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APEC Transportation Safety and Security Project
Satellite Navigation and Communications

Element 2 - SN&C Technology and Safety Review
in the APEC Economies
Part 1: Technology Review

Prepared for
Transportation Development Centre
Safety and Security
Transport Canada

by
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This report reflects the views of the authors and not necessarily those of the Transportation Development Centre.

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Un sommaire français se trouve avant la table des matières.

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16. Abstract

Canada is a member of the Asia-Pacific Economic Cooperation (APEC) which comprises 18 economies: Australia, Brunei Darussalam, Canada, Chile, the People's Republic of China, Chinese Taipei, Hong Kong, Indonesia, Japan, the Republic of Korea, Malaysia, Mexico, New Zealand, Papua New Guinea, the Republic of the Philippines, Singapore, Thailand and the United States. In support of APEC, Transport Canada undertook a study of the implementation of satellite navigation and communications (SN&C) for both air and marine. This study consists of the following elements:

- Element 1 - Inventory of Existing and Planned SN&C Systems in APEC economies;
- Element 2 - SN&C Technology and Safety Review; and
- Element 3 - Costs and Benefits of SN&C for Air and Marine Transportation.

This report presents the results of Part 1: Technology Review of Element 2. The Technology Review report provides a broad introduction to the technologies which make navigation and communication possible in the air and marine environments. The emphasis is on navigation; communications is included to the extent that it supports navigation, surveillance and management of air and marine traffic.

This report has three chapters. The first is concerned with the Global Navigation Satellite Systems which make satellite navigation possible. The second examines how satellite navigation and communications will be used by marine transportation. The third considers air transportation. Navigation, communications and surveillance are covered for each of the transportation modes.

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16. Résumé

Le Canada est membre de l'APEC (Organisation de la coopération économique Asie-Pacifique), qui comprend les 18 pays suivants : Australie, Brunei Darussalam, Canada, Chili, République populaire de Chine, Chine de Taipei, Hong Kong, Indonésie, Japon, République de Corée, Malaisie, Mexique, Nouvelle-Zélande, Papouasie-Nouvelle-Guinée, République des Philippines, Singapour, Thaïlande et États-Unis. À l'appui de l'APEC, Transports Canada a entrepris une étude sur la mise en oeuvre de systèmes de navigation et de communications par satellite (NCS) pour l'aviation et la marine. Cette étude comporte les éléments suivants :

Élément 1 - Inventaire des systèmes actuels et prévus de NCS dans les pays de l'APEC;

Élément 2 - Examen de la technologie et de la sécurité des systèmes NCS;

Élément 3 - Coûts et avantages des systèmes NCS pour les transports aériens et maritimes.

Le présent rapport contient les résultats de la partie 1 : Examen de la technologie, de l'élément 2; on y retrouve une introduction générale aux technologies qui rendent la navigation et les communications possibles dans les environnements aérien et maritime. L'accent est mis sur la navigation; les communications sont examinées dans la mesure où elles facilitent la navigation, la surveillance et la gestion de la circulation aérienne et maritime.

Les trois chapitres du rapport traitent, respectivement, des sujets suivants : les systèmes mondiaux de navigation par satellite; les modalités d'utilisation, par les transporteurs maritimes, des technologies de navigation et de communications par satellite; enfin, le transport aérien. Pour chacun des modes de transport, on a examiné les technologies de navigation, de communications et de surveillance.

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<u>TP 12929E</u> APEC Transportation Safety & Security Project
Satellite Navigation and Communications
Element 1 - Inventory of Existing and Planned SN&C Systems in the APEC Economies
Part 1: Trade, Traffic and APEC

<u>TP 12930E</u> APEC Transportation Safety & Security Project
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Element 1 - Inventory of Existing and Planned SN&C Systems in the APEC Economies
Part 2: Implementation Plans

<u>TP 12931E</u> APEC Transportation Safety & Security Project
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<u>TP 12932E</u> APEC Transportation Safety & Security Project
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Part 2: Safety Review

<u>TP 12933E</u> APEC Transportation Safety & Security Project
Satellite Navigation and Communications
Element 3 - SN&C Costs and Benefits Assessment in the APEC Economies

Executive Summary

INTRODUCTION

APEC Satellite Navigation and Communications Study

The Asia-Pacific Economic Cooperation (APEC) comprises 18 economies: Australia, Brunei Darussalam, Canada, Chile, the People's Republic of China, Chinese Taipei, Hong Kong, Indonesia, Japan, the Republic of Korea, Malaysia, Mexico, New Zealand, Papua New Guinea, the Republic of the Philippines, Singapore, Thailand, and the United States. These economies have agreed to cooperate in four areas: global and regional economic development, global trade liberalization, and regional cooperation in specific sectors. One of the sectors identified is transportation. The Transportation Working Group (TPT/WG) was created to coordinate that effort.

The ambitious agenda for liberalizing trade in the region will bring about a rapid increase in air and marine traffic and a requirement for higher levels of aircraft and shipping throughput. This demand for increased capacity is driving the application of satellite communications, navigation and surveillance technologies and systems. It is apparent from discussions in the TPT/WG that the economies of APEC share an interest in introducing new technologies and systems in a way that maintains or improves transportation safety.

The Canadian Minister of Transport has made a commitment to APEC Ministers of Transportation to lead the promotion of transport system safety in the APEC region. To that end, Transport Canada proposed a study on the implementation of satellite navigation and communications (SN&C) for both air and marine. The study is a component of the APEC Action Program in Transportation.

The study consists of the following elements:

- Element 1 - Inventory of Existing and Planned Satellite Navigation and Communication Systems in the APEC Economies;

- Element 2 - Satellite Navigation and Communication Technology and Safety Review; and

- Element 3 - Costs and Benefits of Satellite Navigation and Communications for Air and Marine Transportation.

Hickling Corporation was contracted to carry out the work. This report presents Part 1: Technology Review Report of the final report for Element 2. A separate report presents the second part, Part 2: Safety Review.

Part 1: Technology Review Report

This Technology Review Report provides a broad introduction to the technologies which make navigation and communication possible in the air and marine environments. The emphasis is on navigation; communications is included to the extent that it supports navigation, surveillance and management of air and marine traffic.

This report is directed at those who wish an overview of the technologies and their implications, such as program managers and policy makers. Readers who require technical details on any of these technologies should consult the publications of organizations responsible for planning and standards, such as the International Civil Aviation Organization (ICAO), the International Marine Organization (IMO), and the International Hydrographic Organization (IHO).

While this report does provide background on when and how these technologies will be implemented, the Study's Element 1 Report, under separate cover, provides more specific information on the implementation plans of the APEC economies.

SATELLITE NAVIGATION

The Global Navigation Satellite System (GNSS) will provide high accuracy, integrity and availability, and a continuous, worldwide navigation service for all phases of a journey for both marine and air transportation. It will make it possible to achieve capacity improvements at limited cost. Aircraft and ships will be able to navigate in any part of the world using a single set of navigational instruments. Three- and four-dimensional navigational accuracy will be improved.

The benefits of satellite-based navigation to the aviation community are particularly relevant in the Asia-Pacific Region. The airspaces in this region are often over remote continental or oceanic areas. In these areas, it is often not possible or practical to rely on ground-based systems. Airborne systems, with their inherent accuracy limitations, must be used, often contributing to the need for large separations, thereby reducing capacity.

The implementation of satellite-based navigation in concert with other SN&C systems will allow for the reduction of separation standards.

Another potential benefit of satellite-based navigation (with the appropriate augmentation) is the availability of non-precision approaches and Category I approaches. Ground-based navigation systems will not need to be implemented (although upgrades to approach and runway lighting may be needed) to provide these levels of service at airports that currently do not have landing guidance. Category II/III approaches may also be possible with local area DGPS and at a lower cost than microwave landing systems.

Also, for provider economies that have implemented extensive ground-based navigation systems, cost savings may be realized as the existing ground-based navigation aids are no longer needed.

The marine community will also realize benefits from the implementation of SN&C technologies. With the anticipated decommissioning of Loran-C, GNSS will be an important navigation system for marine users. The increased accuracy and availability of GNSS (in conjunction with ENC/ECDIS) will allow operations in areas and weather conditions that may not be possible using conventional aids. The increased navigation accuracy will increase safety under all conditions, potentially reducing groundings and other incidents. As was the case for the aviation community, the marine providers of conventional navigation aids such as lighthouses and buoys may realize cost savings as the number of aids may eventually be reduced.

Global Navigation Satellite System

A Global Navigation Satellite System (GNSS) is made up of three parts: a constellation of navigation satellites (space segment and augmentation facilities), ground infrastructure (control segment), and user receivers (user segment). There are currently two space components of the GNSS: Global Positioning System (GPS) and Global Navigation Satellite System (GLONASS). GPS is operated by the U.S. Department of Defence; GLONASS is operated by Russia.

The description here will concentrate on GPS since it is fully operational and widely used. GLONASS, while not fully compatible with GPS, is very similar in design and operation. It is expected that, in the future, many receivers will be able to use signals from both systems.

The *space segment* is composed of 24 satellites, orbiting with 12-hour periods, such that a minimum of five satellites are in view to users worldwide. The *control segment* has five monitor stations and three ground antennas with uplink capabilities. The monitor stations track the satellites to determine satellite clock and orbit states and then update the navigation message of each satellite. The *user segment* consists of an antenna, receiver and processor which computes position, velocity and precise timing for the user.

The GPS transmits two signals. The Standard Positioning Service (SPS) is available to all civilian users worldwide. It currently provides positioning accuracy in the order of 100 m. The Precise Positioning Service (PPS) is available only to the U.S. military and other authorized users. It provides positioning accuracy in the order of 20 m. The SPS accuracy is controlled by the U.S., and is capable of being about as accurate as the PPS.

The navigation data in the signal consists of satellite clock and ephemeris data for the transmitting satellite, GPS constellation almanac data, GPS to UTC time offset information, and ionospheric propagation delay correction parameters.

The concept of GPS position determination is based on the intersection of vectors with known origins and magnitudes. Three-dimensional measurements with time (for velocity) requires four satellites to be in view of the receiver. These measurements are with respect to World Geodetic Systems, 1984 (WGS-84) Earth Centred-Earth Fixed (ECEF) coordinates.

Satellite Navigation Augmentation

The basic GPS signal is augmented to ensure that the requirements for accuracy, integrity, availability, and continuity of the signal are met. These requirements may be different depending on the application.

Accuracy is the degree of conformance of an aircraft's or vessel's measured position with its true position. Basic GPS meets the accuracy requirements for en route through non-precision approaches (NPA) but not for precision approaches. For marine applications, the accuracy meets requirements for offshore and open waters but not for confined waters such as ports and inland waterways. The satellite signal can be augmented with additional information to increase the accuracy of the position calculation. There are a number of approaches to this, some of which can obtain accuracies in the order of 1 cm.

Integrity is the ability of a system to provide timely warnings when part or all of the system is providing erroneous information and thus should not be used for navigation. The level of integrity needed is dependent on the application. In general, the aviation community requires a higher level of integrity monitoring than the marine community.

Availability is the probability that at any time the system will meet the accuracy and integrity requirements for a specific phase of flight or vessel movement. Availability is critical for all phases of flight but in particular for take-offs and landings; and GPS does not meet the availability requirements for air transportation. Availability is not as critical for all phases of vessel movements. Only in confined waters does the availability of GPS not meet marine requirements.

Continuity is the probability that a service will continue to be available for a specified period of time, given that it is available at the beginning of the period (for example, that the system will continue to meet the requirements for approach guidance throughout an approach, given that it is available at the initiation of the approach). For aviation, it is of concern primarily in the approach mode of flight (requiring .99995/approach). The marine community typically requires less stringent continuity requirements (ie., .997 percent of the time).

These four requirements are typically met through augmentation to the GPS. For marine, this is typically achieved through Differential GPS systems which improve the accuracy and integrity of the signals. DGPS uses one or more reference stations at geodetically surveyed locations. Each reference station monitors the GPS signal and can compute corrections since it knows exactly where it is. These differential corrections are then transmitted using existing marine radio beacons to GPS user receivers, which apply the corrections to the GPS signals. The DGPS systems also provide integrity monitoring which will warn the user when the service is not functioning properly. For example, the United States and Canadian Coast Guards have implemented a DGPS service for confined waters such as harbour and harbour approach phases of marine navigation. The system covers both coasts of the United States and Canada, including Alaska and Hawaii, the Great Lakes and St. Lawrence Seaway, and the Mississippi River. The system consists of a network of reference stations which broadcast corrections over radio beacons. Accuracy is expected to be better than 10 m in all harbour approaches. Operations are now achieving accuracies on the order of 1 m. The integrity monitoring provides a broadcast of any faulty condition of the GPS service, the DGPS signal or the transmitter within 10 seconds of the fault. Similar DGPS systems are being implemented in Australia, China, and Hong Kong.

To meet the aviation requirements, augmentation is provided using either wide area augmentation systems or local area augmentation systems. For example, the U.S. Federal Aviation Agency (FAA) has begun development of their Wide Area Augmentation System (WAAS). GPS data will be received and analyzed at reference stations. This data will then be forwarded to master stations for processing of corrections. The corrections are then forwarded to earth stations, transmitted to geostationary satellites and roadcast to users. The system will cover all of the United States, including Alaska and Hawaii, and much of Canada. WAAS will provide three services: integrity data on the GPS and GEO satellites, wide area differential corrections for GPS satellites, and additional ranging capability provided by the GEO satellites. WAAS will support aviation navigation for the en route through Category I precision approach phases of flight. For the marine community to make use of WAAS, changes in their receivers will be required. MTSAT in Japan and EGNOS in Europe are proposing to provide similar capabilities in their regions.

The FAA and others envisage using a Local Area Augmentation System (LAAS) to permit Category II and III landings using GPS. One example of LAAS implementation uses a pseudolite (pseudo satellite) located near the runway. The pseudolite transmits very accurate GPS signals, unaffected by orbital decay, ionospheric interference, or errors compounded by distance. These are expected to achieve accuracies measured in centimetres.

REFERENCE SYSTEMS, CHARTS AND DISPLAYS

Reference Systems Geodetic datums are reference coordinate systems used to establish the precise geographic position and elevation of features on the Earth. GNSSs use a coordinate system which is relative to the centre of mass of the earth (Earth Centered Body Fixed). The current standard is the WGS-84. This provides a true three-dimensional datum. Other coordinate systems are either horizontal or vertical. There has been a proliferation of such systems over time and across regions. The conversion from these old systems to the new ECBF is not trivial. However, it is important since differences among coordinate systems can vary by as much as 800 m and these differences are not uniformly distributed.

Charts The present "paper" charts provide no better than a few metres resolution. The positional accuracy of chart features sometimes varies from chart to chart and, in some cases, within a chart. Digital charts will provide greater resolution and accuracy for navigators and this will be of particular benefit in confined waters. For the first time the systems upon which the charts are made and used will be the same.

Electronic displays The Electronic Chart Display Information System (ECDIS) combines both spatial and textual data into an operational tool for the mariner. The IMO performance standard for ECDIS was formally adopted by the Nineteenth Assembly of the IMO in November 1995 as equivalent to paper charts under the Safely of Life at Sea (SOLAS) convention.

SATELLITE COMMUNICATIONS

Aviation

Communication between pilots and air traffic controllers is presently achieved using HF voice radio in oceanic airspace, and VHF voice radio in domestic airspace. VHF radio provides line-of-sight coverage. Because of the lower frequencies used, the HF radio coverage can extend over much greater areas than VHF or UHF radio. However, HF is much more susceptible to interference and variations in coverage owing to atmospheric conditions.

Therefore, it is expected that voice communications in remote continental and oceanic areas will move away from HF towards satellite systems such as INMARSAT, MTSAT and PALAPA. The availability of these systems is all the more important in regions such as the Asia-Pacific due to the vast expanses of oceanic airspace. In areas such as the South Pacific, satellite communications, both voice and data, already play an important role in air traffic management.

It is true that satellite voice communication is presently very expensive when compared with HF radio in oceanic areas. However, with the increasing use of satellite voice communication by airline passengers and greater availability of satellite systems, costs will decrease significantly in the future.

In the future, there will also be a shift away from voice communication towards data communication. CPDLC is a critical component of ADS that allows for the reduction of separation standards in airspaces where radar coverage is not available. The exchange of data not only allows pilots and controller to communicate directly but will also allow aircraft flight management computers to directly communicate with ground based air traffic management computers for coordination and position reporting. Data communications in oceanic and remote airspaces will be primarily by satellite or HF data link.

In domestic airspace, there are a variety of data link options available with three main options: 1) Satellite Data Link, 2) VHF Data Link, and 3) Mode S Secondary Surveillance Radar. At present the most cost-effective option appears to be VHF Data Link. Satellite data linking is unlikely to be used domestically because of its high cost and because of the high data rates with minimal delays required for applications such as position reporting in busy terminal areas.

Mode Select (S) Secondary Surveillance Radars (SSR) are presently being installed in the United States and Europe. Mode S may provide data link capability between the aircraft computer systems and ground air traffic management systems. Aircraft would need to be fitted with the new Mode S transponders which are connected to the aircraft flight management system or a small data link terminal.

VHF data linking consists of a network of ground VHF stations, data routers, and VHF equipment on the aircraft which connects with the aircraft flight management system or a small data link terminal. Character oriented VHF data link systems such as ACARS have been used in the U.S., Canada, and other countries for some years for pre-departure clearances. Standards are being developed for the use of data linking for ATC purposes.

Improved and expanded communications, both voice and data, are key to the implementation of CNS/ATM and the accrual of the benefits. The benefits of data link will include:

- More direct and efficient linkages between ground and airborne systems, resulting in improved air traffic management services;
- Improved handling and transfer of aeronautical communications;
- Reduced radio frequency channel congestion;
- Inter-operable communications media;
- Increased reliability and reduced communications errors, thereby enhancing safety; and
- Reduced workload and improved efficiency for air traffic controllers, flight service specialists, and pilots.

It is anticipated that in the future, international messages will also be exchanged over the new bit-oriented ATN. The ATN is an air-to-ground and ground-to-ground data communications network which allows for full interoperability between different aeronautical systems. Examples of aeronautical systems connecting to the ATN include VHF data link, satellite data link, computer systems on the aircraft, and computers on the ground used for air traffic services, airline control and administration. The ATN architecture is based on the Open Systems Interconnection reference model of the International Standardization Organization.

Marine

The communications systems that ocean-going ships are required to carry are regulated through the Global Maritime Distress and Safety System (GMDSS) under the SOLAS convention. The GMDSS is being phased in over the period from 1992 to 1999 and applies to all vessels subject to the 1974 SOLAS convention. SOLAS covers all passenger ships that carry more than 12 passengers on international voyages and all cargo ships of 300 GT and over engaged in international trade.

The equipment that a ship must carry to comply with GMDSS is determined by the area in which the vessel operates. The GMDSS may require ships to carry Search and Rescue (SAR) transponders, Emergency Position Indicating Radio Beacons (EPIRBS) and NAVTEX receivers or a combination thereof. GMDSS includes regulations for the carriage of satellite or HF communications. The regulatory requirements for ships operating within territorial seas and inland waters varies from economy to economy. However, VHF would cover most of the inland water communication requirements.

Although a significant number of ships now use satellite communications, the majority still rely on HF or VHF communications. The principal marine satellite communication system in use today is INMARSAT which provides marine communications to approximately 30 000 commercial, private, or government ships around the world from four satellites placed to cover all the major oceans. The number of users is growing dramatically and is expected to reach approximately 90 000 by 1997.

INMARSAT is a partnership of 64 nations providing mobile satellite service. It currently offers four services:

- INMARSAT A is already used extensively for voice, data, image and video communications. It provides good quality service and the only major complaints are the connect time costs and the cost and size of terminals.

- INMARSAT B is a digital replacement for INMARSAT A. It is gradually being put into service. It offers lower costs and improved performance for some applications.

- INMARSAT C is strictly a low-speed data service. It is used for E-mail, emergency situation reporting and low volume data transmissions. It is being used increasingly for automatic position reporting.

- INMARSAT M is a relatively new service. It is not recognized for safety requirements under SOLAS or GMDSS. Its low cost and small size have made it popular for yachts and other small vessels. Briefcase sized terminals are now available

- Approximately 25 percent of the 80 000 large ocean going vessels have installed INMARSAT satellite communications terminals. Only a very small number of vessels under 60 feet have been fitted with satellite communications equipment due to the cost and size of equipment.

- INMARSAT P will be the follow-on system to the existing INMARSAT satellites. It will be competing with proposed regional and global mobile services such as MSAT and Globalstar, and advanced high bandwidth systems such as Iridium and Odessey.

In the future, advanced satellites will provide a two-way interactive link for voice, data and multi-media applications with global coverage capability. They will use transportable briefcase sized terminals, small antennas, and stabilizers easily installed on-board ship. Such systems are expected to become available in 1999. These systems are unsuitable for emergency use because of outages due to rain and other environmental conditions.

SATELLITE SURVEILLANCE

Aviation

The availability of secure communications and accurate navigation systems can be combined to provide global aircraft position information on air traffic management surveillance displays. Such information will meet surveillance needs were radar coverage is not possible or cost-effective. Computer-aided air traffic management tools will be added to support improved airspace efficiency.

Surveillance services enable other pilots or air traffic controllers to know the position of aircraft in a specific area of airspace. Currently, either radar or pilot reporting is used to obtain the position of aircraft. Voice position reporting is used outside radar controlled airspace using VHF radios in domestic airspace, and HF radios in oceanic airspace. In the future increasing use will be made of Automatic Dependent Surveillance (ADS) which will enable the automatic periodic reporting of the aircraft position to air traffic controllers via a data link.

Given the substantial benefits that can be achieved from ADS in the region, many economies have already or will soon implement ADS (a non-standard version). Benefits of ADS will include:

- Enhanced safety and reduced delays;

- More efficient use of airspace and increased capacity;

- More accurate tracking of aircraft in a non-radar environment;

- Reduced horizontal separation minima in a non-radar environment;
- Better accommodation of user preferred fight profiles and reduced flight operating costs (if associated Air Traffic Management functionality exists); and
- Increased flexibility and reduced costs of air traffic control operations.

Marine

The development of Automated Identification Systems (AIS) in the marine world is analogous to ADS in aviation. An AIS system requires:

- A means of precise positioning in the area of desired coverage (e.g., GPS or DGPS);
- A suitable communications link; and
- Appropriate processing and display equipment.

An AIS requires that vessels generate navigation (position, course, speed) and other status information, and then report this information to a surveillance centre, typically a Vessel Traffic Services (VTS) Centre, where the information is processed and displayed. The polling and response sequences between the VTS Centre and participating vessels via an AIS communication link are fully automated.

While ADS is likely to become ubiquitous in the aviation world, AIS in the marine world will probably remain in more specialized applications, such as the following:

- Piracy - surveillance would help law enforcement agencies combat piracy.
- Fishing - surveillance would help fisheries management organizations monitor and control exploitation of fish stocks.
- Inventory Management - surveillance would help shipping companies better manage their resources.

- Vessel Traffic Services - surveillance would help harbour masters and coast guards to better monitor and control vessel traffic in congested areas such as harbours and straits.

Before any AIS system can be widely or effectively implemented, it would be necessary for international standards to be established. In this respect, the IMO Sub-Committee on Safety of Navigation is developing performance standards for ship borne AIS equipment using both Digital Selective Calling (DSC) and broadcast techniques. At the July 1996 meeting of the Sub-Committee, proposals for the carriage of this equipment included a two-stage implementation process, with the DSC system being proposed for certain classes of vessels in 1999, followed by a wider application of a broadcast system sometime after 2001.

CNS/ATM

The aviation community is combining the technical capabilities described above into a system concept known as Communications, Navigation, Surveillance / Air Traffic Management (CNS/ATM). There are significant benefits to be gained from the implementation of CNS/ATM systems. The inherent improvements in communications, navigation, and surveillance will result in improved data handling and transfer among operators, aircraft, and air traffic service providers, global navigation and approach capabilities through GNSS, extended surveillance by ADS and advanced ground-based data processing. The new CNS/ATM systems will also allow a more flexible and efficient use of both en route and terminal airspace.

New CNS systems allow closer interaction between ground systems and airspace users, before, during, and after flight. The full benefits of the new CNS systems will be achieved through ATM automation. The APANPIRG Regional Plan summarized the benefits of CNS/ATM as follows:

- Maintain or enhance the existing level of safety;

- The provision of an ATM system to make more efficient use of airspace and airport capacity and to permit the harmonious treatment of flights transiting all airspace;

- The provision of CNS in a more cost effective manner; and

- The global provision of CNS in a more uniform manner.

Sommaire

INTRODUCTION

Étude de l'APEC sur les systèmes de navigation et de communications par satellite

L'APEC (Organisation de la coopération économique Asie-Pacifique) comprend 18 pays : Australie, Brunei Darussalam, Canada, Chili, République populaire de Chine, Chine de Taipei, Hong Kong, Indonésie, Japon, République de Corée, Malaisie, Mexique, Nouvelle-Zélande, Papouasie-Nouvelle-Guinée, République des Philippines, Singapour, Thaïlande et États-Unis. Ces pays ont convenu de coopérer dans les quatre domaines suivants : le développement économique mondial et régional, la libéralisation des échanges mondiaux, enfin, la coopération régionale dans certains secteurs, notamment les transports. Le Groupe de travail chargé des transports (TPT/WG) a été créé pour coordonner cette activité.

L'ambitieux programme de libéralisation du commerce dans la région entraînera une augmentation rapide du trafic aérien et maritime; il faudra donc améliorer la capacité des aéronefs et des navires. Cette demande de capacité accrue favorise le recours aux technologies et aux systèmes de communications, de navigation et de surveillance par satellite. Il ressort clairement des entretiens au sein du TPT/WG que les pays membres de l'APEC ont un intérêt commun dans l=introduction de nouvelles technologies et de nouveaux systèmes de façon à maintenir ou à améliorer la sécurité des transports.

Le ministre canadien des Transports s'est engagé envers ses homologues de l'APEC à mener la promotion de la sécurité des systèmes de transport dans la région. À cette fin, Transports Canada a proposé une étude sur la mise en oeuvre de systèmes de navigation et de communications par satellite (NCS) pour l=aviation et la marine. Cette étude fait partie du cadre du programme d=action de l'APEC en matière de transports.

Cette étude comporte les éléments suivants :

- Élément 1 - Inventaire des systèmes actuels et prévus de navigation et de communications par satellite dans les pays de l'APEC;

- Élément 2 - Examen de la technologie et de la sécurité des systèmes de navigation et de communications par satellite;

- Élément 3 - Coûts et avantages des systèmes de navigation et de communications par satellite pour les transports aériens et maritimes.

On a retenu les services de la société Hickling pour l=exécution des travaux. Dans le présent rapport, on retrouve la partie 1 : Examen de la technologie, du rapport final de l=élément 2. La partie 2 : Examen de la sécurité, est présentée dans un rapport séparé.

Partie 1 : Examen de la technologie

On y retrouve une introduction générale aux technologies qui rendent la navigation et les communications possibles dans les environnements aérien et maritime. L=accent est mis sur la navigation; les communications sont examinées dans la mesure où elles facilitent la navigation, la surveillance et la gestion de la circulation aérienne et maritime.

Ce rapport présente une vue d=ensemble des technologies et de leurs répercussions; il est destiné aux gestionnaires de programme et aux décideurs. Les lecteurs peuvent obtenir des détails techniques sur l=une ou l=autre de ces technologies dans les publications des organisations chargées de la planification et des normes, comme l=Organisation de l=aviation civile internationale (OACI), l=Organisation maritime internationale (OMI) et l=Organisation hydrographique internationale (OHI).

Tandis que le présent rapport renferme des données de base sur le moment et les modalités de mise en oeuvre de ces technologies, il est possible d=obtenir des renseignements plus précis sur les plans de mise en oeuvre des pays de l=APEC dans le rapport de l=élément 1.

NAVIGATION PAR SATELLITE

À toutes les étapes d=un voyage de transport maritime et aérien, le Système mondial de navigation par satellite (GNSS) fournira des renseignements dont la précision, l=intégrité et la disponibilité sont élevées ainsi qu=un service continu de navigation partout dans le monde. Il permettra d=améliorer la capacité, à faible coût. Partout dans le monde, les aéronefs et navires pourront se déplacer en utilisant un ensemble unique d=instruments de navigation. La précision de la navigation à trois et quatre dimensions sera rehaussée.

Pour la collectivité de l=aviation, les avantages de la navigation par satellite sont particulièrement utiles dans la région Asie-Pacifique où les espaces aériens surplombent souvent des secteurs continentaux ou océaniques isolés. Il est alors habituellement impossible ou non pratique de se fier à des systèmes au sol. Il faut recourir aux systèmes aéroportés dont les restrictions inhérentes en matière de précision nécessitent souvent des écarts importants entre les aéronefs, ce qui réduit la capacité des systèmes.

La mise en oeuvre des systèmes de navigation par satellite et des autres systèmes NCS permettra de diminuer les normes en matière d=écarts.

La navigation par satellite pourrait également offrir l=avantage (moyennant un renforcement adéquat des signaux) de rendre disponibles les approches de non-précision et de catégorie I. Il ne sera pas nécessaire de mettre en oeuvre les systèmes de navigation au sol (même s=il peut être utile d=améliorer le balisage lumineux des approches et des pistes d=atterrissage) pour fournir ces niveaux de service aux aéroports qui, à l=heure actuelle, ne disposent pas d=un système de guidage à l=atterrissage. Le DGPS local rendrait également possible les approches de catégorie II/III et ce, à un coût plus faible que les systèmes d=atterrissage à hyperfréquences.

En outre, dans le cas des pays qui fournissent le service et qui ont mis en oeuvre d=importants systèmes de navigation terrestres, il est possible de réaliser des économies car les aides à la navigation au sol ne seront plus nécessaires.

La collectivité maritime réalisera également des avantages grâce à la mise en oeuvre des technologies NCS. On prévoit retirer du service le système Loran-C; le GNSS sera donc un système de navigation important pour le secteur marine. L=augmentation de la précision et de la disponibilité du GNSS (avec l=aide des CEN et du SVCEI) permettra de naviguer dans des secteurs et dans des conditions météorologiques qui dépassent la portée des aides traditionnelles. L=augmentation de la précision améliorera la sécurité de la navigation dans toutes les conditions, ce qui pourrait réduire le nombre d=échouages et d=autres incidents. Comme dans le cas de la collectivité de l=aviation, les fournisseurs d=aides traditionnelles à la navigation maritime, comme les phares et les bouées, pourraient réaliser des économies si le nombre de ces aides était réduit par la suite.

Système mondial de navigation par satellite

Un système mondial de navigation par satellite (GNSS) est constitué de trois composantes : une constellation de satellites de navigation (segment spatial et installations de renforcement des signaux), une infrastructure au sol (segment contrôle) et des récepteurs (segment utilisateurs). Le GNSS comprend actuellement deux composantes spatiales : le Système de positionnement global (GPS) et le Système global de navigation à satellites (GLONASS). Le GPS est exploité par le département de la Défense des États-Unis et le GLONASS, par la Russie.

Notre étude portera sur le GPS; entièrement opérationnel, ce dernier est largement utilisé. La conception et le mode d=exploitation du GLONASS sont très semblables à ceux du GPS, même si les deux systèmes ne sont pas entièrement compatibles. On peut prévoir que de nombreux récepteurs pourront utiliser les signaux des deux systèmes.

Le *segment spatial* est constitué de 24 satellites dont la période de révolution est de 12 heures; ainsi, partout dans le monde, les utilisateurs ont accès à au moins cinq satellites. Le *segment contrôle* est composé de cinq stations de surveillance et de trois antennes au sol ayant des capacités de liaison montante. Les stations de surveillance suivent les satellites pour en déterminer les données d=horloge et les états d=orbite puis, elles mettent à jour le message de navigation émis par chaque satellite. Le *segment utilisateurs* comprend une antenne, un récepteur et un processeur qui calculent la position, la vélocité et l=heure précise pour l=utilisateur.

Le GPS transmet deux signaux. Le Service de positionnement normalisé (SPN) est offert à tous les utilisateurs civils du monde entier; sa précision actuelle est de l=ordre de 100 m. Le Service de positionnement précis (SPP) n=est accessible qu=aux militaires américains et à d=autres utilisateurs autorisés. Il offre un positionnement dont la précision est de l=ordre de 20 m. Les États-Unis contrôlent la précision du SPN qui pourrait être portée au niveau de celle du SPP.

Le signal comprend les données de navigation suivantes : les données d=horloge et des éphémérides du satellite transmetteur, les données éphémérides de la constellation GPS, les données de conversion du GPS à l=heure UTC, enfin, les paramètres pour la correction du retard de la propagation ionosphérique.

Le principe de la détermination de la position du GPS est fondé sur l=interception de vecteurs dont l=origine et la longueur sont connues. Le récepteur doit pouvoir capter les émissions de quatre satellites pour effectuer les mesures à trois dimensions en fonction du temps (pour calculer la vélocité). Ces mesures sont fondées sur les coordonnées géocentriques à axes fixes du Système géodésique mondial 1984 (WGS-84).

Renforcement des signaux de navigation par satellite

Le signal GPS de base est renforcé de façon à respecter les exigences en matière de précision, d=intégrité, de disponibilité et de continuité. Ces exigences peuvent varier selon l=application utilisée.

La *précision* est le degré de conformité de la position mesurée d=un aéronef ou d=un navire, avec sa position véritable. Le signal GPS de base satisfait aux exigences de précision de la navigation en route, au moyen d=approches de non-précision (NPA), mais non à celles des approches de précision. Pour ce qui est des applications du transport maritime, le niveau de précision répond aux exigences de la navigation en haute mer et dans les eaux libres; toutefois, il n=est pas suffisant pour la navigation en eaux confinées, dans les ports et les voies d=eau intérieures. Le signal du satellite peut être renforcé au moyen de renseignements supplémentaires afin d=accroître la précision du calcul de la position. Un certain nombre d=approches permettent d=atteindre ce but; certaines d=entre elles donnent une précision de l=ordre de 1 cm.

L=*intégrité* est la capacité d=un système de donner un avertissement en temps opportun, lorsqu=une partie ou la totalité de ces composantes fournissent des renseignements erronés et ne doivent donc pas être utilisées pour la navigation. Le niveau de l=intégrité nécessaire varie selon l=application utilisée. En général, la collectivité de l=aviation exige un niveau de surveillance de l=intégrité plus élevé que la collectivité de la marine.

La *disponibilité* est la probabilité que le système pourra répondre aux exigences en matière de précision et d=intégrité pour un segment donné du vol d=un aéronef ou du déplacement d=un navire. À toutes les étapes du vol, mais en particulier lors des décollages et des atterrissages, la disponibilité est cruciale. Le GPS ne satisfait pas aux exigences du transport aérien en matière de disponibilité. Les déplacements des navires dépendent moins, à toutes les étapes, de la disponibilité du GPS; cette dernière est inférieure aux besoins de la marine uniquement dans les eaux confinées.

La *continuité* est la probabilité qu=un service continuera d=être disponible pendant une période donnée, s=il était disponible au début de la période (p. ex. : que le système continue de satisfaire aux exigences du guidage à l=approche tout au long de cette dernière, s=il était disponible au début de l=approche). Dans le cas de l=aviation, la continuité est particulièrement essentielle en vol d=approche (elle doit alors être l=équivalent de 0,99995 p. 100 du temps). Actuellement, la collectivité maritime a des exigences moins strictes en matière de continuité (soit 0,997 p. 100 du temps).

Ces quatre exigences sont habituellement comblées par le renforcement des signaux du GPS. Dans le cas du secteur marine, on a alors recours aux systèmes GPS différentiels qui améliorent la précision et l=intégrité des signaux. Le DGPS fait appel à une station de référence ou plus dont les coordonnées géodésiques sont établies. Chaque station de référence surveille le signal GPS et elle peut calculer les corrections car son propre emplacement est connu. Ces corrections différentielles sont ensuite transmises au moyen des radiobalises maritimes existantes aux récepteurs des utilisateurs du GPS, qui appliquent les corrections aux signaux du système. En outre, les systèmes DGPS surveillent l=intégrité des signaux et avertissent l=utilisateur en cas de mauvais fonctionnement du système. Par exemple, les gardes côtières des États-Unis et du Canada ont mis en oeuvre un système DGPS pour les eaux confinées, comme les havres et les approches des havres. Ce système couvre les deux côtes des États-Unis et du Canada, y compris l=Alaska et Hawaï, les Grands Lacs, la Voie maritime du Saint-Laurent et le fleuve Mississippi. Il comprend un réseau de stations de référence qui diffusent les données corrigées au moyen des radiobalises. La précision doit être supérieure à 10 m pour toutes les approches de havre. Dans les faits, on obtient actuellement une précision de l=ordre de 1 m. La surveillance de l=intégrité assure la diffusion, dans les 10 secondes qui suivent une défaillance, de toute panne du service GPS, du signal DGPS ou du transmetteur. Des systèmes DGPS analogues sont en cours de mise en oeuvre en Australie, en Chine et à Hong Kong.

Afin de répondre aux besoins de l=aviation, les systèmes de renforcement des signaux peuvent avoir une portée étendue ou locale. Par exemple, la U.S. Federal Aviation Agency (FAA) a commencé l=élaboration de son système de renforcement des signaux à grande étendue (WAAS). Les données du GPS seront reçues et analysées aux stations de référence. Elles seront ensuite retransmises aux stations principales pour traitement des corrections. Ces dernières seront ensuite transmises aux stations terrestres, puis aux satellites géostationnaires avant d=être rediffusées aux utilisateurs. Le système couvrira l=ensemble du territoire des États-Unis, y compris l=Alaska et Hawaï, ainsi qu=une grande partie du Canada. Le WAAS assure trois services distincts : l=intégrité des données des satellites GPS et géostationnaires (GEO), les corrections différentielles sur grande étendue qui sont destinés aux satellites du GPS, enfin une portée supplémentaire fournie par les satellites géostationnaires. Le WAAS apporte un soutien à la navigation aérienne en cours de route au moyen des approches de précision de catégorie I. Il faut modifier les récepteurs des navires afin que la collectivité maritime puisse utiliser le WAAS. Au Japon et en Europe, respectivement, le MTSAT et l=EGNOS fournissent des capacités analogues.

La FAA et d=autres organisations envisagent de recourir au système local de renforcement des signaux (LAAS) pour permettre des atterrissages de catégorie II et III au moyen du GPS. L=utilisation d=un pseudolite (pseudo-satellite), situé près de la piste, constitue un exemple de la mise en oeuvre du LAAS. Le pseudolite transmet des renseignements GPS très précis qui ne sont pas modifiés par la dégradation de l=orbite, l=interférence ionosphérique ou les erreurs accentuées par la distance. Il est alors possible d=obtenir une précision de l=ordre de quelques centimètres.

SYSTÈMES DE RÉFÉRENCE, CARTES ET AFFICHAGES

Systèmes de référence Les coordonnés géodésiques sont fournies par des systèmes de référence qui servent à établir l=emplacement géographique précis ainsi que l=élévation du relief. Les GNSS ont recours à un système de coordonnées géocentriques à axes fixes qui est fondé sur le centre de la masse terrestre. La norme actuelle est le WGS-84 qui fournit de véritables données tridimensionnelles. Les autres systèmes de coordonnées peuvent être soit horizontaux soit verticaux. Au cours des années, ces systèmes se sont multipliés dans les diverses régions. La conversion de ces anciens systèmes au nouveau système de coordonnées géocentriques à axes fixes n=est pas une mince affaire. Toutefois, cette étape est importante. En effet, les écarts entre les systèmes de coordonnées peuvent atteindre 800 m; en outre, ils ne sont pas répartis uniformément.

Cartes Les cartes actuelles en papier ne permettent pas une résolution supérieure à quelques mètres. La précision de la position obtenue au moyen des caractéristiques des cartes varie parfois d=une carte à l=autre et, parfois, d=un secteur à l=autre d=une même carte. Les navigateurs peuvent obtenir une résolution et une précision améliorées au moyen des cartes numériques, ce qui est particulièrement avantageux dans les eaux confinées. Pour la première fois, les cartes seront faites et utilisées en fonction de systèmes identiques.

Affichages électroniques Le Système de visualisation des cartes électroniques et d=information (SVCEI) combine les données spatiales et textuelles en un outil opérationnel destiné au navigateur maritime. En novembre 1995, la XIX^{e} assemblée de l=OMI a adopté officiellement la norme de rendement du SVCEI comme l=équivalent des cartes en papier en vertu de la Convention internationale pour la sauvegarde de la vie humaine en mer.

COMMUNICATIONS PAR SATELLITE

Aviation

À l'heure actuelle, les pilotes et les contrôleurs de la circulation aérienne utilisent les communications vocales HF et VHF dans les espaces aériens océanique et terrestre, respectivement. Les communications radio VHF offrent la couverture de la ligne de visée. Comme elle fait appel à des fréquences plus basses, la couverture HF porte sur des superficies plus grandes que les communications VHF ou UHF. Cependant, les communications HF sont plus susceptibles aux interférences et aux variations de couverture dues aux conditions atmosphériques. Par conséquent, dans les régions océaniques et continentales éloignées, on prévoit que les communications vocales ne seront plus fondées sur le système HF mais sur des réseaux de satellites comme INMARSAT, MTSAT et PALAPA. La disponibilité de ces derniers est d=autant plus importante dans des régions comme Asie-Pacifique à cause des vastes étendues d=espaces aériens océaniques. Les communications par satellite, vocales et numériques, y jouent déjà un rôle important dans la gestion de la circulation aérienne.

À l'heure actuelle, les communications vocales par satellite sont très coûteuses par rapport aux communications HF dans les secteurs océaniques. Cependant ces coûts diminueront fortement compte tenu de l=utilisation accrue des communications vocales par satellite de la part des passagers des compagnies aériennes ainsi que de la plus grande disponibilité des systèmes de satellites.

On prévoit également l=abandon des communications vocales en faveur des communications numériques. Le CPDLC est une composante cruciale de l=ADS qui permet de diminuer les normes d=écart dans les espaces aériens où la couverture radar n=existe pas. L=échange de données permet la communication directe non seulement entre les pilotes et les contrôleurs, mais également entre les ordinateurs de gestion de vol des aéronefs et les ordinateurs de la gestion de la circulation aérienne au sol (coordination et compte rendu de la position). Dans les espaces aériens océaniques et éloignés, les communications de données seront assurées surtout par satellite ou par des liaisons HF.

Dans l=espace aérien intérieur, les diverses liaisons de données offrent trois options principales : 1) la liaison de données par satellite; 2) la liaison de données VHF et 3) les radars de surveillance secondaire en mode S. À l'heure actuelle, l=option la plus rentable semble être la liaison de données VHF. Il est peu probable que l=on ait recours à la liaison de données par satellite à cause de son coût élevé et parce que les applications, comme le compte rendu de position à proximité d=aéroports occupés, exigent un coût élevé de transmission des données et des retards minimes.

Aux États-Unis et en Europe, on procède actuellement à l=installation de radars de surveillance secondaire en mode Select (S). Ce dernier offre une capacité de liaisons de données entre les systèmes d=ordinateurs embarqués et les systèmes de gestion de la circulation aérienne au sol. Les aéronefs devront être dotés des nouveaux transpondeurs en mode S qui sont reliés aux systèmes de gestion de vol de l=aéronef ou à un petit terminal de liaisons de données.

La liaison de données VHF est formée d=un réseau de stations VHF au sol, de routeurs et d=un équipement VHF à bord des aéronefs qui est relié au système de gestion de vol ou à un petit terminal embarqué de liaison de données. Depuis quelques années, aux États-Unis, au Canada et dans d=autres pays, on a recours à des systèmes de liaisons numériques VHF fondés sur les caractères pour les autorisations avant le décollage. On procède à l=élaboration de normes pour régir la liaison de données aux fins de l'ATC.

L=amélioration et l=élargissement des communications, vocales et numériques, sont un élément crucial de la mise en oeuvre des systèmes CNS/ATM et de l=augmentation des avantages. Les liaisons de données présentent notamment les avantages suivants :

- liens plus directs et efficients entre les systèmes au sol et embarqués, ce qui permettrait d'améliorer les services de gestion de la circulation aérienne;
- traitement et transfert améliorés des communications aéronautiques;
- diminution de la congestion des canaux des fréquences radio;

- interopérabilité des modes de communications;
- fiabilité accrue et diminution des erreurs de communication, donc augmentation de la sécurité;
- réduction de la charge de travail et hausse de l'efficience des contrôleurs de la circulation aérienne, des spécialistes des services en vol et des pilotes.

On prévoit qu'à l'avenir, les messages internationaux seront également échangés sur le nouveau RTA numérique. Il s=agit d=un réseau de communications numériques air-sol et sol-sol qui permet une interopérabilité complète entre les différents systèmes aéronautiques. Parmi ces derniers, on retrouve les liaisons de données VHF, les liaisons de données par satellite, les systèmes informatiques embarqués ainsi que les ordinateurs au sol qui servent aux services de contrôle de la circulation aérienne, de même qu=au contrôle et à l=administration des sociétés aériennes. L=architecture du RTA est fondée sur le modèle de référence d=interconnexion de systèmes ouverts de l=Organisation internationale de normalisation (ISO).

Marine

Les systèmes de communications dont les navires océaniques doivent être dotés sont réglementés au moyen du Système mondial de détresse et de sécurité en mer (SMDSM), en vertu de la Convention internationale pour la sauvegarde de la vie humaine en mer. Depuis 1992 et jusqu=en 1999, le SMDSM est en cours d=introduction dans tous les navires assujettis à la Convention de 1974. Cette dernière régit tous les navires qui transportent plus de 12 passagers sur des itinéraires internationaux et tous les cargos de 300 tonnes brutes et plus qui participent au commerce international.

Le secteur où un navire est utilisé détermine l=équipement dont ce dernier doit être pourvu pour être conforme au SMDSM. Ainsi, il peut être nécessaire d=équiper les navires de transpondeurs de recherche et de sauvetage (SAR), de radiobalises de localisation des sinistres (EPIRB) et de récepteurs NAVTEX, ou encore, d=une combinaison de ces appareils. Le SMDSM comprend une réglementation sur les communications par satellite et les communications HF. Pour ce qui est des navires qui circulent dans les eaux territoriales et intérieures, les exigences en matière de réglementation varient d=un pays à l=autre. Toutefois, le système VHF devrait répondre à la plupart des exigences en matière de communications sur les eaux intérieures.

Même si un nombre important de navires utilisent maintenant les communications par satellite, la plupart d=entre eux dépendent encore des communications HF ou VHF. À l'heure actuelle, le principal réseau de communications par satellite est INMARSAT; ce dernier fournit des communications maritimes à environ 30 000 navires commerciaux, privés ou gouvernementaux dans le monde entier et ce, au moyen de quatre satellites dont l=emplacement permet de couvrir tous les océans principaux. Le nombre d=utilisateurs augmente rapidement, il devrait s=élever à environ 90 000 en 1997.

INMARSAT est un partenariat de 64 nations qui offre quatre services mobiles de communications par satellite, c=est-à-dire :

- INMARSAT A est déjà beaucoup utilisé pour la transmission de données vocales, numériques et visuelles. Il s=agit d=un service de bonne qualité. Les principales plaintes à son égard portent uniquement sur le coût et le temps de la connexion, ainsi que sur le coût et la taille des terminaux.

- INMARSAT B est un système numérique qui remplace graduellement INMARSAT A. Il permet de réduire les coûts et d=améliorer le rendement de certaines applications.

- INMARSAT C est strictement un service de transmission de données à basse vitesse. On l=utilise pour acheminer le courrier électronique, signaler les situations d=urgence et faire des transmissions de données de faible volume. On y a recours de plus en plus pour effectuer le compte rendu de la position.

- INMARSATINMARSAT M est un service relativement nouveau. Il n=est pas conforme aux exigences de sécurité en vertu de la Convention ou du SMDSM. Les propriétaires de yachts et de petites embarcations l'utilisent de plus en plus à cause de sa taille et de son coût faible. On peut obtenir les terminaux pertinents qui ont la taille d=un porte-documents.

- Environ 25 p. 100 des 80 000 grands navires océaniques disposent de terminaux INMARSAT de communications par satellite. Parmi les navires de moins de 60 pieds de longueur, seul un très petit nombre sont dotés d'équipement de communications par satellite, à cause du coût et de la taille de cet équipement.

- INMARSAT P sera le système qui remplacera les systèmes INMARSAT existants. Il entrera en concurrence avec les systèmes mobiles proposés, régionaux et mondiaux, comme MSAT et Globalstar, ainsi qu'avec les systèmes avancés à largeur de bande élevée, comme Iridium et Odessey.

À l=avenir, les satellites avancés offriront dans le monde entier une liaison interactive bidirectionnelle pour les applications vocales et numériques ainsi que pour les applications multimédia. Ils feront appel à des terminaux portatifs de la taille d=un porte-documents, à de petites antennes et à des stabilisateurs qui seront faciles à installer à bord des navires. Ces systèmes devraient être disponibles en 1999. Ils ne sont pas adaptés aux situations d=urgence car ils peuvent tomber en panne à cause de la pluie et d=autres conditions climatiques.

SURVEILLANCE PAR SATELLITE

Aviation

Il est possible de combiner les systèmes de communications sûres et de navigation de précision pour fournir, sur des affichages de surveillance de la gestion de la circulation aérienne, des renseignements sur la position géodésique d=un aéronef. Ces renseignements combleront les besoins de surveillance aux endroits où la couverture radar est impossible ou non rentable. On ajoutera des outils informatiques de gestion de la circulation aérienne afin d=utiliser l=espace aérien de façon plus efficiente.

Les services de surveillance permettent aux autres pilotes ou aux contrôleurs de la circulation aérienne de connaître la position d=un aéronef dans un secteur donné de l=espace aérien. À l'heure actuelle, on obtient la position d=un aéronef au moyen des relevés radars ou des comptes rendus du pilote. À l=extérieur de l=espace aérien contrôlé par radar, la position est signalée verbalement au moyen des communications VHF, dans l=espace aérien terrestre, et des communications HF dans l=espace aérien océanique. À l=avenir, on aura de plus en plus recours à la surveillance automatique par satellite (ADS) qui permet de signaler automatiquement, à intervalles périodiques, la position de l=aéronef aux contrôleurs de la circulation aérienne, au moyen d=une liaison de données.

À cause des avantages importants qu=il peut apporter dans la région, l=ADS (une version non standard) a été mis en oeuvre, ou le sera bientôt, dans de nombreux pays. L=ADS procure, entre autres, les avantages suivants :

- renforcement de la sécurité et diminution des retards;

- utilisation plus efficiente de l'espace aérien et capacité accrue;
- suivi plus précis des aéronefs dans un environnement non contrôlé par radar;
- diminution des écarts horizontaux minimums dans un environnement non contrôlé par radar;
- meilleure adaptation aux profils de vol souhaités par les utilisateurs et diminution des coûts d'exploitation en vol (à condition de disposer de la fonction connexe de gestion de la circulation aérienne);
- augmentation de la souplesse et diminution des coûts des activités de contrôle de la circulation aérienne.

Marine

Dans le secteur marine, l=introduction des systèmes automatisés d=identification (AIS) a des répercussions analogues à celles de l=ADS en aviation. Un système AIS doit disposer des composantes suivantes :

- un mode de positionnement précis dans le secteur recherché (p. ex. : GPS ou DGPS);
- ne liaison adéquate de communications;
- le matériel pertinent de traitement et d'affichage.

Les navires doivent fournir au AIS les renseignements de navigation (position, direction et vitesse) ainsi que les autres renseignements sur la situation. Ensuite l=AIS transmet ces renseignements à un centre de surveillance, habituellement un centre des services du trafic maritime (STM) où l=information est traitée et affichée. Entre le centre STM et les navires participants, les séquences de demande de renseignements et de réponse, au moyen de la liaison AIS, sont entièrement automatisées.

L=utilisation de l=ADS deviendra vraisemblablement générale dans le monde de l=aviation; toutefois, l=AIS demeurera probablement restreint à des applications de surveillance maritime plus spécialisées, par exemple :

- piraterie - la surveillance faciliterait le travail des organismes d'application de la loi dans ce domaine;
- pêche - la surveillance aiderait les organisations de gestion des pêches à surveiller et à contrôler l'exploitation des stocks;
- gestion du matériel - la surveillance permettrait aux sociétés de navigation d'améliorer la gestion de leurs ressources;
- services du trafic maritime - la surveillance faciliterait le travail des directeurs de port et des gardes côtiers qui doivent surveiller et contrôler le trafic des navires dans des secteurs restreints, comme les ports et les détroits.

Avant qu=un système AIS puisse être mis en oeuvre de façon généralisée ou efficace, il faut élaborer des normes internationales. À cet égard, le sous-comité de l=OMI chargé de la sécurité de la navigation élabore des normes de rendement pour l=équipement AIS embarqué à bord de navires; ce dernier utilise le Système d=alerte par appel sélectif numérique (DSC) et les techniques de radiodiffusion. À la réunion du sous-comité de juillet 1996, on a proposé notamment l=installation de cet équipement dans le cadre d=un processus de mise en oeuvre en deux étapes; on a alors proposé que le système DSC soit imposé à certaines catégories de bâtiments en 1999 et qu=un système de radiodiffusion d=application plus générale soit obligatoire après l=an 2001.

CNS/ATM

Les capacités techniques susmentionnées sont combinées par la collectivité de l=aviation en un concept de système appelé CNS/ATM. La mise en oeuvre de ces systèmes permet de réaliser des gains importants. Les progrès inhérents des communications, de la navigation et de la surveillance donneront lieu aux avantages suivants : amélioration du traitement des données et du transfert de celles-ci entre les opérateurs, les aéronefs et les fournisseurs de services de circulation aérienne, capacités mondiales de navigation et d=approche au moyen du GNSS, surveillance étendue de l=ADS et traitement avancé des données au sol. Les nouveaux systèmes CNS/ATM permettront également d=utiliser de façon plus souple et efficiente l=espace aérien en cours de route et aux aéroports.

Grâce aux nouveaux systèmes CNS, les interactions pourront être plus étroites entre les systèmes au sol et les utilisateurs de l=espace aérien et ce, avant, pendant et après le vol. L=automatisation de l=ATM permettra de réaliser les pleins avantages des nouveaux systèmes CNS. Dans le plan régional APANPIRG, on a résumé comme suit les avantages des systèmes CNS/ATM :

- maintien ou amélioration du niveau de sécurité actuel;
- instauration d'un système ATM pour permettre l'utilisation plus efficiente de l'espace aérien et de la capacité des aéroports ainsi que pour traiter de façon harmonieuse les aéronefs qui traversent tous les espaces aériens;
- augmentation de la rentabilité des systèmes CNS;
- offre plus uniforme des systèmes CNS dans le monde entier.

Table of Contents

List of Tables

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1. Introduction

1.1 Satellite Navigation and Communications Study

The Asia-Pacific Economic Cooperation (APEC) comprises 18 economies, Australia, Brunei Darussalam, Canada, Chile, the People's Republic of China, Chinese Taipei, Hong Kong, Indonesia, Japan, the Republic of Korea, Malaysia, Mexico, New Zealand, Papua New Guinea, the Republic of the Philippines, Singapore, Thailand, and the United States of America. These economies have agreed to cooperate in four areas: global and regional economic development, global trade liberalization, and regional cooperation in specific sectors. One of the sectors identified is transportation. The Transportation Working Group (TPT/WG) was created to coordinate that effort.

The ambitious agenda for liberalizing trade in the region will bring about a rapid increase in air and marine traffic and a requirement for higher levels of aircraft and shipping throughput. This demand for increased capacity is driving the application of satellite communications, navigation and surveillance technologies and systems. It is apparent from discussions in the TPT/WG that the economies of APEC share an interest in introducing new technologies and systems in a way that maintains or improves transportation safety.

The Canadian Minister of Transport has made a commitment to APEC Ministers of Transportation to lead the promotion of transport system safety in the APEC region. To that end, Transport Canada proposed a study on the implementation of satellite navigation and communications (SN&C) for both air and marine. The study is a component of the APEC Action Program in Transportation.

The study is composed of the following elements:

- Element 1 - Inventory of Existing and Planned Satellite Navigation and Communication Systems in the APEC Economies;

- Element 2 - Satellite Navigation and Communication Technology and Safely Review; and

- Element 3 - Costs and Benefits of Satellite Navigation and Communications for Air and Marine Transportation.

Hickling Corporation was contracted to carry out the work for the three elements. This report presents Part 1: Technology Review Report of the final report for Element 2. A separate report presents the second part, Part 2: Safety Review.

1.2 Part 1: Technology Review Report

This Technology Review Report provides a broad introduction to the technologies which make navigation and communication possible in the air and marine environments. The emphasis is on navigation; communications is included to the extent that it supports navigation, surveillance and management of air and marine traffic.

This report is directed at those who wish an overview of the technologies and their implications, such as program managers and policy makers. Readers who require technical details on any of these technologies should consult the publications of organizations responsible for planning and standards, such as the International Civil Aviation Organization (ICAO), the International Marine Organization (IMO), and the International Hydrographic Organization (IHO).

While this report does provide background on when and how these technologies will be implemented, the study's Element 1 Report, under separate cover, provides more specific information on the implementation plans of the APEC economies.

1.3 Report Structure

This report has three chapters. The first is concerned with the Global Navigation Satellite Systems which make satellite navigation possible. The second examines how satellite navigation and communications will be used by marine transportation. The third considers air transportation. Navigation, communications, surveillance is covered for each of the transportation modes. The appendices contain references, an extensive bibliography, a list of web sites and a glossary.

1.4 Acknowledgements

Satellite communications, navigation and surveillance have been extensively documented for air transportation. The third chapter of this report is based on three excellent publications: the 1994 "Federal Radionavigation Plan" of the U.S. Departments of Defence and Transportation; the 1995 "Asia/Pacific Regional Plan for the New CNS/ATM Systems" of the International Civil Aviation Organization Asia and Pacific Office; and the 1995 "Air Navigation Plan" of the Airways Corporation of New Zealand Limited.

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2. Global Navigation Satellite Systems

2.1 Introduction

The infrastructure required for radio navigation is a network of reference stations, whose positions are accurately known, and which broadcast the radio signals to be used by navigators for positioning their own vessels or aircraft. These reference stations can be established and maintained as a public service by public-sector agencies, or for profit by private-sector companies. The navigator's vessel or aircraft must be equipped with an appropriate radio receiver, designed to use the radio signals transmitted by transmitters at these reference stations. These receivers may be widely available from multiple sources, in the case of public-service radio navigation systems, or may have to be leased or purchased from the private sector operator of a radio navigation system.

As shown in Table 2-1, there are three types of reference stations: primary stations, satellites, and differential stations.

Ground-based radio navigation systems use only **primary** reference stations. These stations play two roles: the known locations adopted for these primary stations define the coordinate system in which the navigator is moving; the primary stations are equipped with transmitters which provide the radio signals tracked by the navigator for navigation.

Satellite-based radio navigation systems use both **primary** and **satellite** references. A network of primary ground-based reference stations performs the following tasks:

- Tracks the radio navigation signals transmitted by the satellites (the same signals used by navigators);
- From these signals (with own coordinates known) determines locations of the satellites within an orbital coordinate system;
- Extrapolates these satellite positions, typically one day into the future, using a model of satellite orbital motion; and

- Transmits these predicted satellite positions back up to the satellites (using a "system management" radio link not available to end users) to be stored in satellite memory.

Table 2-1: Role of reference station infrastructures in various radio navigation system architectures

System type	Primary Stations	Satellites	Differential Stations
Ground-Based	User reference & navigation signal		
Satellite-Based	Establish satellite coordinates	User reference & navigation signal	
Differential Ground	User reference & navigation signal		Error correction & integrity monitoring
Differential Satellite	Establish satellite coordinates	User reference & navigation signal	Error correction & integrity monitoring

Satellite-based radio navigation systems use both **primary** and **satellite** references. A network of primary ground-based reference stations performs the following tasks:

- Tracks the radio navigation signals transmitted by the satellites (the same signals used by navigators);
- From these signals (with own coordinates known) determines locations of the satellites within an orbital coordinate system;
- Extrapolates these satellite positions, typically one day into the future, using a model of satellite orbital motion; and
- Transmits these predicted satellite positions back up to the satellites (using a "system management" radio link not available to end users) to be stored in satellite memory.

The satellites then read out these predicted positions to navigators (by superimposing them as modulations on the radio navigation signals). As far as the navigator is concerned, the primary network is a hidden infrastructure, and these satellite positions become the "known" reference locations used for navigation.

Differential navigation methods are used to improve the performance of either long-range ground-based or satellite-based radio navigation. In this case, yet another infrastructure is established. A network of **differential** reference stations, whose positions are known, is used to measure radio navigation errors and monitor the integrity of the satellite signal. These measured errors are assumed to be common over some geographical region surrounding each of these differential reference stations. Error and integrity information is transmitted as a secondary, error-correcting radio signal to navigators. Navigators must be equipped with both a radio receiver to receive the primary ground-based or satellite-based radio navigation signals, and a secondary radio receiver to receive these secondary differential error-correcting radio signals.

Hence, long-range ground-based radio navigation systems, when used differentially, use two independent infrastructures: the primary station network and the differential station network. Satellite-based radio navigation systems, when used differentially, use three infrastructures: the primary (hidden) station network, the satellites themselves, and the differential station network.

2.2 The Present System

There have been two revolutions in marine horizontal positioning during this century. The first occurred as a result of military developments during the Second World War, which resulted in the first ground-based radio positioning systems and the first radars. Since then radio positioning and radar have almost entirely replaced earlier visual and astronomical navigation methods. Publicly-funded radio positioning infrastructures have been established which provide multiple coverage for most well-travelled ocean and air routes. Publicly-funded radio navigation systems are generally long-range, low frequency systems which provide positioning services to an unlimited number of users, over a wide coverage area. Loran-C, Omega, and Transit are used by both the marine and aviation communities; VOR, DME, TACAN, and NDBs are used only by the aviation community; and marine radio beacons are used only the marine community.

2.2.1 Multimodal Systems

Loran-C

The Loran-C radionavigation system has 1.3 million users [United States Congress, 1996]. Originally designed for marine use, it is widely used for air and surface navigation as well. Mass-produced high quality receivers are available at low cost. The system is based on the reception of pulsed transmissions modulating a 100 kHz carrier, from three of more transmitters, over distances of up to 2 000 km (extreme case). The receiver measures the difference in the time of arrival of these pulses from a "master" transmitter and each of two or more "slave" transmitters. These master-slave time differences, or TDs, are associated with a hyperbolic line of position on the earth's surface (a hyperboloidal surface of position for aviators). Two or more of the TDs, or hyperbolas, will intersect to form a position fix. The predictable accuracy of Loran-C is affected by overland phaselag variations, and is 450 m (95 percent) or better. The repeatability, however, is between 20 and 90 m.

Today there are thirty Loran-C "chains" around the world, comprising 75 transmitters, and 120 Loran-C signals (many transmitters belong to two adjacent "chains"). Twelve of these thirty chains stretch around the North Pacific Rim from California to the South China Sea. Two of these chains are not actually Loran-C, but a Russian counterpart, called Chayka.

A regional Loran-C organization, the Far East Radionavigation Service (FERNS), was formed when the United States phased out military use of its Loran-C chains in the north Pacific region in 1994. This organization consists of the countries of Japan, The Peoples Republic of China, The Republic of Korea, and the Russian Federation. Japan took over operation of the former USCG stations in its territory and they are currently being operated by the Japanese Maritime Safety Agency (JMSA). Altogether, FERNS administers 17 Loran-C transmitters within the member countries.

There are twelve Loran-C chains operated in North America by the United States and Canadian Coast Guards, comprising 30 transmitters. The 1994 USFRP states that

> *"The Loran-C system is expected to remain part of the radionavigation system mix until the year 2000, to accommodate the transition to GPS. Continued operation after that date will depend on validating requirements for Loran-C that cannot be met by GPS or another system".*

This is a major change from the 1992 USFRP, which set the 2015 as the sunset for U.S. government support for Loran-C. Many general aviation pilots rely on Loran-C, and are concerned that the transition to the Global Positioning System (GPS) Wide Area Augmentation System (WAAS) proposed to replace it, will not yet be complete by the year 2000 [NBAA, 1995; United States Congress, 1996]. These concerns were noted by the United

States Congress, which has requested the FAA and USCG to report to Congress on what steps DOT will take to ensure that this transition is not premature.

Omega

OMEGA is a Very Low Frequency (VLF), continuous, passive, all weather, medium accuracy, en route worldwide radionavigation system which has been in operation since 1968. The eight Omega transmitter stations, operated by Norway, Liberia, United States (two), France, Argentina, Japan, and Australia transmit four common frequencies (10.2, 11.05, 11-1/3, and 13.6 kHz) and one frequency unique to each station. The accuracy of OMEGA is four nautical miles (95 percent), mainly limited by variations in signal propagation, the uncertainty of which can be reduced somewhat by applying predictive propagation model corrections to the receiver's readings.

OMEGA is usable by both mariners and aviators. Precise time can also be determined from OMEGA. There are two major types of airborne and marine OMEGA receivers available to navigators: fully automatic (recommended) and semi-automatic. Fully automatic receivers have coordinate conversion and corrections for predicted conditions stored internally, while semi-automatic receivers require the navigator to apply propagation corrections manually.

Worldwide weather services launch between 200 000 and 400 000 weather balloons each year to collect data on upper atmosphere wind speed and direction. These balloons use cheap disposable Omega receivers for tracking. Recent analyses indicate that the total system cost of using the presently more expensive GPS receivers would exceed the cost of operating the entire Omega transmitting system.

The 1994 USFRP states:

> *"Because the U.S. navigation needs for Omega will be met by GPS, and Omega use is declining rapidly, continuation of U.S. participation in Omega beyond September 30, 1997 will depend on the financial support of the system by timing and weather users. The Government of Australia has projected that it will terminate operations at its Omega station on September 30, 1997."*

Transit

The first very successful satellite-based positioning system was the Navy Navigation Satellite System (NNSS), also referred to as Transit. Like GPS, Transit has three segments: low-altitude satellites in near polar orbits, a network of ground-based monitor stations to track the satellites and to inject updated satellite orbital parameters in satellite memory; and the user's receiver. Unlike GPS, Transit is not really a complete navigation system, since it provides only infrequent fixes, and requires an independent source of dead reckoning during the 15 minute satellite pass. At its peak, there were about 150 000 Transit receivers in use, but this has declined greatly in recent years. The current Transit constellation contains seven satellites, five operational and two in orbit spares. The 1994 USFRP states:

> *"The Transit launch program ended in 1988. The Navy will terminate operation of the system by the end of 1996."*

2.2.2 Aviation Systems

The four systems that provide the basic guidance for en route air navigation are Non-Directional Beacons (NDB), VHF Omnidirectional Radio Range (VOR), Distance Measuring Equipment (DME), and Tactical Air Navigation (TACAN). Information provided to the aircraft pilot by an NDB or VOR is the azimuth relative to the ground station. DME provides a measurement of distance from the aircraft to the DME ground station. In most cases, VOR and DME are collocated as a VOR/DME facility. TACAN provides both azimuth and distance information and is used primarily by military aircraft. When TACAN is collocated with VOR, it is a VORTAC facility. DME and the distance measuring function of TACAN are the same.

Precision approach systems enable pilots to navigate the aircraft down a defined approach path to the airport touchdown point using both horizontal and vertical guidance. The precision approaches are classified in terms of the level of precision from Category I to Category III (auto land). The level of associated approach and runway lighting increases for each category. Guidance for approach and landing can be provided by an Instrument Landing System (ILS) or a Microwave Landing System (MLS).

NDB

The Non-Directional Beacons (NDB) has for many years provided low cost guidance for both en route and approach purposes. It provides relative bearing information and an indication when the aircraft flies over the beacon. It provides the lowest navigation accuracy and has variable performance due to influences such as the underlying terrain, atmospheric electrical activity and ionospheric effects.

An NDB operates in the low, and medium-frequency bands to provide ground wave signals to a receiver. A radio direction finder (RDF) is used to measure the bearing of the transmitter with respect to an aircraft or vessel.

Aeronautical NDBs operate in the 190 to 415 kHz and 510 to 535 kHz bands. Their transmissions include a coded continuous-wave (CCW) or modulated continuous-wave (MCW) signal to identify the station. The CCW signal is generated by modulating a single carrier with either a 400 Hz or a 1 020 Hz tone for Morse code identification. The MCW signal is generated by spacing two carriers either 400 Hz or 1 020 Hz apart and keying the upper carrier to give the Morse code identification.

Positional accuracy derived from the bearing information is a function of geometry of the Line of Positions (LOPs), the accuracy of compass heading, measurement accuracy, distance from the transmitter, stability of the signal, time of day, nature of the terrain between beacon and craft, and noise. In practice, bearing accuracy is on the order of +3 to + 10 degrees. Achievement of +3 degree accuracy requires that the RDF be calibrated before it is used for navigation by comparing radio bearings to accurate bearings obtained visually on the transmitting antenna. Since most direction finder receivers will tune to a number of radio frequency bands, transmissions from sources of known location, such as AM broadcast stations, are also used to obtain bearings, generally with less accuracy than obtained from radiobeacon stations.

A radiobeacon is an omnidirectional navigational aid. For aviation radiobeacons, out-of-tolerance conditions are limited to output power reduction below operating minimums and loss of the transmitted station identifying tone. The radiobeacons used for nonprecision approaches are monitored and will shut down within 15 seconds of an out-of-tolerance condition.

VOR

The VOR provides more accurate bearing information than an NDB. However the reception is limited to line-of-sight and it is considerably more expensive than an NDB. Doppler VORs provide more accurate and stable guidance, with less interference from site related obstacles.

VORs are assigned frequencies in the 108 to 118 MHz frequency band, separated by 100 kHz. A VOR transmits two 30 Hz modulations resulting in a relative electrical phase angle equal to the azimuth angle of the receiving aircraft. A cardioid field pattern is produced in the horizontal plane and rotates at 30 Hz. A nondirectional (circular) 30 Hz pattern is also transmitted during the same time in all directions and is called the reference phase signal. The variable phase pattern changes phase in direct relationship to azimuth. The reference phase is frequency modulated while the variable phase is amplitude modulated. The receiver detects these two signals and computes the azimuth from the relative phase difference. For difficult siting situations, a system using the Doppler effect was developed and uses 50 instead of four antennas for the variable phase. The same avionics works with either type ground station.

VOR has line-of-sight limitations which could limit ground coverage to 30 miles or less. At altitudes above 5 000 feet, the range is approximately 100 nmi, and above 20 000 feet, the range will approach 200 nmi. These stations radiate approximately 200 watts. Terminal VOR stations are rated at approximately 50 watts and are only intended for use within the terminal areas.

VOR provides system integrity by removing a signal from use within ten seconds of an out-of-tolerance condition detected by an independent monitor.

DME

The DME instrument on the aircraft provides a continuous indication of distance (nautical miles) from the ground DME equipment. The coverage is line-of-sight and the DME is usually co-sited with a VOR or NDB.

The interrogator in the aircraft generates a pulsed signal (interrogation) which, when of the correct frequency and pulse spacings, is accepted by the transponder. In turn, the transponder generates pulsed signals (replies) which are sent back and accepted by the interrogator's tracking circuitry. Distance is then computed by measuring the total round trip time of the interrogation and its reply. The operation of DME is thus accomplished by paired pulse signals and the recognition of desired pulse spacings accomplished by the use of a decoder. The transponder must reply to all interrogators. The interrogator must measure elapsed time between interrogation and reply pulse pairs and translate this to distance. All signals are vertically polarized. These systems are assigned in the 960 to 1 213 MHz frequency band with a separation of 1 MHz.

DME has a line-of-sight limitation, which limits ground coverage to 30 nmi or less. At altitudes above 5 000 feet, the range will approach 100 nmi. En route stations radiate at 1 000 watts. Terminal DMEs radiate 100 watts and are only intended for use in terminal areas.

DME provides system integrity by removing a signal from use within ten seconds of an out-of-tolerance condition detected by an independent monitor.

TACAN

TACAN is a short-range UHF (960 to 1,215 MHz) radionavigation system designed primarily for military aircraft use. TACAN transmitters and responders provide the data necessary to determine magnetic bearing and distance from an aircraft to a selected station. TACAN stations in the U.S. are frequently collocated with VOR stations. These facilities are known as VORTACs.

TACAN has a line-of-sight limitation which limits ground coverage to 30 nmi or less. At altitudes of 5 000 feet the range will approach 100 nmi; above 18 000 feet, the range approaches 200 nmi. The station output power is 5 kW.

TACAN provides system integrity by removing a signal from use within ten seconds of an out-of-tolerance condition detected by an independent monitor.

ILS

ILS is a precision approach system normally consisting of a localizer facility, a glide slope facility, and two or three VHF marker beacons. It provides vertical and horizontal navigational (guidance) information during the approach to landing at an airport runway.

At present, ILS is the primary worldwide, ICAO-approved, precision landing system. This system is presently adequate, but has limitations in siting, frequency allocation, cost, and performance.

ILS reliability approaches 100 percent. However, terrain and other factors may impose limitations upon the use of the ILS signal. Special account must be taken of terrain factors and dynamic factors such as taxiing aircraft which can cause multipath signal transmissions.

In some cases, to resolve ILS siting problems, use has been made of localizers with wide aperture antennas and two-frequency systems. In the case of the glide slope, use has been made of wide aperture, two-frequency image arrays and single-frequency broadside arrays to provide service at difficult sites.

ILS provides system integrity by removing a signal from use when an out-of-tolerance condition is detected by an integral monitor. The shutdown delay for each landing category is given below:

	Shutdown Delay	
	Localizer	**Glide Slope**
CAT I	<10 sec	<6 sec
CAT II	<5 sec	<2 sec
CAT III	<2 sec	<2 sec

MLS

MLS provides a common civil/military landing system to meet the full range of user operational requirements, as defined in the ICAO list of 38 operational requirements for precision approach and landing systems, to the year 2000 and beyond. It was originally intended to be a replacement for ILS, used by both civil and military aircraft, and the Ground Controlled Approach (GCA) system used primarily by military operators. However, Differential GPS (DGPS) systems are now envisioned to satisfy the majority of requirements originally earmarked for MLS.

The MLS signal is transmitted throughout a large volume of airspace, thereby permitting service to multiple aircraft, along multiple approach paths, throughout the approach, flare, touchdown, and rollout manoeuvres. The system permits greater flexibility in air traffic procedures, enhancing safety, and permits curved and segmented approach paths for purposes of noise abatement. MLS allows steep glide path approaches for airports in mountainous terrain, and facilitates short field operations for short and/or vertical takeoff and landing (STOL and VTOL) aircraft.

The MLS signals are generally less sensitive than ILS signals to the effects of snow, vegetation, terrain, structures, and taxiing aircraft. This allows the reliability of this system to approach 100 percent.

MLS integrity is provided by an integral monitor. The monitor shuts down the MLS within one second of an out-of-tolerance condition.

2.2.3 Marine Systems

Marine Radiobeacon

Marine Radiobeacons are nondirectional radio transmitting stations which operate in the low and medium-frequency bands to provide ground wave signals to a receiver. An RDF is used to measure the bearing of the transmitter with respect to a vessel.

Marine radiobeacons can be modified to carry differential GPS correction signals.

Marine radiobeacons operate in the 285 to 325 kHz band. Radiobeacons used for DGPS will be modulated with minimum shift keying (MSK) modulation to broadcast DGPS corrections. In addition, radiobeacons may be operated in a single carrier mode resulting in the elimination of the Morse code identifier.

Positional accuracy derived from the bearing information is a function of geometry of the LOPs, the accuracy of compass heading, measurement accuracy, distance from the transmitter, stability of the signal, time of day, nature of the terrain between beacon and craft, and noise. In practice, bearing accuracy is on the order of +3 to +10 degrees. Achievement of +3 degree accuracy requires that the RDF be calibrated before it is used for navigation by comparing radio bearings to accurate bearings obtained visually on the transmitting antenna. Since most direction finder receivers will tune to a number of radio frequency bands, transmissions from sources of known location, such as AM broadcast stations, are also used to obtain bearings, generally with less accuracy than obtained from radiobeacon stations.

A radiobeacon is an omnidirectional navigational aid. Marine radiobeacons are monitored either continuously or periodically, depending on equipment configuration. Radiobeacons broadcasting operational DGPS corrections are monitored continuously. Notification of outages is provided by a broadcast Notice to Shipping. Outages of long duration are announced in both the Local Notice to Shipping and the Notice to Mariners.

2.3 The New System

The introduction of satellite navigation is well advanced, so far mainly using the GPS provided by the United States, and more recently through the establishment of DGPS infrastructures for marine horizontal positioning.

The GPS system has been declared fully operational, and DGPS infrastructures for marine use will become operational in several jurisdictions during 1996 (notably the 75 DGPS transmitters being established by United States and Canadian Coast Guards, and the 50 DGPS transmitters being established in Europe). Proliferation of DGPS infrastructures throughout the APEC region remains incomplete. The Wide Area Augmentation System (WAAS) for aviation use in North America is scheduled to be completed in 1999. Japan is planning a similar system called Multi-functional Transport Satellite (MTSAT). However, a number of technological opportunities and enabling actions remain, if these technologies are to be fully exploited.

Within the United States, satellite-based positioning means GPS. Elsewhere the perception is different. Internationally, a more generic concept is current, the Global Navigation Satellite System (GNSS). This is not a competitor to GPS (at least not initially), but a way of constructing something more comprehensive than GPS (and reducing the reliance on a single system). The immediate goal of GNSS proponents is to combine three building blocks: GPS, the Russian equivalent system, GLONASS, and navigation and integrity signals from the next generation of INMARSAT satellites.

GNSS is a multi-modal concept, purposely being designed to meet the needs of air and marine transportation, but with important benefits for land transportation, and many non-transportation applications as well.

2.3.1 GPS

GPS is a space-based radionavigation system which is managed for the Government of the United States by the U.S. Air Force, the system operator. GPS was originally developed as a military force enhancement system and will continue to play this role; however, GPS also has significant potential to benefit the civil community in an increasingly large number and variety of applications. In an effort to make GPS service available to the greatest number of users while ensuring that national security interests of the United States are protected, two GPS services are provided. The Precise Positioning Service (PPS) provides full system accuracy primarily to U.S. and allied military users. The Standard Positioning Service (SPS) is designed to provide accurate positioning capability for civil users throughout the world. The GPS has three major segments: space, control, and user.

The GPS Space Segment is composed of 24 satellites in six orbital planes. The satellites operate in circular 20 200 km (10 900 nmi) orbits at an inclination angle of 55 degrees and with a 12-hour period. The spacing of satellites in orbit are arranged so that a minimum of 5 satellites are in view to users worldwide, with a Position Dilution of Precision (PDOP) of six or less.

The GPS Control Segment has five monitor stations and three ground antennas with uplink capabilities. The monitor stations use a GPS receiver to passively track all satellites in view and accumulate ranging data from the satellite signals. The information from the monitor stations is processed at the Master Control Station (MCS) to determine satellite clock and orbit states and to update the navigation message of each satellite. This updated information is transmitted to the satellites via the ground antennas, which are also used for transmitting and receiving health and control information.

The GPS User Segment consists of a variety of configurations and integration architectures that include an antenna and receiver-processor to receive and compute navigation solutions to provide positioning, velocity, and precise timing to the user.

Each satellite transmits three separate spectrum signals on two L-band frequencies, Ll (1575.42 MHz) and L2 (1227.6 Mhz). Ll carries a Precise P (Y) Pseudo-Random Noise (PRN) code and a Coarse/Acquisition (C/A) PRN code; L2 carries the P(Y) PRN code. (The Precise code is denoted as P(Y) to identify that this PRN code can be operated in either a clear unencrypted "P", or an encrypted "Y", code configuration.) Both PRN codes carried on the Ll and L2 frequencies are phase-synchronized to the satellite clock and modulated (using module two addition) with a common 50 Hz navigation data message.

In order to support civil GPS applications, the SPS user is guaranteed system access through the use of the Ll C/A signal while the P(Y) code on Ll and L2 is reserved for PPS requirements. The SPS signal received by the user is a spread spectrum signal centered on Ll with a 2.046 MHz bandwidth. Minimum SPS received power is specified as -160.0 dBW. The navigation data contained in the signal is composed of satellite clock and ephemeris data for the transmitting satellite plus GPS constellation almanac data, GPS to UTC time offset information, and ionospheric propagation delay correction parameters for single frequency users. The entire navigation message repeats every 12.5 minutes. Within this 12.5-minute repeat cycle, satellite clock and ephemeris data for the transmitting satellite is sent 25 separate times so it repeats every 30 seconds. As long as a satellite indicates a healthy status, a receiver can continue to operate using this data for the validity period of the data (up to 4 or 6 hours). Normally, however, the receiver will update this data whenever the satellite and ephemeris information is updated - nominally once every 2 hours.

The concept of GPS position determination is based on the intersection of four separate vectors each with a known origin and a known magnitude. Vector origins for each satellite are computed based on satellite ephemeris. Vector magnitudes are calculated based on signal propagation time delay as measured from the transmitting satellite's PRN code phase delay. Given that the satellite signal travels at nearly the speed of light and taking into account delays and adjustment factors such as ionospheric propagation delays and earth rotation factors, the receiver performs ranging measurements between the individual satellite and the user by dividing the satellite signal propagation time by the speed of light.

These measurements are combined to yield system time and the user's three-dimensional position with respect to World Geodetic Systems, 1984 (WGS-84) Earth Centered-Earth Fixed (ECEF) coordinates. A user's velocity can thus be computed by propagating the user's position with respect to time.

A stand-alone GPS receiver requires four simultaneous measurements from four satellites to determine position in three dimensions and time. The receiver uses the four simultaneous measurements to yield four linearized mathematical equations with four unknowns from which the four unknowns can be solved (e.g., latitude, longitude, altitude, and time). If the user needs only two-dimensional positioning and time determination, only three simultaneous measurements are required for three equations and three unknowns (latitude, longitude, and time). If the user needs only time determination, only one satellite measurement is required for one equation and one unknown (time).

GPS provides two services for position determination, SPS and PPS. Accuracy of a GPS fix varies with the capability of the user equipment.

Standard Positioning Service (SPS): SPS is the standard specified level of positioning and timing accuracy that is available, without restrictions, to any user on a continuous worldwide basis. The accuracy of this service will be established by the DOD and DOT based on U.S. security interests. SPS currently provides a predictable positioning accuracy of 100 m (95 percent) horizontally and 156 m (95 percent) vertically and time transfer accuracy to UTC within 340 nanoseconds (95 percent).

Precise Positioning Service (PPS): PPS is the most accurate direct positioning, velocity, and timing information continuously available, worldwide, from the basic GPS. This service is limited to users specifically authorized by the U.S. P(Y) code capable military user equipment provides a predictable positioning accuracy of at least 22 m (95 percent) horizontally and 27.7 m vertically and time transfer accuracy to UTC within 200 nanoseconds (95 percent).

The basic GPS signal is augmented to ensure that the requirements for accuracy, integrity, availability, and continuity of the signal are met. These requirements may be different depending on the application.

Accuracy is the degree of conformance of an aircraft's or vessel's measured position with its true position. Basic GPS meets the accuracy requirements for en route through non-precision approaches (NPA) but not for precision approaches. For marine applications, the accuracy meets requirements for offshore and open waters but not for confined waters such as ports and inland waterways. The satellite signal can be augmented with additional information to increase the accuracy of the position calculation. There are a number of approaches to this, some of which can obtain accuracies in the order of 1 cm.

Integrity is the ability of a system to provide timely warnings when part or all of the system is providing erroneous information and thus should not be used for navigation. The level of integrity needed is dependent on the application. In general, the aviation community requires a higher level of integrity monitoring than the marine community.

Availability is the probability that at any time the system will meet the accuracy and integrity requirements for a specific phase of flight or vessel movement. Availability is critical for all phases of flight but in particular for take-offs and landings; and GPS does not meet the availability requirements for air transportation. Availability is not as critical for all phases of vessel movements. Only in confined waters does the availability of GPS not meet marine requirements.

Continuity is the probability that a service will continue to be available for a specified period of time, given that it is available at the beginning of the period (for example, that the system will continue to meet the requirements for approach guidance throughout an approach, given that it is available at the initiation of the approach). For aviation, it is of concern primarily in the approach mode of flight (requiring .99995/approach). The marine community typically requires less stringent continuity requirements (ie., .997 percent of the time).

These four requirements are typically met through augmentations to the GPS.

2.3.2 Augmentations to GPS

GPS may exhibit variances from a predicted grid established for navigation, charting, or derivation of guidance information. This variance may be caused by propagation anomalies, errors in geodesy, accidental perturbations of signal timing, or other factors.

DGPS enhances GPS through the use of differential corrections to the basic satellite measurements. DGPS is based upon accurate knowledge of the geographic location of one or more reference stations, which are used to compute corrections to GPS parameters, error sources, and/or resultant positions. These differential corrections are then transmitted to GPS users, who apply the corrections to their received GPS signals or computed position. For a civil user of SPS, differential corrections can improve navigational accuracy from 100 m (2 drms) to better than 7 m (2 drms). A DGPS reference station is fixed at a geodetically surveyed position. From this position, the reference station typically tracks all satellites in view, downloads ephemeris data from them, and computes corrections based on its measurements and geodetic position. These corrections are then broadcast to GPS users to improve their navigation solution. There are two well-developed methods of handling this:

- Computing and transmitting a position correction in x-y-z coordinates, which is then applied to the user's GPS solution for a more accurate position.

- Computing pseudorange corrections for each satellite, which are then broadcast to the user and applied to the user's pseudorange measurements before the GPS position is calculated by the receiver, resulting in a highly accurate navigation solution.

The first method, in which the correction terms for the x-y-z coordinates are broadcast, requires less data in the broadcast than the second method, but the validity of those correction terms decreases rapidly as the distance from the reference station to the user increases. Both the reference station and the user receiver must use the same set of satellites for the corrections to be valid. This condition is often difficult to achieve, and limits operational flexibility.

Using the second method, an all-in-view receiver at the reference site receives signals from all visible satellites and measures the pseudorange to each. Since the satellite signal contains information on the precise satellite orbits and the reference receiver knows its position, the true range to each satellite can be calculated. By comparing the calculated range and the measured pseudorange, a correction term can be determined for each satellite. The corrections are broadcast and applied to the satellite measurements at each user's location. This method provides the best navigation solution for the user and is the preferred method. It is the method being employed by Canadian and U.S. Coast Guard DGPS Services.

An elaboration of the second method is being incorporated in the FAA's WAAS for GPS. In this system, a network of GPS reference/measurement stations at surveyed locations collects dual-frequency measurements of GPS pseudorange and pseudorange rate for all spacecraft in view, along with local meteorological conditions. These data can be processed to yield highly accurate ephemeris, ionospheric and tropospheric calibration maps, and DGPS corrections for the broadcast spacecraft ephemeris and clock offsets (including the effects of Selective Availability (SA). In the WAAS, these GPS corrections and system integrity messages will be relayed to civil users via a dedicated package on geostationary satellites. This relay technique will also support the delivery of an additional ranging signal, thereby increasing overall navigation system availability.

Aviation Wide Area Augmentation System

The WAAS will be a safety-critical system consisting of the equipment and software which augments the DOD-provided GPS Standard Positioning Service. It will provide a signal in space to WAAS users with the specific goal of supporting aviation navigation for the en route through Category I precision approach phases of flight. The signal in space will provide three services:

- Integrity data on GPS and Geostationary Earth Orbiting (GEO) satellites;
- Wide area differential corrections for GPS satellites; and
- An additional ranging capability.

The GPS satellites, data is to be received and processed at widely dispersed sites, referred to as Wide-area Reference Stations (WRS). These data are forwarded to data processing sites, referred to as Wide-area Master Stations (WMS), which process the data to determine the integrity, differential corrections, residual errors, and ionospheric information for each monitored satellite and generate GEO satellite navigation parameters. This information is to be sent to a Ground Earth Station (GES) and uplinked along with the GEO navigation message to GEO satellites. These GEO satellites will then downlink this data on the GPS Link I (L1) frequency with a modulation similar to that used by GPS.

In addition to providing GPS integrity, the WAAS will verify its own integrity and take any necessary action to ensure that the system meets the WAAS performance requirements. The WAAS also has a system operations and maintenance function that provides information to FAA Airway Facilities NAS personnel.

The WAAS user receiver will process:

- The integrity data to ensure that the satellites being used are providing in-tolerance navigation data,
- The differential correction and ionospheric information data to improve the accuracy of the user's position solution, and
- The ranging data from one or more of the GEO satellites for position determination. The WAAS user receivers are not considered part of the WAAS.

The WAAS will collect raw GPS observable data through the GPS L1-C/A pseudorange data, the GPS L1/Link 2 (L2) code differential data (without knowledge of the Y-code), and the satellite navigation data from all GPS satellites that support the navigation service.

WAAS ground equipment will develop messages on ranging signals and signal quality parameters of the GPS and GEO satellites. GEO satellites will broadcast the WAAS messages to the users and provide ranging sources. The signals broadcast via the WAAS GEOs to the WAAS users are designed to require minimal standard GPS receiver hardware modifications. The GPS frequency and GPS-type modulation, including a C/A PRN code, will be used. In addition, the code phase timing will be synchronized to GPS time to provide a ranging capability.

Accuracies for the WAAS are currently based on aviation requirements. For the en route through nonprecision approach phases of flight, a horizontal accuracy of 100 m 95 percent of the time is guaranteed with the requisite availability and integrity levels to support operations in the NAS. For the Category I precision approach phase of flight, horizontal and vertical accuracies are guaranteed at 7.6 m 95 percent of the time.

Integrity augmentation of the GPS SPS by the WAAS is a required capability that is both an operational characteristic and a technical characteristic. The required system performance levels for the integrity augmentation are the levels necessary so that GPS/WAAS can be used for all phases of flight.

Integrity for the WAAS is specified by three parameters: probability of hazardously misleading information (PHMI), time to alarm, and the alarm limit. For the en route through nonprecision approach phases of flight, the performance values are:

PHMI	10-7 per hour
Time to Alarm	8 seconds
Alarm Limit	Protection limits specified for each phase of flight

For the precision approach phase of flight, integrity performance values are:

PHMI	4 x 10-8 per approach
Time to Alarm	5.2 seconds
Alarm Limit	As required to remain within the Category I tunnel

The WAAS is fully capable of being expanded to provide worldwide coverage, primarily using the INMARSAT geostationary satellite network or Japan's MTSAT. INMARSAT have a single satellite available to cover the South West Pacific area, but this may be complemented by using other satellites to provide redundancy coverage.

Aviation Local Area Augmentation System

The FAA and others envisage using a Local Area Augmentation System (LAAS) to permit Category II and III landings using GPS. LAAS are on trial at various airports in the United States. LAAS uses a pseudolite (pseudo satellite) located near the runway. The pseudolite transmits very accurate GPS signals, unaffected by orbital decay, ionospheric interference, or errors compounded by distance. These are expected to achieve accuracies measured in centimetres. This will enable precision approaches, and can be used for multiple runways.

The LAAS is considerably cheaper than installing an ILS or MLS system. Differential GPS receivers with a data linking capability need to be fitted to the aircraft.

Marine Differential GPS

The reference station's and the mariner's pseudorange calculations are strongly correlated. Pseudorange corrections computed by the reference station, when transmitted to the mariner in a timely manner, can be directly applied to the mariner's pseudorange computation to dramatically increase the resultant accuracy of the pseudorange measurement before it is applied within the mariner's navigation solution. The USCG DGPS prototype sites are achieving accuracies on the order of 1 metre.

Maritime radiobeacons are being modified to accept MSK modulation. Real-time differential GPS corrections are input in the Radio Technical Commission for Maritime Services Special Committee 104 (RTCM SC-104) format and broadcast to all users capable of receiving the signals. The USCG does not plan to use data encryption. Radiobeacons were chosen because of existing infrastructure, compatibility with the useful range of DGPS corrections, international radio conventions, international acceptance, commercial availability of equipment, and highly successful field tests.

The data rate of DGPS transmissions will be 100 bps and 200 bps in selected waterways with more stringent VTS requirements. Prior to full implementation of DGPS, a decision may be made to use a 200 bps data rate at all DGPS broadcast sites.

The USCG's DGPS system will broadcast corrections to the user in the RTCM SC-104 format. The RTCM has defined data messages and an interface between the DGPS receiver and the data link receiver.

The accuracy of the USCG's DGPS service is expected to be better than 10 metres (2 drms) in all approaches to major U.S. harbors. Prototype operations are now achieving accuracies on the order of 1 metre.

DGPS system integrity is provided through an on-site integrity monitor and 24-hour operations at a DGPS control center. Users will be notified of an out-of-tolerance condition within five seconds.

In addition to providing a highly accurate navigational signal, DGPS also provides a continuous integrity check on satellite health. System integrity is a real concern with GPS. With the design of the ground segment of GPS, a satellite can be transmitting an unhealthy signal for 2 to 6 hours before it can be detected and corrected by the Master Control Station or before users can be warned not to use the signal. But with the continuous, real-time messages generated by DGPS, unhealthy satellites can still be used, or the navigator's receiver is directed not to use a particular satellite. This can eliminate the danger of the navigator relying on an erroneous signal.

2.3.3 GPS Issues

GPS can be used in a wide variety of modes, with varying performance (and corresponding costs). One characteristic of GPS is that its performance has consistently exceeded what was expected of it. This has challenged those responsible for managing GPS. The evolution of GPS technology has been so successful that it has resulted in serious political and management problems. The most serious of these has been the twenty-year struggle to establish and maintain an appropriate balance between the military and civil uses to which GPS can be put. GPS management has had to adapt to new realities resulting from this technological success of GPS. It is instructive to examine these past GPS “reality checks”.

C/A Code Accuracy

The GPS pseudoranging signal designed for civilian use, the C/A-code, was designed with a chip rate which was one-tenth that of the pseudoranging signal designed for military use, the P-code. C/A-code GPS positioning accuracy was expected to be about 400 m (Kremer et al. 1990). Initial field tests showed that C/A-code GPS positioning accuracy (first generation, or Block I GPS satellites) was 20 - 40 m, and C/A code velocity measurements were a fraction of a metre per second. The response to this challenge was to intentionally dither the satellite clocks to degrade civilian velocity accuracy, and add deliberate errors to the satellite ephemerides to degrade civilian position accuracy. This process, initially called “Denial of accuracy” eventually was relabelled as “Selective Availability”, or SA, and was designed into the second generation (Block II) GPS satellites. Military receivers are able to unscramble SA errors, while civilian receivers are not.

Setting Selective Availability

The "SA level" or amount of degradation can be varied. The peacetime setting for SA can be "dialed up" (the accuracy available to civilians and hostile forces further degraded) in times of emergency, or when required for United States national security purposes. Non-U.S.-military GPS accuracy should be worse in wartime than in peacetime. However, in its first use in conflict during the Gulf War, 1990 - 1991, military applications of GPS had far outstripped the military receiver procurement process, particularly of relatively inexpensive hand-held units to be used in vehicles and on foot. Hand-held C/A code civilian receivers, easily available on short notice, were used instead. Therefore, during the Gulf War, and later during the invasion of Haiti, SA was dialed down to zero or nearly zero, not dialed up.

User Accuracy Needs

The civilian mode of GPS, SPS, differs from the military mode of GPS, PPS, in two ways: SPS is degraded by SA, and uses a single signal frequency; PPS is not degraded by SA, and is a dual frequency system. SPS was designed to match the performance of existing navigation aids, as far as transportation safety is concerned. The planned result was that SPS (with SA on) should meet most civil user needs.

But GPS made possible a new approach to transportation, leading to an explosive growth in civilian GPS use for innovative transportation information systems: ECDIS in the marine world, Future Air Navigation Systems (FANS) in the aviation world, and Intelligent Transportation Systems (ITS), in the land world. These applications provide transportation safety and efficiency advantages which go far beyond that available from navigation aids which pre-date GPS. But they are also "accuracy addicts".

Many civilian users have also become accuracy addicts, and need (or at least want) better performance than that provided by SPS with SA dialed up to its present level, which is officially 100 m horizontally, and 140 m vertically (95%). There have been two responses. The first has been political - the rise of anti-SA lobby among the civilian user community, both within the United States, and internationally. The second has been a technological end-run around SA - the development of DGPS systems. SA clock dither errors affect all users identically. SA ephemeris errors affect receivers within the same region of the earth very similarly. A GPS receiver at a stationary known location can monitor SA (and other) errors and broadcast corrections to nearby users. DGPS performance is much better than SPS, even **without** SA.

GLONASS

Russia has designed a system similar to GPS in most essential ways, called GLONASS [Kleusberg 1990]. One difference is that the clocks in GPS satellites are better than clocks in GLONASS satellites. It was expected that GLONASS (which has no degradation equivalent to SA) would not displace the military or commercial advantages of GPS (even with SA dialed to its present level). However, since the collapse of the Soviet Union, GLONASS development has continued for commercial rather than military purposes. One result has been the design of civilian receivers capable of tracking both GPS and GLONASS satellites. A civilian GPS + GLONASS receiver achieves accuracies comparable to SPS with SA dialed to zero [NRC 1995]. The intention of SA can be defeated by using such receivers.

The Presidential Decision Directive (PDD) of 28 March 1996 responded to this situation by stating:

> *"It is our intention to discontinue the use of GPS Selective Availability (SA) within a decade in a manner that allows adequate time and resources for United States military forces to prepare fully for operations without SA."*

DGPS and U.S. Security

DGPS systems require a monitor station at a known location. It was expected that hostile forces are unlikely to have the sophistication, or to make the effort, to exploit DGPS. Monitor stations can be rendered inoperative by jamming the corrections, or by detection and destruction. Therefore, even though DGPS performance defeats the effect of SA, DGPS poses no threat to military security.

However, the development and implementation of DGPS technology has become very widespread.

- Wide-Area DGPS (WADGPS) technology, using many widely-distributed DGPS monitor stations, communicating with each other and with users, often via communication satellites, provides DGPS services on a continental or larger scale. At least two commercial non-U.S.-controlled WADGPS services are available around the world: the Racal Skyfix system, and the Fugro Starfix II system.

- At least 12 agencies of the U.S. government operate permanent DGPS systems (Army Corps of Engineers, Bureau of Land Management, Coast Guard, Defense, Environmental Protection Agency, Federal Aviation Administration, Forest Service, Geological Survey, NASA, NOAA, National Science Foundation, and the St. Lawrence Seaway).

- Marine DGPS services have been or are being implemented by governments in over a dozen other countries (Canada, Australia, Belgium, Bermuda, China, Estonia, Iceland, India, Finland, France, Poland, Sweden, Norway, Denmark, Germany, The Netherlands, and South Africa, United Kingdom).

- WADGPS services for aviation are planned by the United States, Canada, Australia, New Zealand, and Japan.

- Two companies are using add-ons to the broadcast signals of existing FM radio stations to provide Local Area DGPS (LADGPS) services in North America and around the world. Differential Corrections Inc. (DCI) has an agreement to add LADGPS to any Canadian Broadcasting Corporation FM station within whose signal coverage area there is a sufficient demand for LADGPS services. Pinpoint has an agreement with practically all other FM stations in Canada for a similar service. Each company plans to soon operate from over 100 FM stations in North America, and many more stations around the world. Clients use a DGPS correction receiver resembling a telephone paging unit.

- In addition to all these permanent DGPS infrastructures, users can buy and deploy at will their own small, inexpensive, reliable, easy to operate, temporary DGPS equipment, available from many U.S. and international GPS manufacturers.

This proliferation of permanent DGPS systems, and the availability of simple user-friendly equipment for temporary DGPS systems, removes barriers to the hostile use of DGPS, and greatly increases the difficulty of rendering inoperative all possible DGPS services in a region of conflict. The PDD of 28 March 1996 responded to this issue, by stating that the use of SA will be discontinued within a decade.

GPS Successors

GPS was designed to meet all expected military and civilian navigation and positioning needs. Some believe GPS to be the ultimate navigation system, with no need for a successor system to eventually replace it.

However, many civil, commercial and scientific positioning needs which could be met by GPS are not, impeded by the necessary balance between national security benefits and economic and social benefits. Proposals are being made in other countries for superior, civil, non-U.S.-controlled successors to GPS.

Consequently, the continued growth of GPS, and the full realization of its economic benefits depends on better meeting civil, commercial and scientific needs. As a result of this perception, the Presidential Decision Directive of 28 March 1996 stated that the United States

> *"will cooperate with other governments and international organizations to ensure an appropriate balance between the requirements of international civil, commercial and scientific users and international security interests".*

GPS and Military Control

From the beginning, GPS was designed as a dual-use technology, meeting both military and civilian needs. However, national security (military) benefits from GPS have taken precedence over economic and social (civilian) benefits from GPS are secondary.

However, users have demonstrated very significant GPS civil, commercial and scientific benefits. In addition to marine, air and land transport uses for which GPS was intended, new applications have emerged in resource management (farming, forestry, open-pit mining), facilities management (road and rail inventory systems), geomatics, geodesy and earth science, timing and telecommunications, and recreational personal use (hiking, biking, golf). It has been estimated that the economic impact of servicing these applications (the size of the GPS supplier industry) for the North American market totals $42 billion over the decade starting in 1994, and that this would increase to $64 billion if the use of SA were discontinued [Dyment, 1995]. This does not include the economic impact (efficiencies, productivity, new goods and services) of GPS within the user sector.

Pressure has built to find a new balance between national security GPS benefits and economic and social GPS benefits. Several studies were commissioned to suggest changes in the management and policies regarding GPS [DoD/DoT 1994; OMB 1995; NRC 1995; NAPA 1995; Rand 1995]. The Presidential Decision Directive of 28 March 1996 states that GPS (and U.S. government DGPS systems) will be managed by an interagency GPS Executive Board, jointly chaired by the Departments of Defence and Transportation, and that this Board will

> *"consult with U.S. government agencies, U.S. industries, and foreign governments involved in navigation and positioning system research, development, operation, and use".*

Presidential Decision Directive

The Presidential Decision Directive of 28 March 1996 has removed the uncertainties surrounding the future of GPS which in recent years had begun to affect the full exploitation of the benefits which GPS can provide. Clear policies for the future of GPS have been established. A balance between national security benefits and economic and social benefits has been struck. A process has been established for regularly reviewing this balance, taking into account military and civil concerns, both within the United States and among other nations. A final passage from the Presidential Decision Directive reads:

> *"We will continue to provide the GPS Standard Positioning Service for peaceful civil, commercial and scientific use on a continuous, worldwide basis, free of direct user fees".*

The Future of Alternative Infrastructures

Satellite-based positioning technologies are expected to result in the shut-down of several ground-based radio-positioning system infrastructures which have been the mainstay of marine and air positioning capabilities for the past few decades. Reliance on the single GPS technology could pose a potential risk.

GPS Management

The new management regime for GPS is to be more open, according to the PDD. The Civil GPS Service Interface Committee (CGSIC) holds regular meetings to which APEC could send one or more delegates. Issues under discussion include the selection of an L5 second civil carrier frequency for Block IIF satellites, WAAS, GPS / GLONASS integration, radio interference issues, and issues raised by those attending.

Standards

Easy and widespread use of GPS and DGPS has been facilitated by three standards- building activities:

- The National Marines Electronics Association (NMEA) has designed a standard for interfacing marine electronic devices, such as GPS receivers, radars, autopilots, etc. [NMEA, 1995]. This standard, NMEA 0183, is now widely used in non-marine applications, and is the basis for a very similar international standard, the International Electrotechnical Commission standard IEC 1162-1. The IEC standard has been specified by IMO to meet the Safety of Life at Sea (SOLAS) regulations.

- The Radio Technical Commission for Maritime Services (RTCM) Special Committee 104 (RTCM SC-104) has designed a standard for differential GPS services [RTCM, 1994] which specifies the content and format of correction messages sent from a DGPS monitor to users. RTCM have recently added some additional messages for differential GLONASS (DGLONASS) as well. In fact a combined DGPS / DGLONASS service is already in operation in Russia [Chistyakov, 1996].

- The International GPS Service for Geodynamics (IGS) and its antecedent organizations, developed a standard for the exchange of GPS measurement data. This standard is the Receiver Independent Exchange (RINEX) standard. The easy exchange of scientific GPS data which this standard facilitated contributed significantly to many of the advances in GPS capabilities which navigators now have available to them.

These three standards have succeeded because they have been developed with full participation from all stakeholder groups, and have been universally accepted by GPS manufacturers and users alike. To stay competitive, receivers and software from GPS suppliers must support NMEA 0183, RTCM SC-104, and (for geodetic receivers) RINEX.

2.4 Multimodal Collaboration Opportunity

Duplication of publicly funded DGPS services is an issue of concern to many. For example, within the United States, as noted previously, there are at least ten agencies which maintain some kind of DGPS capability. In many cases, there is good communication and sharing of data and resources among these agencies. But not always. A major question is whether there is a need for the FAA WAAS system, and the USCG beacon DGPS system, or whether they could be more closely coordinated than appears to be the case. We are still in the early days of DGPS, and it is still an open question whether service proliferation will worsen, or whether there will be closer integration among these services in the future. There are multimodal applications for DGPS services, for road and rail transport, as well as marine and air transport, and activities such as agriculture and forestry are starting to make major use of DGPS services as well.

Beacon-transmitter-based DGPS services may be a transition phase. In future, as global satellite communications becomes less expensive and more accessible, it may well be more reliable to combine satellite communications and satellite-based positioning, rather than maintain the presently deployed marine beacon infrastructure. This strategy might also serve to control the mode-to-mode proliferation noted above.

3. Marine Navigation and Communications

3.1 Introduction

Many factors affect the safety of marine transportation. Here we consider only the positioning information available to the navigator. This positioning information consists of two components: position of the navigator's vessel (both horizontal and vertical), and positions of features outside the navigator's vessel (including safe channels, hazards, and other vessels).

Infrastructures which are external to the navigator's vessel are required to provide both components. Without such infrastructures (or when access to these infrastructures fails) the navigator is left with a sharply reduced set of tools with which to safely navigate: alternative technologies for own vessel positioning (e.g., astro navigation, requiring solar or star ephemeris infrastructure), and evidence of approaching hazards from the vessel's echo sounder, radar and visual sighting.

In this report we discuss four tasks, and the related technologies which provide positioning information to the navigator:

- Technologies related to the determination of the navigator's vessel position (own vessel position). We consider these technologies separately for horizontal position and for vertical position, since the requirements and current methods involved are quite different.

- Technologies related to the location of hazards and maintenance of safe passages.

- Technologies related to managing the information relating vessel positions to hazards and safe passages.

Each of these technologies is considered from both the supply (or infrastructure) and from the user demand (or operations) points of view. Future technological opportunities and enabling actions, and the impacts on marine transportation safety, and economy are discussed where appropriate. The roles played by satellite navigation and satellite communications are highlighted.

Most, if not all, of the technologies available for these four tasks are currently undergoing fundamental change. Much of this change is driven by both demand and the evolution of available technology. Although there are other factors in play, much of this change is due to the conversion of analogue operations and infrastructures to digital operations and infrastructures.

Three different technology thrusts are changing marine navigation: satellite-based positioning (SatNav); high density depth (HDD) sensors; and Electronic Chart Display and Information Systems (ECDIS). These technologies are linked in many ways, as indicated in Table 3-1.

Three different technology thrusts are changing marine navigation: satellite-based positioning (SatNav); high density depth (HDD) sensors; and Electronic Chart Display and Information Systems (ECDIS). These technologies are linked in many ways, as indicated in Table 3-1.

Satellite-based navigation is changing the way navigational positioning is both provided and used.

SatNav is also an enabling technology, as far as ECDIS and HDD are concerned. Without the accurate, uniform, reliable positions provided to navigators by SatNav, ECDIS systems would have to handle navigation inputs from a wide variety of navigation systems, of varying quality and coverage. The result would be fewer ECDIS capabilities, more complex design, and more expensive equipment - resulting in less acceptance by mariners, by infrastructure suppliers, and by regulators.

Horizontal and vertical motions of HDD vehicles must be accurately sensed, as is provided by SatNav (not shown in Table 3-1).

Much of the existing data describing hazards and safe passages were never intended to support the features provided by ECDIS systems. HDD data will, in time, better fulfill that role.

A new mode of marine navigation, real-time under-keel clearance (UKC) navigation, is being proposed for critical passages. UKC navigation may well be feasible in the future, by extending the limits of SatNav, ECDIS, HDD and other technologies.

Table 3-1: Links between three main technology trends (Satnav, ECDIS and HDD) and between user and supply sides

Technology trend	User demand		Infrastructure supply
ECDIS (1st Generation)	Integrates bridge information • Reduced decision delay • Selective data display • Hazard alarms • Reduced workload	→ **demand for**	ENC = digital products compatible with ECDIS
	↑ **enables**		↑ **enables**
SatNav	Accurate, uniform, reliable positioning		• Reduced nav aid costs • Reduced accident response costs
	enables ↓		**enables** ↓
ECDIS (later Generation)	3D ECDIS permitting UKC navigation in critical passages	→ **demand for**	Improved ENCs (Future) UKC data product
			↑ **enables**
HDD			• 100% coverage • Realistic seabed depiction

3.2 Navigation

3.2.1 Horizontal Position

The horizontal component of own ship positions are provided by navigation systems. For several decades this has almost universally come to mean **radio**-navigation systems. We are currently in a further refinement, during which this is coming to mean **satellite**-based radio-navigation systems.

Satellite navigation, and particularly **differential** satellite navigation, are presently revolutionizing all modes of navigation (marine, air, land). On the supply side, this new technology is enabling new approaches to be taken to the other navigation infrastructures. It is widely expected that traditional own-ship positioning infrastructures will be replaced by satellite methods. On the demand side, the increased positioning precision available to all navigators is resulting in changes in navigation practice (not always positive), and increasing pressure to enhance the other navigation infrastructures.

Requirements

There are two kinds of requirements for horizontal positioning:

- Horizontal positioning must meet the minimum acceptable requirements to ensure safety.

- Horizontal positioning should meet the requirements to maximize economic benefits.

An interesting series of documents in tracking how these requirements have been met in the past, and are expected to be met in the future, is the sequence of eight biennial United States Federal Radionavigation Plans (USFRP) which have been issued every two years since 1980. These define and discuss the requirements for four regimes of marine horizontal positioning: inland waterway, harbour/harbour approach, coastal, and ocean navigation [DoD/DoT, 1994]. The USFRP approach is to define the minimum requirements to ensure navigational safety, and as well to identify what improved performance is required to provide economic benefits and efficiencies.

According to Shirer [1996] the USFRP is intended to be a biennial snapshot of "how U.S. taxpayers are going to have their tax dollars spent on radionavigation systems". The process of establishing these minimum requirements is a somewhat subjective one. According to the USFRP, it is

> *"based on a combination of requirements studies, user inputs, and estimates ... [and are] ... the product of current technology and operating practices".*

According to Shirer this process is driven in part by politics, rapid technological innovation and change, market forces, and budget realities, as well as input from individuals, user associations, radionavigation-related publications, all levels of government agencies, academic institutions, equipment manufacturers, service providers, and non-navigation users of radionavigation.

The USFRP is prepared jointly by the Department of Defence and Department of Transportation. One of its themes is to define what impact the introduction of satellite-based positioning, provided by the GPS will have on the need for, and therefore future of, older radionavigation systems. Another of its themes is to define the balance between the dual uses of GPS: for national security and military use on one hand, and to provide socio-economic benefits through improved safety and efficiency of all civil transportation modes and other applications on the other hand.

Radionavigation systems have a global reach, and development of the USFRP takes into account activities of international organizations such as the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO) and the International Association of Lighthouse Authorities (IALA). Currently, the European Community is working to develop a European Radionavigation Plan (ERNP) using the USFRP as a model.

The USFRP identifies several trends which will affect on marine horizontal positioning requirements in the future:

- Increased risk from collision, grounding and ramming, due to ever increasing volume of shipping, and of hazardous cargoes in particular.
- Increased size and decreased maneuverability of marine vessels.
- Greater need for traffic management / navigational surveillance integration.
- Greater congestion in inland waterways and harbour/harbour approaches, require more effective use of shore facilities.
- Demands for navigation services to support all weather operations in inland waterways and harbour/harbour approaches.
- Demands for navigation services to support more intensive fishing activities, and resource exploration and exploitation further offshore.
- The requirement to improve transportation efficiency to conserve energy.

However, these factors have not yet had an impact on the USFRP itself. A comparison of the 1982 and 1994 versions of the USFRP indicates no discernible trend in marine horizontal positioning requirements for either safety on economic benefits. The 1994 version states that the minimum requirements for safe navigation are:

Table 3-2: 1994 USFRP maritime user requirements for safety of navigation

Phase	Predictable Accuracy (2drms)	Fix Interval
Ocean	3.7 - 7.4 km minimum 1.8 - 3.7 km desired	15 minutes or less 2 hours maximum
Coastal	460 m for ships 460 - 3700 m small & recreational vessels	2 minutes for ships 5 minutes for small vessels
Harbour/Harbour Approaches	Harbor/Harbor Approaches 8-20 m for large ships, tows 8-20 m for smaller ships	1-5 m resource exploration 6-10 sec for large ships, tows varies for smaller vessels 1 sec for resource exploration

The 1982 version has identical numbers to those in Table 3-2, except that the 8-20 m value for smaller ships in the Harbour/Harbour approaches phase was flagged as "varies" in 1982.

Discussion of perhaps the most critical phase, inland waterways, is duplicated almost word for word between the 1982 and 1994 versions of the USFRP, including the sentences:

> *"Requirements based on the consideration of practically achievable performance and expected benefits have not been defined. However, Research, Engineering and Development (R,E&D) in harbour/harbour approaches navigation is expected to produce results which will have some application to inland waterway navigation."*

> *"Minimum performance criteria ... have not been determined. The R,E&D plans in Section 4 discuss the current and future efforts in the area of inland waterway navigation."*

Operations

Large vessel bridge operations have been and continue to be affected by technological changes. Own vessel horizontal positioning is but one of the activities on the bridge of a vessel. It is somewhat artificial to consider this activity in isolation. This is done so here in order to illustrate the changes which are occurring due to, or at least enabled by, satellite-based positioning.

Evolution

For comparison with the time period over which the infrastructure trends have been embodied in the USFRP, let us consider the changes in large vessel bridge operations, as they pertain to horizontal positioning activities, which have occurred over the past fourteen years.

In 1982, GPS as a practical navigation tool was still years away, real-time DGPS had not yet been thought of, and rudimentary electronic charts were just starting to be used by pilots in Baltimore harbour. The technology available for horizontal navigation included a wide variety of ground-based radionavigation systems (in particular Loran-C, Omega, and marine radiobeacons), the U.S. Navy's Transit satellite navigation system, and radar. Dead reckoning navigation used a magnetic or gyro-compass and engine revolutions or speed logs, and some knowledge of the ocean currents. Radionavigation receivers most often did not come equipped with "coordinate converters" - built-in microprocessors which converted a number of radio range or range difference lines of position into a latitude/longitude position fix.

In 1982, the process of marine positioning was to read two line-of-position values from the radionavigation receiver, and to plot the equivalent position on a paper chart which had been latticed with hyperbolic LOPs for that purpose. There was always the chance of a cycle slip (or lane skip), or, in the case of Loran-C, of locking onto the fourth cycle inside the pulse envelope instead of the correct third cycle - resulting in a 3 km error. More than a few hundred km from shore, the only navigation tools were dead reckoning, astro fixes (if the weather permitted), and Transit satnav (if the vessel owner could afford it). Transit provided about a dozen good position fixes per day, and judging which satellite pass would yield a good fix was something of an art. Accurate dead reckoning during the fifteen minutes it took to collect the satellite data for a Transit fix was crucial. An error of one knot in the estimate of ship's speed during the Transit satellite pass would result in a position error of 350 m. Near to shore, or in congested traffic, the navigator had to keep a constant watch on the radar, to detect potential collisions in time to take corrective action. During ideal conditions (good weather, all equipment working) managing all this information was a demanding job. Under adverse conditions, when navigation equipment malfunctioned, or even worse was suspected of malfunctioning, when the weather was bad, traffic heavy, and a tricky passage coming up, the prudent navigator had no choice but to anchor offshore, or, in deeper water keep a head into the wind, until things improved.

In 1996, activities on the bridge of many vessels have changed considerably. From the navigator's perspective, the evolution to more accurate, more reliable, and more consistent positioning, using satellite-based navigation, has permitted a new approach to vessel route planning and monitoring.

Using a GPS receiver alone in the ocean phase, the vessel's position is updated once a second, with an accuracy of 100 m (95 percent confidence level). After coming within range of a marine radiobeacon which transmits DGPS corrections, this accuracy improves to better than 10 m (approaching 1 m with high quality receivers).

It is impossible to make effective use of these frequent accurate positions if they are plotted manually on a paper chart. However, when the GPS fixes are fed into an electronic chart, then the vessel position is updated once per second on an image of the nautical chart. The frequency of these fixes provides one kind of malfunction detection - if something goes wrong, the continually updated ship's track on the electronic chart should indicate a problem much more promptly than the infrequent manual paper chart fix plots would have in 1982. The navigator is freed from the time-consuming mechanics of position fixing, and can devote more attention to looking out for hazards, keeping the vessel more closely on its planned route, and dealing with adverse conditions as they arise.

Positive Impact on Safety

Satellite-based positioning can provide three safety-related advantages over existing radionavigation systems: improved consistency, improved accuracy (in DGPS mode), and improved reliability (provided the appropriate procedures are followed by mariners). However, none of these advantages is automatically guaranteed.

The consistency of satellite-based positioning is due to its global reach - all position fixes are available within the same, single, global coordinate system. Vessel positions are consistent with positions obtained by all other users of satellite-based positioning, such as shore facilities. However, to realize this consistency, all existing nautical charts would have to be converted to this same coordinate system. Re-publishing paper charts using a different coordinate system is not a simple task. Chart boundaries will change by the amount of the transformation. The required re-compilation would be an enormous expense.

The accuracy of GPS in non-differential mode is not necessarily an improvement, but a degradation of the accuracy available from some existing radionavigation systems. This is primarily due to the imposition of Selective Availability, which is now scheduled to be removed within a decade.

The accuracy of DGPS is normally much better than that of existing radionavigation systems. However, this is dependent upon reliable reception of the DGPS correction message. It is essential that the navigator be constantly aware of the status of the DGPS correction, in order to have any confidence in DGPS accuracy. Many mariners do not appreciate the need for this awareness.

The reliability of GPS and DGPS is dependent on both infrastructural and operational reliability being high. The satellite signals must be reliable both in content (not contain any unexpected errors) and in persistence (satellite transmission faults). The DGPS correction stations must operate reliably, with very few content or signal persistence failures. The DGPS receivers on board the navigating vessel must operate reliably, particularly without appreciable latency (delay) in the application of the DGPS corrections: at present levels of Selective Availability, latency should be kept under 10 seconds. Once Selective Availability is removed, this will likely be relaxed to a few 10's of seconds. At present, vigilant monitoring of the system integrity by the user, the mariner, is the main tool to maintain reliability. This requires an understanding and experience that many mariners do not have, at least as yet.

The wide area augmentation systems now being designed (driven mainly by reliability requirements for aviation use), will incorporate integrity monitoring and user notification of the integrity of some components of the system (the satellite signals and perhaps DGPS monitor correction signals). This will reduce the burden on the navigator, but will not eliminate the need for vigilance, since reliability of the users own receiver(s) generally can only be monitored on the vessel itself.

Negative Impact on Safety

Introduction of GPS and DGPS has led to a new and unexpected source of position-related navigational risk, based on over-reliance upon, and unwarranted confidence in, GPS and DGPS.

In 1982 the prudent navigator knew no one system could be trusted entirely - and as a result continually checked one system against another. Did the dead reckoning match the Transit fix within reason? Did the radar shoreline match where Loran-C was placing the vessel? The navigator was intimately involved with the data used for positioning, and was usually well aware of the quirks and problems which might occur.

In 1996, as a result of deliberate infrastructure planning decisions, GPS has, or soon will, replace most other radionavigation systems. The automated DGPS / ECDIS system of 1996 often inspires inappropriate overconfidence of three different kinds.

Infrastructure Overconfidence

The first kind of overconfidence is in the navigation systems themselves. The case of the ***Royal Majesty*** has become a famous example [U.S. National Transportation Safety Board, 1995; Kerry, 1995]. Briefly, the antenna cable to the GPS receiver on this vessel was broken, so that no satellite signals were tracked. The GPS receiver accommodated this by dead reckoning, and indicating on its screen that it was doing so. No one on board noticed. Therefore dead reckoned fixes from the GPS receiver controlled the autopilot for several hours, resulting in the vessel being 17 miles off course and running aground off Nantucket 10 June 1995. No attempt was made to cross-check GPS with the vessel's Loran-C receiver, three radars, or echo sounder. GPS accuracy was confused with GPS reliability. Navigators still have reason to follow the well-recognized concept that "the prudent navigator never relies on only one system."

Operations Overconfidence

The second kind of overconfidence is in what the new navigation equipment makes possible. The case of the ***Queen Elizabeth II*** is another famous example of this. The vessel had the latest in navigation equipment. The navigator took the vessel through a restricted passage which had been as well charted as the navigator expected. The resulting grounding was due in part to the hydraulic depression of the vessel running at high speed through shallow water, and in part due to a shoal which had not been surveyed in preparing the nautical chart. GPS / ECDIS capabilities were confused with hydrographic charting limitations and shiphandling limitations.

Decision No. 41 of the XIVth International Hydrographic Conference in 1992 at Monaco reads

> *It is resolved that a study be undertaken of the impact of GPS and DGPS on the safety of navigation, with a view to recommending actions to be taken where accuracy of the location of a hazard is deemed to be below the accuracy of navigation by the cited systems.*

This action was prompted by two concerns:

- Many charted hazards were located using positioning methods which are less accurate than the accuracy available from GPS, or even more so from DGPS.

- GPS positions are most naturally reported to the user in the World Geodetic System 1984 (WGS-84) coordinate system. This reference system is consistent throughout the world, having been established by satellite-based positioning techniques. Most existing charts are based on national or regional coordinate systems, many of which were established during the last century using earlier methods. The disagreement between WGS-84 and other recently-established coordinate systems is a few metres. However, the disagreement between these modern global coordinate systems and the earlier regional and national systems can exceed many hundreds of metres.

Table 3-3: Offset between the WGS-84 coordinates for a point in Fremantle, Australia, and the coordinates for the same point, as expressed in various geodetic datums for the Asian region

Country	**Datum Name**	**Difference from WGS-84 (m)**
Singapore	South Asia	31
Seychelles	Mahe 1971	104
Australia	Australian Geodetic 1984	196
Philippines	Mindanao	212
Vanuatu	Santo DOS	218
Philippines	Luzon	223
Ascension Island	Ascension Island 1958	266
Pitcairn Island	Pitcairn Astro 1967	284
Hong Kong	Hong Kong 1963	309
Indonesia	Djakarta, Batavia	315
Easter Island	Easter Island	322
Tristan de Cunha	Tristan Astro 1968	388
Guam	Guam Island 1963	32
Sri Lanka	Kandawala	398
Indonesia	G. Segara Borneo	401
Malaysia	Kertau 48	435
Fuji	Viti Levu 16	508
India	Southeast Asia	611
Thailand/Vietnam	IND-A	709
Japan	Tokyo mean value	771
Taiwan	Hu Tzu Shan	832

The values in Table 3-3 were obtained by simply changing the datum selection within a handheld GPS receiver, and are based on a simple transformation which does not take into account distortions or inconsistencies within a datum. A similar exercise for locations elsewhere in the Asia Pacific region would yield quite different results. Some of these datums may not be (or no longer be) used for nautical charts.

Labour Overconfidence

The third kind of overconfidence concerns the number of people required on the bridge. The "drudgery" of marine horizontal positioning may now be handled by modern tools like satellite-based positioning and ECDIS. The labour involved in keeping charts up-to-date may be replaced by automatic electronic updates. This is expected to lead to sharply reduced personnel costs for the bridge team. However, adverse conditions are not a thing of the past. Equipment breaks down. Emergencies occur. The one-person bridge is not a concept which enhances marine safety.

Enabling Role of Satellite-Based Positioning

GPS and DGPS technologies have made possible technological advances in own-ship vertical positioning, and the positioning of hazards and safe passages. The ECDIS systems presently revolutionizing marine navigation information management would not be possible without GPS and DGPS. The feasibility of three-dimensional navigation based on UKC is also heavily dependent upon satellite navigation and satellite communications capabilities. These topics are pursued in later sections.

3.2.2 Vertical Position

The **vertical** component of own ship's position is extremely critical. Keeping the vessel keel well clear of seabed obstructions is one of the main objectives of safe navigation. In order to do this, the location of the vessel keel must be known. Two kinds of information are required:

- Where is the water level surface at the vessel location (and ahead of that location)?

- How does the vessel sit in the water, and how does this change?

Water level changes are very complex, and will vary both spatially and temporally throughout an area. All water level changes are periodic in some sense - the water level may be rising or falling at any given location and time. However the periods and amplitudes associated with these water level changes vary enormously. Let's make a catalogue:

Tidal changes normally have a main period of 12 hours, although longer and shorter (shallow water) terms may also be involved. The tidal amplitude also varies, from over 10 metres (for example in the Bay of Fundy), dwindling to nothing as we proceed up a tidal estuary or river.

River level changes can be as large (or larger) than tidal variations. The longest period changes are from flooding conditions to dry season conditions, which would have an annual (or perhaps multi-year) component. Shorter periods due to the operation of hydroelectric dams in the navigable river itself, or its tributaries, can raise or lower water levels by several metres as well. These variations would have periods related to electrical power demand - peaks at meal hours, and early evening, weekday / weekend differences, seasonal differences where air conditioners or home heating was needed only seasonally, etc. River levels will also vary as a result of recent precipitation, which may have highly variable periods.

Navigable lakes will have levels which may also change due to precipitation, and hydroelectric outflow. Lakes and bays may also have seishe activity, due to weather effects, which can have periods of minutes to hours, depending on the size of the enclosed basin.

Vessel heave is at the other end of the spectrum. The swell created by distant storms leads to vessel heave, which will have periods typically of five to ten seconds. Heave amplitudes can be several metres. However, when combined with the vessel speed, into or with the swell direction, the effective heave period can be shifted to as short as a few seconds, or as long as several tens of seconds. Heave is not the only vertical motion caused by wind and weather. Storm surges, and wind-driven piling-up of water along shorelines are other examples.

Variations in vessel draft come from four main causes:

- Vessel speed-related vertical changes (Squat & Lift).

- Vessel attitude-related vertical changes. The depth and location of the keel changes as the vessel rolls or pitches. The location of the keel relative to the water level will also change.

- Vessel manoeuvring-related vertical changes. Vertical displacements change as a vessel executes a turn. Maneuvering may induce a roll-type attitude change.

- Vessel-loading-related vertical changes. Draft changes as fuel is expended, and with other load changes, including movement of cargo or equipment on board (accentuated for smaller vessels).

- Vessel-seabed hydrodynamic interactions (as the vessel enters shallow water, or a narrow channel).

All of these changes may vary in time, as the vessel proceeds on its journey.

Existing Infrastructures

Existing infrastructures for vertical vessel position take a very conservative approach. The water levels used are almost always near to the worst possible case (the lowest they are likely to fall). Vessel draft is also often taken to be the fully loaded draft, although exceptions to this approach are becoming more common.

Water Levels

Water levels are routinely monitored at a small number of water level monitoring stations in each maritime nation. These water level monitoring networks perform several functions:

- Determine conservative "near worst case" low water levels for use as reference or datum levels.

- Determine water levels with respect to these datum levels during bathymetric surveying and dredging operations.

- Collect sufficiently long time series from which predictive models of water level changes (with respect to these datum levels) can be derived (most commonly in the form of Tide Tables).

- Use these predictive models to prepare and distribute predicted water levels (above datum) to navigators.

- Alternatively, or in addition, distribute real-time water level information directly from monitoring network stations to navigators (possibly using satellite communications technologies).

There are three deficiencies in the information available to marine navigators concerning the water levels to be encountered along the navigator's planned route:

- Water level variations at monitoring stations do not always represent water level variations elsewhere (indeterminate spatial variations).

- Predicted water levels generally represent only tidal variations, not the many (unpredictable) water level variations found in both tidal and navigable inland waters.

- This vertical positioning infrastructure is based on conservative "near worst case" assumptions, which do not address economic concerns of the shipping industry to "use" all the water available for safe navigation.

Vessel Draft

The main "infrastructure" which has been used to provide the second kind of vertical positioning information, vessel draft, has been the navigator's experience and knowledge of the ship - in other words operational resources rather than external infrastructures. This will vary widely from navigator to navigator.

On the other hand, this information is important to safety of navigation only when the vessel under-keel clearance is critical. Navigators who are satisfied with the traditional "near worst case" water level reporting infrastructure will generally not be taking their vessel into waters where under-keel clearance is a concern.

Operational Demands

For a number of critical passages, the lack of more precise information about both water level variations and vessel draft has economic consequences. It has been estimated that for each decimetre of increased vessel loading (increased vessel draft) a trans-Atlantic container vessel will earn an additional $10 000 per voyage (with corresponding increases in Port revenues). Presumably the economies would be even greater within the APEC region, with the greater distances involved.

There is a growing demand from the shipping industry for improved infrastructures to permit three-dimensional navigation based on UKC. This demand is based on economic considerations, but certainly has safety consequences.

The Port of Perth, Australia has implemented a relatively simple UKC facility which permits oil tankers to safely transit the restricted port approaches with an additional 5 percent load (one "free" tanker load in 20).

The infrastructure required to fully implement an UKC strategy must take into account changes both in the vessel's vertical position and changes in the water levels. Both satellite navigation (in its most precise mode) and satellite communications will play major roles in such an infrastructure.

UKC navigation is still an un-met demand. There are many opportunities for technological innovation which would contribute to meeting this demand. Many technological and institutional questions remain.

Existing UKC infrastructures

For shipping through deep water routes, and for vessels drawing so little water as to avoid any risks of grounding, there is no economic benefit to moving away from the conservative vertical positioning strategy of "near worst case" water levels, and conservatively estimated vessel draft.

However, when the under-keel clearance is an issue, as it is in several ports in APEC member economies, then alternative infrastructures may be considered. Let us consider three examples:

Fremantle Port Authority & British Petroleum

British Petroleum tankers approaching Fremantle must pass over two areas of restricted keel clearance. One is a coral reef, the other a sandwave field. Tidal variations in Fremantle are matched by variations due to swell and storm surges coming off the Indian Ocean. The Fremantle Port Authority has installed water level gauges and wave rider buoys at locations along the shore, on an offshore island, and near the areas with restricted keel clearances. These devices continually radio their observations in to the Port Authority offices, where software modelling is used to continually update the estimate of what the safe keel clearances will be many hours into the future. The final decision on what the safe keel clearances are, and will be, remain the judgement of the harbourmaster. This infrastructure has been funded by British Petroleum, but is available for all shipping to use. While a vessel is still some distance from the harbour approaches, the Port Authority is contacted, the vessel draft is given, and the next time window providing safe keel clearance for that vessel is established. On rare occasions, conditions are such that the vessel may not approach the harbour for a day or so. However, the result to date has been that British Petroleum can load 5 percent more petroleum on each vessel. No reduction in safety, or groundings, have occurred since this system came into operation.

Port Phillip Bay

The narrow passage known as The Rip, into Port Phillip Bay, the harbour for the Port of Melbourne, has a submerged rock ledge which restricts keel clearances of vessels entering and leaving port. The Port of Melbourne has installed a network of water level gauges around the Bay, and at The Rip, tied to central modelling computer which measures and predicts what the water level will be at The Rip up to two days in the future. When a vessel is still a few days from port, radio communication is established, and the vessel is given a time window during which safe keel clearance is predicted. The vessel alters speed to time its arrival at The Rip within that time window. As conditions change, and the water level predictions change, the vessel is kept informed.

St Lawrence River

Between Quebec City and the Port of Montreal, there are locations in the shipping channel with restricted keel clearances. Since 1992, a Coastal Ocean Water-Level Information System (COWLIS), or SINECO in French, has been in operation along this river. This system consists of over a dozen water level gauges, communicating with a central computer which uses other information sources (such as rainfall, hydroelectric dam operating levels, etc.), and modelling software, to predict water levels at or between the water level sensors, up to 48 hours in advance. The results from this modelling can be accessed by the Coast Guard (for vessel traffic control uses), by port authorities (to schedule sailings), and by ship owners in European ports trying to optimize their cargoes to be loaded to the maximum possible draft.

Emerging UKC infrastructure

It is now possible to construct an alternative vertical positioning infrastructure, using satellite navigation and complementary technologies, which is capable of measuring the combined effect of both water level variations (at the vessel itself), and vessel vertical motions, at the sub-decimetre level.

This technology is known as Real-Time Kinematic DGPS, or RTK/DGPS. It is also sometimes known as On-The-Fly carrier phase ambiguity resolution, or OTF/DGPS. In order to explain the significance of OTF, it is necessary to discuss some details of the GPS signal structure.

The GPS signal has two main components - the code, which is normally used to measure ranges to the satellite, and the carrier, which was originally intended just to be a vehicle for the code. However, it was recognized early in the development of GPS that the carrier could also be used for range measurements. After all, many radio-positioning systems dating back as far as the 1940s are based on carrier-tracking range (or range difference) observations.

The problem is that a GPS receiver (or any carrier-tracking radionavigation system receiver) can directly measure only the fractional wavelength part of the carrier signal. For example, if the receiver was 345.67 wavelengths away from the transmitter, the receiver could only directly measure the 0.67 fractional part. The 345 full cycles of the carrier must be determined by using external information.

This process, however we do it, is called “resolving the integer wavelength ambiguity”. That really means we are able to count how many full cycles of a carrier exist between our receiver and the transmitter. This is only practical using a kind of differential GPS called “double differencing” which means that at least six satellites should be tracked, and the latest generation of dual-frequency GPS receivers should be used, ones which incorporate a technology called “narrow correlator” code tracking loops, which dramatically lowers the noise level on the code measurements (from a few metres rms for “normal” code tracking loops, to about 10 centimetres rms for the best narrow correlator tracking loops). The dual frequency receivers allow a combined L1 / L2 carrier signal to be formed which has a “beat” frequency, and a “widelaning” wavelength of 86 cm, rather than the L1 wavelenegth of 20 cm. Therefore it should be possible in theory to resolve the carrier phase integer ambiguities, and start doing carrier-based positioning, in a single GPS measurement epoch. In practice it takes a few 10s of seconds under the most favorable conditions.

The main advantage of OTF/DGPS is that it provides real-time three-dimensional navigation accuracies of a few centimetres. This contrasts with slightly better than a metre, under ideal conditions, when using code-DGPS methods. This accuracy is not required for marine horizontal positioning. But it provides very useful information for vertical changes in water levels, vessel draft, or both.

OTF technology was proposed during the late 1980s, the first prototype system was developed for the U.S. Army Corps of Engineers in 1993, and the first commercial OTF product was announced in 1994 [Deloach et al., 1994a, 1994b, 1995a, 1995b]. Since then several competing products have been announced. Some differential signal infrastructures have, or plan to, provide DGPS correction signals which support OTF. A joint venture between the U.S. Army Corps of Engineers and the U.S. Coast Guard has provided for some of the USCG

DGPS Beacon reference stations to also provide an OTF correction signal for Corps work (this is done on a separate much faster radio link than the 100 or 200 bps Beacon transmissions). One of the FM subcarrier DGPS signal suppliers offers to provide an OTF correction signal capable of providing 3D accuracies better than 5 cm.

OTF has been suggested as a new infrastructure for UKC navigation. However, this technology is still in its infancy, and many accuracy, reliability, cost, and areal coverage questions remain to be answered. The Canadian Coast Guard (CCG) has started to replace tide staffs with OTF techniques for its own work, in surveying the channel between Quebec City and Montreal [Marceau et al., 1996]. Similar developments have been investigated for surveys of the Mirimachi River [Phelan, 1996]. CCG is also considering how OTF techniques may be used by commercial shipping for UKC navigation over this same waterway. A study of ship's dynamic response to changes in channel geometry and vessel speed (vessel squat) was made on board several deep-draft ships transitting this waterway, based on OTF techniques [Morse et al., 1996]. The conclusion of this squat study was that the acceptable minimum UKC clearance in the St. Lawrence River is 60 cm to account for unpredictable water level changes, and/or bathymetric anomalies, and another 30 cm to account for vessel squat changes.

The maximum distance between a vessel and an OTF/DGPS shore monitor station, in order to ensure reliable ambiguity resolution, is probably no more than a few 10's of kilometres. This may improve when L4, a second "civil" frequency is added to the GPS satellite signal with the Block IIF satellites to be launched starting earlier in the next century. On the other hand, the sunspot maximum expected at about the same time, may increase ionospheric refraction levels sufficiently to reduce the maximum effective range of OTF (dual frequency widelaning for OTF, and dual-frequency ionospheric refraction correction cannot BOTH be done with the present GPS signal).

OTF/DGPS can determine where a vessel's keel is with respect to the vertical reference surface implied by the heights adopted for the OTF reference shore monitor station(s). However, the seabed must also be known with respect to the same vertical reference surface, in order to determine the under keel clearance of the vessel at the instant of the OTF fix. This requires a rethinking of the vertical reference surfaces used in nautical charting [Wells et al., 1996]. This is currently under active study on several fronts:

- At the International Federation of Surveyors (FIG) Congress in Melbourne, Australia in February 1994, FIG Commission IV (Hydrography) established the following Working Group: WG420a Vertical Chart Datum determination using GPS. This group will study the issues involved in using GPS for water level sensing.

- The International Hydrographic Organization (IHO) circulated a request for information from member states on activities related to vertical-reference surfaces in hydrography, and at a meeting in April 1996 recommended that all nations standardize on one vertical reference surface, based on tidal variations, (Lowest Astronomical Tide, or LAT), and agree to use the WGS-84 as an ellipsoidal vertical reference surface.

- National Oceanic and Atmospheric Association (NOAA) and Defence Mapping Agency (DMA) are jointly considering the adoption of a reference ellipsoid as a vertical-reference surface for bathymetry. The motivation in this case is a global one - the variety of Chart Datums presently used by various countries and agencies around the world presents difficulties in ensuring that the bathymetry obtained from each of them is consistent.

- At its meeting on Bali in 1992, the IAG GALOS (Geodetic Aspects of the Law of the Sea) Committee passed a resolution urging the adoption of a global vertical datum to facilitate a more consistent international maritime boundary delimitation. This resolution was then addressed in Vanicek [1994].

- The IAG Special Study Group 3.124 on *Global Vertical Datum* was established in 1987 with Erwin Groten of the Technische Hochschule in Darmstadt, Germany as Chair. During its eight years of existence, this Special Study Group has accumulated a wealth of information and ideas on this topic.

But knowing the real-time under-keel clearance is not as essential as knowing what it will be sometime in the near future (say one hour ahead of the vessel's current position), so that action can be taken to avoid a possible grounding. Therefore OTF technology must be only one part of an infrastructure which includes predictive modelling of water levels both at the vessel location and further along the channel.

UKC navigation is not related to enhanced safety of navigation. It is driven purely by the requirement for enhanced productivity in shipping, making use of all the water available for safe navigation in channels with restricted clearances.

On the other hand, UKC navigation uses technologies which involve a number of uncertainties:

- Is the seabed surveyed completely, and depicted accurately on board the vessel transitting the passage?
- Is the water level monitoring technology (OTF or some alternative) operating correctly?
- Are the bathymetry and water level information referred to the same vertical reference surface?
- Is the UKC prediction software correctly predicting future keel clearances?
- Is the vessel's squat behaviour correctly understood and predictable?

If any one of these questions cannot be answered "yes" with certainty, then UKC navigation may considerably increase the risks involved in marine transportation.

Finally, UKC infrastructures can be expensive. A strategy for recovering the costs from users and clients should be adopted.

3.2.3 Hazard and Safe Passage Locations

Hazards can be categorized as stationary features, whose locations are known; as stationary features whose existence is suspected but which have not yet been accurately charted; as stationary features whose existence is unsuspected and hidden beneath the sea surface; and as objects which are not stationary (mainly other ships).

The purpose of nautical charting is NOT to locate all possible stationary hazards to navigation, but to establish the limits of safe navigation channels, passages, and lanes. It is commonly stated that safe navigation is about knowing where there are NO hazards, not about knowing where all the hazards are. This implies that vessels which wander out of these safe areas are in double jeopardy - they have wandered into an area which has not been certified as safe for navigation, and because of that, the identification and location of all possible hazards is less likely to have been done as thoroughly as within the areas designated as safe.

Requirements

The infrastructure required for identifying and delimiting areas designated as safe for navigation, for locating and identifying stationary hazards, particularly within such designated safe areas, and providing this information to the navigator includes (not an exhaustive list):

- A bathymetric surveying capability to determine features of the seabed.
- Where necessary, a dredging program to maintain safe channel depths.
- A aids-to-navigation system (buoys, fixed aids) to delimit areas and passages designated as safe.
- A capability of encapsulating bathymetric (and other) information concerning safe navigation areas, in a presentation which can be used by mariners (the nautical chart).
- A capability to maintain this information up-to-date (Notices to Shipping and Notices to Mariners).
- A capability of applying these corrections to the nautical chart itself.

Existing Infrastructure

Bathymetric surveys are performed (or contracted) by public agencies in maritime nations, as a service to mariners. Traditionally, such surveys are based on three strategies: representative-sampling, anomaly detection, and shoal-biasing. As little as 5 percent of the seabed is sampled by echo-sounder profiles, and the nature of the seabed between these profiles is inferred from knowledge of the seabed geology and roughness. In hazardous waters, an attempt is made to obtain closer to 100 percent sampling, but traditional positioning and depth-determination technologies have made that difficult to guarantee.

Complementary technologies, such as side-scan sonar imaging (which identifies anomalies in seabed shape or composition, but does not determine depths) or magnetic surveys (designed to detect ferrous metal objects on the seabed, such as wrecks and anchors) are sometimes used to detect possible anomalies in the areas between sounding lines. Any suspected depth anomaly detected along the sounding line itself, or by one of these complementary sensors, or reported by any mariner throughout history, triggers a more detailed "shoal examination" survey, designed to determine the shoalest (shallowest) depth of the object causing the anomaly. In critical (narrow) passages, shoal detection is sometimes done by a mechanical sweep technology, in which a bar or a taut wire is suspended down to the depth to be guaranteed for safe passage, and "swept" along the passage. If the bar or wire is not snagged by an obstruction, then the passage is declared clear of obstructions to the swept depth. Any snags trigger another shoal examination.

Finally, the selection of depth data points to be presented to end users is shoal-biased (the least depth is selected) at each stage in processing the data. The result is a conservative "near worst case" chart of the detected features, but always with some risk that anomalies may remain undetected. Because of this risk, often "doubtful shoals" which have been reported by even one mariner, but have never been successfully detected by detailed bathymetric shoal examinations, remain on the nautical chart.

Non-stationary objects which are potential hazards (other ships) are usually detected and located using own ship's radar, combined with ship's heading information. Radar also gives information about the location of some stationary features, such as islands, shorelines, and some port features such as bridges and wharves.

In some congested jurisdictions, (ports and heavily used channels) vessel traffic management infrastructures are in place, based on shore-based radar tracking of marine traffic. These systems are analogous to air traffic control radars used in aviation. Such systems also require a communications infrastructure, in order to communicate traffic management instructions to vessels within that area.

Emerging infrastructures

Navigational hazards and safe passages have traditionally been captured and supplied to the navigator in the form of nautical charts. As a result of the great improvement in the accuracy, reliability and consistency of own vessel positioning capabilities which satellite navigation technology has recently made available to the navigator, there is now a large discrepancy between the accuracy of the navigator's position, and the accuracy of the positions and depths shown on many existing nautical charts.

For many existing charts, the positional accuracy available at the time the seabed was surveyed is much worse than that now available with satellite navigation (particularly DGPS). Under the sparse sampling strategy, many hazards remain undetected. Until about 1990, available technologies permitted little else.

New satellite-based horizontal and vertical positioning technologies, combined with new HDD bathymetric surveying technologies, make it possible to provide 100 percent seabed sampling (almost equivalent to continuous shoal examinations, under the traditional strategies), and to replace the shoal-biasing strategy with a realistic representation of the seabed. These new technologies include airborne laser bathymetry (LIDAR) and multibeam sonar systems. The new HDD technologies are complex and expensive, and require new skills to be used effectively and reliably. Even once HDD systems are widely deployed, it will be many decades before the legacy of traditional bathymetric surveys has been replaced by HDD surveys. Replacing the shoal-biasing strategy just because HDD systems make it possible is not necessarily in the best interests of enhancing safe navigation.

The APEC region is undergoing an explosion in the adoption of these new HDD systems for mapping seabed hazards and safe passages. The world's expertise (and operational capability) in LIDAR systems resides almost exclusively within APEC member economies (Canada, United States, Australia). Multibeam sonar systems are currently being acquired by several APEC member economies, representing a very substantial investment. For 1996 alone, announcements have been made for the purchase of nine systems for Indonesia; eight systems for Australia; two systems for Hong Kong; three additional systems for Canada; and one system for South Korea. Malaysia, the Philippines and New Zealand are expected to announce further purchases. Japan has a substantial population of multibeam systems. Perhaps the densest population of multibeam systems in the world is within the United States.

One of the lessons learned over the past decade has been that while the multibeam sonar sensor (and the airborne LIDAR sensor) are the core technologies within a HDD system, several ancillary sensing technologies are equally essential in order to provide an effective seabed mapping tool. Satellite navigation (and to a lesser extent satellite communication) technologies are among these ancillary technologies. Great advances have recently been made in providing multibeam survey vessels (and LIDAR aircraft) with sub-decimetre real-time three-dimensional position and attitude sensors, based to a large extent upon DGPS technology. However, some limitations remain to be addressed, particularly in areal coverage and vertical positioning reliability and consistency.

Two of the factors affecting consistency between users and suppliers, within APEC nations, and between APEC economies, are the conventions used to represent horizontal and vertical positions.

The "zeroes" used for latitudes and longitudes (and the size and shape assumed for the earth) are adopted by convention. Such conventions, referred to as a Geodetic Horizontal Datums, vary from country to country, and are usually inconsistent with the convention (datum) built into satellite navigation positions. For the APEC region, with its many island economies (each with its own datum) this problem is particularly severe. Differences of up to 800 metres exist between what different countries mean by "latitude" and "longitude".

Such datum differences are rather esoteric, the impact of which is not usually fully understood or appreciated by marine navigators. However, the implications of determining own ship's position on one datum, and attempting to inappropriately relate that to features on a nautical chart which uses a different datum, can have serious safety ramifications.

The "zero" water depth available for marine navigation is called Chart Datum. The methods used to determine Chart Datum vary between countries, but all share the goal of using Chart Datum to represent "near worst case" navigable water depths. Proposals for new approaches to this vertical reference surface are emerging in many quarters. These proposals are heavily reliant upon satellite navigation (and satellite communications) technologies.

3.3 Communications

3.3.1 Introduction

The main marine communications technology trends can be summarized as follows:

- The Asia Pacific region will be served with satellite communications from year 2000 and onwards. The competition between service providers will result in low cost voice communications anywhere. Transmission of short packets of data, which uses the space segment very efficiently, will be nearly free.

- The cellular technology used in these new satellite systems will result in terminal costs lower than current cellular phones. Data terminals will be even cheaper. These terminals will be used for more than point-to-point two-way communication; such as broadcasting of weather, tidal, maritime warnings, etc.

- The cost of GPS equipment is likely to continue to fall; eventually a GPS receiver will cost no more than an FM radio.

- The use of personal computers, even on small ships, will increase significantly.

- Electronic charts will be used extensively.

- Manufacturing based on just-in-time systems will treat materials in transit as inventory and will need to know the location and status of materials at regular intervals.

We believe that all the above factors will lead to system convergence. All available information will be used selectively to improve the operation and safety of a ship.

New low cost maritime ship management and control systems will be fairly crude; however, over time, more information will be integrated and combined to make life simpler for even small ship operators.

This technology convergence will present major integration challenges. What data is needed? What is the quality of the data provided? How should the integrated data be presented? What flexibility should be given to the user? What are the liability issues? What level of standardization should be imposed to accelerate the developments? How can the efficiency and safety improvements be estimated and measured? How can the Big Brother watching concerns be overcome?

3.3.2 The Current Systems

The communications systems that ocean going ships are required to carry are regulated under the SOLAS Convention and the Global Maritime Distress and Safety System (GMDSS). The GMDSS is being phased in over the period from 1992 to 1999 and applies to all vessels subject to the 1974 SOLAS convention. SOLAS covers all passenger ships that carry more than 12 passengers on international voyages and all cargo ships of 300GT and over engaged in international trade.

The equipment that a ship must carry to comply with GMDSS is determined by the vessel's area of operation:

Area	**Equipment**	**Range**
Area A1	VHF	Within range of shore based VHF (20-30 miles)
Area A2	VHF and MF	100 miles from shore and within range of shore based MF (excluding A1)
Area A3	VHF, MF, and HF or Sat	Within coverage of maritime communications satellites (70(N and 70(S, excluding A1 and A2).
Area A4	VHF, MF and HF	All other areas.

GMDSS may require ships to carry Search and Rescue (SAR) transponders, Emergency Position Indicating Radio Beacons (EPIRBS) and NAVTEX receivers or a combination thereof. GMDSS includes regulations for the carriage of satellite or HF communications.

The regulatory requirements for ships operating within territorial seas and inland waters varies from economy to economy. However, VHF would cover most of the inland water communication requirements.

Shortwave

The first use of wireless communications was in fact for maritime use. Shortwave has been extensively used since Marconi's experiments on SS Electra. Shortwave suffers from sensitivity to ionosphere effects, and this makes reliable data communications difficult. HF usage is nearly free and advanced Digital Signal Processor (DSP) techniques are used to maximize link availability. HF transceivers tend to consume several hundred watts of power and require fairly large antennas. Transceivers are selling for U.S.$ 5 000 -10 000.

VHF

The 156 MHz VHF systems are very popular in coastal waters. These systems have a dedicated emergency channel (Ch 16) and often provide telephone interconnects. The range depends on the height of the antenna; commercial ships can have a range of more than 50 km and use VHF extensively for communications with harbourmasters. VHF data is becoming increasingly popular.

Handheld VHF transceivers now sell for U.S.$ 250, and the prices are stable due to a mature technology. It is possible to access specific terminals using Selective Calling (SC), however there is no privacy.

Cellular UHF

Cellular system cover landmasses and typically up to 25 km from shore. The technology is well established and extensively marketed. Data services are also offered. The manufacturing cost for handsets is less than U.S.$ 200. The 900 MHz GSM (Global System for Mobile Communications) standard has been adopted by many of the countries in the Asia-Pacific region. This standard will allow for international roaming. The GSM authentication and encryption methods are very secure.

Current Satellite Systems

The principal marine satellite communication system in use today is INMARSAT which provides marine communications to approximately 30 000 commercial, private, or government ships around the world from four satellites placed to cover all the major oceans. Approximately 25 percent of the 80 000 large ocean going vessels have installed INMARSAT satellite communications terminals. Only a very small number of vessels under 60 feet have been fitted with satellite communications equipment due to cost and size of equipment. The number of users is growing dramatically and is expected to reach approximately 90 000 by 1997.

INMARSAT currently offers several systems for maritime use:

INMARSAT-A

The INMARSAT-A system was introduced in 1982 and is currently used by around 25 000 vessels. The system offers global telephony, data (up to 9.6 kbit/s), telex and is approved by IMO under the SOLAS convention. The INMARSAT-A system also supports a duplex 64 kbit/s High Speed Data service.

The 1 m tracking dish antenna and the equipment cost of U.S.$ 30 000 has limited the market to large commercial shipping. Typical end user charges are U.S.$ 8/minute, with off peak discounts.

INMARSAT-B

The INMARSAT-B system is the digital replacement of INMARSAT-A introduced in 1992. It is more powerful and bandwidth efficient than its successor, and user charges are typically 40 percent lower. The equipment is slightly smaller and equipment retails for approximately U.S.$ 25 000.

INMARSAT-M

The INMARSAT-M system was introduced in 1992 to provide low cost data and voice. The system uses efficient digital voice compression and supports data and fax at rates up to 2.4 kbit/s. A typical antenna has a diametre of 50 cm and requires only course satellite tracking. The equipment is retailing for approximately U.S.$ 12 000. INMARSAT-M is not approved by IMO under the SOLAS convention.

INMARSAT-C

The INMARSAT-C system offers store and forward data communications at 600 bit/s. It interfaces to telex, X.25, and terrestrial fax delivery systems. The system also offers group calls which are used to distribute weather and maritime warnings. These broadcasts can address ships in specific geographic areas or members of groups.

The system uses an omnidirectional antenna and terminals sells for approximately U.S.$6 000. Nearly 20 000 maritime INMARSAT-C terminals are currently in use. The INMARSAT-C system is approved under the SOLAS convention.

Future INMARSAT Systems

The introduction of the INMARSAT-3 satellites in 1996 allows INMARSAT to introduce a new generation of smaller terminals. The Mini-M system expected to be introduced in 1997 will offer similar services to INMARSAT-M, using smaller and lower cost equipment. Maritime terminals are expected to be offered at around U.S.$ 8 000.

The Spot-C system is the next generation INMARSAT-C system, using small terminals. The terminal prices are estimated to be around U.S.$ 3 000. The services are similar to the standard INMARSAT-C; communications prices may be reduced in response to competition.

The INMARSAT-D system was initially developed as a one way paging system. The receive only terminals may be offered for around U.S.$ 500. The system also supports a return acknowledge channel and a data reporting channel suitable for supporting GPS position reporting. These terminals may retail at U.S.$ 1 000.

Domestic Mobile Satellite Systems

Canada, Australia and the U.S. have L-band satellites in orbit. These satellites provide good coverage of the landmasses and coastal waters. The terminals used are similar to the Mini-M terminals. The Australian satellite (Optus) covers wide coastal waters as far north as New Guinea.

3.3.3 Future Satellite Systems

Little Low Earth Orbit Systems

There are a large number of low earth orbit satellites proposed. Table 3-4 summarizes the main characteristics of some of the proposed systems. The best financed proposals have been developed by Orbcomm and Starsys and these are addressed in more detail.

Table 3-4: Proposed LEO systems

System	Orbit height (km)	Estimated start of service
Orbcomm	7 50	1996
Starsys	1 000	1998
Iris	8 50	1996
E-sat	1 260	1998

Orbcomm

The Orbcomm satellites use a 750 km inclined orbit. Two experimental satellites have been launched and will soon offer an initial service. By 1997 or 1998, a constellation of up to 36 satellites will provide nearly continuos global coverage. The satellites transmit in the 137 MHz band and receive in the 148 MHz band. The satellites will transmit BPSK data at 9 600 bit/s and receive up to six channels at 4 800 bit/s. The Federal Communications Commission (FCC) has limited the terminal transmit duty cycle to 1.5 percent. The terminals will transmit 5 W into an omnidirectional antenna. Terminals are expected to retail at U.S.$ 700.

Starsys

The Starsys system is based on a constellation of up to 24 satellites using a 1 000 km inclined orbit. Service is expected to start in 1998. The satellites transmit in the 400 MHz and receives at 148 MHz. The satellites will transmit BPSK data at 2 400 bit/s and receive up to 12 channels at 600 bit/s using CDMA. The FCC has limited the transmit duty cycle to 0.25 percent. The terminals will transmit around 4 W into an omnidirectional antenna.

Big LEO Systems

There is a lot of momentum in the mobile satellite industry. The total planned investments in new systems are likely to exceed U.S.$ 10 billion over the next five years. It is doubtful if the market is sufficient to support all these new systems.

The new planned systems will offer cellular-like services on a global scale, and many terminals will be dual mode satellite/cellular. All the proposed systems are proprietary designs and limited information is provided in the public domain. The systems are all designed to comply with international radiation safety standards, and this limits the average terminal transmit power to 0.25 - 1 W. All the systems plan to use a GSM type switching structure.

The cost of these new handsets are expected to be in the U.S.$ 1,000-1,500 range.

Iridium

Motorola developed the Iridium concept in the early 90s. Iridium Inc. is developing a 66 satellite system using 750 km polar orbits. Commercial service is likely to start in 1998, but trials are planned for early 1997. In addition to the cellular type voice and data services, paging and fax will also be offered.

The Iridium system uses advanced on-board switching in their satellites. Each satellite supports 48 spotbeams. The end user charge has been quoted as U.S.$ 3/minute, however competition is likely to force this price lower.

The Iridium satellites will transmit and receive at 1620 MHz using a Time Division Duplex technique.

Globalstar

Globalstar was proposed by Qualcomm and will use 48 satellites in inclined 1460 km orbits. The satellites transmit in the 2.5 GHz band and receive in the 1615 MHz band. CDMA is used to allow frequency sharing with Odyssey. Each satellite uses 15 spotbeams. The Globalstar system design uses path diversity to overcome the effects of shadowing by trees and buildings. The system is scheduled for service introduction in 1998.

Intermediate Circular Orbit (ICO) Satellites

Satellites in the ICO orbit move relatively slowly over the horizon, thereby making it likely that the satellite link will be reliable for the duration of the call.

Global ICO Communications

The Global ICO system was developed by INMARSAT, and a new company was set up to maximize business flexibility and investment structure. The system consists of 10 satellites in 10 000 km orbits and will operate in the 2.1/2.2 GHz band. Each satellite will use around 130 spotbeams. The system is based on GSM type TDMA techniques. The system is scheduled for service introduction in the year 2000.

Odyssey

The Odyssey system concept was developed by TRW. It consists of 12 satellites in inclined 10 340 km orbits and will operate in the 1.6/2.5 GHz bands. The systems uses CDMA techniques. Service start is scheduled for 1999. The satellites will support about 63 spotbeams.

Geostationary Earth Orbit (GEO) Satellite Systems

Hughes, the leader in Geostationary satellite technology, has developed satellites that can support more than 200 spotbeams using advanced onboard digital processing techniques. A geostationary satellite positioned over the Asia-Pacific region can serve nearly 2/3 of the world population from a single satellite. Consortia in India (Aces) and the Philippines (Agrani) plan to offer fixed and mobile services in the 1.5/1.6 GHz bands around 1999. The Super GEO technology appears to offer the highest capacity for the lowest cost.

3.3.4 Intermodal Opportunities

The mindsets in the aeronautical and maritime businesses vary significantly. The aeronautical industry's first concern has to be safety. The aeronautical industry also believes in tight management of its assets, and will embrace new technology where significant benefits to the safety and operations of flights can be proven. The aeronautical industry also has stringent requirements and standards that are tightly enforced.

The maritime industry is much more fragmented; some standards do exist, (Veritas certifications) however, the enforcement has proven to be difficult. The maritime shipping industry tends to be more conservative to new technology and is usually satisfied with the current technology.

It is possible in theory to use Aeronautical systems for maritime purposes, e.g., air traffic control would be similar to a tight harbour control. However the airline industry would not allow their systems to be integrated with other systems.

3.4 Surveillance

The development of Automated Identification Systems (AIS) is proceeding in some countries. AIS has particular application to Vessel Traffic Services (VTS) in harbour, harbour approaches, and river operations, as well as other special circumstances. Either as a stand alone system, or in combination with radar surveillance, AIS has the potential to greatly improve the functionality and cost performance of VTS systems, and reduce navigational risk.

An AIS system requires:

- A means of precise positioning in the area of desired coverage (e.g., GPS or DGPS);
- A suitable communications link; and
- Appropriate processing and display equipment.

An AIS requires that vessels generate navigation (position, course, speed) and other status information, and then report this information to a surveillance centre, typically a VTS Centre, where the information is processed and displayed. The polling and response sequences between the VTS Centre and participating vessels via an AIS communication link are fully automated.

AIS (subject to any regulatory carriage requirements) has the potential to provide a more effective method of tracking vessels in VTS zones while reducing the reporting burden on the marine industry. AIS will improve the safety of navigation through increased position accuracy and automation of some operational aspects (e.g., reporting requirements) and as a result, contribute to the reduction of collisions and groundings which often cause environmentally damaging spills. The service costs of an ADS system may also be significantly lower than competing radar-based systems, particularly for large area coverage.

The mariner, recognizing the value of having the positions of all the vessels in his area displayed on his own ECDIS or ECS, is requesting that such information and other critical information be broadcast to ships from a VTS centre through the data network.

Many countries are now adopting mandatory satellite-based tracking and reporting systems for vessels fishing in their EEZ. For example, Canada and the other members of the North Atlantic Fisheries Organization, are beginning to introduce satellite tracking systems as part of fisheries management. The United States and Australia are also employing these systems. The use of such systems is resulting in improved and more up-to-date information on the catch rate and location of harvesting activity. Most of the systems used are INMARSAT-C based, with GPS being employed as the positioning system. An added bonus has been improved safety for those fishing in the monitored areas.

The commercial shipping and fishing industries themselves are now employing satellite tracking and data communications to manage their own operations more effectively. These are known as fleet management systems, with some systems providing real-time monitoring of such things as fuel consumption, speed, heading, etc. Fishing vessels are using the technology to locate buyers and negotiate prices as they proceed in from the fishing grounds.

There are two technologies under consideration for the communications link. The first is DSC, a component of the existing GMDSS. This is available now, and some nations (Britain and the Netherlands) propose to use this to identify ships within their Vessel Traffic Management System (VTMS) jurisdictions. However, the DSC technology has some limitations. Vessel DSC devices can respond to interrogations from a shore-based VTMS. But the data capacity is too limited to permit vessel-to-vessel interrogations, or to pass additional useful information, such as heading and course and speed over the ground.

The second technology is a broadcast system capable of providing continuous interrogation and exchange of information between all vessels in an area. The National Maritime Administration of Sweden is conducting trials of an experimental broadcast system, based on the use of DGPS, and a transmitter on each vessel which broadcasts a digital message every five seconds, containing position, speed and identification [Tryggö, 1994]. This experiment will address the following questions:

- What value has such a broadcast system for traffic control?
- Can "pilotage from shore" be used effectively with such a system?
- What value has such a system when vessels meet in narrow waters? (The test area includes the Trollhètte Canal).
- Can such a system reduce the need for pilots on board, without affecting safety?
- What impact does this system have on the need for conventional Aids to Navigation?

Before any AIS system can be widely implemented, it would be necessary for international standards to be established, so that vessel equipment would be useful in all countries. The IMO Safety of Navigation Committee has been asked to propose such standards. At its 15-19 July 1996 meeting, a two-staged implementation was proposed: DSC in 1999, and the broadcast approach between 2001 and 2004. However, this is a controversial topic.

3.5 Information Management

Better methods of data management and presentation are required, if hydrography is to meet the needs of its "clients". Development of exchange format, international data standards, and application of database management tools to high volume spatial data are some of the challenges presently being addressed. Distributed networks of databases, print-on-demand technology for paper charts, and automated chart updating systems (chart datacasting) are other issues of concern.

Several information sources are available on the vessel bridge for navigators to use for safe navigation. These include: own position from a navigation system; designated safe navigation areas and stationary hazards from a nautical chart; updates for the nautical chart information from Notices to Mariners; radar targets, which may be stationary or non-stationary hazards; ship's heading and speed information; and instructions from vessel traffic management systems.

The navigator's two roles are to:

- Integrate all these information sources, in order to maintain a current awareness of own vessel's current and near-future locations, within the context of the areas designated as safe, and all stationary and non-stationary hazards which may exist; and

- Based on this information, to take appropriate actions (course and / or speed changes), in order to minimize risk of collision or grounding, to comply with vessel traffic management instructions, and to minimize vessel operating costs (maximizing efficiency).

3.5.1 Existing Infrastructure

In many jurisdictions much of this information is maintained by a special kind of infrastructure - professional pilots who board each vessel entering their jurisdiction, in order to provide that information (expertise and experience) to the vessel's Master while transiting that jurisdiction.

3.5.2 Emerging Infrastructure

The management of bridge navigation information is currently undergoing a revolutionary change, as ECDIS replace traditional hard-copy information management methods. ECDIS is the most far-reaching of the technology changes discussed in this report, as far as both infrastructure supply and user practice is concerned.

On the supply side, the provision of information about hazards and safe passages is being converted from primarily analogue methods to digital methods. This has required a redefinition of the basic charting product - a digital database which can be derived either from a paper chart or an Electronic Navigational Chart (ENC) for use with ECDIS. This redefinition has led to:

- Redesign of the data pipeline from field survey measurement to navigator's use.
- Development of new national and international standards for digital data formats, ECDIS performance, and ENC updating.
- Development of new tools to implement a digital pipeline meeting these standards.
- Development of partnerships between public agencies (who oversee digital data quality) and various private sector entities (who implement some of the steps in the data pipeline).

Regulatory Infrastructure

The IMO has a mandate from the United Nations to administer regulations governing world maritime shipping, according to the following extracts from the IMO statement of aims and objectives [Lavery, 1984]:

- To provide machinery for co-operation among governments in the field of governmental regulations and practices relating to technical matters of all kinds affecting shipping engaged in international trade.
- To encourage the general adoption of the highest practicable standards in matters concerning maritime safety, efficiency of navigation, the prevention and control of marine pollution from ships and related legal matters.

The two IMO Acts which most affect mariners are its International Convention for the prevention of pollution from ships (MARPOL), and its International Convention for SOLAS. SOLAS consists of eight chapters:

I	General provisions
II	Construction
III	Life-saving appliances
IV	Radiotelegraphy and radiotelephony
V	Safety of navigation
VI	Carriage of grain
VII	Carriage of dangerous goods
VIII	Nuclear ships

SOLAS IV concerns communications, including satellite-based communications, and SOLAS V concerns all three aspects of navigation safety discussed in this report (own ship's position; hazards and safe passages; information management). SOLAS V Regulation 20 states that ships must carry and use up-to-date paper charts. This IMO regulation has been imbedded in the laws of most, if not all, maritime nations.

The introduction of new technologies designed to enhance navigational safety is regulated by the IMO, under SOLAS V. Since 1989 the IMO has been considering the use of a new technology designed to reduce the risks involved in integrating navigation information on the ship's bridge. The new technology is referred to as ECDIS.

The 19th biennial assembly of the IMO in November 1995 formally approved *IMO Performance Standards* for ECDIS. As a result of the IMO approval, national maritime safety administrations can change their regulations to consider ECDIS as the legal equivalent to the charts required to be carried and used by regulation SOLAS V/20.

The IMO ECDIS Performance Standard took almost a decade to develop, involving cooperation between the IMO and other international bodies. Although the performance standard itself has been approved, it depends on more detailed documents being prepared by these other bodies.

The IEC is responsible for developing standards for ECDIS equipment, and for specifying tests and checks to ensure an ECDIS is IMO-compliant.

The International Hydrographic Organization (IHO), is responsible for developing ECDIS standards for data structure, content, display, and updating, and a strategy for supplying ENC data for use with ECDIS. The IHO standards are contained in two publications: S-57 IHO Transfer Standard for Digital Hydrographic Data, (Edition 3 is to be approved in September 1996) and S-52 IHO Specification for Chart content and Display of ECDIS (a draft was approved in November 1994).

The work of IMO, IHO and IEC on ECDIS standards is coordinated by a Harmonization Group for ECDIS (HGE), which has met 16 times since 1989. Most recently HGE was asked to provide guidance on two issues:

- What should an IMO-compliant ECDIS use for backup?

- Should IMO develop either guidelines or a performance standard for simpler electronic chart systems (ECS), which are not designed as paper chart replacement systems (do not meet the IMO ECDIS standard)?

HGE recommendations on these issues were considered at the June 1996 meeting of the IMO Sub-Committee on Navigation.

Case Study: CHS & CSL.

In February 1993, Captain John Pace of Canada Steamship Lines (CSL) visited the office of the head of the Canadian Hydrographic Service (CHS), the Dominion Hydrographer, Ross Douglas. Captain Pace announced that CSL had decided to equip much of their fleet with ECDIS systems, and required 98 official ENCs from the CHS within five months. This request became known within the CHS as the "Big Bang"[Holroyd, 1995].

Until that time the CHS had been setting their own deadlines for preparing data for ENCs. An Electronic Chart Pilot Project had just started, which would require the CHS to supply some ENCs to be used in test areas, but which was mainly designed to identify how the CHS should go about producing ENCs. The initial reaction to the CSL request within the CHS was that it could not be done. However, this was not considered acceptable by CHS management, and a more rational reaction arose: what changes will make this possible?

Providing the infrastructure to support ECDIS products, rather than paper nautical chart products, requires significant re-tooling by an agency like CHS. All the information about stationary hazards and safe passages which formerly was provided in the form of a hard copy paper chart must be converted into digital form. It is relatively easy and inexpensive to use a laser-scanning device to reproduce an image of the existing paper charts for electronic display. However such **raster** digital images do not meet the IMO ECDIS standards, which specify that chart information must be in an (intelligent) **vector**-based digital form.

Vector digital charts allow the navigator to interact with the information (extracting the details about a buoy's position and flashing characteristics, for example, by simply placing a cursor over the symbol designating that buoy on the ECDIS CRT display). Raster digital charts do not allow such interactions. The conversion process to vector digital form is extremely time-consuming and expensive.

In order to deliver the vector charts required by CSL, the CHS' first response was to seriously re-deploy its personnel in every region to this task, cutting back (and falling seriously behind) on new field surveys and traditional paper chart production. The second response was to mobilize industrial resources as well, by establishing partnerships with industry to produce the ENCs. At the same time as the vector-based ENC production, it was realized that a demand for more easily produced Raster Chart Data Products were also required. The result was that by 30 August 1996, almost 500 ENCs and almost 350 Raster charts had been released.

In the process, the CHS changed permanently and positively, adopting a new structure and mission, building new production methods, establishing working relationships with several industrial partners, and strengthening the commitment of CHS staff to meeting the needs of their clients.

The ENCs themselves were constructed according to standards which the CHS had first to develop (and maintain consistent with the evolving international standards being developed at that time by the IHO). The ENC product specification describes all the possible content items within an ENC, and defines those which are essential, and those which may be omitted. The digital chart file standards describe the file organization, which in the CHS case is based on the CARIS NTX data model.

Each region within the CHS was responsible for data conversion to vector digital CARIS files, including quality control of the process, and maintenance of the resulting files. CHS headquarters coordinated the production schedules, and the standards, including detailed structural quality control procedures. Headquarters also did any customization, checked completed ENCs on an independent viewer, and released them as official CHS data products to CHS clients, including Nautical Data International (NDI), one of the new CHS industrial partners.

The new ENC production system still needs some fine tuning and streamlining, and automating. This is the goal of the ChartNet project, the first phase of which has resulted in the Compusult Integrated Data Access (CIDAS) system. It is intended that this evolve into an ENC production management system. Methods for updating ENCs have yet to be implemented. New digital chart file standards are to be released by the IHO in October 1996 (S-57 version 3), and the CHS production system will have to switch to that format. This conversion involves implementation of the CARIS Object Manager product, conversion of existing ENCs to S-57 format, and developing new Quality Control methods appropriate to S-57.

And what of Canadian Steamship Lines? During their first year of ECDIS use, CSL experienced a significant drop in the number of ship collisions and groundings, as well as enhanced productivity from two ECDIS-related sources:

- The navigation season in the St. Lawrence Seaway is limited by the danger that ice may move navigational buoys off position, converting them into navigational hazards rather than navigation aids. Using ECDIS systems and DGPS, CSL was able to safely navigate the Seaway, even when the buoys were removed, and could therefore extend its own Seaway shipping season past the normal dates.

- ECDIS systems permitted better route planning and monitoring, meaning that CSL vessels could make their runs more efficiently, particularly in inclement weather.

Product Infrastructure

Commercial ECDIS systems, which satisfy all the existing standards, are available, since their development has parallelled development of the various ECDIS standards. Such current-generation systems are feasible only through extensive reliance upon satellite navigation, and some reliance (for DGPS corrections, and chart updates) upon satellite communications.

Data Infrastructure

However, providing the infrastructure to support ECDIS products, rather than paper nautical chart products, requires significant re-tooling by the agencies responsible. DGPS must be in place. More seriously, all the information about stationary hazards and safe passages which formerly was provided in the form of a hard copy paper chart must be converted into digital form. It is relatively easy and inexpensive to use a scanning device to reproduce an image of the existing paper charts for electronic display. However, such raster digital images do not meet the IMO ECDIS standards, which specify that chart information must be in an (intelligent) vector-based digital form. Vector digital charts allow the navigator to interact with the information (extracting the details about a buoys position and flashing characteristics, for example, by simply placing a cursor over the symbol designating that buoy on the ECDIS CRT display). Raster digital charts do not allow such interactions. The conversion process to vector digital form is extremely time-consuming and expensive.

Future Infrastructures

Mechanisms for providing updates to ENCs have been proposed, but have not yet been implemented. National or (preferably) international infrastructures to provide this essential component of an ECDIS system have still to be developed. Satellite communications may well play an important role in this.

Backup systems for an ECDIS are widely judged to be necessary, but there is still disagreement as to what is, and is not, acceptable as a backup. The three broad classes of backups are paper charts; another ECDIS system; or a raster-image system based on the paper charts. Which one of these will be selected is still uncertain.

Future Generation ECDIS

The widespread introduction of first generation ECDIS into shipping operations is still to come. However, it is not too early to consider the additional safety and economic benefits which might accrue to both the shipping industry, and to ECDIS information providers, from future generation ECDIS systems. Three obvious extensions of current ECDIS capabilities come to mind:

- 3D ECDIS for UKC navigation;
- A fleet management vessel tracking and reporting infrastructure. Most simply, this would involve a "black box" attached to a vessel's ECDIS system which would regularly and automatically report the vessel's position, and other parameters of interest (weather, fuel status, etc.), via a satellite communications link, to the shipping company dispatching office; and
- Port vessel traffic management infrastructures. A similar (or same) ECDIS "black box" would regularly and automatically report the vessel's position, and other parameters of interest (cargo, fuel status, etc.) via a satellite communications link, to port authorities.

3.5.3 Existing Operations

The information management roles played by the navigator include:

- Using information about stationary hazards and safe passages (from nautical charts and other sources) to prepare a planned route, prior to sailing;

- Integrating information provided by own vessel horizontal and vertical positioning data sources while under way, with information about stationary hazards and safe passages (from nautical charts), and non-stationary hazards (from radar);

- Using this integrated information to maintain a current awareness of own vessel's current and near-future locations, within the context of safe passages and all stationary and non-stationary hazards; and

- Based on this information, to take appropriate actions (course and / or speed changes), in order to minimize risks of collision or grounding, to comply with vessel traffic management instructions, and to minimize vessel operating costs or efficiency.

These tasks are traditionally based upon independent data sources, such as:

- Vessel horizontal position from a radio-positioning system;

- Vessel vertical position (Under Keel Clearance) from predicted tide tables, and estimated draft;

- Stationary hazards and safe passages from paper charts; and

- Non-stationary hazards (other ships) from radar.

The job of integrating and maintaining an awareness of the relationships among these data sources is difficult, time-consuming, involves delays before essential information is extracted, and poses serious navigational risks under critical operating conditions (bad weather, complex narrow safe passages, heavy vessel traffic, or combinations of these).

3.5.4 Emerging Operations

As a direct result of the emergence of satellite navigation which provides global, consistent, accurate and reliable marine own ship's positioning, it has become feasible to consider the development of a new, digital approach to the information management tasks of the navigator.

ECDIS contributes five essential features to marine navigation [IMO 1995]:

- All information sources relevant to navigation (at least satellite-based positions, radar, digital ENC chart data) are integrated into one system capable of intercomparing and cross-checking these sources against each other.

- Navigation calculations and display updates are effectively instantaneous, eliminating delays in navigation decision-making, reducing the navigational workload and permitting convenient route planning and monitoring.

- The ECDIS display can be easily switched between the minimum "display base" mode (showing own vessel, coastline, traffic routing systems, safety contour (keel depth), and hazards and navaids within the safety contour) to modes showing a richer mix of features.

- ECDIS alarms are automatically sounded when the vessel deviates from the planned route, exceeds off-track limits, approaches a critical point, or crosses the safety contour (among other conditions).

- The ENC used within an ECDIS system will be capable of being simply and reliably updated, reducing the navigational workload (manual updating of paper charts has been estimated to require a half-person-year per vessel).

Bridge Resource Management

The stated purpose of ECDIS is to contribute to safe navigation. But 80 percent of reported marine incidents are caused by human error. ECDIS (and satellite-based positioning) technology alone may reduce their occurrence somewhat, but these technologies cannot by themselves eliminate human errors.

The changes in bridge duties brought by these technologies does provide an opportunity to rethink bridge operations from the human management perspective. ECDIS "has the potential to change navigation practices forever by redefining navigation as a process involving enhanced information management techniques to support improved navigation decision-making" [Pace, 1996]. ECDIS makes possible careful route planning and early detection of navigational errors and changing conditions. To realize the full safety benefits this can bring, this must be complemented by a Bridge Resource Management (BRM) culture, in which members of the bridge team establish pre-planned emergency response procedures, quickly respond to changing conditions, and most importantly, openly communicate among all team members [Pace, 1996]. Such changes are unlikely to be easily achieved.

4. Aviation Navigation and Communications

4.1 Introduction

In the early 1980s, civil aviation recognized the increasing limitations of the present Communication, Navigation, Surveillance/Air Traffic Management (CNS/ATM) systems and the need to make improvements to meet future needs. Thus the Council of ICAO established the Special Committee on Future Air Navigation Systems (FANS) in 1983 to study new concepts and new technologies and to recommend a system that would overcome the present and foreseen problems and take aviation into the 21st century.

The FANS Committee made an extensive study of existing systems and the applications of new technologies. It concluded that the limitations of the existing systems are intrinsic to the systems themselves and were so restrictive to effective ATM that the problems could not be overcome on a global scale except by new concepts and new CNS systems which would in turn support more efficient ATM. The FANS Committee concluded that the exploitation of satellite technology was the only viable solution to overcome the limitations of the present system and meet future needs on a cost effective global basis.

The system concept developed by the FANS Committee was endorsed by the ICAO 10th Air Navigation Conference in 1991. This Conference recommended that ICAO complete and maintain a global co-ordinated plan and accomplish the planning for implementation of future CNS/ATM systems through ICAO regional planning and implementation groups. The FANS Committee completed the global co-ordinated plan in October 1993.

The implementation of CNS/ATM systems is a state responsibility where a state or group of states working together should follow the framework of the ICAO global CNS/ATM plan. In the Asia/Pacific region this is accomplished by the Asia/Pacific Air Navigation Planning and Implementation Regional Group (APANPIRG). The group has completed an overall plan for the region and is proceeding with more detailed implementation planning with the following tasks:

- Coordinate the updating, on a regular basis, of the Asia/Pacific Regional Implementation Plan for the new CNS/ATM systems in the light of new developments, particularly with satellite based systems;

- Monitor the research and development, trials and demonstrations within the Asia-Pacific region and information from other regions;
- Coordinate the plans of States, international organizations, airlines and industries for the implementation of the Asia/Pacific Regional Implementation Plan for the new CNS/ATM systems;
- Provide a forum for the active exchange of information between states and for the solution of planning and implementation problems as they arise; and
- Facilitate the transfer of CNS/ATM systems expertise, equipment, trials data, etc. between states.

Forecasts of civil aviation activity in the Asia-Pacific show that the Region has the greatest traffic growth world wide. Transpacific aircraft movements are expected to increase at an average annual rate of 4.9 percent in the period 1993 to 2000. The passenger traffic in the top ten city pairs in Asia-Pacific and Transpacific areas shows an increase at an average annual growth rate of 8.3 percent from l992 to l998.

4.2 The Present System

4.2.1 Oceanic Airspace Operations

In Oceanic airspace, air traffic management is based on procedural rules. Aircraft fly on fixed routes and air traffic controllers monitor aircraft using paper flight strips, a plotting table and by communicating with aircraft. Communication between aircraft and air traffic controllers is by voice using high frequency radios relayed via radio operators.

A flight plan is initiated by the pilot or airline and provides information on the aircraft, route and expected times for departure, arrival, and reporting points on the route. The flight plan information is recorded on a paper strip which is placed on the flight strip board by the controller. As the flight progresses the pilot reports the aircraft's position at reporting points and the controller updates the information on the paper strip.

The pilot reports the aircraft's position based on navigation instruments on the aircraft. These instruments can be tuned to OMEGA or, if within range of land, radio navigation aids such as LORAN-C, VOR, and NDBs, or connected to inertial navigation systems. Altitude information is provided by a barometric altimetre. Any changes in altitude or route are coordinated between the pilot and the air traffic controller using HF radio. Controllers manually calculate separation distances between aircraft.

When the aircraft is within approximately 250 miles, the aircraft can be plotted on a radar display with the information provided by secondary surveillance radar systems. At this stage of flight, voice communication can be direct between pilot and controller using VHF radio, and the pilot can also navigate using the ground-based VOR/DME navigation aids.

Flight plan information is sent or received using an international text based message switching system called the Aeronautical Fixed Telecommunications Network (AFTN), or in some cases telephone or HF radio. Coordination is required between ATM centres. This is achieved by voice communication using direct telephone circuits, public telephone circuits, or the AFTN.

Meteorological information is provided to aircraft en route by a twice hourly voice message over the HF radio (VOLMET).

4.2.2 Domestic Airspace Operations

In domestic airspace air traffic management is based on fixed routes, procedural rules and radar control where available. Air traffic controllers monitor aircraft using a combination of paper flight strips, electronic data display, radar plan view display, and by communicating with the aircraft. Communication between aircraft and controllers is by voice using VHF radios.

A flight plan is initiated by the pilot or airline and provides information on the aircraft, route and expected times for departure, arrival, and reporting points en route. This flight plan information is automatically printed on paper strips and presented in flight data lists on electronic displays. Aircraft position information is automatically updated by the radar data processing system which combines aircraft plotting information from both monopulse secondary surveillance radars and primary surveillance radars. The primary radars provide coverage in the main terminal areas, with secondary radars used for en route and terminal area surveillance. Outside the coverage of radar, pilots report the aircraft's position and the controllers update the information on paper strips placed on a flight progress board.

The pilot navigates and reports the aircraft's position based on navigation instruments on the aircraft. These instruments can be tuned to ground-based navigation systems NDB, DME, VOR. Altitude information is provided by a barometric altimetre. Any changes in altitude or route are coordinated between the pilot and controller using VHF radio. Within adar coverage the controller ensures separation between aircraft by monitoring the distance between aircraft displayed on the radar plan view display and issuing instructions to maintain separation where necessary.

During the landing or departure phases of the flight, the pilot navigates by a combination of ground based navigation systems (NDB, DME, VOR, ILS), published procedures, or radar vectoring provided by air traffic controllers.

Flight plan information may be sent or received from AFTN terminals, entered directly into the air traffic management system at flight data positions, or automatically generated by the aeronautical database for repetitive flight plans, or exchanged automatically between sectors within the flight data processing system.

Meteorological information and other aeronautical information relevant to the flight route or airport are available as reports from the aeronautical database. At main airports relevant aeronautical information is provided by a repeating broadcast voice message over VHF radio. Meteorological data such as wind, temperature and pressure is derived from sensors on the airport and presented at the towers and centres.

Domestic airspace is divided into manageable control sectors with one or more controllers having responsibility within each sector. Coordination between sectors are achieved using either automated handover sequences on radar or electronic data displays or by voice. Voice communication is achieved using the network of voice switching systems.

4.2.3 CNS Deficiencies

There are three major shortcomings of current CNS systems:

- The propagation limitations of current line-of-sight systems and/or accuracy and reliability limitations imposed by the variability of propagation characteristics of other systems;
- The difficulty, caused by a variety of reasons, to implement present CNS systems and operate them in a consistent manner in large parts of the world; and
- The limitations of voice communications and the lack of digital air-ground data interchange systems in the air and on the ground.

These limitations are intrinsic to the systems themselves. Although their effects are not the same for every part of the world, it is evident that one or more of these factors inhibits the further development of air navigation almost everywhere. New CNS systems should surmount these limitations to allow ATM on a global scale to evolve and become more responsive to users' needs.

Over the oceans, the systems which can currently be used are severely limited. Thus air ground communications are limited to high frequency (HF) communications, often with the need for intermediate communicators. While "on-board" navigation systems such as inertial navigation system (INS) or inertial reference system (IRS) are available for the larger aircraft, long range radio navigation has been limited to very low frequency (VLF)/Omega and LORAN-C. Surveillance has been limited to pilot reports of position via HF communications. These limitations have resulted in the large separation standards which apply in oceanic airspace.

Because of the presence of deserts, mountains and jungles in the Asia-Pacific Region, it is difficult, and in many cases impossible, to implement the present CNS systems. In some cases, implementation is little more than what is possible over the oceans. Even when there is wider implementation, the performance achieved often limits ATM.

The present ground communications system, the AFTN is limited in throughput, data integrity, and the ability to handle bit-oriented message and data exchanges. The evolution of the communications path to full ATN capability is seen as evolving from the implementation of ground-ground ATN routers that in some cases will not initially meet all conformance requirements. This initial ATN router capability will be used to provide the establishment of ATN routing domains, AFTN/ATN gateways, and trial and demonstration support for air to ground (A/G) routers and applications.

4.2.4 ATM Deficiencies

Present day ATM in the Asia-Pacific region suffers shortcomings which include:

- Lack of surveillance facilities over large areas of the region which require relief from congestion;
- Air route availability constrained by point source navigation aids (NAVAIDS) resulting in choke points;

- Dissimilar MS procedures and separation standards causing Flight Information Region (FIR) boundary changes to flight profiles;
- The uncoordinated provision of present CNS equipment resulting in duplication of resources and services;
- A lack of appropriate parallel Air Traffic Services (ATS) route structures to relieve route congestion; and
- Poor quality communications facilities and language difficulties.

With the continued high growth rate of air traffic in the Asia-Pacific region in particular, the existing CNS systems will not be able to provide for the efficiency and regularity of flights at acceptable safety levels. New CNS systems are therefore essential to create the air traffic capacity that will be needed.

The new CNS systems will make improvements in their own right, and will also be the basis of improvement in ATM. This will permit more flexible and efficient use of airspace, both en route and in terminal areas. This is needed to improve the accommodation of preferred flight profiles in all phases of flight. In particular, airspace boundaries are to be made transparent to the users.

4.3 The New System

4.3.1 Oceanic Airspace Operations

Satellite-based systems offer the advantage of providing accurate position information to pilots and air traffic controllers over the entire oceanic area, direct communication between pilots and air traffic controllers, and automatic coordination with other centres. Aircraft operators can select their preferred route and flight level and achieve considerable benefits by fuel savings and increased payload. While en route they can more readily adapt their route or altitude according to changing conditions. Because of the new systems, controllers can improve traffic flow and reduce delays with a greater range of available routes and safely reduced separation standards.

GPS receivers provide accurate position information to the pilot and aircraft flight management systems, with coverage over most of the world. This information can be automatically sent via a data link to the air traffic control centre and aircraft situation displays.

Pilots and controllers can communicate directly by messages sent via a data link between the aircraft and the ground. Pilots will be able to request and receive approval for altitude and route changes. This means reduced delays in communication and reduced data exchange errors. If voice communication is still required satellite voice communication is also available.

Oceanic facilities for flight information regions can coordinate more effectively and reliably by automatically exchanging data.

Airline operators can propose their preferred route prior to departure based on weather conditions and aircraft performance. This can result in a reduction in flight time and fuel consumption with an increase in payload of passengers and cargo. While en route they can adapt their route or altitude according to changing conditions.

Controllers will be able to more efficiently manage the flow of aircraft because systems can cater for more routing options. Separation standards will be safely reduced from 100 to 30 nautical miles and from 2 000 to 1 000 feet. Conflict risk will be reduced with the introduction of conflict detection and probe in air traffic management systems and with airborne collision avoidance systems.

4.3.2 Domestic Airspace Operations

Satellite-based systems offer the advantage of providing accurate aircraft position information to pilots and air traffic controllers, direct communication between pilots and air traffic controllers and the aeronautical database, increased surveillance coverage, automatic conflict detection and more flexible and direct routing. Some airports will experience reduced closures resulting from weather conditions.

GPS receivers provide accurate position information to the pilot and aircraft flight management systems. Augmented GPS signals can provide the potential for providing non-precision and Category I precision approaches. At a number of airports, the minimum decision height where pilots need to visually sight the runway before landing will decrease, because the satellite based navigation systems are not affected by terrain or other adverse site conditions. This will reduce the number of hours each year an airport is closed because of low cloud conditions.

The accurate position information can be automatically sent via a data link to the air traffic control centre or control tower with the aircraft position displayed on an ADS display. With low cost VHF data link equipment the present surveillance coverage can be extended to areas which presently do not have radar coverage.

Pilots and controllers can communicate directly by messages sent via a data link between the aircraft and ground. Pre-departure clearances are a typical example of an application of data link procedures. Pilots can access the aeronautical database via data link when en route to obtain the latest weather and other aeronautical information for the route.

Short-term conflict alert software can automatically warn controllers if an unsafe situation is developing. This provides an enhanced level of safety.

More direct or efficient routing can be achieved as routes and minimum route altitudes will not be restricted by the position and performance of ground based navigation and surveillance equipment.

4.3.3 Communications

Communication with aircraft over the whole Asia and Pacific Regions for both voice and data will be by direct satellite to aircraft links. In terminal areas, and in some high density airspace, very high frequency (VHF) and secondary surveillance radar (SSR) Mode S would be used.

In both domestic and oceanic airspace there will be an increasing use of data linking between aircraft and ground systems. This will allow aircraft flight management computers or small data terminals to directly connect to ground based air traffic management computers for coordination and position reporting. The pilot will also be able to directly connect to the aeronautical database for information on weather and other conditions relevant to the airport of departure or arrival or route being flown.

The air-ground data link is expected to be via VHF data link in most domestic airspaces and via the Aeronautical Mobile Satellite Service (AMSS) in oceanic airspace. Although Mode S Secondary Surveillance Radar is being proposed as an alternative domestic data link system. Greater use will be made of the new ATN which will allow full interoperability between aircraft, ground, and other international systems and networks.

Flexibility

The new CNS concept is very flexible in that each state has the choice of implementing specific system elements to meet its individual requirement for forming a complete, operable CNS/ATM system. Thus, the communication elements can be implemented using any or all or any combination of satellite, VHF or SSR Mode S. States with busy airspaces would probably use all of these, but small States with continental airspace only could implement the new CNS/ATM concept by communications and ADS on VHF alone.

Communications Services Envisaged

Aeronautical communications include:

- Safety communications requiring high integrity and rapid response:
  - Safety-related communications carried out by ATS for Air Traffic Control (ATC), flight information and alerting;
  - Aeronautical operational control (AOC) communications carried out by aircraft operators, which also affect air transport safety, regularity and efficiency (aeronautical operational control); and
- Non-safety related communications:
  - private correspondence of aircraft operators (aeronautical administrative communications (AAC)); and
  - public correspondence (aeronautical passenger communications (APC)).

Continued Requirement for Terrestrial Air/Ground Communication

Terrestrial communications will continue to be required. Their inherent short transmission delays are better suited where the rapid exchange, short transactions style of voice communication is required. While there will be a trend to move towards more data link communications for many functions, it is anticipated that voice communication is expected to be needed for a long time in the future.

While not an operational factor, the potential lower cost of a terrestrial service over a satellite service is a significant factor in the continued use of terrestrial facilities where they can be made available.

Dependence on Data Interchange

It is envisaged that the use of automated data interchange technology will expand, as more and more automation of ATM systems takes place. In the A/G and G/G environments this expanded use will reduce the dependence on voice communications where ultimately voice will only be used in emergency and irregular situations not supported by automation.

For aeronautical safety service communications, civil aviation currently uses the aeronautical HF band from 3 to 30 MHz and the aeronautical VHF band from l 18 to 137 MHz. It is now preparing to implement data interchange with the SSR Mode S at 1030 MHz and 1090 MHz and will, before long, begin to use the bands allocated to AMS(R)S, i.e. 1545 - 1555 MHz and 1646.5 - 1656.5 MHz. Civil aviation may use the 5 - 5.25 GHz band for feeder links to aeronautical mobile communications satellites in addition to the use of this band for MLSs.

The Role of VHF

VHF is currently used for ATS and AOC voice communications, within line-of-sight range. Their excellent operational reliability, and the number of channels available with the 25 KHz intervals, make them the basis for safety communications in many continental control areas in spite of the fact that in some states cases of interference by frequency modulation (FM) commercial broadcast signals are frequent. However, future saturation is probable. Therefore, a further improvement in the utilisation of the VHF band should be strived for.

VHF data link communications (character-oriented) for AOC has been used for several years by some airlines and business aircraft. ATS applications using VHF data link are now being implemented and are expected to increase in the future. New systems are now under development (i.e., higher data rate, bit-oriented, Open Systems Interconnection (OSI) compatible and ATN compliant) and are expected to be in operation by l995. The use of VHF data link for ATC applications should reduce voice communications requirements in the near term.

The Role of HF

Mobile HF communications are the only means currently in use for "over-the-horizon" contacts. These communications have reliability limitations imposed partly by the variability of propagation characteristics. Aeronautical operations are currently limited by the range of possibilities offered by HF. The eventual replacement of HF by L-band satellite communications will be a major step forward.

SSR Mode S

SSR Mode S, in addition to its fundamental surveillance function, can provide a limited two way air-ground sub-network suitable for the exchange of ATS information between aircraft and ground stations.

Utilization of AMS(R)S

The exploitation of satellite technology in the future global air navigation infrastructure is the key to a development that will have benefits for international civil aviation into the next century. A system architecture for satellite communication services that provides for all four kinds of communications (ATC, AOC, AAC, and APC) and encourages multiple user participation through a minimum system capability up to a complex multi-function system is under development by ICAO. It permits integration of services to the degree that institutional considerations, operational priorities, and the need to preserve a spectrum for aeronautical safety communications, may allow. Also, by applying the OSI concept, the architecture offers interoperability of the satellite elements of the system with the aircraft and with ground communication networks, including interoperability of satellite services of separate providers.

Transition

An opportunity offered to enable early use of current technology by the application of ARINC Specification 622 over character-based data communication systems such as Aircraft Communications Addressing and Reporting System (ACARS), will provide for significant benefits in ATM. Several states are proceeding with implementation of ATS ground facilities to meet and take early advantage of aircraft CNS packages, both of which are based on the ARINC Specification 622. The implementation plans recognize that eventual transition to the ATN is an objective and that ARINC Specification 622 is an intermediate interim step designed to gain early CNS/ATM benefits from existing technology.

Aeronautical Telecommunications Network

The ATN will provide for the interchange of digital data between a wide variety of end system applications supporting end users, such as: aircraft operators, air traffic controllers, and aeronautical information specialists. The ATN, based on the International Organization for Standardization (ISO) OSI reference model, allows for the inter-operation of dissimilar air-ground and ground-to-ground subnetworks as a single internet environment. End systems attach to ATN subnetworks and communicate with end systems on other subnetworks, by using ATN routers. ATN routers can be either mobile (aircraft based) or fixed (ground based). The ATN routers select the logical path across a set of ATN subnetworks that can exist between any two end systems. This path selection process uses the network level addressing, quality of service and security parameters provided by the initiating end system.

Thus the initiating end system does not need to know the particular topology, or availability of, specific subnetworks.

Present day aeronautical communication is supported by a number of organizations using various networking technologies. The most imminent need is the capability to communicate across heterogeneous subnetworks both internal and external to administrative boundaries. The ATN can use private and public subnetworks spanning organizational and international boundaries, to support aeronautical applications. The ATN will support a data transport service between end-users which is independent of the protocols and the addressing scheme internal to any one participating subnetwork. Data transfer through an aeronautical internet will be supported by three types of data communication subnetworks: avionics subnetworks, ground subnetworks, and air-ground subnetworks. Air-ground subnetworks of VHF, AMS(R)S, Mode S, (and possibly HF) will provide linkage between aircraft-based and ground-based routers (intermediate systems). Additionally, application services provided by non-aeronautical host computers may be accessed by aeronautical host computers (aircraft-based and/or ground-based) given suitable interconnections and administrative arrangements.

In support of a multi-national and multi organizational environment, the ATN will provide a network management framework which will allow routers to operate on a largely autonomous basis. In this context, routers will be capable of performing routing management tasks based on operational, policy and security considerations contained within local management databases.

In summary, the ATN is designed to transfer data between end-users independent of protocols and addressing schemes internal to any one participating subnetwork. In order to meet this objective, all participating subnetworks must be interconnected via internetwork routers observing common internetworking conventions and standards. This strategy will provide network-independent interface for all ATN users.

The ATNP Working Groups, in terms of the their work programme, has proposed the following information for consideration by the various committees of APANPIRG/CNS/ATM/IC/SG. The contingent requirements for final development of Standards and Recommended Practices (SARPs) and Guidance Materials for augmentation of CNS/ATM capabilities may be expressed in the following areas of interest:

- Address assignments for ATN compliant end-user systems within the present AFTN structure (e.g., X.25 platform technology).

- Supportive Operational Requirements (OR)
  - ATC/Host to ATC/Host Communications
  - Transitional protocols in interim phases
  - Digitized ATS Speech Communications
  - Air Traffic Management Flow Control

4.3.4 Navigation

Future navigation systems will rely on a constellation of navigation satellites known as the GNSS. It will consist of a number of satellite systems such as GPS, GLONASS and commercial satellite service providers such as INMARSAT. The system will be used throughout all phases of flight to provide accurate position information.

With the aid of supplementary correction and system integrity signals, navigation accuracy can be further enhanced to provide navigation for precision approaches to airports. The supplementary signals will be provided by a wide area augmentation system or a network of local differential GPS systems.

Area Navigation (RNAV) capability will be progressively introduced in compliance with the ICAO Required Navigation Performance (RNP) Standards. The GNSS will provide navigation coverage over the whole Asia-Pacific Region. MLS, ILS, and the GNSS will be used for approach and landing in accordance with the ICAO strategy. Current navigation aids (NDB/VOR/DME) will be progressively withdrawn.

Required Navigation Performance

Modern aircraft are increasingly equipped to utilize newer techniques, generally referred to as RNAV, the use of which is appropriate and inevitable because they facilitate a flexible route system. Therefore, the future navigation system is based on the availability of airborne RNAV capability. The minimum navigation performance specifications (MNPS), concept, now in use in North Atlantic and Northern Canadian airspace, and which enables a required navigational performance to be achieved by a variety of navigation equipment, could be extended, albeit in a somewhat modified form, to other airspaces. A new concept has been developed and called RNP to extend RNAV to other airspace. RNP is broadly defined as the maximum deviation from assigned track within which the aircraft can be expected to remain with a given degree of probability. This concept avoids the need for ICAO selection between competing systems from the outset; however, it will not prevent ICAO from dealing with navigation techniques which are in wide use internationally. The RNP concept has been approved by the ICAO Council and was assigned to the Review of General Concept of Separation Panel (RGCSP) for further elaboration and recommendation. The RGCSP agreed that four RNP types were required for general application in en route operations. These were RNP1, RNP4, RNP10, RNP12.6 and RNP20. The RGCSP agreed that RNP4, RNP12.6 and RNP20 could apply from 1995. The RGCSP further considered that RNP1 could apply from 1998. RNP10 has been approved for application in the Asia-Pacific region.

Global Navigation Satellite System

Satellite navigation systems are evolving. GNSS, where the user performs on-board position determination from information received from broadcast transmissions by a number of satellites, is providing highly reliable, highly accurate and high integrity global coverage independently. Although the RNP concept allows for more than one satellite navigation system to be in use simultaneously, from an aircraft equipment point of view, maximum interoperability is essential as it would significantly simplify avionics and thereby reduce cost. It would also be attractive if one system could serve as a complement to and/or in a backup role for the other.

Criteria to enable adequate integrity monitoring and health warning services for satellite navigation systems are being developed by GNSS Panel (GNSSP). Two distinct approaches to the problem of integrity, namely, receiver autonomous integrity monitoring (RAIM) and the provision of a GNSS integrity channel (GIC) have been identified. Both are under investigation in several states and international organizations. Subject to the satisfactory development of integrity monitoring, it is confidently expected that GNSS will meet the requirements for sole means of navigation for civil aviation.

The Present Radio Navigation Systems

The present radio navigation systems serving en route navigation and non-precision approaches will be able to meet the RNP conditions and co-exist with satellite navigation systems. However, it is foreseen that satellite systems will eventually become the sole means of navigation and that the present radio navigation systems will be progressively withdrawn. The timing of such withdrawal will depend on many factors, among which the implementation and quality of the new systems will be prominent, and will probably differ in various regions of the world. Because of its impact on international civil aviation on a worldwide scale, the transition/withdrawal needs to be planned by ICAO.

Approach and Landing Guidance Systems

The Special COM/OPS Divisional meeting in March/April 1995 developed the following global strategy. Based on the considerations of the COM/OPS DIV 95 Meeting and a need to consult aircraft operators and international organizations as appropriate, the global strategy is to:

- Continue ILS operations to the highest level of service as long as operationally acceptable and economically beneficial;
- Implement MLS where operationally required and economically beneficial;
- Promote the use of MMR or equivalent airborne capability to maintain aircraft interoperability;
- Validate the use of GNSS, with such augmentations as required, to support approach and departure operations, including Category I operations, and implement GNSS for such operations as appropriate;
- Complete feasibility studies for Category II and III operations, based on GNSS technology, with such augmentations as required. If feasible, implement GNSS for Category II and III operations where operationally acceptable and economically beneficial; and
- Enable each region to develop an implementation strategy for future systems in line with the global strategy.

The strategy previously developed by APANPIRG for the Asia-Pacific region in the provision of precision approach and landing guidance, set out below, is in accordance with the global strategy.

- ILS be retained as an ICAO standard system for as long as it is operationally acceptable and economically beneficial;
- Implement MLS where necessary to maintain or improve operational capability at locations where this capability would not otherwise be possible;

- Promote the validation of GNSS, with such augmentation as may be required, to support non-precision and Category I operations;

- Support R&D programmes on feasibility studies for Category II and III operations, based on GNSS technology. If feasible, implement GNSS for Category II and III operations where operationally acceptable and economically beneficial; and

- That ICAO develop SARPs for the GNSS solutions for approach, landing and departure operations based on the RNP parametres.

Vertical Navigation

It is recognised that barometric altimetry does not function at the very high altitudes at which future multi-Mach aircraft will operate. In those cases, geocentric altitude measurement from satellite navigation systems may meet the requirement.

The following guidelines are applicable to the new navigation systems:

- GNSS should be permitted for supplemental en route use first, and later for use as a sole-means navigation system to replace en route radio navigation systems. During the early portion of the transition period, some airspace users may wish to use GNSS as a supplemental system in order to achieve the benefits of accurate navigation that is available everywhere. Later, after integrity questions have been resolved and experience has been gained, GNSS may be permitted as a sole-means system.

- The ground infrastructure for current mandated navigation systems must remain available during the transition period. GNSS may only be used in conjunction with other approved navigation systems during the transition period.

- States and/or regions should consider segregating traffic according to navigation capability, and granting preferred routes to aircraft with more accurate navigation capability. This will provide incentive for aircraft operators to equip rapidly with more accurate navigation capability.

- States and/or regions should co-ordinate to ensure that separation standards and procedures for appropriately equipped aircraft are introduced approximately simultaneously in each FIR through which major air traffic passes.

4.3.5 Surveillance

Future surveillance systems will rely on data links between aircraft and the ground systems. ADS systems automatically send aircraft position reports via the data link to the air traffic management systems which display the position information on large screens similar to present radar displays. The position information will be provided by the GNSS navigation system. The data links will be via the Aeronautical Mobile Satellite Service in oceanic airspace and via VHF data link in domestic airspace.

ADS will be used over the oceans and many continental airspaces in the Asia and Pacific Regions. SSR (augmented as necessary with Mode S) will continue to be used in terminal areas and in some high density airspaces. The use of primary radar will diminish.

Automatic Dependant Surveillance

The introduction of air-ground data links, together with sufficiently accurate and reliable aircraft navigation systems, present the opportunity to provide surveillance services in areas which lack such services in the present infrastructure, in particular oceanic areas and other areas where the current systems prove difficult, uneconomic, or even impossible, to implement. ADS is a function for use by ATS in which aircraft automatically transmit, via a data link, data derived from on-board navigation systems. As a minimum, the data includes four-dimensional position information. Additional data may be provided as appropriate. The ADS data would be used by the automated ATC system to present information to the controller. In addition to areas which are at present devoid of traffic position information other than pilot provided position reports, ADS will find beneficial application in other areas, including high-density areas, where ADS may serve as an adjunct and/or backup for SSR and thereby reduce the need for primary radar. Also, in some circumstances, it may even substitute for secondary radar. As with current surveillance systems, the full benefit of ADS requires supporting complementary two-way pilot-controller data and/or voice communication (voice for at least emergency and non-routine communication).

Primary Surveillance Radar

Primary Surveillance Radars (PSRs) are independent surveillance systems because they do not need any electronic equipment on the aircraft. The ground based equipment has a rotating antenna which transmits pulses which are reflected back from the aircraft and detected by the radar. It only provides information on the bearing and distance from the aircraft to the radar.

The main advantage of retaining PSRs in the terminal area is to reduce the risk of not seeing aircraft because the aircraft ADS or SSR transponder equipment is not turned on or is faulty. Future PSRs are expected to have a weather channel (including wind shear detection) option. However, a PSR is presently two to three times more expensive than a SSR. Another significant disadvantage with PSRs is the generation of false tracks owing to clutter such as waves, trees, rain or other moving targets. If PSRs are not used in terminal areas it may be necessary to have duplicated ADS and/or SSR transponders fitted to all aircraft entering terminal areas.

Although the use of primary radar is already declining, its need will continue to exist in those airspaces where there is a mix of SSR-equipped aircraft with non-SSR equipped aircraft, with compatible services provided to both categories. However, as such circumstances are decreasing, the need for primary radar will reduce. The reduction of primary radar will be further advanced by the introduction of ADS in its role as an adjunct/backup for SSR. Secondary radar, through the Mode S system and its data link, and ADS will be of such high integrity that it will diminish the justification of primary radar for air traffic services provided to international civil aviation. It is recognised, of course, that primary radar for other purposes, including weather detection, will continue to be needed.

Secondary Surveillance Radar

The SSR interrogates transponder equipment installed on the aircraft. A "Mode A" aircraft transponder enables position and identification information to be obtained and a "Mode C" transponder provides additional height information. The system is dependent on the transponder on the aircraft working at all times.

SSR is in wide use in many parts of the world where terrestrial line-of-sight surveillance systems are appropriate. In several states the accuracy and over-all performance of position information is improved by the application of monopulse techniques and/or the use of large vertical aperture antennas. By enhancing SSR with Mode S, the selective address and data-link capabilities will further enhance the beneficial role of SSR for surveillance purposes. Mode S is expected to come into use in some areas during the 1990s.

Airborne Collision Avoidance Systems

More aircraft are being fitted with Airborne Collision Avoidance Systems (ACAS). These systems interact with the transponder in aircraft operating nearby and warn the pilot of impending collisions and appropriate action to avoid the collision.

Surface Movement Surveillance

Airport Surface Detection Equipment (ASDE) is a small radar which detect the position of aircraft and vehicles on the runway and taxiway areas of an airport. The equipment is installed at busy airports with multiple runways and at taxiways where there is a high level of poor visibility conditions such as fog.

There is a probable need, at very high activity airports, for advanced systems for airport surface navigation, communications and surveillance which provide more capability than surface movement radar alone. There is some indication that technologies such as Mode S data link, satellite navigation and ADS techniques might be used in which no additional avionics would be required. Since some airports may need such systems in the near term, developments of the above system elements are encouraged.

4.3.6 Air Traffic Management

The general objective of ATM is to enable aircraft operators to meet their planned times of departure and arrival and adhere to their preferred flight profiles with minimum constraints without compromising agreed levels of safety.

The future systems must evolve from the present system so as to meet user needs to the maximum extent possible, while gaining the potential benefits from the application of new technologies.

The reality is that transition and integration are the most difficult institutional problems facing ATM system designers. It is simply impractical to evolve from one system to another in time frames less than several years in duration.

The implementation of the global CNS concept will greatly influence the future development in the field of ATM. However, the provision of ATM has to be considered additionally on a regional basis. The ATM concept is intended to be applied worldwide but achieved through variable phases of regional implementation.

The ATM environment is highly dependent on the type of airspace and its traffic density and, therefore, its detailed implementation requirements will vary around the world. In addition, the degree to which the requirements can be met is heavily influenced by the practicality of providing adequate CNS services.

As new CNS systems will provide for closer interaction between the ground systems and airspace users before and during flight, improvements to ATM will permit a more flexible and efficient use of the airspace and will enhance traffic safety and regularity of flight. ATM may be viewed as the principal beneficiary of the CNS improvements, i.e., it is the resultant benefits to ATM which constitute the rationale for incurring the costs of CNS improvements. In turn, improvements in ATM will ultimately benefit all airspace users.

The following directions of change in ATM are envisaged and are to be supported by the future CNS systems:

- Improved handling and transfer of information between operators, aircraft, and ATS units;

- Extended surveillance by using aircraft positions derived from airborne systems' automatic dependent surveillance;

- Advanced ground-based data processing systems, allowing for:

  - The ability to take advantage of the navigation accuracy in four dimensions of modern aircraft;

  - Improved accommodation of preferred flight profiles in all phases of flight, based on the operator's objectives; and

  - Improvement in conflict detection and resolution, automated generation and transition on conflict-free clearances and rapid adaptation to changing traffic conditions;

- These three aims of development, together with improved planning, will allow more dynamic airspace and ATM, particularly in high-density airspaces.

The goals for future ATM systems include:

- Maintain or increase the existing level of safety;

- Increased system capacity and full utilization of capacity resources as required to meet traffic demand;

- Dynamic accommodation of user-preferred three-dimensional and four-dimensional flight trajectories;

- Accommodation of full range of aircraft types and airborne capabilities;

- Improved provision of information to the users such as weather conditions and improved weather forecasting provisions, traffic situation, availability of facilities;

- Improved navigation and landing capabilities to support advanced approach and departure procedures;

- Increased user involvement in ATM decision making including air-ground computer dialogue for flight negotiation;

- Creation, to the maximum extent possible, of a single continuum of airspace, where boundaries are transparent to users;

- Organization of airspace in accordance with ATM provision and procedures,

- Minimisation of airborne delays and holding, coupled with adjustment of flight-track schedules to achieve efficient traffic flows as well as efficient airspace and airport usage; and

- Increased ATS emphasis on strategic planning to minimize future aircraft conflict and conflict resolution manoeuvring by the ATS system.

ATM systems will be designed to accommodate normal peak traffic demand and should be easily expandable to meet anticipated future growth. When unexpected traffic loads are experienced, future ATM systems must provide a tactical capability for safely providing economic flow management. A number of factors must be considered in designing the ATM system to achieve the expected benefits. In particular the design must consider:

- Information about the environment and the means to improve the quality and timeliness of that information, and its accessibility to both aircraft and the ATM system so as to provide for an efficient traffic flow;

- Information concerning air traffic flows en route, in transition, and approaching the airport, as well as dynamic intonation on current and projected capacity resources, and ways to improve the quality and currency of this data;

- Information on the positions and manoeuvre intentions of aircraft and the ways such information can best be used within the ATM system;

- The procedure and separation standards which establish the limits on the number of aircraft which can be served, and ways to improve them; and

- The use of ATM automation tools to help air traffic managers and the ATM system sort, process and display information so as to help air traffic managers visualize the data, consider the range of alternatives and best utilize available airspace and airport resources.

Large parts of the world lack reliable coverage by CNS systems. Without proper measures, the efficiency will further decrease in the future because of predicted growth in air traffic and the widening gap between airborne and ground capabilities.

The examples presented below are applicable, to some extent, to even the most developed current ATC systems environments:

- The information flow within and between ATC units (ground-ground communication) and between ATC units and aircraft under their control (air-ground communication) is insufficient to support further significant improvements. However, it is recognised that the utilization of flight plan data processing and radar data processing as well as automated assistance to air traffic flow management is fairly extensive with various degrees of refinement;

- ATC needs improved data and procedures for surveillance, prediction and optimization of the air traffic flow;

- The most advanced ATC systems are still working on the basis of data representing the aircraft performance and environmental conditions which only poorly approximate reality. Hence, only limited accommodation of optimised flight profiles is achieved;

- The capability of advanced airborne equipment in the field of planning and optimization of flight paths has outstripped that of the ground systems to support it. Operators are pressing to be able to more fully exploit such capabilities. Obviously, a way to accommodate aircraft will be through implementation of concepts which take these capabilities more fully into account; and

- Route structures are generally inflexible although, increasingly, direct routings are allowed when controller workloads permit.

4.3.7 Benefits and Costs

The benefits of CNS/ATM can be summarized as:

- The maintenance or enhancement the existing level of safety;

- The provision of an ATM system to make more efficient use of airspace and airport capacity and to permit the harmonious treatment of flights transiting all airspace;

- The provision of CNS in a more cost effective manner; and

- The global provision of CNS in a more uniform manner.

The FANS Committee carried out a preliminary global cost-benefit analysis and reported in 1988 that the estimates of cost showed that the new CNS/ATM systems would cost no more to implement and operate than the present system and there would be annual benefits of $5 billion. Several states have carried out cost-benefit analyses for areas over which they have responsibility and these analyses have shown the benefits exceeding the costs by approximately three times.

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Appendix C: Web Sites

Selected web sites related to Marine Transportation:

Canadian Coast Guard	http://www.ccg.org/
Coast Guard links of interest	http://www2.innav.gc.ca/innav/sites.htm
Canadian Ports Corporation	http://canada.gc.ca/depts/agencies/cpoind_e.html
Canadian Port & Harbours Association	http://www.newswire.ca/cpha/
Atlantic Pilotage Authority Canada	http://canada.gc.ca/depts/agencies/apaind_e.html
Intertanko	http://www.wwis.no/org/org1/Welcome.html
GENS - Professional Maritime Server	http://www.gens.no/
Seaports info pages	http://www.seaportsinfo.com/mainmenu.html
Seaports port & maritime services	http://www.seaportsinfo.com/indsvcs.html
Singpore links to other ports	http://www.singaport.gov.sg/profile/portlink.htm

Selected web sites related to Air Transportation:

ICAO	http://www.cam.org/~icao
IATA	www.route-one.co.uk/users/fx34/wats1.html

Selected web sites related to GPS and DGPS:

System information:

U.S. Coast Guard information center	http://www.navcen.uscg.mil

U.S. Naval Observatory http://www.usno.navy.mil
http://www.laafb.af.mil/SMC/CZ/homepage/

GPS background information:

Tutorial http://www.utexas.edu/depts/grg/gcraft/notes/gps/gps.html

GPS World http://www.gpsworld.com/

Royal Institute of Navigation http://hydrography.ims.plym.ac.uk/rin.htm

Equipment suppliers:

3S Navigation http://truegnss.com/index.htm

Ashtech http://www.ashtech.com/

Canadian Marconi http://www.marconi.ca/

Del Norte Technology http://www.onramp.net/del_norte/

Leica http://www.leica-gps.com/

Magellan http://www.orbital.com/Prods_n_Servs/Services/Magellan/index.html

Navtech GPS Store http://www.navtechgps.com/

Rockwell http://www.cacd.rockwell.com/

Starlink http://www.starlinkdgps.com/home.htm

Trimble http://www.drive.net/gps.html

DGPS corrections suppliers:

Pinpoint / Accqpoint http://accqpoint.com/

DCI http://www.dgps.com

Omnistar http://www.omnistar.com/

Racal http://www.racal.com/

Selected web sites related to Loran-C:

International Loran Association	http://webeecs.ent.ohiou.edu/avn//Loran/Home.html
Megapulse - leaders in Loran technology	http://www.megapulse.com/

Selected web sites related to hydrography

Hydrographic Society	http://hydrography.ims.plym.ac.uk/hydsoc.html

Selected web sites related to electronic charts and ECDIS:

CHS-EC Division	http://wwwintra.chshq.dfo.ca/chs_hq/ecdis/ecdis.html
CHS-ENCs	http://csx.cciw.ca/dfo/chs/dd/enc.html
ChartNet	http://wwwintra.chshq.dfo.ca/cidas/cidas.html
C-Map	http://www.c-map.com/
C-Map library	http://www.c-map.com/cmaplibr.html
Nautical Data International	http://www.ndi.nf.ca/
Offshore Systems Limited	http://www.osl.com/
Navionics	http://www.navionics.com/
Seven C's	http://www.sevencs.com/

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Appendix D: Glossary

A/G	Air Ground
AAC	Airline Administrative Communications
ACARS	Aircraft Communications Addressing and Reporting System
ACAS	Airborne Collision Avoidance System
Aces	Proposed geostationary mobile communications satellite system
ADS	Automatic Dependent Surveillance
AFTN	Aeronautical Fixed Telecommunications Network
AIS	Automatic Identification System
AMS(R)S	Aeronautical Mobile-Satellite (R) Service, (R) means en-route
AMSS	Aeronautical Mobile Satellite System
AOC	Aeronautical Operational Control
APANPIRG	Asia/Pacific Air Navigation Planning and Implementation Regional Group
APC	Aeronautical Passenger Correspondence
APEC	Asia Pacific Economic Cooperation
ARINC (xxx)	ARINC Specification (+ number)
ASDE	Airport Surface Detection Equipment
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Services
BPS	Bits Per Second
BPSK	Binary Phase Shift Keying
BRM	Bridge Resource Management
C/A	Coarse/Acquisition
CCG	Canadian Coast Guard
CCW	Coded Continuous Wave
CDMA	Carrier Detect Multiple Access
CGSIC	Civil GPS Service Interface Committee
Chayka	Russian version of Loran C
CHS	Canadian Hydorgraphic Service
CIDAS	Compusult Integrated Data Access
CNS	Communications, Navigation and Surveillance
CNS/ATM	Communication, Navigation, Surveillance/Air Traffic Management
COWLIS	Costal Ocean Water Level Information System
CRT	Cathode Ray Tube

CSL	Canadian Steamship Lines
DGPS	Differential Global Positioning System
DMA	Defense Mapping Agency
DME	Distance Measuring Equipment
DME/P	Precision Distance Measuring Equipment
DOD	Department of Defense
DOT	Department of Transportation
drms	Distance Root Mean Squared
DSC	Digital Selective Calling
DSP	Digital Signal Processor
ECBF	Earth Centered Body Fixed
ECDIS	Electronic Chart Display Information System
ECEF	Earth Centered Earth Fixed
ECS	Electronic Chart System
ENC	Electronic Navigational Chart
EPIRB	Emergency Position Indicating Radio Beacon
ERNP	European Radio Navigation Plan
FAA	Federal Aviation Administration
FANS	Future Air Navigation Systems
FCC	Federal Communications Commission
FERNS	Far East Radio Navigation Service
FIG	International Federation of Surveyors
FIR	Flight Information Region
FM	Frequency Modulation
G/G	Ground-to-Ground
GCA	Ground Control Approach
GEO	Geostationary Earth Orbit
GES	Ground Earth Station
GIC	GNSS Integrity Channel
Global ICO	Proposed intermediate circular orbit mobile communications satellite system
Globalstar	Proposed low earth orbit mobile communications satellite system
GLONASS	Global Navigation Satellite System (Russian Federation)
GMDSS	Global Marine Distress Safety System
GNSS	Global Navigation Satellite System
GNSSP	Global Navigation Satellite System Panel
GPS	Global Positioning System
GSM	Global System for Marine Communications
GT	Gross Tonnes
HDD	High Density Depth
HF	High Frequency

HGE	Harmonization Group for ECDIS
Hz	Hertz (cycles per second)
IALA	International Association of Lighthouse Authorities
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICO	Intermediate Circular Orbits
IEC	International Electrotechnical Commission
IGS	International GPS Service for Geodynamics
IHO	International Hydrographic Organization
ILS	Instrument Landing System
IMO	International Maritime Organization
INMARSAT	International Maritime Satellite Organisation
INS	Inertial Navigation System
Iridium	Proposed low earth orbit mobile communications satellite system
IRS	Inertial Reference System
ISO	International Standards Organization
ITS	Intelligent Transportation Systems
JMSA	Japanese Maritime Safety Agency
kHz	Kilohertz
km	Kilometre
kW	KiloWatts
LAAS	Local Area Augmenation System
LADGPS	Local Area Differential GPS
LAT	Lowest Astronomical Tide
LEO	Low Earth Orbit
LIDAR	Airborne laser bathymetry
LOP	Line of Position
LORAN - C	Long Range Navigation - C
MARPOL	International Convention for the prevention of pollution from ships
MCS	Master Control Station
MCW	Modulated Carrier Wave
MF	Medium Frequency
Mhz	Megahertz
MLS	Microwave Landing System
MNPS	Minimum Navigational Performance Specifications
MSK	Minimum Shift Keying
MTSAT	Multi-Functional Transport Satellite
NAVAID	Navigational Aid
NDB	Nondirectional Beacon
NDI	Nautical Data International
nmi	Nautical Mile

NMEA	National Marine Electronics Association
NNSS	Navy Navigation Satellite System (Transit)
NOAA	National Oceanic and Atmospheric Administration
NPA	Non-precision Approach
Odessey	Proposed intermediate circular orbit mobile communications satellite system
Omega	Ground-based VLF Navigation System (not an acronym)
OPTUS	Name of one of Australia's Telecommunications Providers
OSI	Open System Interconnection
OTF	On-The-Fly
PDD	Presidential Decision Directive
PDOP	Position Dilution of Precision
PHMI	Probablility of Hazardously Misleading Information
PPS	Precise Positioning Service
PRN	Pseudo-Random Noise
PSR	Primary Surveillance Radar
R&D	Research and Development
R,E&D	Research, Engineering and Development
RDF	Radio Direction Finder
RGCSP	Review of the General Concept of Separation Panel
RINEX	Receiver Independent Exchange
RNAV	Area Navigation
RNP	Required Navigation Performance
RTCM	Radio Technical Commission for Maritime Services
RTK	Real-Time Kinematic
SA	Selective Availability
SAR	Search and Rescue
SARPS	Standards and Recommended Practices (ICAO)
SatNav	Satellite Navigation
SC	Special Committee (RTCA)
SINECO	French for COWLIS
SOLAS	International convention for the Safety of Life at Sea
SPS	Standard Positioning Service
SSR	Secondary Surveillance Radar
Starsys	Proposed low earth orbit mobile communications satellite system
STOL	Short Take-Off and Landing
TACAN	Tactical Air Navigation
TD	Time Difference
TDMA	Time Division Multiple Access
UHF	Ultra High Frequency
UKC	Under Keel Clearance
USCG	United States Coast Guard

USFRP	United States Federal Radionavigation Plan
VHF	Very High Frequency
VLF	Very Low Frequency
VOLMET	Volet Meteorological
VOR	VHF Omnidirectional Radio Range
VORTAC	Collocated VOR and TACAN
VTMS	Vessel Traffic Management System
VTOL	Vertical Take-Off and Landing
VTS	Vessel Traffic Services
WAAS	Wide Area Augmentation System
WADGNSS	Wide Area Differential GNSS
WADGPS	Wide Area Differential GPS
WGS	World Geodetic System
WGS-84	World Geodetic Reference System 1984
WMS	Wide Area Master Stations
WRS	Wide Area Reference Stations

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