency. In fact, the lack of knowledge about the GMDSS system is the main cause of the problem of false alarms. Training of GMDSS is becoming an urgent need, particularly with the introductory phase of GMDSS which started in 1992 and will end by 1999.

The introduction of the GMDSS system requires that the knowledge of GMDSS should be incorporated into basic training for ship's officers. Eventually, all ship's officers will be capable of handling communications in distress situations as well as performing other general communications. It is the duty of maritime institutions, in co-operation with the shipping industry and telecommunication organizations, to provide ship's officers with a full knowledge of the GMDSS system. According to Brodje and Jaen (1993, p6), 'there are an estimated 260,000 officers world-wide who will have to be trained and certificated to the new GMDSS standards.'

Recognizing the importance of training GMDSS for ship's officers, IMO and ITU are urging member states to provide GMDSS courses for ship's officers. Requirements for training and certification for GMDSS operators are provided in the 1991 amendments to the STCW convention of IMO and 1992 amendments to the ITU's Radio Regulations. IMO has also adopted the Resolution A 703(17) in 1991, providing guidelines for the training of radio personnel in the GMDSS system. Much effort has been made by IMO in order to standardize the GMDSS courses.

6.2.2. GMDSS Courses

GMDSS courses are being conducted in a number of countries in the world, mostly in developed countries. There are five different types of courses, which lead students to the respective GMDSS certificates, namely:

- First-class Radio Electronic Certificates
- Second-class Radio Electronic Certificates
- General Operator's Certificates
- Restricted Operator's Certificates
- Maintenance of the GMDSS installations on board ships.

However, most of the GMDSS courses being conducted are short courses leading to the issue of the General Operator Certificates (GOC) (See Table 6.2).

Table 6.2 - Duration of GOC Courses Being Conducted

Country	Duration (weeks)	Country	Duration (weeks)
Australia	2	Norway	3
China	3	Philippines	1
Denmark	2	Singapore	1
Finland	3	South Korea	1
Germany	1	Sweden	2
Greece	5	UK	1-2
Hongkong	2	USA	2
Malaysia	2		

(source: author)

Normally, GOC courses are run by maritime institutions and telecommunications authorities. On the successful completion of the course, General Operator's Certificates are awarded to the participants. Unfortunately, there are currently no standards on the training syllabus. Brodje and Jaen (1993, p6) warned that 'the training syllabi available vary widely in content and the duration of courses is proving just too short in some countries.' There is also another problem of the GMDSS training facilities which are either 'woefully inadequate or simply non-existent' (Brodje and Jaen, 1993, p6).

IMO is trying to introduce a Model Course in order to facilitate and standardize the training of GMDSS. A Model Course on GOC certificate for the GMDSS system developed by the Danish Maritime Authority has been submitted to the IMO for consideration and validation.

In some countries, much effort has been made in order to improve the GMDSS training standards. For example in the UK, the 5-day GOC courses are now extended from eight to ten days. New standards for examination and certification have been introduced since January 1994 in all thirteen regional GMDSS training centres in the UK. A common syllabus and examination guideline also has been developed and adopted in the European Conference of Postal and Telecommunications Administrations (CEPT), which is formed by several European countries.

The GOC course syllabus normally covers a full range of all GMDSS facilities, including the operation of the equipment, knowledge and practice of the radio procedures both for the distress and safety communications and general communications. A course length of at least two weeks is recommended to provide the students with intensive knowledge of the GMDSS system as well as skills in operating the equipment. The main part of a GOC course is practically based to develop the operational skills of handling the huge range of equipment, both terrestrial and satellite communications. In general, a GMDSS GOC course needs to cover the following areas:

- Knowledge of maritime mobile service and maritime mobile-satellite service.
- Operation of the full range of equipment including VHF, MF, HF transceivers plus Digital Selective Calling, INMARSAT ship earth stations (INMARSAT-A and INMARSAT-C), NAVTEX receiver, EPIRBs, SARTs, 2182 KHz watch-keeping receivers, etc.
- Knowledge and practice of radio procedures for distress and safety communications for the GMDSS system and subsystems.
- Skills and operational procedures for general communications.

6.2.3. Required Knowledge of Satellite Communications in the Training of GMDSS

The GMDSS is based on automated communication systems, both satellite-based and terrestrial. Satellite communications undoubtedly play a major key role because it is inherently automated, reliable and easy to operate. Apart from distress and safety communications, which the GMDSS system concentrates on, satellite communications also offer tools for general communications. This allows GMDSS operators to perform daily operational communications which are very important in modem shipping nowadays.

Therefore, training satellite communications for ship's officers is obviously compulsory in any GMDSS courses. Ship officers are required to have detailed knowledge of the maritime satellite communications system, i.e. INMARSAT, and its services as well as practical capability of operation of all GMDSS satcom equipment including INMARSAT-A, INMARSAT-C and satellite EPIRBS. In general, the following areas of knowledge and skills of satcom should be incorporated into the GMDSS teaching syllabus:

General Knowledge of the Maritime-Mobile Service

- INMARSAT system description, including the space segment, ground segment, and user segment
- Different types of INMARSAT Ship Earth Station (the main concern is about INMARSAT-A and INMARSAT-C)
- INMARSAT Maritime Services and applications
- Satellite communications for distress and safety system including INMARSAT distress and safety communications and satellite EPIRBs
- Description of EGC system, including FleetNET and SafetyNET
- Radio procedures for distress and safety communications via satcoms
- General communications via satcoms.

Practical Knowledge of the Usage of INMARSAT Equipment

- INMARSAT-A Ship Earth Station:
    - Component of an INMARSAT-A terminal
    - Preparing an INMARSAT-A terminal for use (including satellite acquisition)
    - Distress and safety communications
    - Telex services
    - Telephone services
    - Facsimile and data communications.

- INMARSAT-C Ship Earth Station:
  - Component of an INMARSAT-C terminal
  - Preparing an INMARSAT-C terminal for use, including log in, log out, automatic scan
  - Distress and safety communications
  - Telex services
  - Data reporting and polling services.
- INMARSAT Enhanced Group Call:
  - EGC services for shore-to-ship broadcast
  - SafetyNET (including concept of METAREAS and NAVAREAS)
  - FleetNET
  - All ships messages and INMARSAT System messages.

Practical knowledge of the usage of satellite EPIRBS

- 406 MHz satellite EPIRBS (COSPAS-SARSAT)
  - Operation
  - Technical Characteristics
  - Manual usage
  - Float-free function
  - Testify.
- 1.6 GHz satellite EPIRBS (INMARSAT)
  - Operation
  - Technical characteristics
  - Manual usage
  - Float-free function
  - Testify.

6.2.4. Application of Simulation Methodology in Training of Satcoms and GMDSS

Recent years have seen the increasing use of simulators for training purposes in many countries of the world. A large number of simulators, including radar/ARPA, shiphandling/bridge, engine room, cargo handling, navigation instruments and VTS simulators, have been delivered to maritime education and training institutions. Simulators have proved to be an efficient tool for training practical skills, particularly in critical situations that rarely happen in real life.

For the purpose of training satellite communications and GMDSS for ship's officers, the role of GMDSS simulators is critical in building the students' confidence for the real world of distress and safety communications. The use of simulators for training has a number of advantages over that of real-life equipment, as described below.

- Students can experience critical situations including distress communications which are not allowed to be practiced with real-life equipment.
- Instructors can easily control the communication situation, supervise student performance and assess student's skills.
- A wide range of training capability can be achieved, in terms of variety of equipment, scenarios, etc.
- Exercises can be stored and repeated for debriefing and evaluation.
- There are no communication charges in comparison to using real equipment for training. (Charges are about 4-8 US dollars per minute if communications are handled through a live SES)
- There is a flexibility in choosing types of simulator and in expanding the system in accordance with available resources.

Currently there are two types of Satcom/GMDSS simulators, which are real-format and PC-based simulators.

- *Real-format simulator:* consists of a central computer processor and real-format instruments which simulate all GMDSS facilities. The cost is relatively high. A configuration of one instructor and five students may cost about half million US dollars.

- *PC-based simulator:* consists of a number of networked personal computers with sufficient software. The cost is relatively cheap. A system of one instructor and five student terminals may cost about thirty thousand US dollars.

There are a number of manufacturers who have developed and are developing GMDSS simulators. Of them, the most well known are Radio Holland, Poseidon, Maracs, Norcontrol, JRC, and Transas.

Radio Holland (Netherlands)

A complete satcom simulator system has been developed by Radio Holland. It comprises of an instructor and up to thirty students' positions operated as INMARSAT-A or INMARSAT-C SESs within a network. Distress communications as well as general communications (via INMARSAT system) can be achieved, using both telex and voice services. Radio Holland has also developed real-format GMDSS simulators for learning GMDSS procedures. All GMDSS facilities on board are simulated in the system.

Poseidon (Norway)

Poseidon Simulation System AS is one of the first developers of PC-based GMDSS simulators. A Poseidon GMDSS simulator unit includes one instructor and up to fifteen students stations. All GMDSS communication functions can be performed on the PC monitors in the same procedures as with the real equipment. The Poseidon GMDSS PC-based simulator is relatively cheap. At the time of writing, twenty seven units have been delivered to various GMDSS training centres and MET institutions around the world.

Maracs Electronic (Greece)

Maracs has developed a GMDSS simulator based on a local area network. The system consists of an instructor console and up to twenty students' own ships. Distress signals and full range of GMDSS facilities are simulated.

Other manufacturers

Norcontrol (Norway) and Japan Radio Company (Japan) are developing their own real-format GMDSS simulators but no delivery has been recorded yet. Transas Marine (UK) is also developing a PC-based GMDSS simulator.

6.3. Satellite Communications for Distance Education and Onboard Training

6.3.1. The Concept of Distance Education

Distance education has attracted great interest in the last two decades. It originated from correspondence education, which is a method of education through self-instructional written texts and correspondence between students and tutors. Since the media, other than correspondence, became more and more widely used, the term 'correspondence education' has been gradually replaced by other terminologies such as 'distance education', 'independent study', 'home study', 'external studies', 'teaching at a distance'. 'Independent study' and 'home study' are most commonly used in the United States, whilst 'external studies' is applied in Australia and South Pacific and 'teaching at a distance' is popular in the United Kingdom. However, the term 'distance education' is most widely used and has already gained international acceptance.

Distance education has been defined differently in various items of literature about the subject. One of the most generally accepted definitions is stated by Homberg (1989, p3), as below.

> The term distance education covers various forms of study at all levels which are not under continuous, immediate supervision of tutors present with their students in lecture rooms or on the same premises but which, nevertheless, benefit from planning, guidance and teaching of a supporting organization.

Analyzing various definitions of distance education, Keegan (1989, p15) concluded that the six essential characteristics of distance education were:

- the separation of teachers and students
- the influence of an educational organization
- the use of technical media to carry the educational content
- the provision of occasional meetings for both diadetic and socialization purposes
- the participation in the most industrialized form of education.

The separation of teachers and students is the main characteristic in distinguishing distance education from the conventional face-to-face educational methods.

Normally, students in distance education are those in full-time employment, housewives, institutionalized, and those in certain occupations that have traditionally been associated with distance study such as seafarers, shiftworkers, police, army.

In distance education, students work on their own with self-instructional learning materials. They also interact with educational organizations by various means of distance-study media and by occasional meetings. Counseling and support to the students are provided by tutors in the organizations. Due to the growing demand for distance education, a large number of universities and institutions were created in the 1970s and 1980s. Of them, the most famous ones are the Open University in UK, Fernuniversität in Germany, Athabasca University in Canada, and the Open College of Further Education in Australia.

Compared with conventional face-to-face education methods, distance education has a number of advantages, as below, inte alia:

- Distance education can reach audiences who would not be reached by conventional means.
- Distance education reduces the staff-student ratios and hence can be cheaper than conventional education.
- Distance education can overcome the problem of lack of teachers and skills, particularly for some developing countries.
- Distance education can meet the demands for learner freedom.

6.3.2. Onboard Training and Distance Study for Mariners

As mentioned earlier, seafaring is one of the special occupations that have traditionally been associated with distance study, since seafarers are quite often separated from ashore education and training institutions. Muirhead (1994, p8) noted that 'seafarers, as result of their environment, have long been denied access to effective education and training opportunities at sea.' To overcome the problem of lack of competent skills, a significant amount of maritime education and training needs to be carried out onboard ships, where effective learning and skills acquisition. Furthermore, the rapid development of technology, as well as the changes in requirements of the industry, have led to the fact that initial training becomes outdated very fast. Therefore, onboard training and distance study for seafarers has become more and more important.

According to Muirhead (1994, 11), there are three reasons for giving priority to onboard education and training, namely:

- the need to meet the on board training obligations of ship operators
- the potential of communications technology to provide effective training on board
- the increased desire for access to further education by ship board personnel.

In general, most of the on board education and training, except that directly instructed by experienced shipboard personnel, can be considered as distance study. However the scope, level and duration may vary depending upon the training purposes. This may include:

- sea training for cadets, guided by MET institutions
- competency based training for shipboard personnel, required by shipping companies or on shore training centres
- continuing education with distance study programmes, instructed by either maritime institutions or suitable specialized institutions.

Again, educational organizations supporting on board training and distance study, including maritime institutions, training centres, shipping companies, play a critical role. Learning materials need to be well prepared in all forms:

- print-based such as unit guides, study guides, reading books
- audio-based such as cassette tapes
- visual-based: video tapes, compact disc interactive workstations (CD-ROM and CD-I)
- computer-based: software computer aided learning.

Two-way communications between shore and ship need to be established so that cadets as well as other shipboard personnel can make contact with the tutors ashore if they need any instructional advice.

6.3.3. Satellite Communications for Onboard Training and Distance Study

In distance education, the effectiveness of the learning process is much dependent on the communications between students and the tutors. The emergence of sophisticated communication technology is the main factor contributing to the development of distance education.

In the maritime field, the increasing use of satellite technology has opened a new horizon for monitoring on board training programmes. Satcoms will provide a steady link between the students on board ships with the training institutions on shore. Various services are available via satcoms, including telephone, telex, facsimile, electronic mail and data communication. Most of the learning materials for distance study, including print-based, audio-based, visual-based and computer-based, can be transmitted to the students on board ship via satcoms. Furthermore, satcoms provide effective support to facilitate educational process, transferring both instructional advice from the tutor and feedback from the students.

The Communication Link

Practically, the communication link is based on the INMARSAT system. Ships participating in distance training programmes need to be equipped with INMARSAT-A or INMARSAT-C Ship-Earth-Stations and Enhanced Group Call facilities. On the other hand, maritime institutions are also installed with INMARSAT terminals and commissioned as FleetNET information providers. This will then enable the institutions to make contact with all the ships of its designated fleet. For further development to improve the communication efficiency, the use of PC computers with appropriate software is valuable. A combination of computers and communication technology represents a powerful tool in meeting the task and demand of education in future

Economical communication modes

Although the communications charges via satellite are currently rather high, the increasing use of satcoms will bring the cost down in the near future. Depending on the equipment available, the amount and nature of learning material as well as efficient modes of communication should be chosen to reduce the transmission costs. Short messages can be transferred through telephone, telex and facsimile services. Data compression techniques are a promising means of saving money. Electronic mail may be of enormous value to the student in interacting with a busy tutor and at a very much lower cost than telephone call and telex. High Speed Data, which allows the fast transmission of computer files, voice and video conferencing, will benefit distance learning students. Shipboard computer facilities can be connected with computer systems ashore. Students can access and interact with electronic data bases.

Communication links and monitoring on board training programmes

For the purposes of monitoring and facilitating the on board training programmes and distance studies, satcoms are very helpful for the interaction between the students and their tutors. These interactions may include, inte alia:

- advice and instructions
- guidance on assessment
- diagnostic analyses of the problems
- provision of information and explanations
- assignments submission
- comments on student papers
- feedback on student progress

A pilot program to monitor on board training, as described by Muirhead (1994, p3), has been implemented by the Australian Maritime College. Utilizing EGC facility FleetNET to communicate with individual ships in the designated fleet, the program has proven that part of watchkeeping officers' training can be carried out at sea.

In conclusion, it is worth noting that satcoms development has promoted the growing need of on board training and distance study for seafarers, as Muirhead (1994, p2) has remarked:

> Satellite Communication Technology offers a powerful new option with which to tackle the problems facing the maritime industry and to open the window of learning and training opportunities to the mariners onboard ships.

CHAPTER VII

CONCLUSIONS

The increasing number of satellites placed into orbit and the growing application of satellite technology in many fields of human life have proven the essential role of satellites in our time. Particularly in the maritime world, satellite technology has significantly contributed to the improvement of safety and efficiency of shipping as well as the protection of the marine environment. The applications of satellite technology are widespread and expanding. Marine users greatly benefit from the utilization of satellite technology in maritime communication, marine navigation as well as meteorology and oceanography. As a result of this study, a number of conclusions can be drawn as shown below.

Satellite Communication

Satellite communication has proven its superiority over its terrestrial counterparts in many aspects including availability, reliability, mobility and ubiquity. Since the foundation of INMARSAT, more developments have been made in the field of maritime communication.

INMARSAT has successfully achieved its primary objective, which is to improve communications for the safety of life at sea and for the efficient management of shipping. INMARSAT ship-earth-stations are not only a good managerial tool but also the best choice for distress and safety communication functions as well. Consequently, the number of INMARSAT terminals fitted on board ships and the communication flow via INMARSAT satellites are continuously increasing.

INMARSAT is constantly working to improve and expand the range of its services. Much attention has been paid to the enhancement and development of the three segments of the INMARSAT communication system, i.e. the satellites, the land-earth-stations and the ship-earth-stations. Intensive studies are taking place within the framework of the Project 21. The goal is to reach more and more customers by investing in more powerful satellites, providing more services, developing smaller and cheaper shipboard terminals, as well as reducing the communication charges.

Satellite communication is an ideal tool to fulfill the requirements of the newly-introduced Global Maritime Distress and Safety System. INMARSAT and COSPAS-SARSAT play an essential role in the GMDSS system. Reliability and user-friendly characteristics of satellite communication allow shipping to replace specialized radio operators without reducing the level of safety. However, it is worth bearing in mind that INMARSAT and coastal states are responsible for providing sufficient GMDSS facilities, including the broadcasting of Maritime Safety Information via the INMARSAT's SafetyNET service.

Satellite Navigation

Since it is generally accepted that terrestrial radio navigation systems are gradually being displaced by satellite navigation systems, the role of satellite technology is critical in marine navigation. The ideal features provided by satellite navigation systems have brought about new perspectives for marine navigation in general and for precise navigation in particular. The newly-developed Global Positioning System (GPS) is currently considered as the most suitable candidate for a sole-means navigation system in the future.

For the first time in the history of navigation, navigators can have access to a real-time, weather-independent, highly accurate and worldwide system - the GPS system. Nowadays, the applications of GPS can be seen in many fields of the maritime world. Obviously, GPS has great impact on marine navigation, especially on the improvement of safety and efficiency of navigation.

Using the differential technique, the accuracy of the GPS system will be greatly improved. The growing needs for precise navigation as well as the increasing use of integrated systems, including the Electronic Chart and Information Display System, have obviously sped up the worldwide deployment of differential GPS.

Although transmission of DGPS corrections by radiobeacons seems to be the best cost-effective method for coastal navigation, extensive studies and experiments have been conducted to develop other methods such as multi-site DGPS or wide-area DGPS. It should be borne in mind that the worldwide deployment of DGPS requires international standards for DGPS correction broadcast and for DGPS shipboard terminals. Users should also have free access to any DGPS service.

Apart from its obvious advantages over the other radio navigation systems, the GPS system also has a number of drawbacks which GPS users need to bear in mind, e.g. the state-owned, military-controlled status, the integrity problem, etc. With the increasing use of GPS, the man-machine-environment relationship is significantly changed, which may bring some dangers to safe navigation. In addition, GPS users can also be disadvantaged by sea charts which do not fit with GPS in terms of reference datum and positional accuracy of charted features.

In the future, further studies into the development of satellite navigation should be taken into consideration. An integrity method should be chosen among various methods which are currently under study such as Receiver Autonomous Integrity Monitoring (RAIM), GPS Integrity Channel (GIC) or Satellite Self Monitoring. International, regional and national GPS Information Centres need to be established to provide information on the status of the system. The performance standards and carriage requirements of GPS and DGPS should also be discussed.

Remote Sensing Satellites

Remote sensing satellites can provide comprehensive information on a large scale for weather determination, which is very important for safe navigation. Marine users can access either directly from satellite images of clouds, ice, sea state, etc., or indirectly from weather and routeing services provided by meteorology offices.

Further applications of remote sensing satellites can also be seen in many areas other than weather and routeing information, for example in monitoring and controlling of the marine environment, sea chart mapping.

Impact on Maritime Education and Training

The widespread utilization of satellite technology in many fields of the maritime world also has a strong impact on maritime education and training. Ship officers need to be equipped with knowledge and skills for the effective operation of satellite-aided equipment on board to improve the safety and efficiency of shipping. In turn, satellite technology can support them by enhancing their study when at sea if it is needed.

The training in the use of satellite communications for ship's officers is a compulsory part of the GMDSS training. Warnings from the Search and Rescue authorities about the problem of false alarms have proven that the maritime education and training has not matched up with the implementation of the GMDSS system. From now up to the turn of the century, there is an urgent need for GMDSS training for ship's officers through short courses. A model course is needed to standardize the training, examination and certification on a global scale. The possibility to incorporate GMDSS training into the basic training for ship's officers should be taken into consideration.

The increasing use of GPS in shipboard operations has led to the fact that GPS and related topics, such as electronic chart and integrated navigation, are more weighted, whilst time allocation for some other topics is shortened or eliminated. Effective use of GPS for the safety and efficiency of navigation requires not only sufficient background about the GPS system itself but also a thorough understanding of its impact on shipboard operations. Therefore, teaching GPS needs also to be considered in a broader context, where the relationship between GPS, data processing and the human element is addressed.

Satellite communication provides an excellent means for on board training and distance studying for mariners. Sea training for cadets, competency-based training for shipboard personnel as well as distance education for those who are interested in continuing education while at sea can be effectively supported by satellite communication links between ships and shore-based institutions. With the developments in technology, the problem of high communication charges can be solved and mariners will greatly benefit from this new approach to maritime education and training.

To summarize, various applications of satellite technology in maritime communication, marine navigation as well as marine meteorology and oceanography have painted a general picture of the utilization in the maritime world. Undoubtedly, satellite technology is having a strong impact on many fields in the maritime world, from ships at sea to companies ashore, from communication to navigation, from safety of life to efficiency of shipping, from shipboard operations to shore-based education and training.

With the development of technology it will be no surprise in the future if ships are equipped with handheld mobile satellite telephones and the global satellite navigation system will be accepted as a sole-means navigation system. It is also hoped that future satellite systems can simultaneously perform all three functions, i.e. communication, navigation and remote sensing, providing marine users with convenient one-stop services. Finally, it is worth mentioning that only imagination will limit the utilization of satellite technology in our time.

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APPENDICES

APPENDIX - A	Navstar GPS Satellites: Operational Status
APPENDIX - B	INMARSAT Space and Ground Segments: Operational Status
APPENDIX - C	COSPAS-SARSAT Space Segment : Operational Status
APPENDIX - D	INMARSAT Ship Earth Stations: Features and Services
APPENDIX - E	IINMARSAT Coast Earth Stations: Contacts and Services

APPENDIX - A

NAVSTAR G.P.S. SATELLITES OPERATIONAL STATUS (March 1994)

No.	SVN	PRN	Plane	Start	End	Remark
BLOCK I						
1	1	4	C	1978	1985	
2	2	7	A	1978	1981	
3	3	6	A	1978	1992	
4	4	8	C	1979	1989	
5	5	5	C	1980	1983	
6	6	9	A	1980	1991	
7	7	-	-	-	-	Launch failure
8	8	11	C	1983	1993	
9	9	13	C	1984	-	
10	10	12	A	1984	-	
11	11	3	C	1985	-	
BLOCK II						
12	14	14	E-1	1989	-	
13	13	2	B-3	1989	-	
14	16	16	E-3	1989	-	
15	19	19	A	1988	-	
16	17	17	D-3	1990	-	
17	18	18	F-3	1990	-	
18	20	20	B-2	1990	-	
19	21	21	E-2	1990	-	
20	15	15	D-2	1990	-	

APPENDIX - A (contd.)

No.	SVN	PRN	Plane	Start	End	Remark
BLOCK IIA						
21	23	23	E-4	1990	-	
22	24	24	D-1	1991	-	
23	25	25	A-2	1992	-	
24	28	28	C-3	1992	-	
25	26	26	F-3	1992	-	
26	27	27	A-2	1992	-	
27	32	1	F-1	1992	-	
28	29	29	F-4	1993	-	
29	22	22	B-1	1993	-	
30	31	31	C-3	1993	-	
31	37	7	C-4	1993	-	
32	39	9	A-1	1993	-	
33	35	5	B-4	1993	-	
34	30	30	D-4	1993	-	
35	34	4	C-1	1994	-	

(Source: US DoD)

APPENDIX - B

INMARSAT - SPACE AND GROUND SEGMENTS OPERATIONAL STATUS (August 1993)

	AOR-W	AOR-E	IOR	POR
OPERATIONAL SATELLITES	INMARSAT2 F4 54.0°W	INMARSAT2 F2 15.5°W	INMARSAT2 F1 64.5°E	INMARSAT2 F3 178.0°E
SPARE SATELLITES	MCS-B 50.0°W	MARECS B2 15.0°W	MCS-A 66°E	MCS-D 180.0°E
INMARSAT-A NCS	SOUTHBURY	SOUTHBURY	YAMAGUCHI	YAMAGUCHI
INMARSAT-M/B NCS	SOUTHBURY	SOUTHBURY	THERMOPYLAE	SANTA PAULA
INMARSAT-C NCS	GOONHILLY	GOONHILLY	THERMOPYLAE	SENTOSA
INMARSAT-E CES RCC	NILES CANYON ALAMEDA	RAISTING BREMEN	PERTH CANBERRA	PERTH CANBERRA
CES RCC				NILES CANYON ALAMEDA

(source: INMARSAT)

APPENDIX - C

COSPAS-SARSAT - SPACE SEGMENT OPERATIONAL STATUS (October 1993)

Satellite	Date Launched		406 MHz SARP		121.5 MHz SARR	406 MHz Repeater
			Global Mode	Local Mode		
Sarsat-2	12 Dec.	1984	O(1)	O	O	O
Sarsat-3	17 Sept.	1986	N(2)	N(2)	O	O
Sarsat-4	24 Sept.	1988	O	O	O(3)	N(4)
Cospas-4(5)	4 July	1989	O	O	O	NA
Cospas-5	27 Feb.	1990	O	O	O	NA
Cospas-6	12 Mar.	1991	O	O	O	NA
Sarsat-5(6)	August	1993	*	*	*	*
Sarsat-6	Projected	1994	-	-	-	-
Cospas-7	As required		-	-	-	NA
Cospas-8	As required		-	-	-	NA

Notes:

O	- Operational	(1)	- Local mode available to all LUTs, global mode available through USMCC only.
NA	- Not applicable		
N	- Not operational	(2)	- Failed in September 1988.
SARP	- SAR processor	(3)	- Some Electromagnetic Interference (EMI) degradation.
SARR	- SAR repeater	(4)	- Failed in September 1988.
		(5)	- Limited availability in Southern hemisphere due to unstable orientation.
		(6)	- Satellite failure after launch.

(Source: COSPAS-SARSAT)

APPENDIX - D INMARSAT SHIP EARTH STATIONS FEATURES AND SERVICES

FEATURES	INMARSAT-A™	INMARSAT-B™	INMARSAT-C™	INMARSAT-M™
World Coverage [1]	Global	Global	Global	Global
Overall Weight	Average 120 kg	Average 100kg	Average 10kg	Average 25kg
Size of antenna: diamter & height	Approx 0.9 - 1.2m	Approx 0.9m	Approx 0.3m	Approx 0.5m
Antenna type and means of tracking satellite	Parabolic (dish shaped) antenna, mechanically steered and gyro-stabilised against vessel motion	As with Inmarsat-A	Small omni-directional antenna, with no moving parts, does not need to be steered or stabilised	As with Inmarsat-A/B
Communications type	Real-time (Immediate)	Real-time (Immediate)	Store-and-forward	Real-time (Immediate)
SERVICES				
Voice	Yes	Yes	No	Yes
Telex	Yes	Yes	Yes	No
Group 3 fax (rates)	To 9,600 bits per second	9,600 per second	No	2,400 bits per second
Data rates[2]	To 9,600 bit per second	To 16,000 bits per second	600 bits per second	2,400 bits per second
X-25 (Dedicated data channel)	Yes	Yes	Yes	Yes
X-400 (Electronic mailbox)	Yes	Yes (enchancement)	Yes	Yes (enhancement)
High Speed Data	56/64kilobits per/sec	56/64kilobits per/sec	No	No
Full motion "store and forward" video	Yes	Yes	No	No
Short Data/Position	No	No	Yes	No
GROUP CALL[3]	Yes	Yes	Yes	Yes
SafetyNet℠[4]	Yes, with Inmarsat-C/EGC Receiver Installed	Yes, with Inmarsat-C/EGC receiver installed	Yes	Yes, with Inmarsat-C/EGC receiver installed
FleetNET℠[5]	Yes, with Inmarsat-C/EGC receiver installed	Yes, with Inmarsat-C/EGC receiver installed	Yes	Yes, with Inmarsat-C/EGC receiver installed
DISTRESS & SAFETY				
GMDSS compliant	Yes, if properly installed (See Inmarsat DIGs[6])	Yes, if properly installed (See Inmarsat DIGs)	Yes, if properly installed (See Inmarsat DIGs)	No
Distress Button	Yes	Yes	Yes	Yes

(1) World Coverage: Worldwide availability except at extreme polar latitudes.
(2) Data Rate: Higher rates may be achieved with data compression techniques.
(3) Group Calls: Simultaneous broadcasts to selected groups of users or geographic areas.
(4) Services broadcast include distress and safety information, weather and navigational information for fleet management.
(5) For fleet management, subscription services like news and other commercials applications.
(6) Design and Installation Guidelines (DIGs) for the GMDSS are available from Inmarsat.

(Source: INMARSAT)

APPENDIX - E

INMARSAT COAST EARTH STATIONS CONTACTS AND SERVICES

Country	Operator	Telephone	Facsimile	CES	AOR-E	AOR-W	IOR	POR
Australia	Telstra	+61 2 901 2103	+61 2 906 5175	Perth			A C M	A C M
Brazil	EMBRATEL	+55 21 216 7738	+55 21 233 7349	Tangua	A C			
China	Beijing Marine	+86 1 421 3131	+86 1 421 3509	Beijing			A C	A C
Denmark	Telecom Denmark	+45 4252 9111	+45 4252 9341	Blaavand	C			
Egypt	National Telecom	+20 2 352 1220	+20 2 77 1306	Maadi	A			
France	France Telecom	+33 56 83 14 13	+33 56 83 13 05	Pleumeur-B. Aussaguel	A C M	A C	 M	
Germany	DBP Telekom	+49 8807 74269	+49 8807 4228	Raisting	A C			
Greece	OTE SA	+30 1 611 8100	+30 1 806 7099	Thermopylae			A C	
India	Videsh Sanchar Nigam	+91 22 262 4020	+91 20 95 4321	Arvi			A C	
Iran	Telecom Co of Iran	+98 21 86 1022	+98 21 85 8566	Boumehen			A	
Italy	Telespazio SPA	+39 6 4069 3379	+39 6 4069 3624	Fucino	A			
Japan	KDD	+81 3 3347 5016	+81 3 3347 6306	Yamaguchi			A B M	A B M
Korea	KTA	+82 2 750 3745	+82 2 750 3749	Kumsan			A C	A C
Netherlands	PTT Telecom	+31 2550 62 440	+31 2550 62 424	Burum	A C M		A C M	
Norway	Norwegian Telecom	+47 22 77 7206	+47 22 77 7178	Eik	A	A	A C M	
Poland	Polish Telecom	+48 22 20 3887	+48 22 26 3665	Psary	A		A	
Portugal	CP Radio Marconi	+351 1 720 7226	+351 1 795 5738	Sintra	C			
Russia	Far East Shipping Co	+7 095 274 0046		Nakhodka				A
Saudi Arabia	Ministry of PTT	+966 1 404 1515	+966 1 405 9008	Jeddah			A	
Singapore	Singapore Telecom	+65 331 6766	+65 334 6110	Sentosa			C	A C
Turkey	PTT Genel Mudurlugu	+90 4 312 2583	+90 4 311 5248	Ata	A C		A C	
UK	British Telecom	+44 71 492 4996	+44 71 606 4640	Goonhilly	A C M	A C M		
Ukraine	Black Sea Shipping Co	+7 048 224 5117	+7 048 222 1758	Odessa	A		A	
USA	COMSAT Mobile Communications	+1 301 428 2400	+1 301 601 5953	Santa Paula Southbury Anatolia (Turkey)	 A B C M	 A B C M	 A	A B C M
USA	IDB Mobile Communications	+1 202 973 5105	+1 202 973 5101	Staten Island Niles Canyon Gnangara (Australia)	A	 A	 A	 A

(Source: INMARSAT)