1992 FEDERAL RADIONAVIGATION PLAN

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Letter of Promulgation

This letter promulgates the seventh edition of the Federal Radionavigation Plan, which was prepared jointly by the Departments of Defense and Transportation. It supersedes the 1990 Federal Radionavigation Plan.

The Federal Radionavigation Plan is published to provide information on the management of those Federally provided radionavigation systems used by both the military and civil sectors. It supports the planning, programming and implementing of air, marine, land and space navigation systems to meet the requirements shown in the President's budget submission to Congress. This plan is the official source of radionavigation policy and planning for the Federal Government, and has been prepared with the assistance of other Government agencies.

The Federal Radionavigation Plan is revised biennially. Your suggestions for the improvement of future editions are welcomed.

Richard B. Cheney
Secretary of Defense

Andrew H. Card, Jr.
Secretary of Transportation

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13. ABSTRACT (Maximum 200 words)

The Federal Radionavigation Plan (FRP) delineates policies and plans for radionavigation services provided by the U.S. Government to ensure efficient use of resources and full protection of national interests. Developed jointly by the U.S. Departments of Defense and Transportation, the FRP sets forth the Federal interagency approach to the implementation and operation of radionavigation systems.

The FRP is updated biennially. This seventh edition describes respective areas of authority and responsibility, and provides a management structure by which the individual operating agencies will define and meet requirements in a cost-effective manner. Moreover, this edition contains the current policy on the radionavigation systems mix. The constantly changing radionavigation user profile and rapid advancements in systems technology, require that the FRP remain as dynamic as the issues it addresses. This edition of the FRP builds on the foundation laid by previous editions and further develops national plans towards providing an optimum mix of radionavigation systems for the foreseeable future.

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Preface

The Department of Defense (DOD) and the Department of Transportation (DOT) have developed the seventh edition of the Federal Radionavigation Plan (FRP) to ensure full protection of national interests and efficient use of resources. The plan sets forth the Federal interagency approach to the implementation and operation of Federally provided, common-use radionavigation systems.

The FRP is a review of existing and planned radionavigation systems used in air, space, land, and marine navigation and for purposes other than navigation in terms of user requirements and current status. The FRP contents reflect DOD responsibility for national security, as well as DOT responsibilities for public safety and transportation economy.

The plan is updated biennially. The established DOD/DOT interagency management approach allows continuing control and review of U.S. radionavigation systems. Your inputs on this plan are welcome. Interested parties and advisory groups from the private sector are invited to submit their inputs to the Chairman of the DOT Navigation Working Group (Attn: DRT-20), Department of Transportation, Research and Special Programs Administration, Washington, DC 20590.

Public Radionavigation User Conferences that will provide radionavigation system users the opportunity to comment on this document are planned to be held in November and December, 1993.

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Executive Summary

The Federal Radionavigation Plan (FRP) delineates policies and plans for Federally provided radionavigation services. It also recognizes that the existence of privately operated radio-determination systems may impact future government radionavigation planning. This plan describes areas of authority and responsibility and provides a management structure by which the individual operating agencies can define and meet radionavigation requirements in a cost-effective manner. It is the official source of radionavigation policy and planning for the Federal Government. This edition of the FRP updates and replaces the 1990 FRP and incorporates common-use radionavigation systems (i.e., systems used by both civil and military sectors) covered in the Department of Defense (DOD) Chairman, Joint Chiefs of Staff (CJCS) Master Navigation Plan (MNP). The MNP covers many radionavigation systems used exclusively by the military, and has not been superseded by the FRP.

This document describes the various phases of navigation and other applications of radionavigation services, and provides current and anticipated requirements for each. As requirements change, radionavigation systems may be added or deleted in subsequent revisions to this plan.

The FRP covers common-use, Federally operated systems. These systems are sometimes used in combination or with other systems. Privately operated systems are recognized in the interest of providing a complete picture of U.S. radionavigation.

The systems covered in this plan are:

- Loran-C
- Omega
- VOR and VOR/DME
- TACAN
- ILS
- MLS
- Transit
- Radiobeacons
- GPS
- Differential GPS
- Vessel Traffic Services

Differential GPS (DGPS) is an enhancement to the GPS system; however, due to the unique characteristics of DGPS, it is addressed as a separate system in this document. Vessel Traffic Services (VTS) are also discussed, because DGPS is an essential component of the system being installed at Valdez, Alaska, and has the potential for application in future VTS.

A major goal of DOD and the Department of Transportation (DOT) is to select a mix of these common-use civil/military systems which meets diverse user requirements for accuracy, reliability, availability, integrity, coverage, operational utility, and cost; provides adequate capability for future growth; and eliminates unnecessary duplication of services. Selecting a future radionavigation systems mix is a complex task, since user requirements vary widely and change with time. While all users require services that are safe, readily available and easy to use, military requirements stress unique defense capabilities, such as performance under intentional interference, operations in high-performance vehicles, worldwide coverage, and operational capability in severe environmental conditions. Cost remains a major consideration which must be balanced with a needed operational capability.

Navigation requirements range from those for small single-engine aircraft or small vessels, which are cost-sensitive and may require only minimal capability, to those for highly sophisticated users, such as airlines or large vessel operators, to whom accuracy, flexibility, and availability may be more important than initial cost. The selection of an optimum mix to satisfy user needs, while holding the number of systems and costs to a minimum, involves complex operational, technical, institutional, international and economic trade-offs. This plan establishes a means to address user inputs and questions, and arrive at an optimum mix determination. This edition of the FRP builds on the foundation laid by previous editions and further develops national plans toward providing an optimum mix of radionavigation systems. The constantly changing radionavigation user profile and rapid advancements in systems technology require that the FRP remain as dynamic as the issues it addresses. This issue of the FRP contains the current policy on the radionavigation systems mix.

This document is composed of the following sections:

Section 1 - *Introduction to the Federal Radionavigation Plan:* Delineates the purpose, scope and objectives of the plan, presents the DOD and DOT authority and responsibilities for providing radionavigation services, and describes the DOD/DOT policy and plan for the radionavigation system mix.

Section 2 - *Radionavigation System User Requirements:* Provides civil and military requirements for air, space, land, and marine navigation.

Section 3 - *Radionavigation System Use:* Describes how the various radionavigation systems are used in meeting civil requirements, and the status and plans for each system.

Section 4 - *Radionavigation Research, Engineering and Development Summary:* Presents the research, engineering, and development efforts planned and conducted by DOT and DOD.

Appendix A - *System Descriptions:* Describes present and planned navigation systems in terms of ten major parameters: signal characteristics, accuracy, availability, coverage, reliability, fix rate, fix dimensions, system capacity, ambiguity, and integrity.

Appendix B - *Interim Guidance for Installation and Approval of Global Positioning System (GPS) Equipment in Aircraft:* Provides interim guidance from the Federal Aviation Administration on GPS equipment.

Appendix C - *Chart Reference Systems:* Discusses geodetic datums and the chart reference systems based upon them.

Appendix D - *Definitions*

Appendix E - *Glossary*

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1

Introduction to the Federal Radionavigation Plan

This section describes the background, purpose, and scope of the Federal Radionavigation Plan (FRP). It summarizes the events leading to the preparation of this document and the national objectives for coordinating the planning of radionavigation services. The remaining contents of Section 1 set forth National Policy, Radionavigation Authority and Responsibility, and Radionavigation System Planning.

1.1 Background

The first edition of the FRP was released in 1980 as part of a Presidential Report to Congress, prepared in response to the International Maritime Satellite (INMARSAT) Act of 1978. It marked the first time that a joint Department of Transportation/Department of Defense (DOT/DOD) plan for common-use systems (e.g., systems used by both the civil and military sectors) had been developed. Now, this biennially-updated plan serves as the planning and policy document for all present and future Federally provided radionavigation systems. This edition also reflects input obtained at the radionavigation user conferences held in 1991.

The 1979 DOD/DOT Interagency Agreement for joint radionavigation planning, as well as for the development and publication of the FRP, was renewed in 1990. This agreement recognizes the need to coordinate all Federal radionavigation system planning and to attempt, wherever consistent with operational requirements, to utilize common systems. Since the publication of the first edition of the FRP, there have been significant changes in the radionavigation environment. Although the Global Positioning System (GPS) is a principal driving force in the FRP, other external factors such as breakthroughs in low-cost Loran-C receiver technology, marketplace pressures, and increasing private sector involvement have affected the evolution of the FRP.

The FRP also has an impact on international radionavigation planning. This has been recognized in the process of selecting the future radionavigation systems mix. The FRP has been distributed to working groups within the International Maritime Organization (IMO), the International Civil Aviation Organization (ICAO), the International Association of Lighthouse Authorities (IALA), and other organizations.

The 1990 FRP began an expanded discussion of land uses of radionavigation systems. This was driven primarily by a recognition of the use of systems such as GPS and Loran-C in land transportation applications. The 1992 FRP continues to update discussions on land applications.

The 1991 radionavigation user conferences indicated a strong support for GPS as the primary navigation system of the future in commercial aviation. Users emphasized GPS as a national resource and focused on the applications of differential GPS (DGPS) in aviation, challenging the need for MLS in areas where DGPS can meet civil aviation needs. There were indications that the FRP should adopt a more global perspective, at least for GPS, considering the international civil aviation community's interest in global satellite navigation systems. Marine radiobeacons received increased attention because of their widespread international use and planned use in maritime DGPS services. The conferences also clearly indicated that many users of radionavigation services are anticipating the operational availability of GPS. Omega discussions focused on the extensive use of the system in meteorological radiosondes.

The need to consolidate and reduce the number of systems is a major objective of DOD and DOT. The constantly changing radionavigation user profile and rapid advancements in systems technology require that the FRP remain as dynamic as the issues addressed. The current DOD/DOT policy on the radionavigation systems mix is presented in Section 1.6.

1.2 Purpose

The purpose of this FRP is to:

- Present an integrated Federal policy and plan for all common-use civil and military radionavigation systems.

- Provide a document for specifying radionavigation requirements and addressing common-use systems and applications.
- Outline an approach for consolidating radionavigation systems.
- Provide government radionavigation system planning information and schedules.
- Define and clarify new or unresolved common-use radionavigation system issues.
- Provide a focal point for user input.

1.3 Scope

This plan covers Federally provided, common-use radionavigation systems, acknowledging that these systems can be used for other purposes. It also briefly addresses privately owned systems such as RACONs, radiodetermination satellite systems, and others that interface with or impact Federally provided systems. The plan does not include systems which mainly perform surveillance and communication functions.

The major systems subject to the planning process described in this FRP are:

- Loran-C
- Omega
- VOR and VOR/DME
- TACAN
- ILS
- MLS
- Transit
- Radiobeacons
- GPS
- Differential GPS
- VTS

Differential GPS (DGPS) is an enhancement to the GPS system; however, due to the unique characteristics of DGPS, it is addressed as a separate system in this document.

Transit, a satellite-based radiodetermination system, is discussed because of its widespread use in marine navigation.

Vessel Traffic Services (VTS) are also discussed, because DGPS is an essential component of the system being installed at Valdez, Alaska, and has the potential for use in future VTS.

1.4 Objectives

The radionavigation policy of the United States has evolved through statute, usage, and in the interest of national defense and public safety. The objectives of U.S. Government radionavigation policy are to:

- Support national security.
- Provide safety of travel and promote environmental protection.
- Promote efficient transportation.

1.5 Policies and Practices

The following policies and practices support the above objectives:

a. Implementation and operation of radio aids to navigation. Services which contribute to safe, expeditious, and economic air, land and maritime commerce and which support United States national security interests are provided.

b. Installation and operation of radionavigation systems in accordance with international agreements.

c. Avoidance of unnecessary duplication of radionavigation systems and services. The highest degree of commonality and system utility between military and civil users is sought through early consideration of mutual requirements.

d. Recognition of electromagnetic spectrum requirements in the planning and management of radionavigation systems.

e. Promotion of transportation safety and environmental protection by requiring certain vessels and aircraft to be fitted with radionavigation equipment as a condition for operating in the controlled airspace or navigable waters of the United States.

f. Direction to ensure that radionavigation services available to civil users meet projected demand, performance, safety, and environmental protection requirements considering economic constraints on radionavigation system providers and users.

g. Evaluation of domestic and foreign radio aids to navigation, with support for the development of those systems having the potential to meet unfulfilled operational requirements; those offering major economic advantages over existing systems; and those providing significant benefits in the national interest.

h. Promotion of international exchange of scientific and technical information concerning radionavigation aids.

i. Guidance and assistance in siting, testing, evaluating, and operating radio aids to meet unique aviation requirements not supported by the Federal Government.

j. Promotion of national and international standardization of civil and military radionavigation aids.

k. Establishment, maintenance, and dissemination of system and signal standards and specifications.

l. Development, implementation, and operation of the minimum special radionavigation aids and services for military operations.

m. Operation of common-use radionavigation systems as long as the United States and its allies accrue greater military benefit than potential adversaries. Operating agencies may cease operations or change characteristics and signal formats of radionavigation systems during a dire national emergency, as declared by the National Command Authority (NCA).

n. Control of Loran-C stations to support non-marine users without degrading service to maritime users.

o. Provision of the GPS Standard Positioning Service (SPS) for continuous, worldwide civil use at the highest level of accuracy consistent with U.S. national security interests.

p. Equipping of military vehicles, as appropriate, to satisfy civil aviation and maritime navigation safety requirements. However, the primary concern will be that U.S. military vehicles and users are equipped with navigation systems which best satisfy mission requirements. Standardization, although important, may be disregarded when unique military systems provide the capability to operate safely without reference to civil radionavigation systems.

q. Establishment of mechanisms, where practical, for users of Federally provided radionavigation aids to bear their fair share of the costs for development, procurement, operation, and maintenance of these systems.

r. Provision, through DOD/DOT interagency agreements, of comprehensive management for all Federally provided common-use radionavigation systems.

s. Ensuring, in accordance with established national policy, reliance on the private sector to support the design, development, installation, operation, and maintenance of all equipment and systems required to provide common-use radionavigation aids in support of this FRP (within the constraints of national security).

1.6 DOD/DOT Policy on the Radionavigation System Mix

The Department of Transportation is responsible under 49 U.S.C. 301 for ensuring safe and efficient transportation. Radionavigation systems play an important role in carrying out this responsibility. The two main elements within DOT that operate radionavigation systems are the United States Coast Guard (USCG) and the Federal Aviation Administration (FAA). The agency responsible for coordinating radionavigation planning within DOT is the Research and Special Programs Administration (RSPA).

The USCG has the responsibility to provide U.S. aids to navigation for safe and efficient marine navigation. The FAA has the responsibility for the development and implementation of radionavigation systems to meet the needs for safe and efficient air navigation, as well as for control of all civil and military aviation, except for military aviation needs peculiar to warfare and primarily of military concern. The FAA also has the responsibility to operate aids to air navigation required by international treaties.

Other elements within DOT have ongoing interests in radionavigation planning. These elements include the St. Lawrence Seaway Development Corporation (SLSDC), the Maritime Administration (MARAD), and the Office of Commercial Space Transportation (OCST). Additional DOT organizations periodically involved in radionavigation planning are the Federal Highway Administration (FHWA), the Federal Railroad Administration (FRA), the National Highway Traffic Safety Administration (NHTSA), and the Federal Transit Administration (FTA).

The Department of Defense (DOD) is responsible for developing, testing, evaluating, implementing, operating, and maintaining aids to navigation and user equipment required for national defense and ensuring that military vehicles operating in consonance with civil vehicles have the necessary navigational capabilities.

All common-use systems operating or planned were considered in developing the policy on the mix of Federally provided radionavigation systems. The statement that follows is the DOD/DOT radionavigation policy for 1992.

Federal Policy and Plans for the Future Radionavigation Systems Mix 1992

Purpose: This statement sets forth the policy and plans for Federally provided radionavigation systems.

Objectives: The Federal Government operates radionavigation systems as one of the necessary elements to enable safe transportation and encourage commerce within the United States. It is a goal of the Government to provide this service in a cost-effective manner. In order to meet both civil and military radionavigation needs, the Government has established a series of radionavigation systems over a period of years. Each system utilizes the latest technology available at the time it was introduced to meet existing or unfulfilled needs. This statement addresses how and for what period each system should be part of the Federal radionavigation systems mix.

The Department of Defense is deploying a new high-technology radionavigation system, the Global Positioning System (GPS), which will have wide civil application on a global basis. This system has the potential to meet or better the accuracy and coverage capabilities of most other radionavigation systems. Consequently, if the full civil potential of GPS is realized, the Department of Transportation will consider phasing out some of the existing radionavigation systems.

Any decision to discontinue Federal operation of existing systems will depend upon many factors including: (a) resolution of GPS accuracy, coverage, integrity, and financial issues; (b) determination that the systems mix meets civil and military needs currently met by existing systems; (c) availability of civil user equipment at prices that would be economically acceptable to the civil community; (d) establishment of a transition period of 10-15 years; and (e) resolution of international commitments.

Radionavigation systems operated by the U.S. Government will be available subject to direction by the National Command Authority (NCA) because of a real or potential threat of war or impairment to national security. Radionavigation systems will be operated as long as the U.S. and its allies accrue greater military benefit than do adversaries. Operating agencies may cease operations or change characteristics and signal formats of radionavigation systems during a dire national emergency.

Individual System Plans:

Loran-C: Loran-C is the Federally provided radionavigation system for the U.S. Coastal Confluence Zone (CCZ). It provides navigation, location, and timing services for both civil and military air, land and marine users. Loran-C is approved as a supplemental air navigation system. It is also approved for nonprecision approaches at certain airports. The Loran-C system now serves the 48 conterminous states, their coastal areas, and certain parts of Alaska. It is expected to remain part of the radionavigation mix through the year 2015.

The DOD requirement for the Loran-C system will end December 31, 1994. Operations conducted by the United States Coast Guard at overseas stations will be phased out by the end of 1994. In the case of stations located outside the U.S., discussions continue between the U.S. and the respective foreign governments concerning the continuation of service after the DOD requirement terminates.

Omega: Omega is currently the only operational radionavigation system that provides global coverage and serves maritime and aviation users. The civil aviation requirement for Omega will remain in effect until GPS is approved to meet the Required Navigation Performance (RNP) criteria for the oceanic en route phase of flight. This is expected to occur in 1995. The U.S. does not expect to end Omega operations before the year 2005. However, the U.S. operates Omega with six partner nations (Norway, Liberia, France, Argentina, Australia, and Japan); therefore, the system is dependent upon continued participation by these nations under bilateral agreements with the U.S. Continued operation after this date would also depend on identifying navigation or non-navigation requirements that are not met by other systems.

The DOD requirement for Omega will end December 31, 1994; however, limited use is expected as long as the system remains operational.

VOR/DME: VOR/DME provides users with the primary means of air navigation in the National Airspace System (NAS). VOR/DME, as the international standard for civil air navigation in controlled airspace, will remain a short-range aviation navigation system through the year 2010.

The DOD requirement for and use of VOR/DME will terminate when aircraft are properly integrated with GPS and when GPS is certified to meet RNP for national and international controlled airspace. The target date is the year 2000.

TACAN: TACAN is a short-range navigation system used primarily by military aircraft.

The DOD requirement for and use of land-based TACAN will terminate when aircraft are properly integrated with GPS and when GPS is certified to meet RNP in national and international controlled airspace. The target date is the year 2000. The requirement for shipboard TACAN will continue until a suitable replacement is operational.

ILS, MLS: ILS is the standard civil landing system in the U.S. and abroad, and is protected by ICAO (International Civil Aviation Organization) agreement to January 1, 1998. ICAO has selected the MLS as the international standard precision approach system, with implementation targeted for 1998. MLS is expected to gradually replace ILS in national and international civil aviation. The FAA and DOD plan to have MLS collocated with ILS to minimize the transition impact.

Transit: Transit is a satellite-based positioning system operated by DOD.

Transit will terminate and system operation will be discontinued in December 1996.

Radiobeacons: Maritime and aeronautical radiobeacons serve the civilian user community with low-cost navigation. Some maritime radiobeacons will be modified to carry differential GPS correction

Differential GPS:

Differential GPS (DGPS) is a system in which differences between observed and predicted GPS signals at a particular location are transmitted to users as a differential correction to upgrade the precision and performance of the user's receiver processor. Several DOT agencies are planning to provide DGPS services.

Maritime DGPS: The USCG plans to provide DGPS service for the harbor and harbor approach phase of maritime navigation. Maritime DGPS will use fixed GPS reference stations which will broadcast pseudo-range corrections using maritime radiobeacons. The USCG DGPS system will provide radionavigation accuracy better than 10 meters (2 drms) for U.S. harbor and harbor approach areas by 1996, free of charge to the user. Until the DGPS service is declared operational by the USCG, users are cautioned that signal availability and accuracy are subject to change due to the dependence on GPS, testing of this developing service, and the uncertain reliability of prototype equipment.

Aeronautical DGPS: The FAA, in cooperation with DOD, is planning to use differential corrections to GPS/SPS in the provision of RNP in the National Airspace System, including approaches to landing in all weather conditions.

All licensed communication links, including those used to transmit differential GPS corrections, are subject to the direction of the NCA. DOD/DOT will not constrain the use of SPS-based differential GPS service as long as applicable U.S. statutes and international agreements are adhered to.

1.7 DOD Responsibilities

DOD is responsible for developing, testing, evaluating, operating, and maintaining aids to navigation and user equipment required for national defense, and for ensuring that military vehicles operating in consonance with civil vehicles have the necessary navigational capabilities. Specific DOD responsibilities are to:

a. Define performance requirements applicable to military mission needs.

b. Design, develop, and evaluate systems and equipment to ensure cost-effective performance.

c. Maintain liaison with other government research and development activities affecting military radionavigation systems.

d. Develop forecasts and analyses as needed to support the requirements for future military missions.

e. Develop plans, activities, and goals related to military mission needs.

f. Define and acquire the necessary resources to accomplish mission requirements.

g. Identify special military route and airspace requirements.

h. Foster standardization and interoperability of systems with NATO and other friendly countries.

i. Operate and maintain ground radionavigation aids as part of the National Airspace System (NAS) when such activity is economically beneficial and specifically agreed to by the appropriate DOD and DOT agencies.

j. Derive and maintain astronomical and atomic standards of time and time interval, and to disseminate these data.

The Defense Mapping Agency (DMA) is responsible for military mapping, charting, and geodesy aspects of navigation, including geodetic surveys, accuracy determination, and positioning. Within DOD, DMA acts as the primary point of contact with the civil community on matters relating to geodetic uses of navigation systems. Unclassified data prepared by the DMA are available to the civil sector.

The U.S. Naval Observatory (USNO) is responsible for determining the positions and motions of celestial bodies, the motions of the Earth and precise time; for providing the astronomical and timing data required by the Navy and other components of DOD and the general public for navigation, precise positioning, and command, control and communications; and for making these data available to other government agencies and to the general public.

DOD carries out its responsibilities for radionavigation coordination through the internal management structure shown in Figure 1-1. The two major parts of the structure represent the administrative and the operational chains of command reporting to the Secretary of Defense.

1.7.1 Operational Management

The President or the Secretary of Defense, with the approval of the President, is the National Command Authority. The Chairman, Joint Chiefs of Staff (CJCS), supported by the Joint Staff, is the primary military advisor to the National Command Authority. The Service Chiefs provide guidance to their military departments in the preparation of their respective detailed navigation plans. The JCS are aware of operational navigation requirements and capabilities of the Unified and Specified Commands and the Services, and are responsible for the development, approval, and dissemination of the CJCS Master Navigation Plan (MNP).

The MNP is the official navigation policy and planning document of the CJCS. It is a coordinated navigation system plan which addresses operational defense requirements.

The following organizations also perform navigation management functions:

The Deputy Director for Defense-Wide Command, Control and Communications Support, Joint Staff, is responsible for:

- Analysis, evaluation, and monitoring of navigation system planning and operations.
- General navigation matters and the CJCS MNP.

The Commanders of the Unified and Specified Commands perform navigation functions similar to those of the JCS. They develop navigation requirements as necessary for contingency plans and JCS exercises that require navigation resources external to that command. They are also responsible for review and compliance with the CJCS MNP.

1.7.2 Administrative Management

Three permanent organizations provide radionavigation planning and management support to the Assistant Secretary of Defense for Command, Control, Communications and Intelligence (ASD/C^3I). These organizations are the Positioning/Navigation (POS/NAV) Executive Committee; the

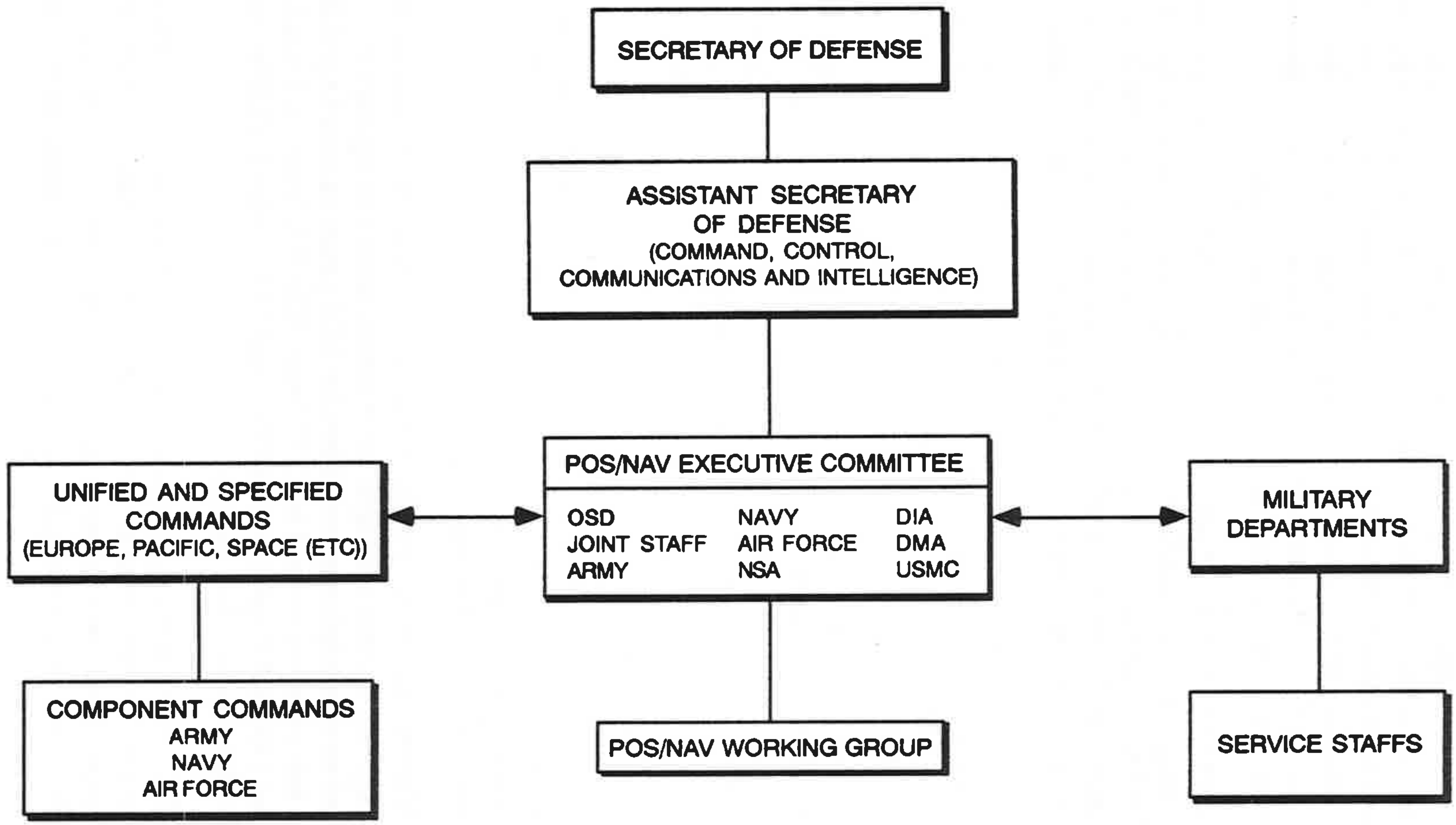


Figure 1-1. DOD Navigation Management Structure

POS/NAV Working Group; and the Military Departments/ Service Staffs. Brief descriptions are provided below.

The DOD POS/NAV Executive Committee is the DOD focal point and forum for all DOD POS/NAV matters. It provides overall management supervision and decision processes, including intelligence requirements (in coordination with the Defense Intelligence Agency and the National Security Agency). The Executive Committee contributes to the development of the FRP and coordinates with the DOT Navigation Council.

The DOD POS/NAV Working Group supports the Executive Committee in carrying out its responsibilities. It is composed of representatives from the same DOD components as the Executive Committee. The Working Group identifies and analyzes problem areas and issues, participates in the revision of the FRP, and submits recommendations to the Executive Committee.

The Military Departments/Service Staffs are responsible for participating in the development, dissemination and implementation of the CJCS MNP and for managing the development, deployment, operation, and support of designated navigation systems.

A special committee, the GPS Phase-In Steering Committee, has been established to guide the development and implementation of the policies, procedures, support requirements, and other actions necessary to effectively phase GPS into the military operational forces.

1.8 DOT Responsibilities

DOT is the primary government provider of aids to navigation used by the civil community and of certain systems used by the military. It is responsible for the preparation and promulgation of radionavigation plans in the civilian sector of the United States.

DOT carries out its responsibilities for civil radionavigation systems planning through the internal management structure shown in Figure 1-2. The structure was originally established by DOT Order 1120.32 (April 27, 1979), and subsequently revised by DOT Order 1120.32A (June 10, 1985), DOT Order 1100.60A (September 24, 1990), and DOT Order 1120.32B (December 9, 1991) for the following purposes:

a. To coordinate policy recommendations and integrate navigation planning among the operating elements of DOT, and to ensure the most efficient implementation of those policies and plans without decreasing the responsibility, or usurping the authority of the individual operating elements.

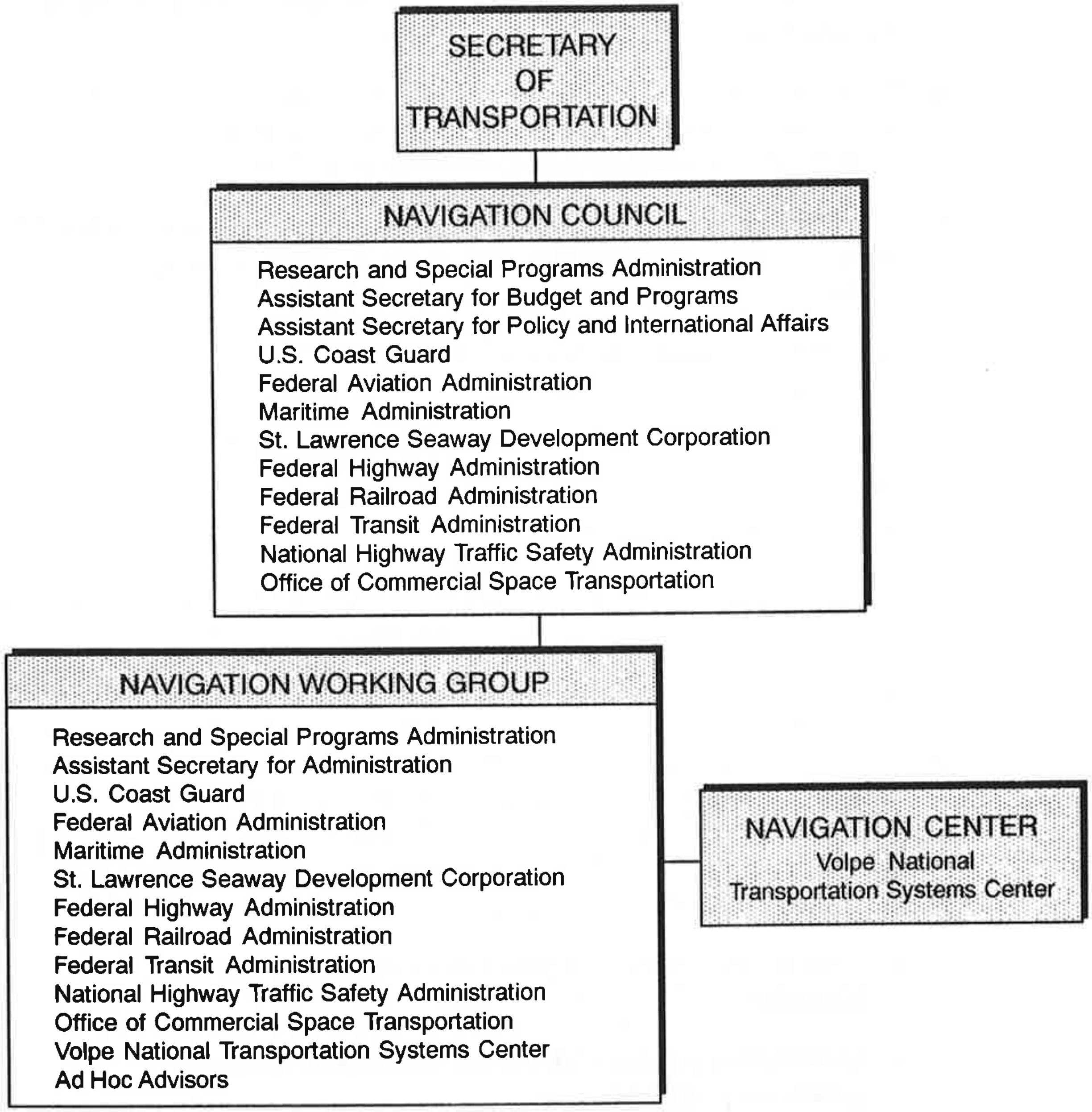


Figure 1-2. DOT Navigation Management Structure

b. To facilitate coordinated navigational planning on a continuing multimodal basis within DOT; and to serve as a focal point for recommendations on DOT navigation policies and plans.

c. To provide the Secretary of Transportation with consolidated information and to provide the means to obtain coordinated high-level review of proposed navigational policies and plans.

d. To establish a plan allowing the DOT operating elements the maximum latitude to conduct navigational system research, development, and implementation while avoiding duplication of effort.

e. To provide supplemental technical resources for the navigation planning, implementation, coordination, and decisionmaking of the operating elements.

f. To coordinate input from those elements of DOT not having a continuous interest in navigational problems.

g. To provide a DOT focal point for multimodal or interdepartmental navigational issues.

h. To provide liaison with DOD.

i. To add the land mode administrations (FHWA, FTA, FRA, and NHTSA) to the Navigation Council and Navigation Working Group.

The DOT Navigation Council is the top level of the structure. It is chaired by the Research and Special Programs Administrator, and includes one policy level representative each from the Office of the Assistant Secretary for Budget and Programs, the Office of the Assistant Secretary for Policy and International Affairs, the USCG, the FAA, MARAD, the SLSDC, the OCST, FHWA, FTA, FRA, and NHTSA. Other operating elements participate as required. The DOT Navigation Council:

- Formulates coordinated policy recommendations to the Secretary.
- Coordinates policies with similar committees in other government agencies.
- Provides unified Departmental comments on the proposed rulemakings of other governmental agencies in regard to radionavigation and related matters.
- Provides guidance to the subordinate Navigation Working Group.

The Navigation Working Group is the core of the structure. It is chaired by an RSPA representative and includes one representative each from the USCG, Office of the Assistant Secretary for Administration, FAA, MARAD, SLSDC, the OCST, FHWA, FTA, NHTSA, and the DOT Volpe National Transportation Systems Center (Volpe Center). Each representative may be assisted by advisors. Ad hoc advisors from other operating elements having an interest in navigation are invited to attend meetings as appropriate. The Center for Navigation, Volpe Center, also provides technical assistance to the Navigation Working Group. The Navigation Working Group facilitates the coordination of:

- Navigation requirements developed by the DOT operating elements.
- Navigation plans.
- Navigation R,E&D and implementation programs.
- DOT navigation planning with DOD, the National Aeronautics and Space Administration (NASA), the Department of Commerce, and other Federal agencies, as required.
- Multimodal navigation issues with other governmental agencies, industry, and user groups, as directed by the Navigation Council.
- Department comments on the proposed rulemakings of other governmental agencies in regard to radionavigation and related matters.
- Suggestions for the improvement of future editions of the FRP.

The Secretary of Transportation, under 49 U.S.C. 301, has overall responsibility for navigational matters within DOT and promulgates radionavigation plans. Three DOT elements have statutory responsibilities for providing aids to navigation: the USCG, the FAA and the SLSDC. In addition, several other elements of DOT and NASA have responsibilities and interests which may be satisfied by radionavigation or radiolocation systems.

RSPA coordinates radionavigation issues and planning which affect multiple modes of transportation, including those that are intermodal in nature.

The USCG has the responsibility to define the need for, and to provide, aids to navigation and facilities required for safe and efficient navigation. Section 81 of Title 14, United States Code states the following:

"In order to aid navigation and to prevent disasters, collisions, and wrecks of vessels and aircraft, the Coast Guard may establish, maintain, and operate:

(1) aids to maritime navigation required to serve the needs of the armed forces or of the commerce of the United States;

(2) aids to air navigation required to serve the needs of the armed forces of the United States peculiar to warfare and primarily of military concern as determined by the Secretary of Defense or the Secretary of any department within the Department of Defense and as requested by any of those officials; and

(3) electronic aids to navigation systems (a) required to serve the needs of the armed forces of the United States peculiar to warfare and primarily of military concern as determined by the Secretary of Defense or any department within the Department of Defense; or (b) required to serve the needs of the maritime commerce of the United States; or (c) required to serve the needs of the air commerce of the United States as requested by the Administrator of the Federal Aviation Administration.

These aids to navigation other than electronic aids to navigation systems shall be established and operated only within the United States, the waters above the Continental Shelf, the territories and possessions of the United States, the Trust Territory of the Pacific Islands, and beyond the territorial jurisdiction of the United States at places where naval or military bases of the United States are or may be located. The Coast Guard may establish, maintain, and operate aids to marine navigation under paragraph (1) of this section by contract with any person, public body, or instrumentality."

The FAA has responsibility for development and implementation of radionavigation systems to meet the needs of all civil and military aviation, except for those needs of military agencies which are peculiar to air warfare and primarily of military concern. FAA also has the responsibility to operate aids to air navigation required by international treaties.

MARAD investigates position determination using existing and planned navigation systems, conducts precision navigation experiments, and investigates the application of advanced technologies for navigation and collision avoidance. These efforts are designed to enhance U.S. Merchant Marine efficiency and effectiveness.

The SLSDC has responsibility for assuring safe navigation along the seaway. The SLSDC provides navigational aids in U.S. waters in the St. Lawrence River and operates a Vessel Traffic Control System with the St. Lawrence Seaway Authority of Canada.

FHWA, NHTSA, FRA, and FTA have the responsibility to conduct research, development, and demonstration projects, including projects on land uses of radiolocation systems. They also assist state and local governments in planning and implementing such systems and issue guidelines concerning their potential use and applications.

The Office of Commercial Space Transportation (OCST) in DOT is charged with: (1) promoting, encouraging, and facilitating commercial space transportation by the U.S. private sector; and (2) ensuring public safety with respect to commercial space transportation, operation of launch sites and spaceports by the U.S. private sector, and commercial satellites not otherwise licensed by another Federal agency. Accordingly, OCST is interested in the demand for space launches by providers of satellite-based services including radiodetermination.

NASA supports navigation through the development of technologies for navigating aircraft and spacecraft. NASA is responsible for development of user and ground-based equipment, and is also authorized to demonstrate the capability of military navigational satellite systems for civil aircraft, ship, and spacecraft navigation and position determination.

1.9 DOD/DOT Interagency Agreement

A Memorandum of Agreement (MOA) between DOD and DOT for radionavigation planning became effective in 1979; it was updated in 1984 and again in 1990. This agreement requires coordination between the DOD and DOT internal management structures for navigation planning. The MOA recognizes that DOD and DOT have joint responsibility to avoid unnecessary overlap or gaps between military and civil radionavigation systems/services. Furthermore, it requires that both military and civil needs be met in a manner cost-effective for the Government and civil user community.

Implicit in this joint responsibility is assurance of civil sector radionavigation readiness for mobilization in national emergencies. The agreement provides that DOD and DOT will jointly:

- Inform each other of the development, evaluation, installation, and operation of radio aids to navigation with existing or potential joint applications.
- Coordinate all major radionavigation planning activities to ensure consistency while meeting diverse navigational requirements.
- Attempt, where consistent with diverse requirements, to utilize common systems, equipment, and procedures.

- Undertake joint programs in the research, development, design, testing, and operation of radionavigation systems.
- Prepare a standard definition of requirements and a joint requirements document (FRP).
- Assist in informing or consulting with other government agencies involved in navigation system research, development, operation, or use, as necessary.
- Publish a single DOD/DOT FRP to be implemented by internal departmental actions. This plan will be reviewed and updated biennially.

1.10 Determination of Future Radionavigation Systems Mix

Many factors determine the choice of the systems mix to satisfy diverse user requirements. They may be categorized according to operational, technical, economic, institutional and/or international parameters. System accuracy and coverage are the foremost technical parameters, followed by system availability and reliability. Certain unique parameters, such as anti-jamming performance, apply to military needs.

The current investment in ground and user equipment must also be considered. In some cases, there may be international commitments which must be honored or modified in a fashion mutually agreeable to all parties.

In most cases, current systems were developed to meet distinct and different requirements, and they will be retained until such needs no longer exist or can be met by an acceptable systems mix. This development of systems to meet unique requirements led to the development of multiple radionavigation systems and was the impetus for early radionavigation planning. The first edition of the FRP was published to plan the mix of radionavigation systems and promote an orderly life cycle for them. It described an approach for selecting radionavigation systems to be used in the future. Early editions of the FRP, including the 1984 edition, reflected that approach with minor modifications to the timing of events. By 1986, it became apparent that a final recommendation on the future mix of radionavigation systems was not appropriate and major changes to the timing of system life-cycle events were required. Consequently, it was decided that starting with the 1986 FRP, a current recommendation on the future mix of radionavigation systems would be issued with each edition of the FRP. This current recommendation reflects dynamic radionavigation technology, changing user profiles, and input received at radionavigation user conferences sponsored by DOT and DOD.

1.10.1 Approach to Selection

There are long-term and short-term aspects that need to be addressed in the overall selection process. The long-term goal is to establish, through an integrated DOD/DOT planning and budgeting process, a cost-effective, user-sensitive, mix of systems for the post-2000 time frame. As part of this long-term goal, until GPS is fully implemented and it can be clearly established which civil requirements being met by existing systems can be met by GPS, there may be a need to improve or expand existing systems. The selection process for the systems to be used in the future allows the flexibility to adopt incremental improvements where justified over the short term. Similarly, the process permits system upgrading and research and development to allow the satisfaction of operational requirements which are not met by existing or planned systems. An example was the combined effort of the USCG and the FAA to provide mid-continent Loran-C coverage.

Figure 1-3 shows the process for selecting the Federally provided radionavigation systems to be used in the future. It is recognized that GPS may not meet the needs of all civil users of radionavigation systems. Therefore, some system life cycles are independent of the GPS implementation date. After GPS is fully operational and its ability to meet user needs has been verified, systems it would potentially replace will be reviewed for future requirements or phase-out.

DOT will maintain liaison with the civil users of radionavigation systems through user conferences or other appropriate means prior to updating the FRP. Input received will become a vital part of the biennial decision-making process on radionavigation system life cycles. This consultation, review, and recommendation cycle will be continued until the ability of GPS to meet civil user needs has been determined. At that time, long-term phase-out or phase-over continuation plans will be considered for those systems replaceable by GPS. During 1993 and 1994, international, intragovernmental, and user consultations will take place on the future of Federally provided radionavigation systems. Developments in GPS and the changing needs of civil users will be reviewed. The status and impact of commercial systems will also be considered as a part of this process. In addition, as an alternative to the phasing out of civil radionavigation systems, consideration will be given to the possibility of phasing over their operation to the private sector.

For each common-use system, the following process is used to select systems to be part of the future radionavigation systems mix. DOT will evaluate civil requirements for a system including requirements for redundancy and, if needed, the system will be retained as part of the systems mix. Evaluating civil user requirements and determining a cost-effective mix of systems requires an open dialogue with civil users and international organizations, such as IMO and ICAO. It also requires a review of U.S. international

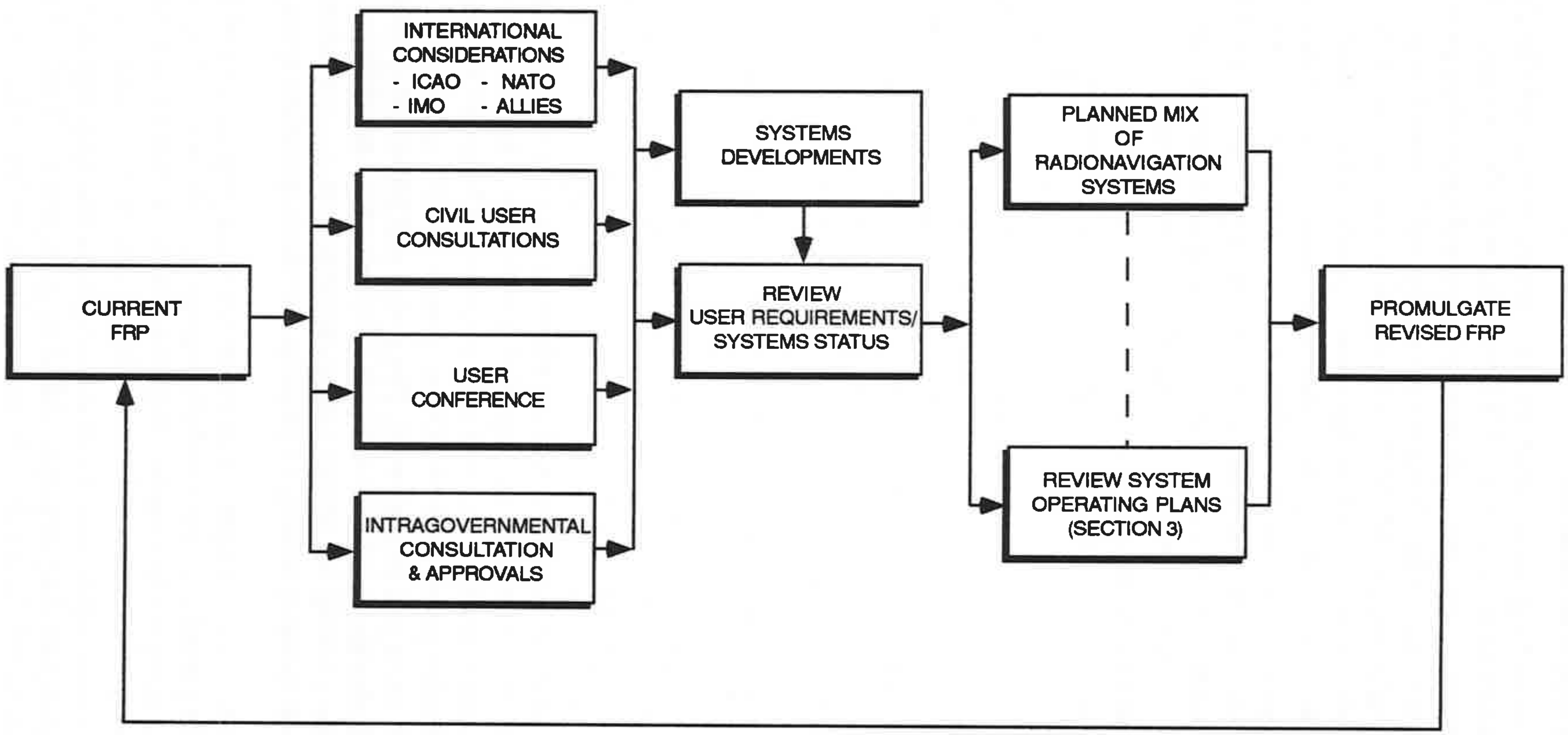


Figure 1-3. DOD/DOT Radionavigation Systems Planning Process

commitments and resolution of any conflicts. DOD decides whether a given system is necessary to meet military requirements and if so, the system will be retained as part of the systems mix. An intensive effort is necessary and desirable to establish a stable framework for long-range planning by users and others affected by the transition to a new combination of systems. Consideration of operational, technical, economic, and institutional issues will dominate this selection process. However, the goal is to meet all military and civil requirements with the minimum number of common-use systems. Finally, a national policy will reflect: (1) national security requirements, (2) consultations with U.S. allies and civil users, and (3) DOD/DOT deliberations.

1.10.2 Operational Issues

Mobile users and operators want the safest, most direct, and economical path to their destinations or, in some cases, the user wants to locate a fixed point or boundary. Users must be able to respond correctly and quickly to traffic control services. They must navigate with accuracy consistent with their environment, the capability of others sharing their space, the performance of their craft, and the rules, regulations, and procedures which govern operations. Areas of operation, mission, economics, personal preference, and Federal regulations largely determine the radionavigation aids chosen by operators. They choose different kinds of equipment to use the particular aid selected, and generally wish to limit or minimize the cost.

1.10.3 Special Military Considerations

A. Military Selection Factors

Operational need is the principal influence in the DOD selection process. Precise navigation is required for vehicles, anywhere on the surface of the Earth, under the sea, and in and above the atmosphere. Other factors that affect the selection process are:

- Flexibility to accommodate new weapon systems and technology.
- Immunity of systems to enemy interference or exploitation.
- Interoperability with the systems used by allies and the civil sector.
- Reliability and survivability in combat.
- Interruption, loss or degradation of system operation by enemy attack, political action, or natural causes.

- Geodetic accuracy relative to a common reference system, to support strategic and tactical operations.

- Worldwide mobility requirements.

B. Civil/Military Compatibility

DOD aircraft and ships operate in, and must be compatible with, civil environments. Thus, there are potential cost advantages in the development of common civil/military systems.

The activities experienced in activation of the maritime Ready Reserve Force during Desert Shield/Desert Storm have identified a potential need for improved navigation accuracy for ships involved in military sealift support. New GPS receiver concepts for systems with optional security modules are under consideration to be used when commercial ships are called into use in national emergencies.

C. Review and Validation

The DOD radionavigation system requirements review and validation process:

- Identifies the unique components of mission requirements.

- Identifies technological deficiencies.

- Determines, through interaction with DOT, the impact of new military requirements on the civil sector.

The requirements review and validation process will investigate system costs, user populations, and the relationship of candidate systems to other systems and functions.

1.10.4 Technical Considerations

In evaluating future radionavigation systems, there are a number of technical factors which must be considered:

- Received signal strength

- Multipath effects

- Signal accuracy

- Signal acquisition and tracking continuity

- Signal integrity

- Availability
- Vehicle dynamic effects
- Signal coverage
- Noise effects
- Propagation
- Interference effects (natural, man-made)
- Installation requirements
- Environmental effects
- Human factors engineering
- Reliability

1.10.5 Economic Considerations

A number of systems may play major roles in navigation in the future. Some of these systems, such as VOR/DME, are limited to use by a single class of users (i.e., aircraft) in specific areas. Others, such as Loran-C, have wider coverage areas and application. Still others, such as GPS, have broad application and global coverage. The optimal policy must consider government investment in future radionavigation systems to meet user requirements, as well as the significant user investment in existing systems and other economic aspects.

There are many benefits derived from radionavigation systems, including improved safety of navigation, greater efficiency in transportation and other commercial activity, and more effective national security. Efficiency in commercial enterprise produces economic benefits which are generally obvious, but not so easily quantifiable. Improvements in general safety and security provide additional, significant economic benefits through the prevention of loss of life and limb, and protection of capital investment.

Direct cost to the Government, as the operator of radionavigation services, and to the user, who must buy the equipment needed to use the services, must be carefully analyzed. The analysis of these costs must consider the initial investment, operation, maintenance and replacement costs, as well as the unamortized capital investment remaining at the time that replacement of the system is contemplated. In the civil sector, the cost of user equipment, more than any other single factor, influences the acceptability of a new system by the majority of civil users. Substantial unamortized investment in user equipment for a current system will cause strong resistance to replacement and the demand for an extended phase-out period.

DOD and DOT are major investors in navigational systems, subsystems, and components. The acquisition of a system which is not cost-effective diverts DOD and DOT resources from more productive uses; therefore, affordability from a life cycle/cost view is a prime concern.

1.10.6 Institutional Considerations

The National Transportation Policy, released by the President on February 26, 1990, is supportive of radionavigation system improvement activities to provide safe and efficient movement of vehicles and cargo in the air, on the highways and railroads, and in the shipping lanes.

The principal institutional considerations in the formulation of a strategy for radionavigation systems selection include the following:

A. *Cost Recovery for Radionavigation Services*

Because of the nature of the electromagnetic medium, radionavigation services presently provided to meet U.S. requirements are available to any suitably equipped user. There is no direct charge or fee levied by the U.S. Government for the use of any of the Federally provided radionavigation systems. The only cost recovery for radionavigation services from civil users, either domestic or foreign, is obtained from the aviation community for DOT provided air transportation services. This cost recovery is achieved through indirect measures, and at this time covers only part of DOT's costs. There is presently no corresponding cost recovery from the marine users of DOT provided radionavigation services.

The National Transportation Policy supports the institution of user fees to recover costs from users of Federally funded or Federally provided services who are not now paying user fees. Fees would be set at an amount so as to generate total revenue from each of the user groups consistent with the cost of the services provided to that group. This policy is part of the Administration's effort to impose user fees where a service provides benefits to identifiable recipients above and beyond those which accrue to the general public. The costs of DOT provided services would be recovered through an appropriate and convenient fee system.

- The USCG will attempt to establish a cost recovery program for those services in which there is a direct transaction such as licensing, inspections, permits, and similar services.

- A majority of the costs of services provided by the FAA is already recovered through the Airport and Airway Trust Fund, which is financed by a system of user fees, including a passenger ticket tax, an aviation gasoline fuel tax, a jet fuel tax, a freight waybill tax, and an international departure tax.

B. Signal Availability in Times of National Emergency

The availability of accurate navigation signals at all times is essential for safe navigation. Conversely, guaranteed availability of optimum performance may diminish national security objectives, so that contingency planning is necessary. The U.S. national policy is that all radionavigation signals (Loran-C, Omega, VOR/DME, TACAN, GPS, DGPS, Transit, and radiobeacons) will be available at all times except during a dire national emergency as declared by the National Command Authority (NCA), when only those radionavigation signals serving the national interest will be available.

C. International Acceptance of Navigational Systems

The goals of standardization and cost minimization of user equipment influence the search for an international consensus on a selection of radionavigation systems. For civil aviation, the ICAO establishes standards for internationally used radionavigation systems. For the international maritime community, a similar role is played by the IMO. Traditionally, IMO has been less stringent in establishing radionavigation requirements for the maritime community than ICAO has been for the aviation community. The IALA also has a working group and a technical committee attempting to develop international radionavigation guidelines. IMO is reviewing existing and proposed radionavigation systems to identify a system or systems that could meet the requirements of, and be acceptable to, members of the international maritime community.

In addition to technical and economic factors, national interests must also be considered in the determination of a system or systems to best meet the civil user's needs. Further international consultations will be required to resolve the issues.

D. Role of the Private Sector

Radionavigation services have historically been operated by the government for reasons of safety and security, and to enhance commerce. These systems are used for air, land and marine applications, including navigation and positioning, and also for time and frequency dissemination.

For certain applications such as positioning and surveying over a limited area, a number of privately operated systems are available to the user as an alternative or adjunct service. The authorization of commercial Radiodetermination Satellite Service (RDSS) by the Federal Communications Commission (FCC) was expected to make radiolocation information available over a wide coverage area. However, former contenders for RDSS have gone into bankruptcy and no longer exist. At the 1992 World Administrative Radio Conference (WARC), a portion of the RDSS frequency allocations were transferred to the Mobile Satellite Service (MSS). Several MSS applicants have announced plans for providing radiolocation services in addition to voice communications. A few experimental licenses were issued by the FCC early in 1992.

Several commercial concerns are now offering differential GPS (DGPS) services for positioning and surveying applications. Operators using licensed U.S. communications links to transmit DGPS corrections are subject to constraints as directed by the National Command Authority (NCA).

Since the role of privately operated systems is increasing, and there is current interest in an increased private sector role in Federally provided radionavigation systems, the whole issue of the private sector role in radionavigation services needs to be examined. Some of the factors to be considered include:

- Impact of privately operated services on usage and demand for Federally operated services.
- Impact of permitting privately operated systems to provide basic safety of navigation services in conjunction with communications services.
- Need for a Federally provided safety of navigation service if commercial services are available.
- Liability considerations.
- Consideration of phase-over to private operation as a viable alternative to phase-out of a Federally operated radionavigation service.

1.10.7 Criteria for Selection

Criteria have been defined to compare alternative navigation system configurations. At the minimum, future systems should meet the following selection criteria:

A. ***Service: Necessary service should be provided to meet the needs of the military and civil communities.***

- Military Operations: At a minimum, navigation services to support accomplishment of DOD tactical and strategic missions should be provided in an effective and efficient manner.
- Transportation Safety: At a minimum, navigation services sufficient to allow safe transportation should be provided.
- Economic Efficiency: To the extent possible and consistent with cost-effectiveness, navigation services which benefit the economy should be provided.

B. ***Viability: Radionavigation systems should be responsive and flexible to the changing operational and technological environments.***

- Orderly Transition: Modification and transition of systems should occur in an orderly manner to accommodate technical improvements.
- Flexibility: Radionavigation services should be provided to a variety of user classes with the minimum number of systems.
- Coverage: Radionavigation services should be provided in all relevant operating areas.
- Evolving Technology: Research and introduction of new systems and concepts should be considered, particularly where unmet requirements or cost savings exist.

C. ***Standardization: A necessary degree of standardization and interoperability should be recognized and accommodated for both domestic and foreign operations.***

- International Acceptance: Navigation services and systems should be technically and politically acceptable to diverse groups, including NATO and other allies, ICAO, and IMO.
- Civil/Military Interoperability: The basic capabilities to permit common use and common operational procedures by civil and military users should be provided.
- Equipment Standardization and Compatibility: Civil and military navigation equipment should be compatible to the extent feasible.

D. *Costs: The required level of service should be achieved in an economical manner.*

- Combined User/Government Costs: Life-cycle costs of a mix of radionavigation systems for government and users should be consistent with adequate service and reasonable benefits.

- Transition Period Cost: Parallel (new and old) system operations should be carried out over a sufficient period to minimize user investment cost penalties and to permit equipment replacement to occur at normal intervals.

2

Radionavigation System User Requirements

The requirements of civil and military users for radionavigation services are based upon the technical and operational performance needed for military missions, transportation safety, and economic efficiency. For civil users, and for military users in missions similar to civil users (e.g., en route navigation), the requirements are defined in terms of discrete "phases of navigation." These phases are categorized primarily by the characteristics of the navigational problem as the mobile craft passes through different regions in its voyage. For example, the ship navigational problem becomes progressively more complex and risky as the large ship passes from the high seas, into the coastal area, and finally through the harbor approach and to its mooring. Thus, it is convenient to view each segment separately for purposes of analysis.

Unique military missions and national security needs impose a different set of requirements which cannot be viewed in the same light. Rather, the requirements for military users are more a function of the system's ability to provide services that equal or exceed tactical or strategic mission requirements at all times in relevant geographic areas, irrespective of hostile enemy action.

In the discussion that follows, both sets of requirements (civil and military) are presented in a common format of technical performance characteristics whenever possible. These same characteristics are used to define radionavigation system performance in Section 3.

2.1 Phases of Navigation

Each mode of transportation has various phases with different requirements to provide safe and cost-effective operation during each phase.

2.1.1 Air

The two basic phases of air navigation are en route/terminal and approach/landing.

A. En Route/Terminal

The en route/terminal phase includes all portions of flight except that within the approach/landing phase. It contains five subphases which are categorized by differing geographic areas and operating environments as follows:

1. Oceanic En Route: This subphase covers operations over ocean areas generally characterized by low-traffic density and no independent surveillance coverage.

2. Domestic En Route (High Altitude and Low Altitude Routes): Operations in this subphase are typically characterized by moderate to high traffic densities. This necessitates narrower route widths than in the oceanic en route subphase. Independent surveillance is generally available to assist in ground monitoring of aircraft position.

3. Terminal: The terminal subphase is typically characterized by moderate to high traffic densities, converging routes, and transitions in flight altitudes. Narrow route widths are required. Independent surveillance is generally available to assist in ground monitoring of aircraft position.

4. Remote Areas: Remote areas are special geographic or environmental areas characterized by low-traffic density and terrain where it has been difficult to cost-effectively implement comprehensive navigation coverage. Typical of remote areas are mountainous terrain, offshore areas, and large portions of the state of Alaska.

5. Operations Between Ground Level and 5,000 feet Above Ground Level (AGL): This subphase is characterized by en route flights between ground level and 5,000 feet AGL. Most rotorcraft operations are conducted in this subphase as well as some fixed wing operations. This subphase typically has limited communication, navigation, and surveillance service because radio signals are easily blocked by terrain and buildings. Traffic density is increasing which may require Air Traffic Control (ATC) services and structure.

B. Approach/Landing

The approach/landing phase is that portion of flight conducted immediately prior to touchdown. It is generally conducted within 10 nautical miles (nm) of the runway. Two subphases may be classified as nonprecision approach and precision approach and landing.

2.1.2 Marine

Marine navigation in the U.S. consists of four major phases identified as inland waterway, harbor/harbor approach, coastal, and ocean navigation. Standards or requirements for safety of navigation and reasonable economic efficiency can be developed around these four phases. Specialized requirements, which may be generated by the specific activity of a ship, must be addressed separately.

A. Inland Waterway

Inland waterway navigation is conducted in restricted areas similar to those for harbor/harbor approach. However, in the inland waterway case, the focus is on nonseagoing ships and their requirements on long voyages in restricted waterways, typified by tows and barges in the U.S. Western Rivers System and the U.S. Intracoastal Waterway System.

In some areas, seagoing craft in the harbor phase of navigation and inland craft in the inland waterway phase share the use of the same restricted waterway. The distinction between the two phases depends primarily on the type of craft. It is made because seagoing ships and typical craft used in inland commerce have differences in physical characteristics, manning, and equipment. These differences have a significant impact upon their requirements for aids to navigation. Recreational and other relatively small craft are found in large numbers in waters used by both seagoing and inland commercial traffic and generally have less rigid requirements in either case.

B. Harbor/Harbor Approach

Harbor/harbor approach navigation is conducted in waters inland from those of the coastal phase. For a ship entering from the sea or the open waters of the Great Lakes, the harbor approach phase begins generally with a transition zone between the relatively unrestricted waters where the navigational requirements of coastal navigation apply, and narrowly restricted waters near and/or within the entrance to a bay, river, or harbor, where the navigator enters the harbor phase of navigation. Usually the harbor phase requires navigation of a well-defined channel which, at the seaward end, is typically from 180 to 600 meters in width if it is used by large ships, but may narrow to as little as 120 meters farther inland. Channels used by smaller craft may be as narrow as 30 meters.

From the viewpoint of establishing standards or requirements for safety of navigation and promotion of economic efficiency, there is some generic commonality between the harbor and harbor approach phases. In each case, the nature of the waterway, the physical characteristics of the vessel, the need for frequent maneuvering of the vessel to avoid collision, and the closer proximity to grounding danger impose more stringent requirements for accuracy and for real-time guidance information than for the coastal phase.

For analytical purposes, the phases of harbor approach and harbor navigation are built around the problems of precise navigation of large seagoing and Great Lakes ships in narrow channels between the transition zone and the intended mooring.

C. Coastal Navigation

Coastal navigation is that phase in which a ship is within 50 nm from shore or the limit of the continental shelf (200 meters in depth), whichever is greater, where a safe path of water at least one mile wide, if a one-way path, or two miles wide, if a two-way path, is available. In this phase, a ship is in waters contiguous to major land masses or island groups where transoceanic traffic patterns tend to converge in approaching destination areas; where interport traffic exists in patterns that are essentially parallel to coastlines; and within which ships of lesser range usually confine their operations. Traffic-routing systems and scientific or industrial activity on the continental shelf are encountered frequently in this phase of navigation. Ships on the open waters of the Great Lakes also are considered to be in the coastal phase of navigation.

The boundary between coastal and ocean navigation is defined by one of the following which is farthest from land:

- 50 nautical miles from land.
- The outer limit of offshore shoals, or other hazards on the continental shelf.
- Other waters where traffic separation schemes have been established, and where requirements for the accuracy of navigation are thereby made more rigid than the safety requirements for ocean navigation.

D. *Ocean Navigation*

Ocean navigation is that phase in which a ship is beyond the continental shelf (200 meters in depth), and more than 50 nm from land, in waters where position fixing by visual reference to land or to fixed or floating aids to navigation is not practical. Ocean navigation is sufficiently far from land masses so that the hazards of shallow water and of collision are comparatively small.

2.1.3 Land

In comparison with the air and marine communities, there are still no well-defined phases of land navigation, as user requirements are not yet clearly defined. Ongoing work on Intelligent Vehicle Highway Systems (IVHS) architecture development is expected to result in clarification of user requirements.

In-vehicle land navigation applications using radionavigation systems are under development. Extensive deployment and use of land navigation systems may depend on the development of digitized map (display) screens. These systems are being developed by the automotive and commercial vehicle industry. Some of the potential applications include automatic vehicle location (AVL), automatic vehicle monitoring (AVM), response to emergency and medical services requests, provision of passenger and driver information, and collision avoidance applications relevant to railroad, mass transit and highway systems.

A number of ongoing and planned IVHS field operational tests are evaluating such systems with digital maps combined with various radionavigation techniques including GPS and radiobeacons. See Appendix A for a summary of IVHS technology areas and Section 4.3.2.C for a brief description of the IVHS field tests.

The railroad industry is privately developing a train control system that will utilize radionavigation for train location information.

Examples of surveying applications include densification control, corridor and project control, mapping control, structure control, cadastral surveys, and airborne GPS photogeometry control.

2.1.4 Space

For Earth-orbiting space activities, the mission phases can be generally categorized as the ground launch phase, the on-orbit phase, and the reentry and landing phase. In addition to the government sponsored space activities coordinated by NASA, there is a growing U.S. commercial space transportation industry seeking to launch both government and private payloads. There is also a growing private sector presence in space commerce that reflects sizable investments in such emerging uses as materials processing, land mobile services, radiodetermination, and remote sensing.

A. Ground Launch Phase

This phase is defined as that portion of the mission from the point at which a vehicle leaves the launch pad to the point wherein the vehicle (or the payload launched by the vehicle) is inserted into Earth orbit.

B. On-Orbit Phase

This is the phase wherein key operations or data gathering from an experiment to meet the primary mission objectives is performed. During this phase, the launch vehicle may deploy a satellite or perform positional maneuvers in support of onboard experiments. Vehicles capable of reentry may also retrieve a satellite for return to Earth. This phase essentially ends when the vehicle has completed its mission or initiates de-orbit maneuvers. In this phase, free-flying spacecraft perform their experiments and operations in their required orbits. In those cases where the spacecraft will not be returned to Earth, this operational phase continues until such time as the spacecraft is shut down or can no longer perform its functions. For those spacecraft to be returned to Earth, this phase essentially ends when the spacecraft is either retrieved by a reentry vehicle or returns to Earth on its own.

C. Reentry and Landing Phase

This phase begins when a reentry vehicle, possibly with onboard experiments or a retrieved spacecraft, initiates de-orbit maneuvers. The vehicle goes through atmospheric entry and makes an unpowered landing. This phase ends when the vehicle comes to a full stop.

2.2 Civil Radionavigation Requirements

The radionavigation requirements of civil users are determined by a DOT process which begins with acknowledgment of a need for service in an area or for a class of users. This need is normally identified in public safety and cost/benefit need analysis generated internally, from other Federal agencies, from the user public, or as required by Congress. User conferences have highlighted land user needs not previously defined.

Radionavigation services provide civil users with the following:

- Service adequate for safety.

- Economic performance/benefit enhancement.
- Support of an unlimited number of users.
- Continuous availability for fix information.

Radionavigation system replacement candidates must be subjected to a total system analysis in terms of safety and economic performance. This involves the evaluation of a number of complex factors. Replacement decisions will not be made on the basis of a simple comparison of one performance characteristic such as system accuracy.

2.2.1 Process

The requirements for an area or class of users are not absolutes. The process to determine requirements involves:

- Evaluation of the acceptable level of safety risks to the Government, user, and general public as a function of the service provided.
- Evaluation of the economic needs in terms of service needed to provide cost-effective benefits to commerce and the public at large. This involves a detailed study of the service desired measured against the benefits obtained.
- Evaluation of the total cost impact of any government decision on radionavigation users.

This process leads to government selection of a system. The decision is driven primarily by considerations of safety and economic benefit.

2.2.2 User Factors

User factors requiring consideration are:

- Vehicle size and maneuverability.
- Regulated and unregulated traffic flow.
- User skill and workload.
- Processing and display requirements for navigational information.
- Environmental constraints; e.g., weather, terrain, man-made obstructions.
- Operational constraints inherent to the system.

- Economic benefits.

For most users, cost is generally the driving consideration. The price users are willing to pay for equipment is influenced by:

- Activity of the user; e.g., recreational boaters, air taxi, general aviation, mineral exploration, helicopters, and commercial shipping.
- Vehicle performance variables such as fuel consumption, operating costs, and cargo value.
- Cost/performance trade-offs of radionavigation equipment.

Thus, in the civil sector, evaluation of a navigation system against requirements involves more than a simple comparison of accuracy and equipment performance characteristics. These evaluations must involve the operational, technical, and cost elements discussed above. Performance requirements are defined within this framework.

2.3 Civil Air Radionavigation Requirements

Aircraft navigation is the process of piloting aircraft from one place to another and includes position determination, establishment of course and distance to the desired destination, and determination of deviation from the desired track. Requirements for navigational performance are dictated by the phase of flight operations and their relationship to terrain, to other aircraft, and to the air traffic control process. Aircraft navigation may be achieved through the use of visual procedures during Visual Flight Rules (VFR) operations but requires use of electronic or other nonvisual aids under low-visibility conditions and above Flight Level (FL) 180 (18,000 ft).

Aircraft separation criteria, established by the FAA, take into account limitations of the navigational service available and, in some airspace, the ATC surveillance service. Aircraft separation criteria are influenced by the quality of navigational service, but are strongly affected by other factors as well. The criteria relative to separation require a high degree of confidence that an aircraft will remain within its assigned volume of airspace. The dimensions of the volume are determined by a stipulated probability that performance of the navigation system will not exceed a specified error.

Since navigation is but one function performed by the pilot, the workload for navigation in conjunction with communications, flight control, and engine monitoring must be small enough so that the pilot has time to adequately see and avoid other aircraft when operating using see-and-avoid rules.

The following are basic requirements for the current and future aviation navigation system. The words "navigation system" mean all of the elements to provide the necessary navigation services to each phase of flight. While navigation systems are expected to be able to meet these requirements, implementation of specific capabilities is to be determined by the users, and where appropriate, regulatory authorities.

No single set of navigational and operational requirements, even though they meet the basic requirement for safety, can adequately address the many different combinations of operating conditions encountered in various parts of the world. Requirements applicable to the most exacting region may be considered extravagant when applied to others.

a. The navigation system must be suitable for use in all aircraft types which may require the service without limiting the performance characteristics or utility of those aircraft types; e.g., maneuverability and fuel economy.

b. The navigation system must be safe, reliable, and available; and appropriate elements must be capable of providing service over all the used airspace of the world, regardless of time, weather, terrain, and propagation anomalies.

c. The integrity of the navigation system, including the presentation of information in the cockpit, shall be as near 100 percent as is achievable and, to the extent feasible, should provide flight deck warnings in the event of failure, malfunction, or interruption.

d. The navigation system must have a capability of recovering from a temporary loss of signal in such a manner that the correct current position will be indicated without the need for complete resetting.

e. The navigation system must automatically present to the pilot adequate warning in case of malfunctioning of either the airborne or source element of the system. It must assure ready identification of erroneous information which may result from a malfunctioning of the whole system, and if possible, from an incorrect setting.

f. The navigation system must provide in itself maximum practicable protection against the possibility of input blunder, incorrect setting, or misinterpretation of output data.

g. The navigation system must provide adequate means for the pilot to check the accuracy of airborne equipment.

h. The navigation systems must provide information indications which automatically and radically change the character of its indication in case a divergence from accuracy occurs outside safe tolerance.

i. The navigation system signal source element must provide timely and positive indication of malfunction.

j. The navigational information provided by the systems must be free from unresolved ambiguities of operational significance.

k. Any source-referenced element of the total navigation systems shall be capable of providing operationally acceptable navigational information simultaneously and instantaneously to all aircraft which require it within the area of coverage.

l. In conjunction with other flight instruments, the navigation system must in all circumstances provide information to the pilot and aircraft systems for performance of the following functions:

- Continuous tracking guidance.
- Continuous determination of distance along track.
- Continuous determination of position of aircraft.
- Position reporting.
- Manual or automatic flight.

The information provided by the navigation system must permit the design of indicators and controls which can be directly interpreted or operated by the pilot at his normal station aboard the aircraft.

m. The navigation system must be capable of being integrated into the overall ATC system (communications, surveillance, and navigation).

n. The navigation system should be capable of integration with all phases of flight, including the precision approach and landing system. It should provide for transition from long-range (overwater) flight to short-range (domestic) flight with minimum impact on cockpit procedure/displays and workload.

o. The navigation system must permit the pilot to determine the position of the aircraft with an accuracy and frequency that will (a) ensure that the separation minima used can be maintained at all times, (b) execute properly the required holding and approach patterns, and (c) maintain the aircraft within the area allotted to the procedures.

p. The navigation system must permit the establishment and the servicing of any practical defined system of routes for the appropriate phases of flight.

q. The system must have sufficient flexibility to permit changes to be made to the system of routes and siting of holding patterns without imposing unreasonable inconvenience or cost to the providers and the users of the system.

r. The navigation system must be capable of providing the information necessary to permit maximum utilization of airports and airspace.

s. The navigation system must be cost-effective to both the Government and the users.

t. The navigation system must employ equipment to minimize susceptibility to interference from adjacent radio-electronic equipment and shall not cause objectionable interference to any associated or adjacent radio-electronic equipment installation in aircraft or on the ground.

u. The navigation system must be free from signal fades or other propagation anomalies within the operating area.

v. The navigation system avionics must be comprised of the minimum number of elements which are simple enough to meet, economically and practically, the most elementary requirements, yet be capable of meeting, by the addition of suitable elements, the most complex requirements.

w. The navigation system must be capable of furnishing reduced service to aircraft with limited or partially inoperative equipment.

x. The navigation system must be capable of integration with the flight control system of the aircraft to provide automatic tracking.

y. The navigation system must be able to provide indication of a failure or out-of-tolerance condition of the system within 10 seconds of occurrence during a nonprecision approach.

2.3.1 Navigation Signal Error Characteristics

The unique signal characteristics of a navigation system have a direct effect on determining minimum route widths. The distribution and rate of change, as well as magnitude of the errors, must be considered. Error distributions may contain both bias and random components. The bias component is generally easily compensated for when its characteristics are constant and known. For example, VOR radials can be flight-checked and the bias error reduced or eliminated through correction of the radial used on aeronautical charts.

The Loran-C and Omega seasonal and diurnal variations can also be compensated for by implementing correction algorithms in aircraft equipment logic and by publishing corrections periodically for use in air equipment.

The distribution of the random or nonpredictable varying error component becomes the critical element to be considered in the design of navigation systems. For any selected route width and system accuracy, those systems which have a broad error distribution tend to produce a higher risk of collision than those with a narrow distribution. The rate of change of the error within the distribution is also an important factor, especially when the system is used for approach and landing.

Errors varying at a very high frequency can be readily integrated or filtered out in the aircraft equipment. Errors occurring at a slower rate can be troublesome and result in disconcerting indications to the pilot. An example of one of these would be a "scalloped" VOR signal that causes the Course Deviation Indicator (CDI) to vary. If the pilot attempts to follow the CDI closely, the plane will start to "S" turn frequently. The maneuvering will cause unnecessary pilot workload and degrade pilot confidence in the navigation system. This indication can be further aggravated if navigation systems exhibit different error characteristics during different phases of flight or when the aircraft is maneuvering. The method of determining the total system error is affected by the navigation signal error characteristics. In most current systems the error components are ground system errors, airborne receiver errors, and flight technical errors. These errors are combined using the Root-Sum-Square (RSS) method. In analyzing new systems, it may be necessary to utilize alternative methods of combining errors, but each element must be properly considered.

In summary, the magnitude, nature, and distribution of errors as a function of time, terrain, aircraft type, aircraft maneuvers, and other factors must be considered. The evaluation of errors is a complex process, and the comparison of systems based upon a single error number will be misleading.

2.3.2 Current Aviation Navigation Requirements

The current aviation navigation requirements for all phases of flight are listed in Table 2-1.

En Route/Terminal Phase: The en route/terminal phase of air navigation (as defined in Section 2.1.1.A) includes the following subphases:

- Oceanic En Route
- Domestic En Route
- Terminal
- Remote Area
- Operations Between Ground Level and 5,000 feet AGL

Table 2-1. Controlled Airspace Navigation Accuracy to Meet Current Civil Requirements

PHASE	SUB-PHASE		ALTITUDE FL/FT (AGL)	TRAFFIC DENSITY	ROUTE WIDTH (nm)	SOURCE ACCURACY 2drms (Meters)		SYSTEM USE ACCURACY 2drms (Meters)
EN ROUTE/ TERMINAL	Oceanic		FL 275 to 400	Normal	60	N/A		12.6nm*
	Domestic		FL 180 to 600	Low	16	2,000		7,200
				Normal	8	1,000		3,600
			500 FT to FL 180	High	8	1,000		3,600
	Terminal		500 FT to FL 180	High	4	500		1,800
	Remote		500 FT to FL 600	Low	8 to 20	1,000 to 4,000		3,600 to 14,400
	Special helicopter operations		500 to 5,000 ft	Low (off-shore)	Not determined	1,000 to 2,000		3,600 to 7,200
			500 to 3,000 ft	High (land)	4	500		1,800
APPROACH AND LANDING	Nonprecision		250 to 3,000 ft	Normal	N/A	100		150
	Precision	CAT I	N/A	Normal	N/A	± 17.1 **	± 4.1 ***	N/A
						CAT I Decision Height Point ****		
		CAT II	N/A	Normal	N/A	± 5.2 **	± 1.7 ***	N/A
						CAT II Decision Height Point ****		
		CAT III	N/A	Normal	N/A	± 4.1 **	± 0.6 ***	N/A
						At Runway Threshold ****		

* The distribution of this error is detailed in the "Report of the Limited North Atlantic Regional Air Navigation Meeting," dated 1976; ICAO Montreal, Canada.
** Lateral position ground equipment (2 sigma) accuracy in meters for Precision Approach and Landing.
*** Vertical position ground equipment (2 sigma) accuracy in meters for Precision Approach and Landing.
**** Assumes a 3 ° glideslope and 8,000 ft distance between runway threshold and localizer antenna.

The general requirements in Section 2.3 are applicable to the en route/terminal phase of navigation. In addition, to facilitate aircraft operations in this phase, the system must be capable of being operationally integrated with the system used for approach and landing.

Federal Aviation Regulations (FAR) paragraphs 91.119 and 91.121 specify the vertical separation required below and above Flight Level 290. The current separation requirement is 1,000 feet below FL 290, and 2,000 feet at and above FL 290. In order to justify the 1,000-foot vertical separation below FL 290, the RSS altitude keeping requirement is ±350 feet (3 sigma). This error is comprised of ±250 feet (3 sigma) aircraft altimetry system error, of which the altimeter error is limited to ±125 feet by Technical Standard Order (TSO) C-10B below FL 290.

The minimum performance criteria currently established to meet requirements for the en route/terminal phase of navigation are presented in the following sections.

A. Oceanic En Route

The system must provide navigational capability commensurate with the need in specific areas in order to permit safe navigation and the application of lateral separation criteria. An organized track system has been implemented in the North Atlantic to gain the benefit of optimum meteorological conditions. Since an independent surveillance system such as radar is not available, separation is maintained by procedural means (e.g., position reports and timing).

The lateral separation standard on the North Atlantic organized track system is 60 nm. The following system performance is required to achieve this separation:

1. The standard deviation of the lateral track errors shall be less than 6.3 nm, 1 sigma (12.6 nm, 2 drms).
2. The proportion of the total flight time spent by aircraft 30 nm or more off track shall be less than 5.3×10^{-4}; i.e., less than 1 hour in 2,000 flight hours.
3. The proportion of the total flight time spent by aircraft between 50 and 70 nm off track shall be less than 1.3×10^{-4}; i.e., approximately 1 hour in 8,000 flight hours.

B. Domestic En Route

Domestic air routes are designed to provide airways that are as direct as practical between city pairs having significant air traffic. Via navaids or radials, the protected airspace at FL 600 and below is 4 nm on each side of the route to a point 51 nm from the navaid, then increases in width on either side of the centerline at a 4.5 degree angle to a width of 10 nm on each side of the route at a distance of 130 nm from the navaid.

Current accuracy requirements for domestic en route navigation are based on the characteristics of the VOR/DME/VORTAC system and therefore relate to the angular characteristics of the VOR and TACAN azimuth systems and range characteristics of the DME/TACAN range systems. "System Use Accuracy," as defined by ICAO, is the RSS of the ground station error contribution, the airborne receiver error, the display system contribution, and the Flight Technical Error (FTE). Flight Technical Error is the contribution of the pilot (or autopilot) in using the presented information to control aircraft position. Error values on which the current system is based are as follows:

1. Azimuth Accuracy in Degrees:

Error Component	2 Sigma Deviation Values	Source
VOR Ground	$\pm 1.4^{o}$	Semi-Automatic Flight Inspection (SAFI) System
VOR Air	$\pm 3.0^{o}$	Equipment Manufacturer
Course Selection (CSE)	$\pm 2.0^{o}$	FAA Tests
Flight Technical (FTE)	$\pm 2.3^{o}$	FAA Tests
System Use Accuracy Error (95% Confidence)	$\pm 4.5^{o}$	(RSS derived)

2. Range Accuracy

   Where DME service is used, the system use accuracy is defined as ± 0.5 nm or 3 percent of distance (2 sigma), whichever is greater. This value covers all existing DME avionics. When DME is used with an RNAV system, the range accuracy must be at least ± 0.2 nm plus 1 percent of the distance (2 sigma).

3. Area Navigation (RNAV)

   When RNAV computation equipment is used, an additional error contribution is specified and combined in RSS fashion with the basic VOR/DME system error. The additional maximum RNAV equipment error allowed, per FAA Advisory Circular AC 90-45A, is ± 0.5 nm. RNAV system performance and route design is based on the following error budget:

Error Component	2 Sigma Deviation Values	Source
VOR Ground	$\pm 1.4^{\circ}$	SAFI
VOR Air	$\pm 3.0^{\circ}$	Equipment Manufacturer and FAA Tests
DME Ground	± 0.1 nm	SAFI

The VOR/DME and RNAV error values identified below result in 95 percent of the aircraft remaining within ± 4 nm of the airway centerline out to 51 nm from a VOR facility and within ± 4.5 degrees (originating at the VOR facility) of the airway centerline when beyond 51 nm from a VOR facility.

Error Component	2 Sigma Deviation Values	Source
DME Air	± 0.2 nm + 1% of Range	Equipment Manufacturer*
FTE	± 1.0 nm	FAA Tests**
CSE	$\pm 2.0^{\circ}$	FAA Tests
RNAV System	± 0.5 nm	Equipment Manufacturer and FAA Tests

*Only DME aircraft equipment with this accuracy or better is used.
**FTE - 0.5 nm in the approach phase.

C. *Terminal*

Terminal routes are transitions from the en route phase to the approach phase. The accuracy capability of navigation systems using VOR/DME in terms of bearing and distance to the facility is defined in the same manner as described for en route navigation. However, the usually closer proximity to facilities provides greater effective system use accuracy, since both VOR and FTE are angular in nature and are related to the distance to the facility. The DME distance error is also reduced, since it is proportional to distance from the facility, down to the minimum error capability. Thus the minimum terminal route width is ± 2 nm within 25 nm of the facility, based on RSS combination of error elements.

D. *Remote Areas*

Remote areas are defined as regions which do not meet the requirements for installation of VOR/DME service or where it is impractical to install this system. These include offshore areas, mountainous areas, and a large portion of the state of Alaska. Thus the minimum route width varies and can be greater than ±10 nm.

E. Operations Between Ground Level and 5,000 feet AGL

Operations between ground level and 5,000 feet AGL occur in offshore, mountainous, and high-density metropolitan areas as well as on domestic routes. For operations from U.S. coastline to offshore points, the following requirements must be met:

- Range from shore to 300 nm.
- Minimum en route altitude of 500 feet above sea level or above obstructions.
- Accuracy adequate to support routes ±4 nm wide or narrower with 95 percent confidence.
- Minimum descent altitude to 100 feet in designated areas.

For helicopter operations over land, the following requirements must be met:

- Accuracy adequate to support ±2 nm route widths in both en route and terminal areas with 95 percent confidence.
- Minimum en route altitudes of 1,200 feet AGL.
- Navigation signal coverage adequate to support approach procedures to minimums of 250 feet above obstruction altitudes at heliports and airports.

Approach/Landing Phase: This phase of flight is one of two types: (1) nonprecision approach, or (2) precision approach and landing.

The general requirements of Section 2.3 apply to the approach/landing phase. In addition, specific procedures and clearance zone requirements are specified in TERPS (United States Standard for Terminal Instrument Procedures, FAA Handbook 8260.3B).

Altimetry accuracy requirements are established in accordance with FAR 91.411 and are the same as those for the en route/terminal phase.

The minimum performance criteria currently established to meet requirements for the approach/landing phase of navigation vary between precision and nonprecision approaches.

A. Nonprecision Approach

Nonprecision approaches are based on any navigational system that meets the criteria established in TERPS. Minimum safe altitude, obstacle clearance area, visibility minimum, final approach segment area, etc., are all functions of the navigational accuracy available and other factors. The unique features of Area Navigation (RNAV) for nonprecision approaches are specified in FAA Advisory Circulars No. 90-45A, "Approval of Area Navigation Systems for Use in the U.S. National Airspace System;" No. 20-130, "Airworthiness Approval of Multi-Sensor Navigation Systems in U.S. National Airspace System (NAS) and Alaska;" and 20-121A, "Airworthiness Approval of the Loran-C Navigation System for Use in U.S. National Airspace (NAS) and Alaska."

The achieved capability for nonprecision approaches varies widely, depending on the location of the navigational facility in relation to the fix location and type of navigational system used. Approximately 30 percent of the nonprecision approach fixes based on VOR in the U.S. achieve a cross track navigational accuracy of $\pm$100 meters (2 sigma) at the missed approach point (MAP). This accuracy is based upon the $\pm$4.5 degrees VOR system use accuracy and the MAP being less than 0.7 nm from the VOR facility.

Currently, the integrity requirement for nonprecision approaches is to provide the pilot with either a warning or a removal of signal within 10 seconds of the occurrence of an out-of-tolerance condition.

B. Precision Approach and Landing

Precision approach and landing radio aids provide vertical and horizontal guidance and position information. The Instrument Landing System (ILS) and Microwave Landing System (MLS) are of this type. International agreements have been made to achieve an all-weather landing capability through an evolutionary process, reducing landing weather minima on a step-by-step basis as technical capabilities and operational knowledge permit. The performance objectives for the various landing categories are shown in Table 2-1.

The MLS and ILS system integrities, during precision approaches, warn the pilot of an out-of-tolerance condition by removing these signals from service. The response time for providing these warnings vary from 10 seconds (ILS localizer - Category I) to 1 second (MLS) depending on the system and category of operation.

C. Current System Requirements Summary

The system use accuracy criteria to meet the current route requirements are summarized in Table 2-1. These route widths are based upon present capacities, separation requirements, and obstruction clearance requirements. Availability requirements are being developed.

2.3.3 Future Aviation Radionavigation Requirements

The future aviation radionavigation requirements for all phases of flight are listed in Table 2-2.

The FAA is currently developing a new method of stating navigation requirements to take advantage of new technologies. The new method for stating radionavigation requirements is called Required Navigation Performance (RNP) and will be based on risk analysis using so-called tunnels or windows in space. Aviation radionavigation requirements in the next edition of the FRP are expected to be expressed using this method.

Altimetry requirements for vertical separation of 1,000 feet, below FL 290, are not expected to change. Increased altimetry accuracy is needed at and above FL 290 to permit 1,000 feet separation. The required future 3 sigma value of the aircraft altimetry system error has not been specified, but it must be accurate enough to support the 1,000 feet vertical separation at all flight levels.

En Route/Terminal Phase

A. Oceanic

Lateral separation specifications have been designed to allow a lateral separation of 60 nm. This was put into effect for certain areas of the North Atlantic in early 1981. The 60 nm separation requires a lateral track error of less than $\pm$12.6 nm (2 drms). Further lateral separation reductions are desirable. More timely, accurate, and reliable aircraft position data will enable reductions in lateral separation, resulting in greater capacity and ability to fly user-preferred routes.

B. Domestic En Route

At the present time, the number of VOR/DMEs is sufficient to allow most routes to have widths of $\pm$4 nm. This is possible as most VOR facilities are spaced less than 100 nm apart on the route. However, greater spacings are used in low traffic density areas, remote areas, and on most of the high-altitude route structure. Parts of the high-altitude route structure have a distance between VOR facilities resulting in route widths up to 20 nm.

Traffic increases are causing route capacity problems. More use of RNAV will allow the implementation of random and parallel routes than with the use of current VOR/DME facilities. No increase in VOR/DME ground

Table 2-2. Controlled Airspace Navigation Accuracy to Meet Projected Future Civil Requirements

PHASE	SUB-PHASE	ALTITUDE FL/FT (AGL)	TRAFFIC DENSITY	ROUTE WIDTH (nm)	SOURCE ACCURACY 2 drms (Meters)	SYSTEM USE ACCURACY 2 drms (Meters)
EN ROUTE/ TERMINAL	Oceanic	FL 275 to 400	Normal	Less than 60	N/A	Better than 12.6nm*
	Domestic	FL 180 to 600	Normal	8	1,000	3,600
			High	8	1,000	3,600
		500 ft to FL 180	Normal	8	1,000	3,600
	Terminal	500 ft to FL 180	High	4	500	1,800
	Remote	500 ft to FL 600	Normal	8 to 20	1,000 to 4,000	3,600 to 14,400
	Special helicopter operations	500 ft to 5,000 ft	Low (off-shore)	8	1,000	3,600
		500 ft to 3,000 ft	High (land)	4	500	1,800
APPROACH AND LANDING	Nonprecision	250 to 3,000 ft	Normal	N/A	100	150
	Precision	At runway threshold	Normal	N/A	± 4.0** / ± 0.6***	N/A

** The distribution of this error is detailed in the "Report of the Limited North Atlantic Regional Air Navigation Meeting," dated 1976; ICAO Montreal, Canada.*
*** This value is the ground equipment (2 sigma) azimuth accuracy in meters at the approach reference datum.*
**** This value is the ground equipment (2 sigma) elevation accuracy in meters at the approach reference datum.*

accuracy is required to meet the navigational requirements imposed by the air traffic levels estimated for the year 2000. The current nominal VOR system signal-in-space accuracy that permits 8 nm route widths is ±1,000 meters (2 drms). Any replacement system must have an equivalent accuracy.

C. Terminal

The major change forecasted for the terminal area is the increased use of RNAV and time control to achieve optimum runway utilization and noise abatement procedures. Some current multi-DME RNAV and VOR avionics can provide system use RSS cross track navigational accuracies better than ±500 meters (2 sigma) in terminal areas using the current VOR/DME facilities. A ±500 meter (2 sigma) cross track navigational accuracy is expected to meet the terminal requirements through the year 2000.

D. Remote Areas

Many areas, such as Alaska, the Rocky Mountains and other mountainous areas, and some offshore locations, cannot be served easily or at all by VOR/DME. Presently, nondirectional beacons (NDB), Omega, and privately owned facilities such as TACAN are being used in combination to meet the user navigational needs in these areas. Omega and Loran-C are being used as supplements to VOR/DME to meet these needs. The accuracy and coverage of these systems seem adequate to handle the traffic densities projected for the different areas. For all-weather operations, a system signal in space accuracy of 4,000 meters (2 drms) is proposed, with 1,000 meters (2 drms) or higher accuracy in specific areas.

E. Low-Altitude Operations

Both offshore and onshore low-altitude operations will have navigational requirements at least as stringent as those discussed in Section 2.3.2.E, and coverage extended from 300 nm to 500 nm from shore. Area navigation should be implemented for low traffic density operations. As traffic density increases, the establishment of low-altitude routes may be necessary. Operations in metropolitan areas will require integration of the en route/terminal phase with nonprecision and precision approaches.

Approach/Landing Phase

A. Nonprecision Approach

Changes in navigational requirements for nonprecision approaches are expected due to new and/or modified noise abatement procedures and encroachment on obstacle clearance zones by urban development.

The current estimate of the future requirements for the nonprecision approach navigation system accuracy of 100 meters (2 drms) is that it be able to perform as well as an on-airport VOR. This requirement has been selected for the following reasons:

- Approximately 30 percent of the runways with nonprecision approaches use on-airport VOR.
- These are typically used at the busiest airports. Since they are in urban areas, they have had the most pressure for reduction of clearance areas for additional noise abatement and obstacle encroachment problems.
- Any replacement navigation system must satisfy operational requirements of the function it performs for applicable phases of flight at least as well in all navigational phases as the system it is replacing.

The critical factor in the final approach segment of a nonprecision approach is the size of the obstacle clearance area. The basic VOR obstacle clearance area is a trapezoid beginning at the facility with a width of 2 nm (±1 nm each side of the facility) and expanding linearly to a width of 5 nm (±2.5 nm each side of course) at a distance of 30 nm. A triangular secondary area is attached to each side of the trapezoid. The apex of the secondary area is at the end of the trapezoid nearest the facility and the area expands to a width of 1 nm at 30 nm. This is illustrated in Figure 2-1.

The 100 meter (2 sigma) system accuracy requirement is based on the VOR system accuracy at a distance of 0.7 nm from the VOR. Current RNAV capabilities cannot meet this requirement; however, it seems feasible to provide improved RNAV systems that can meet this requirement.

VORs also meet the integrity criteria for nonprecision approaches by warning the pilot of an out-of-tolerance condition through the removal of the signal from service within 10 seconds after the condition begins. This is not intended to exclude methods meeting the 10-second criteria with other systems.

B. Precision Approach and Landing

The requirements for precision approaches and landings are not expected to change by the year 2020 and are presented in Table 2-2. Availability requirements are being developed.

In order to enhance all-weather operations, a uniform guidance accuracy requirement is proposed as follows:

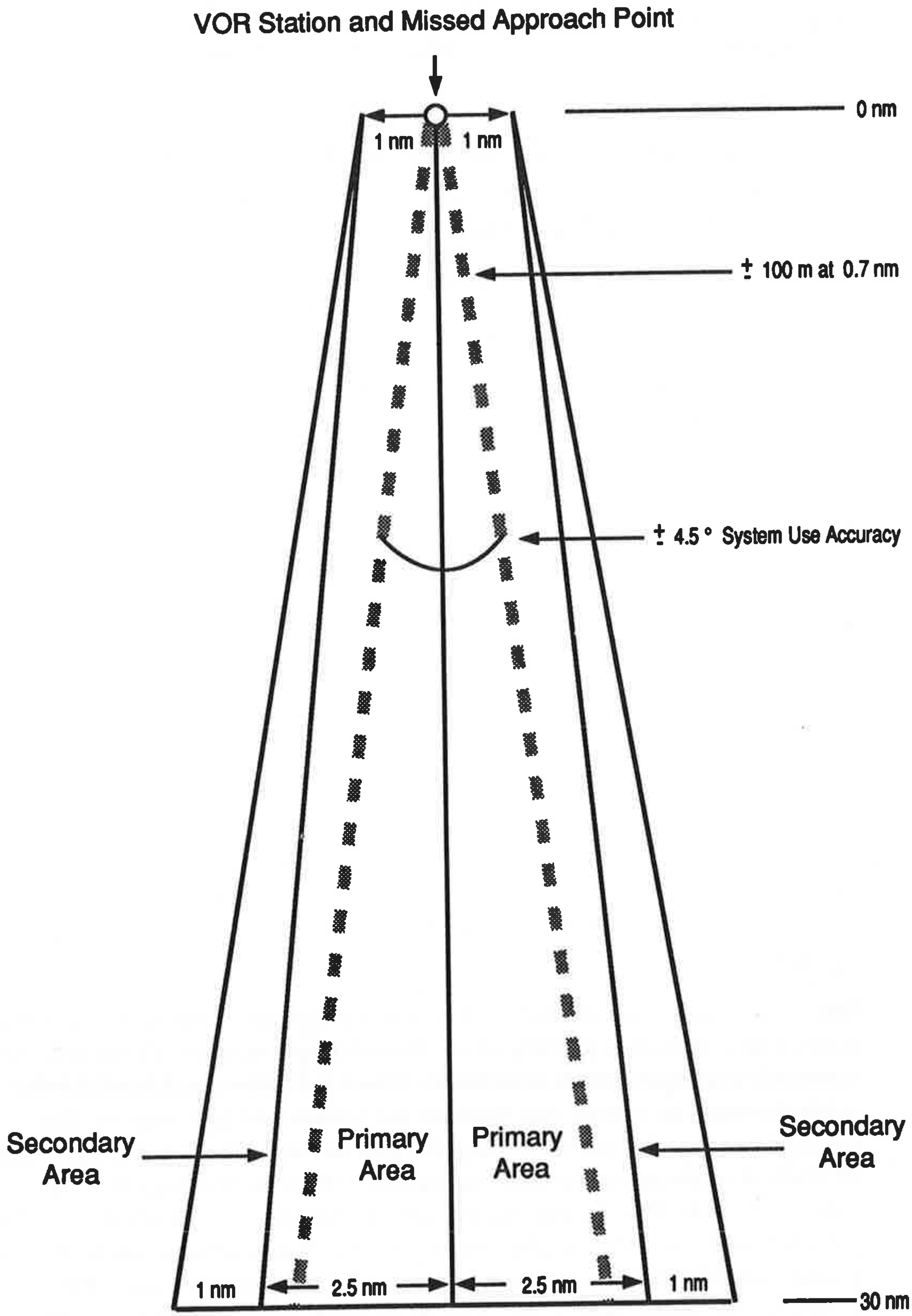


Figure 2-1. Nonprecision Approach Obstacle Clearance Area for Current VOR with MAP at VOR Facility

Accuracy (2 sigma) at the Approach Reference Datum

Lateral	±13.0 feet (±4.0 meters)
Vertical	±2.0 feet (±0.6 meters)

Future Systems Performance Requirements Summary: Table 2-2 represents the best estimate of future minimum accuracy and route criteria to meet the aviation navigational requirements up to the year 2000.

The effectiveness of meeting one or more of these requirements with a combination of subsystems and alternatively with a minimum number of subsystems should be assessed and fully coordinated among government agencies and users.

Consideration should be given to the situation that not all users need all services. Pending the results of this assessment, there is no compelling argument from the aviation user's standpoint for a single source of navigation information.

The life-cycle costs to the Government and to each category of user must be an important element of this continuing assessment of each subsystem.

2.4 Civil Marine Radionavigation Requirements

The navigational requirements of a vessel depend upon its general type and size, the activity in which the ship is engaged (e.g., point-to-point transit, fishing) and the geographic region in which it operates (e.g., ocean, coastal), as well as other factors. Safety requirements for navigation performance are dictated by the physical constraints imposed by the environment and the vessel, and the need to avoid the hazards of collision, ramming, and grounding.

The above discussion of phases of marine navigation (Section 2.1.2) sets the framework for defining safety of navigation requirements. However, the economic and operational dimensions also need to be considered for the wide diversity of vessels that traverse the oceans and U.S. waters. For example, navigation accuracy (beyond that needed for safety) is particularly important to the economy of large seagoing ships having high hourly operating costs. For fishing and oil exploration vessels, the ability to locate precisely and return to productive or promising areas and at the same time avoid underwater obstructions or restricted areas provides important economic benefits. Search and Rescue (SAR) effectiveness is similarly dependent on accurate navigation in the vicinity of a maritime distress incident.

For system planning, the Government seeks to satisfy minimum safety requirements for each phase of navigation and to maximize the economic utility of the service for users. Since the vast majority of marine users are required to carry only minimal navigational equipment, and even then do so only if persuaded by individual cost/benefit analysis, this governmental policy helps to promote maritime safety through a simultaneous economic incentive.

Tables 2-3, 2-4, and 2-5 identify system performance needed to satisfy maritime user requirements or to achieve special benefits in three of the four phases of marine navigation. The tables are divided into two categories. The upper half are those related to safety of navigation. The Government recognizes an obligation to satisfy these requirements for the overall national interest. The lower half are specialized requirements or characteristics needed to provide special benefits to discrete classes of maritime users (and additional public benefits which may accrue from services provided by users). The Government does not recognize an absolute commitment to satisfy these requirements, but does endeavor to meet them if their cost can be justified by benefits which are in the national interest. For the purpose of comparing the performance of systems, the requirements are categorized in terms of system performance characteristics representing the minimum performance considered necessary to satisfy the requirements or achieve special benefits.

2.4.1 Inland Waterway Phase

Very large amounts of commerce move on the U.S. inland waterway system, much of it in slow-moving, comparatively low-powered tug and barge combinations. Tows on the inland waterways, although comparatively shallow in draft, may be longer and wider than large seagoing ships which call at U.S. ports. Navigable channels used by this inland traffic are often narrower than the harbor access channels used by large ships. Restricted visibility and ice cover present problems in inland waterway navigation, as they do in harbor/harbor approach navigation. The long, ribbon-like nature of the typical inland waterway presents special problems to the prospective user of precise, land-based area navigation systems. Continual shifting of navigable channels in some unstable waters creates additional problems to the prospective user of any radionavigation system which provides position measurements in a fixed coordinate system.

Special waterways, such as the Saint Lawrence River and some Great Lakes passages, are well defined, but subject to frequent fog cover which requires ships to anchor. This imposes a severe economic penalty in addition to the safety issues. If a fog rolls in unexpectedly, a ship may need to proceed

Table 2-3. Current Maritime User Requirements/Benefits for Purposes of System Planning and Development - Harbor/Harbor Approach Phase

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS								
	ACCURACY (meters, 2 drms)		COVERAGE	AVAILABILITY	RELIABILITY	FIX INTERVAL	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY
	PREDICTABLE	REPEATABLE							
SAFETY OF NAVIGATION - LARGE SHIPS & TOWS	8-20***	-	U.S. harbor & harbor approach	99.7%	**	6-10 seconds	Two	Unlimited	Resolvable with 99.9% confidence
SAFETY OF NAVIGATION - SMALLER SHIPS	8-20	8-20	U.S. harbor & harbor approach	99.7%	**	***	Two	Unlimited	Resolvable with 99.9% confidence
RESOURCE EXPLORATION	1-5*	1-5m*	U.S. harbor & harbor approach	99%	**	1 second	Two	Unlimited	Resolvable with 99.9% confidence

BENEFITS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO ACHIEVE BENEFITS								
FISHING, RECREATIONAL AND OTHER SMALL VESSELS	8-20	4-10	U.S. harbor & harbor approach	99.7%	**	***	Two	Unlimited	Resolvable with 99.9% confidence

** Based on stated user need.*
*** Dependent upon mission time.*
**** Varies from one harbor to another. Specific requirements are being reviewed by the Coast Guard.*

Table 2-4. Current Maritime User Requirements/Benefits for Purposes of System Planning and Development - Coastal Phase

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS								
	ACCURACY (2 drms)		COVERAGE	AVAILABILITY	RELIABILITY	FIX INTERVAL	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY
	PREDICTABLE	REPEATABLE							
Safety of Navigation All Ships	0.25nm (460m)	-	U.S. coastal waters	99.7%	**	2 minutes	Two	Unlimited	Resolvable with 99.9% confidence
Safety of Navigation Recreation Boats & Other Smaller Vessels	0.25nm-2nm (460-3,700m)	-	U.S. coastal waters	99%	**	5 minutes	Two	Unlimited	Resolvable with 99.9% confidence

BENEFITS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO ACHIEVE BENEFITS								
Commercial Fishing (Including Commercial Sport Fishing)	0.25nm (460m)	50-600 ft (15-180m)	U.S. coastal/ fisheries areas	99%	**	1 minute	Two	Unlimited	Resolvable with 99.9% confidence
Resource Exploration	1.0-100m*	1.0-100m*	U.S. coastal areas	99%	**	1 second	Two	Unlimited	Resolvable with 99.9% confidence
Search Operations, Law Enforcement	0.25nm (460m)	300-600 ft (90-180m)	U.S. coastal/ fisheries areas	99.7%	**	1 minute	Two	Unlimited	Resolvable with 99.9% confidence
Recreational Sports Fishing	0.25nm (460m)	100-600 ft (30-180m)	U.S. coastal areas	99%	**	5 minutes	Two	Unlimited	Resolvable with 99.9% confidence

** Based on stated user need.*
*** Dependent upon mission time.*

Table 2-5. Current Maritime User Requirements/Benefits for Purposes of System Planning and Development - Ocean Phase

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS									
	ACCURACY (2 drms)			COVERAGE	AVAILABILITY	RELIABILITY	FIX INTERVAL	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY
	PREDICTABLE	REPEATABLE	RELATIVE							
SAFETY OF NAVIGATION - ALL CRAFT	2-4nm (3.7-7.4km) minimum 1-2nm (1.8-3.7km) Desirable	-	-	Worldwide	99% fix at least every 12 hours	**	15 minutes or less desired; 2 hours maximum	Two	Unlimited	Resolvable with 99.9% confidence

BENEFITS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO ACHIEVE BENEFITS									
LARGE SHIPS MAXIMUM EFFICIENCY	0.1-0.25nm* (185-460m)	-	-	Worldwide, except Polar regions	99%	**	5 minutes	Two	Unlimited	Resolvable with 99.9% confidence
RESOURCE EXPLORATION	10-100m*	10-100m*	-	Worldwide	99%	**	1 minute	Two	Unlimited	Resolvable with 99.9% confidence
SEARCH OPERATIONS	0.1-0.25nm (460m)	0.25nm	185m	National maritime SAR regions	99%	**	1 minute	Two	Unlimited	Resolvable with 99.9% confidence

** Based on stated user need.*
*** Dependent upon mission time.*

under hazardous conditions to an anchorage clear of the channel or risk stopping in a channel.

Requirements: Requirements based on the consideration of practically achievable performance and expected benefits have not been defined. However, R,E&D in harbor/harbor approach navigation is expected to produce results which will have some application to inland waterway navigation.

Minimum Performance Criteria: These 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.

2.4.2 Harbor/Harbor Approach Phase (HHA)

The pilot of a vessel in restricted waters must direct its movement with great accuracy and precision to avoid grounding in shallow water, hitting submerged/partially submerged rocks, and colliding with other craft in congested waterways. Unable to turn around, and severely limited in the ability to stop to resolve a navigational problem, the pilot of a large vessel (or a tow boat and barge combination) may find it necessary to hold the total error in navigation within limits measured in a few feet while navigating in this environment. It would appear that a major step in maximizing the effectiveness of radionavigation systems in the harbor/harbor approach environment is to present the position information on some form of electronic display. This would provide a ship's captain, pilot, or navigator a continual reference, as opposed to plotting "outdated" fixes on a chart to show the recent past. It is also recognized that the role of the existing radionavigation system decreases in this harbor/harbor approach environment, while the role of visual aids and radar escalates.

Requirements: To navigate safely, the pilot needs highly accurate verification of position almost continuously, together with information depicting any tendency for the vessel to deviate from its intended track and a nearly continuous and instantaneous indication of the direction in which the pilot should steer. Table 2-3 was developed to present estimates of these requirements. To effectively utilize the requirements stated in the table, however, a user must be able to relate the data to immediate positioning needs. This is not practical if one attempts to plot fixes on a chart in the traditional way. To utilize radionavigation information that is presented at less than 10-second intervals on a moving vessel, some form of an automatic display is required. Technology is available which presents radionavigation information along with other data.

Minimum Performance Criteria: The radionavigation system accuracy required to provide useful information in the harbor/harbor approach phase of marine navigation varies from harbor to harbor, as well as with the size of the vessel. In the more restricted channels, accuracy in the range of 8 to 20 meters (2 drms) relative to the channel centerline may be required for the largest vessels. A need exists to more accurately determine these radionavigation requirements for various-sized vessels while operating in such restricted confines. Radionavigation user conferences have indicated that for many mariners, the radionavigation system becomes a secondary tool when entering the harbor/harbor approach environment.

Further efforts will be directed toward verifying user requirements and desires for radionavigation systems in the harbor/harbor approach environment. The USCG, through its R,E&D program, is conducting a study to analyze and model the navigation requirements for major U.S. harbors. The requirements for smaller vessels in the harbor/harbor approach phase of navigation are less stringent than for large ships. The user conferences also indicated that the smaller vessel operator is less likely to depend on a radionavigation system in the harbor/harbor approach environment than on radar or visual means.

2.4.3 Coastal Phase

There is need for continuous, all-weather radionavigation service in the coastal area to provide, at the least, the position fixing accuracy to satisfy minimum safety requirements for general navigation. These requirements are delineated in Table 2-4. Furthermore, the total navigational service in the coastal area must provide service of useful quality and be within the economic reach of all classes of mariners. It should be sufficient to assure that no boat or ship need be lost or endangered, or that the environment and public safety not be threatened, because a vessel could not navigate safely with reasonable economic efficiency.

Requirements: Requirements on the accuracy of position fixing for safety purposes in the coastal phase are established by:

- The need for larger vessels to navigate within the designated one-way traffic lanes at the approaches to many major ports, in fairways established through offshore oil fields, and at safe distances from shallow water.

- The need to define accurately, for purposes of observing and enforcing U.S. laws and international agreements, the boundaries of the Fishery Conservation Zone, the U.S. Customs Zone, and the territorial waters of the U.S.

Minimum Performance Criteria: Government studies have established that a navigation system providing a capability to fix position to an accuracy of 0.25

nm will satisfy the minimum safety requirements if a fix can be obtained at least every 15 minutes. As a secondary economic factor, it is required that relatively higher repeatable accuracy be recognized as a major advantage in the consideration of alternative candidate radionavigation systems for the coastal area. As indicated in Table 2-4, these requirements may be relaxed slightly for the recreational boat and other small vessels.

In such activities as marine scientific research, hydrographic surveying, commercial fishing, and petroleum or mineral exploration, as well as in Navy operations, there may be a need to establish position in the coastal area with much higher accuracy than that needed for safety of general navigation. In many of these special operations which require highly accurate positions, the use of radiodetermination would be classified as radiolocation rather than radionavigation. As shown in Table 2-4, the most rigid requirement of any of this general group of special operations is for seismic surveying with a repeatable accuracy on the order of 1 to 100 meters (2 drms), and a fix rate of once per second for most applications.

2.4.4 Ocean Phase

The requirements for safety of navigation in the ocean phase for all ships are given in Table 2-5. These requirements must provide the Master with a capability to avoid hazards in the ocean (e.g., small islands, reefs) and to plan correctly the approach to land or restricted waters. For many operational purposes, repeatability is necessary to locate and return safely to the vicinity of a maritime distress, as well as for special activities such as hydrography, research, etc. Economic efficiency in safe transit of open ocean areas depends upon the continuous availability of accurate position fixes to enable the vessel to follow the shortest safe route with precision, minimizing transit time.

Requirements: For safe general navigation under normal circumstances, the requirements for the accuracy and frequency of position fixing on the high seas are not very strict. As a minimum, these requirements include a predictable accuracy of 2 to 4 nm coupled with a maximum fix interval of 2 hours or less. These minimum requirements would permit reasonably safe oceanic navigation, provided that the navigator understands and makes allowances for the probable error in navigation, and provided that more accurate navigational service is available as land is approached. While these minimum requirements would permit all vessels to navigate with relative safety on the high seas, more desirable requirements would be predictable accuracy of 1 to 2 nm and a fix interval of 15 minutes or less. The navigation signal should be available 95 percent of the time. Further, in any 12-hour period, the probability of obtaining a fix from the system should be at least 99 percent.

Larger recreational craft and smaller commercial fishing vessels which sail beyond the range of coastal navigation systems require, for a reasonable level of safety, some means of establishing their position reliably at intervals of a few hours at most. Even more so than with larger ships, this capability is particularly important in time of emergency or distress. Many operators of these craft, however, will accept the risk of ocean sailing without reliable radionavigation unless that capability is available at relatively low cost.

Minimum Performance Criteria: Economic efficiency in transoceanic transportation, special maritime activities and safety in emergency situations require or benefit from navigational accuracy higher than that needed for safety in routine, point-to-point ocean voyages. These requirements are summarized in Table 2-5. The predictable accuracy requirements may be as stringent as 10 meters for special maritime activities, and may range to 0.25 nm for large, economically efficient vessels, including search operations. Search operations must also have a repeatable accuracy of at least 0.25 nm. As indicated in Table 2-5, the required fix interval may range from as low as once per 5 minutes to as high as once per minute. Signal availability must be at least 95 percent and approach 99 percent for all users.

These requirements are based on current estimates and are to be used for the purposes of system planning. There has not been sufficient analysis to establish quantitative relationships between navigational accuracy and economic efficiency. The expensive, satellite-based navigation systems used by ships engaged in science and resource exploration, and the increasing use of relatively expensive satellite navigation by merchant ships and larger, ocean-going fishing vessels are evidence of the perceived value attached to highly accurate ocean navigation by the vessel owners.

2.4.5 Future Marine Radionavigation Requirements

The marine radionavigation requirements presented in the preceding discussions and tables are based on a combination of requirements studies, user inputs, and estimates. However, they are the product of current technology and operating practices, and are therefore subject to revision as technologies and operating techniques evolve. The USCG, through an R,E&D effort, is attempting to further refine the harbor/harbor approach requirements. This effort may also have some application in the inland waterway phase of marine navigation. The principal factors which will impact future requirements are safety, economics, energy conservation, environment, and evolving technologies.

Special radionavigation requirements may arise from new environmental laws and regulations designed to reduce marine vessel casualty events. Also, the role of commercial ships in military sealift missions may require additional navigation systems capabilities.

Safety:

A. *Increased Risk from Collision, Grounding, and Ramming*

Hazardous cargoes (petroleum, chemicals, etc.) are carried in great volumes in U.S. coastal and inland waterways. Additionally, the ever increasing volume of other shipping and the increasing numbers of smaller vessels act to constantly increase the risk of collision, grounding, and ramming. Economic constraints also cause vessels to be operated in a manner which, although not unsafe, places more stringent demands on all navigation systems.

B. *Increased Size and Decreased Maneuverability of Marine Vessels*

The desire to minimize costs and to capture economies of scale in marine transportation have led to design and construction of larger vessels and unitized tug/barge combinations, both of which are relatively less powerful and maneuverable than their predecessors. Consequently, more demanding navigational requirements are needed to compensate for these drawbacks.

C. *Greater Need for Traffic Management/Navigational Surveillance Integration*

The foregoing trends further strengthen the need for governmental involvement in marine vessel traffic management to assure reasonable safety in U.S. waters. Radionavigation systems may become an essential component of traffic management systems. Differential GPS is expected to play an increasingly important role in such areas as Vessel Traffic Services (VTS).

Economics:

A. *Greater Congestion in Inland Waterways and Harbor/Harbor Approaches*

In addition to the safety penalty implicit in greater congestion in restricted waterways, there are economic disadvantages if shore facilities are not used effectively and efficiently. Accurate radionavigation systems can contribute to better productivity and decreased delay in transit.

B. *All Weather Operations*

Low visibility and ice-covered waters presently impede full use of the marine transportation mode. Evolving radionavigation systems may eventually alleviate the impact of these restrictions.

Environment: As onshore energy supplies are depleted, resource exploration and exploitation will move further offshore to the U.S. outer continental shelf and to harsher and more technically demanding environments. In addition, more intensive U.S. fishing activity is anticipated as the result of legislative initiatives and the creation of the U.S. Fishery Conservation Zone. In summary, both sets of activities may generate demands for navigational services of higher quality and for broadened geographic coverage in order to allow environmentally sound development of resources.

Energy Conservation: The need to conserve energy resources and to reduce costs provides powerful incentives for increased transportation efficiency, some of which could come from better navigation systems.

2.5 Civil Land Radionavigation User Requirements

Many civil land applications for radionavigation systems are still in the developmental stage, and vehicular radionavigation systems are being developed and tested by state and Federal government agencies and private industry. Other applications are beyond the development stage, particularly in the area of automatic vehicle location (AVL) and automatic vehicle monitoring (AVM) where the use of radionavigation systems has experienced tremendous growth. One specific application is fire and police use of AVL as part of an automated dispatch system.

Several tens of thousands of radionavigation receivers are estimated to be in use by land vehicles in this country in general transportation, emergency services, and the transportation of hazardous materials. The majority of these receivers are installed on trucks that engage in interstate commerce. One railroad company is conducting a pilot program to evaluate an advanced train control system using radionavigation receivers.

A variety of space and terrestrial radio communication systems is used to communicate between the vehicles and the control/dispatch sites. Vehicle onboard status of systems and fuel consumption to determine allocation of fuel taxes are among the types of information communicated along with position.

While civil land applications for radionavigation systems appear to be concentrated in the transportation community, electronic chart development and receiver miniaturization may lead to the development of a portable land navigator for the camper or backwoods sports enthusiast. Such a device conceivably could be a multipurpose unit plugging into a boat or car when needed to navigate those vehicles.

Although IVHS is in the early stage of development and testing, it is clear that large scale deployment will include a number of navigation mechanisms and they will most likely be shared with other systems and services. For example, IVHS may use GPS, which is already being shared with numerous other systems and communities, along with radiobeacon systems or FM radio location systems. Such an approach for sharing brings benefits of more efficient use of the scarce radio frequency spectrum as well as reduction of capital cost of infrastructure and related operations, administration and maintenance costs.

Requirements: There is no definitive statement of requirements for land vehicle radionavigation. Requirements to achieve cost benefits are also undefined at this time. It appears, however, that significant safety benefits and possible economic benefits can be derived by users traversing long distances, especially during inclement winter weather. The ability to more closely coordinate air and land search parties following accidents or disasters could save time, resulting in the saving of lives as well as search and rescue costs.

Depending on the functionalities and configuration of the IVHS system in question and its application to the demographics of a particular area, the specifications for navigational requirements will vary. Thus, the requirements will be different for urban, suburban, and rural implementations. Greater precision is required in the urban environment where often multipath and shadowing effects, due to high-rise buildings, cause radionavigation systems to fail. Precision is required in suburban areas where traffic is dense but the detrimental effects of high-rise buildings are not present; and for rural case, the requirements are less stringent. Furthermore, emergency medical services can be enhanced through improved radionavigation capability. Also, effective collision avoidance, for example at intersections, may require improved radionavigation capability.

While the Government has no statutory responsibility to provide radionavigation services for land radionavigation applications or for non-navigation uses, their existence and requirements are recognized. Table 2-6 provides a preliminary assessment of these requirements. Additionally, the FRP process attempts to accommodate such users as radionavigation plans and changes are instituted.

Minimum Performance Criteria: The minimum performance criteria for land radionavigation can only be estimated. Comments made at the radionavigation user conferences indicated that some prospective users desire accuracy on the order of 5 to 15 meters. The accuracy requirements for monitoring the position and status of vehicles are somewhat less stringent;

Table 2-6. Requirements for Land Use, Surveying, Timing and Other Applications

APPLICATION	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS								
	ACCURACY (Meters-2 drms)			COVERAGE	AVAILABILITY	FIX INTERVAL	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY
	PREDICTABLE	REPEATABLE	RELATIVE						
AVM/AVL	30	-	-	Nationwide	99.7%	1 second	Two	Unlimited	Resolvable with 99.9% confidence
SITE REGISTRATION	30	-	-	Nationwide	99.7%	1 second	Two	Unlimited	Resolvable with 99.9% confidence
RESOURCE MANAGEMENT	30	-	-	National Economic Zone	99.7%	1 second	Two	Unlimited	Resolvable with 99.9% confidence
GEOPHYSICAL SURVEY	5	<1	<1m	Worldwide	99.7%	1 second	Three	Unlimited	Resolvable with 99.9% confidence
GEODETIC CONTROL	1	-	5mm + 1 part in 10^6	Worldwide	99.7%	1 second	Three	Unlimited	Resolvable with 99.9% confidence

Table 2-6. Requirements for Land Use, Surveying, Timing and Other Applications (Cont.)

APPLICATION	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS									
	ACCURACY (Meters-2 drms)			COVERAGE	AVAILABILITY	FIX INTERVAL	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY
	PREDICTABLE	REPEATABLE	RELATIVE						
COMMUNICATIONS NETWORK SYNCHRONIZATION	-	1 part in 10^{11} (freq) *	-	Nationwide	99.7%	Continuous	N/A	Unlimited	N/A
SCIENTIFIC COMMUNITY	-	1 part in 10^{14} (freq)	-	Worldwide	99.7%	Continuous	N/A	Unlimited	N/A
METEOROLOGY	Velocity 1m/sec	-	-		TBD	TBD	TBD		TBD
COLLISION AVOID.	1	-	Critical Locations	-	0.1 second	Two	Unlimited	-	
POWER NETWORK SYNCHRONIZATION		1ms **		North America	99.7%	1 second	Two	Unlimited	Resolvable with 99.9% confidence

* Proposed ITU Standard based on American Telephone and Telegraph "Stratum 1 Requirement".
** At any substation. 8ms (1/2 cycle) system-wide.

however, the accuracy requirements for collision avoidance may be more stringent.

2.6 Space Radionavigation Requirements

Several programs conducted or supported by NASA are evaluating GPS for precise position determination for spacecraft. TOPEX/POSEIDON, launched on August 10, 1992, and ARISTOTELES, planned for launch in 1998, carry high-accuracy dual-band GPS flight receivers on an experimental basis. The Extreme Ultraviolet Explorer (EUVE), carrying the lower-accuracy single-frequency version of the TOPEX/POSEIDON GPS receiver on an experimental basis, was launched in June 1992. The EUVE GPS receiver was turned on and began operating successfully several days after launch.

Proposed uses of GPS include:

- Control and navigation of space missions including launch vehicles, automated spacecraft, and interplanetary or lunar spacecraft returning to Earth orbit for landing or rendezvous with an orbiting platform.
- Real-time determination of a position reference for in-orbit pointing of spaceborne remote sensing devices.
- Incorporation of real-time spacecraft position data accurate to $\pm$100 meters in the telemetered data stream of geophysical spacecraft payloads with potential, in some cases, for sub-10 meter accuracy in near-real time.
- Refinement of post-pass orbit data when greater accuracy is required. For missions such as TOPEX/POSEIDON, the post-pass orbit accuracies will be at the 10 cm level using GPS flight data.
- Navigation of the Shuttle during its approach and landing on Earth. NASA has flight tested GPS equipment on the Shuttle Training Aircraft in preparation for equipping the Shuttle with GPS receivers.
- Support of deep space navigation. GPS tracking can be used by the NASA Deep Space Network (DSN) to improve knowledge of the Earth's pole position and speed of rotation. These qualities are major error sources, and the use of GPS will result in significant reduction of the present demand for measurements with large deep-space tracking antennas. GPS ground tracking will also provide ionospheric and tropospheric

calibrations for deep-space tracking and a geocentric correction to the DSN antenna coordinates. GPS can provide centimeter-level knowledge of these quantities, significantly improving the deep-space tracking error budget.

- Highly accurate time transfer. GPS tracking at observatories separated by thousands of kilometers can provide sub-nanosecond synchronization for clocks at these sites. This calibration is important for deep-space tracking and astronomical observations.

In addition, NASA is investigating the requirements for radionavigation systems to be placed on or in orbit around planets to support interplanetary navigation. Applications include navigation to and from the planets, and precise determination of position and attitude of spacecraft in the vicinity of the planets.

2.7 Military Radionavigation Requirements

Military forces must be prepared to conduct operations anywhere in the world, in the air, on and under the sea, on land, and in space. During peacetime, military platforms must conform to applicable national and international rules in controlled airspace, on the high seas, and in coastal areas. Military planning must also consider operations in hostile environments.

2.7.1 General Requirements

Military navigation systems should have the following characteristics:

- Worldwide coverage.
- User-passivity.
- Capability of denying use to the enemy.
- Support of unlimited number of users.
- Resistance to meaconing*, interference, jamming, and intrusion.
- Resistance to natural disturbances and hostile attacks.
- Effectiveness of real-time response.

* Meaconing refers to imitative navigational signal deceptions.

- Availability for combined military operations with allies.
- Freedom from frequency allocation problems.
- Use of common grid for all users.
- Position accuracy that is not degraded by changes in altitude for air and land forces or by time of year or time of day.
- Accuracy when the user is in high "G" or other violent maneuvers.
- Maintenance by operating level personnel.
- Continuous availability for fix information.
- Non-dependence on externally generated signals.

The ideal military positioning/navigation system should be totally self-contained so that military platforms are capable of performing all missions without reliance on information from outside sources. No single system or combination of systems currently in existence meets all of the approved military navigation requirements. No known system can provide a common grid for all users and at the same time be passive, self-contained, and yield the worldwide accuracies required. The nature of military operations requires that essential navigation services be available, with the highest possible confidence that these services will equal or exceed mission requirements. This, among other considerations, necessitates a variety of navigational techniques and redundant installations on the various weapon system platforms for military operations. Currently, the DOD is unable to conduct some military missions with the precision and accuracy demanded without some aid from external radionavigation systems. However, there has been significant progress in the development of reliable self-contained systems (inertial systems, Doppler systems, and terrain/bottom contour matching).

While the survivability of any radionavigation system is scenario-dependent, in almost any scenario the GPS is considered more survivable than other systems because:

- Moving transmitters in space are less vulnerable than ground-based transmitters.
- Spread spectrum transmission techniques protect against jamming.
- Anti-spoofing is available.

- Transmitters are hardened against electromagnetic pulse (EMP).

In comparison, Loran-C and Omega stations are typified by large fixed antennas whose transmissions are more easily jammed and subject to natural atmospheric interference. Loran-C coverage is limited when viewed from a worldwide perspective, and six of the eight Omega transmitters are located in areas not controlled by the United States.

While reliance on a single POS/NAV system is unwise, redundant or backup systems for military operations should not be more vulnerable, less-capable external systems. Rather, DOD must invest in reliable, accurate, self-contained systems that are uniquely tailored to match platform mission requirements. Therefore, DOD POS/NAV architecture will be based upon GPS, which provides accurate worldwide positioning, velocity and time, backed by modern, accurate, and dependable self-contained systems.

2.7.2 *Service Requirements*

The CJCS MNP provides specific DOD requirements for navigation, positioning, and timing accuracy organized by primary missions and functions with specifically related accuracy requirements. These requirements are used for information and guidance in the development and procurement of military navigation systems.

2.8 Surveying, Timing, and Other Applications

Use of radionavigation systems for applications other than navigation is rapidly increasing. While there may be many diverse uses, the majority fall into the following categories:

- **Radiolocation:** Using radionavigation systems signals for surveying and site registration. Noting the location of a place or event for record purposes, or returning to it at a later time.

- **Time/Frequency Dissemination:** Using radionavigation system signals to accurately time nonassociated electronic systems.

- **Intelligent Vehicle Highway Systems (IVHS):** Using radionavigation systems to improve surface vehicle mobility, safety, and environmental compatibility.

Many non-navigation uses for radionavigation systems have developed over the years. Previous government studies and inputs from users had given a preliminary indication of such usage, and the extent of these non-navigation uses was emphasized at user conferences. They included such uses as wildlife migratory studies, forestry conservation, communications timing systems, site registration systems, and weather balloon tracking.

It is estimated that several hundred thousand weather balloons launched worldwide each year use radionavigation receivers to measure wind direction and speed.

A significant non-navigation application is the continuous monitoring of seismically active regions. NASA is in the process of installing dozens of GPS ground receivers as part of a combined U.S.-international tracking network. Ultimately, these receivers will be capable of sensing millimeter-level shifts in the Earth's crust, providing early warning of such movements as well as enabling rapid deployment of portable GPS equipment. GPS ground networks will provide a broad base for a variety of geodetic studies, with accuracies ranging from millimeters over short (<1000 km) scales to centimeters over long (intercontinental) scales, including studies of Earth orientation and Earth rotation.

2.8.1 Radiolocation (Site Registration and Automatic Vehicle Monitoring and Location (AVM/AVL)

Studies and field measurements to date have led to some preliminary estimates of radiolocation service accuracies required by user groups. No other characteristics have been determined.

2.8.2 Timing/Frequency Offset Applications

There are currently no definitive statements of the requirements for timing and frequency offset applications. One national telephone company uses Loran-C extensively for communication network synchronization. It is estimated that a worldwide GPS ground network may be able to provide clock synchronization to better than one nanosecond and relative determination to one part in 10^{14}. These clock calibrations will be useful for deep space tracking and at astrophysical observatories. Several power companies are experimenting with GPS for measuring phase differences between major power transmission stations and substations, for event recording, for post-disturbance analysis, and for measuring the relative frequency of power systems.

2.8.3 Intelligent Vehicle Highway Systems (IVHS)

Please refer to Appendix A for a summary description of IVHS applications.

3

Radionavigation System Use

This section summarizes the plans of the Federal Government to provide general-purpose and special-purpose radio aids to navigation for use by the civil and military sectors. It focuses on three aspects of planning: (1) the efforts needed to maintain existing systems in a satisfactory operational configuration; (2) the development needed to improve existing system performance or to meet unsatisfied user requirements in the near term; and (3) the evaluation of existing and proposed radionavigation systems to meet future user requirements. Thus the plan provides the framework for operation, development, and evolution of systems.

The Government operates radionavigation systems which meet most of the current and projected civil user requirements for safety of navigation and promotion of reasonable economic efficiency. These systems are adequate for the general navigation of military craft as well, but none completely satisfies all the needs of military missions nor provides highly accurate, three-dimensional, worldwide navigation capability. GPS is being developed to satisfy many of these general and special military requirements. GPS may have broad potential for satisfying current civil user needs or for responding to new requirements that present systems do not satisfy. It could ultimately become the primary worldwide system for military and civil navigation and position location. Likewise, civil development of MLS promises to provide the technology required to satisfy military requirements for a highly mobile precision approach system.

3.1 Existing Systems Used in the Phases of Navigation

It is generally accepted that the needs for navigation services derive from the activities in which the users are engaged, the locations in which these activities occur, the relation to other craft and physical hazards and to some extent, the type of craft. Because these differences exist, navigation services are divided by classes or types of users and the phases of navigation. These divisions are summarized in Tables 3-1 through 3-3. These tables also show current application of the existing radionavigation systems in the various phases of navigation. Detailed descriptions of the existing and proposed radionavigation systems are given in Appendix A.

The systems listed in Table 3-1 are used singly or in combination to support functions of the various phases of civil navigation. Tables 3-2 and 3-3 compare common-use systems to mission applications for military use. The following sections describe the approach employed to define the needs, requirements, and degree to which existing systems satisfy these needs.

3.1.1 Air Navigation

VOR/DME forms the basis of a safe, adequate, and trusted international air navigational system, and there is a large investment in ground equipment and avionics by both the Government and users. In view of this, it is intended to maintain the VOR/DME system at its present capability through the year 2010. The current ICAO protection date extends through 1995.

As evidenced by user conferences, there is increasing interest and usage of Loran-C for air navigation. Loran-C has been certified as a supplemental aid.

Oceanic En Route: Oceanic en route air navigation is currently accomplished using inertial reference system/flight management computers, inertial navigation systems (INS), Omega, Loran-C, or a combination of these systems. Use of Doppler and celestial navigation is still approved although their use is almost nonexistent. Use of VOR/DME, TACAN, and Loran-C is approved where there is adequate coverage.

Domestic En Route: Domestic en route air navigation requirements are presently being met, except in some remote and offshore areas. The basic short-distance aid to navigation in the U.S. is VOR alone, or collocated with either DME or TACAN to form a VOR/DME or a VORTAC facility. This system is used for en route and terminal navigation for flights conducted under Instrument Flight Rules (IFR). It is also used by pilots operating on Visual Flight Rules (VFR). The U.S. and all other member states of ICAO have agreed to provide VOR/DME service to international air carriers up to January 1, 1995. Loran-C, Omega, and inertial are also used for domestic en

Table 3-1. Civil Radionavigation System Applications

APPLICATIONS	SYSTEMS							
	LORAN-C	OMEGA	VOR/DME	MLS/ILS	TRANSIT	RADIO-BEACONS	GPS	DGPS
AIR								
EN ROUTE/TERMINAL								
Remote Areas	X	X	E	-	-	X	X	-
Special Helicopter	X	E	E	-	-	X	X	-
Oceanic En Route	X	X	-	-	-	-	X	-
Domestic En Route	X	X	X	-	-	X	X	-
Terminal	X	-	X	-	-	X	X	-
AIRPORT SURFACE	-	-	-	-	-	-	-	E
APPROACH/LANDING								
Nonprecision	X	-	X	-	-	X	X	E
Precision	-	-	-	X	-	-	-	E
MARINE								
Ocean	X	X	-	-	X	X	X	-
Coastal	X	-	-	-	-	X*	X	X
Harbor & Harbor Approach	-	-	-	-	-	X*	-	X
Inland Waterways	-	-	-	-	-	-	-	X
LAND								
Navigation	X	X	-	-	X	-	X	X
SPACE								
Navigation/Tracking	-	-	-	-	-	X	X	X
Terminal Approach	-	-	-	-	-	-	X	X
Terminal Landing	-	-	-	X	-	-	X	X
OTHER								
AVM/AVL	X	X	-	-	-	-	X	X
Site Registration	E	-	-	-	X	-	X	X
Surveying	-	-	-	-	X	-	X	X
Timing/Frequency	X	X	-	-	X	-	X	X
Meteorology	X	X	-	-	-	-	X	-

LEGEND

X = Current or Planned Application
E = System in Evaluation
- = System Not Used
** = Includes Racons*

Table 3-2. DOD Radionavigation System Applications

USAF AND ARMY AVIATION MISSIONS	SYSTEMS								
	LORAN-C	OMEGA	VOR/DME	TACAN	MLS/ILS	TRANSIT	RADIO-BEACONS	GPS	DGPS
EN ROUTE									
Foreign Domestic	-	-	X	X	-	-	X	X	-
Domestic	-	-	X	X	-	-	X	X	-
Combat Theatre	-	-	-	X	-	-	X	X	-
Overwater	X	X	-	-	-	-	-	X	-
Remote Area	X	X	-	-	-	-	X	X	-
TERMINAL	-	-	X	X	-	-	X	X	-
APPROACH/LANDING									
Nonprecision	-	-	X	X	-	-	X	X	E
Precision Landing	-	-	-	-	X	-	-	E	E
SPACE									
Launch/Abort	-	-	-	X	X	-	-	X	-
Orbital	-	-	-	-	-	-	-	X	-
Re-Entry	-	-	-	-	-	-	-	X	-
SURVEYING	-	-	-	-	-	-	-	X	-
TARGET ACQUISITION	-	-	-	X	-	-	X	X	-
AERIAL RENDEZVOUS	-	-	-	X	-	-	X	X	-

LEGEND

X = Current or Planned Application
E = System in Evaluation
- = System Not Used

Table 3-2. DOD Radionavigation System Applications (Cont.)

NAVAL MISSIONS	SYSTEMS								
	LORAN-C	OMEGA	VOR/DME	TACAN	MLS/ILS	TRANSIT	RADIO-BEACONS	GPS	DGPS
EN ROUTE, GENERAL PURPOSE									
Ship	X	X	-	-	-	X	X	X	-
Submarine	X	X	-	-	-	X	-	X	-
Air	-	-	-	-	-	-	X	X	-
SEARCH & RESCUE									
Ship	-	-	-	-	-	X	-	X	-
Air	-	-	-	X	-	-	-	X	-
MINE COUNTERMEASURES									
Ship	X	X	-	-	-	X	-	X	E
Air	-	-	-	X	-	X	-	X	E
MINE LAYING									
Ship	X	-	-	-	-	X	-	X	E
Submarine	-	X	-	-	-	-	-	X	E
Air	-	X	-	X	-	-	-	X	E
AMPHIBIOUS WARFARE									
Ship	-	X	-	-	-	X	X	X	-
Air	-	-	-	X	-	-	-	X	-
ANTI-AIR WARFARE									
Ship	X	X	-	-	-	X	-	X	-
Air	-	-	-	X	-	-	-	X	-
SURFACE WARFARE									
Ship	X	X	-	-	-	X	-	X	-
Submarine	X	X	-	-	-	X	-	X	-
Air	-	X	-	X	-	-	-	X	-
ANTI-SUBMARINE WARFARE									
Ship	-	X	-	-	-	X	-	X	-
Submarine	-	X	-	-	-	X	-	X	-
Air	X	X	X	X	X	-	X	X	-
LOGISTICS									
Surface	X	X	-	-	-	X	-	X	-
Submarine	X	X	-	-	-	X	-	X	-
Air	X	X	X	X	X	-	X	X	-
SURVEYING									
Surface	X	X	-	-	-	X	-	X	E
Submarine	X	X	-	-	-	-	-	X	E
Air	X	X	X	X	-	-	X	X	E

LEGEND

X = Current or Planned Application
E = System In Evaluation
- = System Not Used
** = Includes Racons*

Table 3-3. Defense Mapping Agency Radionavigation System Applications

APPLICATIONS	SYSTEMS				
	LORAN-C	OMEGA	TRANSIT	GPS	DGPS
WORLDWIDE POSITIONING OF SATELLITE (ORBITAL TRACKING)					
Low Altitude	-	-	X	X	-
Medium Altitude	-	-	X	X	-
High Altitude	-	-	X	X	-
GEODETIC POSITIONING BY SATELLITE (RELATIVE)	-	-	X	X	-
GEODETIC POSITIONING (CONVENTIONAL)	-	-	X	X	-
DEEP OCEAN BATHYMETRIC SURVEY	X	X	X	X	-
COASTAL HYDROGRAPHIC	X	-	-	X	X

LEGEND

X = Current and Planned Application
- = System Not Used

route navigation. When inertial is used, its performance must be monitored through the use of an approved externally referenced radio aid to navigation.

Terminal: Terminal air navigation requirements are presently met using VOR, VOR/DME, VORTAC, TACAN, NDB, or Loran-C.

Approach and Landing: Nonprecision approach navigation requirements are presently met using ILS localizer, VOR, VOR/DME, VORTAC, TACAN, Loran-C, or NDB. Precision approach and landing requirements are presently met by ILS and MLS.

3.1.2 Marine Navigation

Marine navigation comprises four major phases: inland waterway, harbor/harbor approach, coastal, and oceanic. The phase of navigation in which a mariner operates determines which radionavigation system or systems will be the most useful. While some radionavigation systems can be used in more than one phase of marine navigation, no current system meets all requirements for the harbor/harbor approach and inland waterway phases of marine navigation.

Inland Waterway Phase: This phase of navigation is concerned primarily with those vessels which are not oceangoing. Specific quantitative requirements for navigation on rivers and other inland waterways have not yet been developed. Visual and audio aids to navigation, radar, and intership communications are presently used to enable safe navigation in those areas. No change in this practice is expected in the immediate future. The completion of Loran-C coverage across the 48 conterminous states provides some capability, but does not meet the requirements of inland waterways navigation.

Harbor/Harbor Approach Phase: Navigation in the harbor/harbor approach areas is accomplished through use of fixed and floating visual aids to navigation, radar, and audible warning signals. The growing desire to reduce the incidence of accidents and to expedite movement of traffic during periods of restricted visibility and ice cover has resulted in the implementation of Vessel Traffic Services (VTS) and investigation of the use of radio aids to navigation. Specific quantitative requirements for navigation in the harbor/ harbor approach phases have not yet been developed. These requirements are significantly more demanding than for ocean and coastal navigation and will vary somewhat from one harbor to another.

The USCG plans to install DGPS for harbor/harbor approach. The coverage will include all coasts, Hawaii, and the Great Lakes. The system will be complete by the end of 1996 and will provide between 4 and 20 meter accuracy.

Coastal Phase: Requirements for operation within the coastal area are now fully met. In 1974, Loran-C was designated as the Federally provided primary civil marine radionavigation system for coastal areas of the conterminous 48 states, southern Alaska, and the Great Lakes. This service was fully implemented in 1980.

The marine radiobeacon system provides primary service in the coastal area and Great Lakes for recreational boaters and backup service for all categories of users. Radiodirection Finders (RDF), required in some merchant ships by international agreement for search and rescue purposes, are also used with the radiobeacon system for navigation.

Ocean Phase: Navigation on the high seas is accomplished by the use of dead-reckoning, celestial fixes, self-contained navigation systems (e.g., inertial), Loran-C, Omega, and Transit. Worldwide coverage by most ground-based systems such as Loran-C is not practicable. The Omega system, however, with all eight stations operational, does provide essentially worldwide coverage.

3.1.3 Land Navigation

The Government does not have a specific responsibility under law to provide radionavigation systems for civil land use. However, under the general provisions for improving the safety and efficiency of transportation, a number of projects have been sponsored by government and industry to evaluate the feasibility of using existing and proposed radionavigation systems for land navigation. Many land navigation applications are still in the developmental stage, while others are beyond the developmental stage, particularly in IVHS and automatic vehicle monitoring. Loran-C, GPS, and dead-reckoning map-matching are being evaluated as systems that could improve the safety and efficiency of land navigation.

Other navigational alternatives for use with IVHS include microwave and infrared beacons, triangulation from broadcast stations, and vehicle location using cellular transmissions.

3.1.4 Space Navigation

There are numerous applications of GPS for space navigation; many are discussed in Section 2.6. Several spacecraft, including TOPEX/POSEIDON (launched August 10, 1992) and ARISTOTELES (scheduled for 1998 launch), will carry high-accuracy GPS receivers on an experimental basis. An experimental single-frequency version of the TOPEX/POSEIDON GPS receiver is operating successfully on the EUVE satellite, launched in June 1992. Among the potential applications are determination of position and attitude of spaceborne remote sensing instruments; positioning and guidance of spacecraft in the vicinity of launch vehicles or orbiting platforms; and navigation of interplanetary spacecraft near Earth.

3.1.5 Uses Other Than Navigation

These uses are concerned primarily with the application of GPS, Loran-C, and Omega for radiolocation and time and frequency dissemination. As with land navigation, the Government does not have a responsibility under law to provide radionavigation systems for these users. However, these applications represent a rapidly growing segment of the user community.

3.2 Existing and Developing Systems - Status and Plans

3.2.1 Loran-C

Loran-C was developed to provide military users with a radionavigation capability having much greater coverage and accuracy than its predecessor Loran-A. It was subsequently selected as the Federally provided radionavigation system for civil marine use in the U.S. coastal areas. It is now designated by the FAA as a supplementary system in the National Airspace System (NAS).

A. Operating Plan

Loran-C was designated as the Federally provided navigation system for the U.S. coastal areas in 1974. Implementation of the program authorized at that time has been completed. Studies have shown that further expansion to provide coverage to the Caribbean, Eastern Hawaii, and Northern Alaska areas is not cost-beneficial. An increase in aviation use has prompted action to expand ground wave coverage across the continental U.S. and Alaska. The FAA is preparing Loran-C nonprecision approach procedures.

The U.S. Coast Guard is pursuing a Loran-C equipment recapitalization program. Older transmitters in Alaska will be replaced through 1993 to result in only two transmitter types to be maintained in the U.S. and Canada after U.S. operations overseas are terminated. Timing and control equipment is being redesigned to make use of modern technology while meeting expanded requirements for integrity, time synchronization, and economy of operation.

The FAA has designated Loran-C as a supplemental system in the National Airspace System. The FAA will fully implement Loran-C in the NAS by approving nonprecision approaches at selected airports that have adequate Loran-C coverage. Toward that end, FAA has deployed 196 local Loran-C monitors throughout the NAS to provide calibration values required for nonprecision approaches. The FAA and the USCG are also developing automatic blink equipment and a concept of operations to support nonprecision approaches in the NAS. The FAA and USCG are preparing a National Aviation Standard for Loran-C which will specify aviation requirements for user and provider systems. The FAA has prepared airworthiness Advisory Circular AC 20-121A, and Technical Standard Order TSO-C60b. RTCA Special Committee #137 has issued a Minimum Operational Performance Standard (MOPS) for Loran-C receivers.

Figure 3-1 outlines the operating plan for the Loran-C system. The coverage is shown in Appendix A.

B. User Community

Initially, the major user of Loran-C was the military, since civil marine use was limited due to the high cost of Loran-C receivers and the lack of coverage over much of the U.S. coastal areas. Technological advances rapidly lowered user receiver costs, and coastal coverage limitations have been eliminated by system improvements and expansion. As a result, there is presently extensive civil marine and aviation use of Loran-C. In addition, there is growing terrestrial use in radiolocation and for precise time and time interval applications. The projected number of civil and military users is shown in Table 3-4.

C. Acceptance and Use

Users of Loran-C constitute one of the largest communities employing a single radionavigation system. This population has been growing steadily, especially in the land and aviation user applications. Use of the system is expected to continue due to the system's reliability, accuracy, coverage, and cost factors. At radionavigation users conferences, strong support has been expressed for the continued and expanded operation of the system in the foreseeable future.

There has been enormous activity nationally with Loran-C. This is obvious in the maritime and aviation community with the recent expansion of loran coverage in the United States. The land uses now include monitoring vehicles involved in interstate, commercial, and emergency services; in the transportation of hazardous material; and in a variety of vehicle control/dispatching functions.

In addition to the stations located in the U.S., there are four Loran-C chains in operation overseas to serve U.S. Department of Defense requirements for radionavigation service. These chains are located in Japan, Northern Atlantic, and the Mediterranean. Service from these chains, as from North American chains, is available to all users, military and civilian, of all nations.

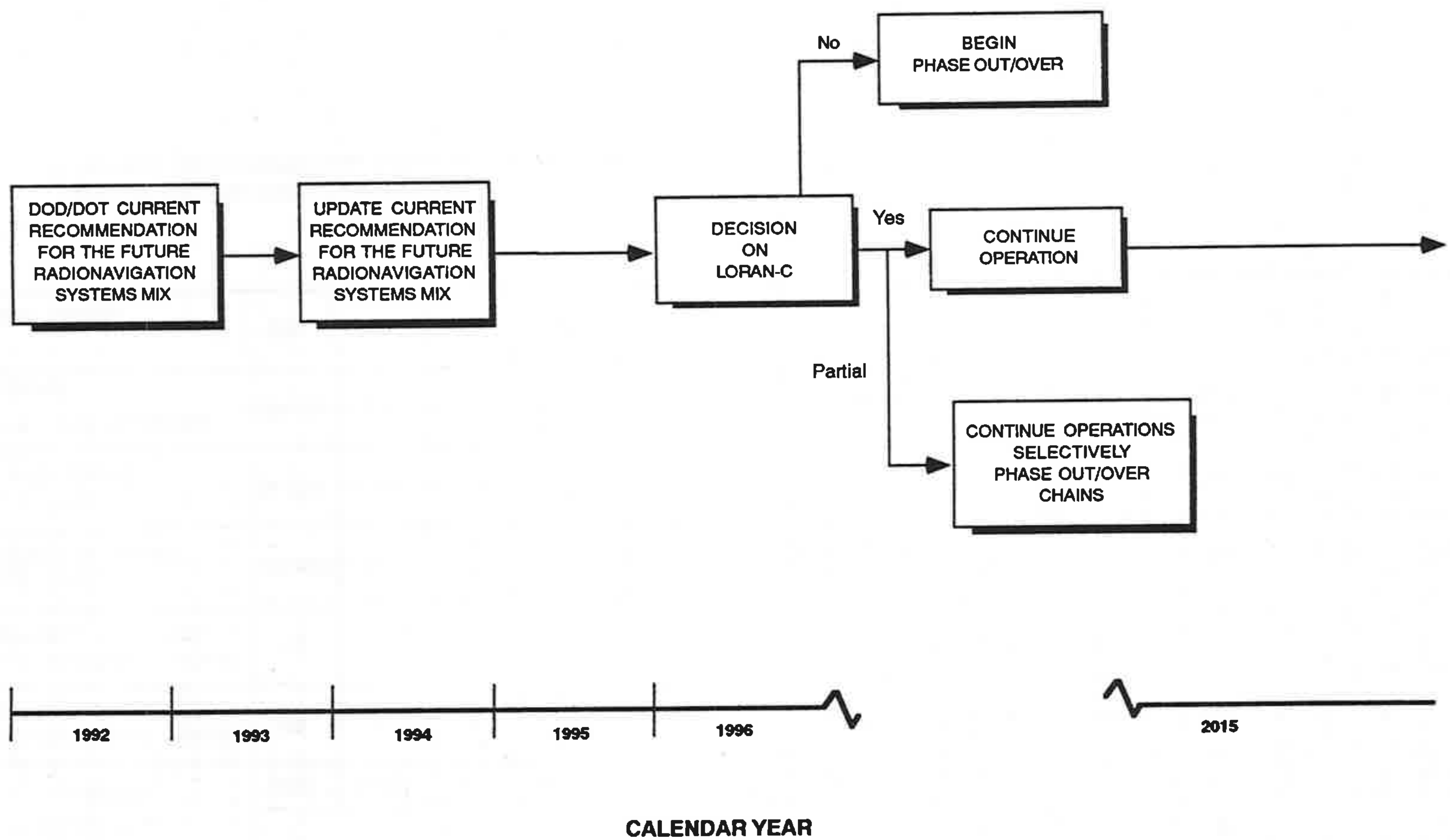


Figure 3-1. Operating Plan for Loran-C

Table 3-4. Loran-C Projections

FACILITIES/ USERS	CALENDAR YEARS													
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
U.S./CANADIAN TRANSMITTING FACILITIES	28	27	27	27	27	27	27	27	27	27	27	27	27	27
U.S. OVERSEAS TRANSMITTING FACILITIES	15	11	10	0	0	0	0	0	0	0	0	0	0	0
U.S. CIVIL AVIATION USERS [1]	120,000	150,000	180,000	200,000	220,000	230,000	240,000	250,000	250,000	250,000	245,000	240,000	235,000	230,000
U.S. CIVIL LAND USERS [2]	24,200	26,600	29,300	29,000	28,500	28,000	27,500	27,000	26,500	26,000	25,500	25,000	24,500	24,000
U.S. CIVIL MARITIME USERS	490,000	510,000	530,000	530,000	570,000	580,000	585,000	590,000	590,000	590,000	580,000	570,000	560,000	550,000
DOD USERS	500	450	250	200	100	50	0	0	0	0	0	0	0	0

1 Includes non-DOD Federal users.
2 Civil land users include survey, timing and other applications.

Canada, as a partner nation with the U.S., operates four Canadian funded and crewed stations, two on each coast. These stations operate in conjunction with stations in the U.S. and Greenland to form three Canadian chains. These three chains operate under Canadian operational control and support, and with USCG regional management.

Internationally, several nations have specified Loran-C as their national radionavigation system. The International Association of Lighthouse Authorities (IALA) is currently helping to facilitate the planned expansion of Loran-C for maritime use in Northern Europe, and the turnover of operations in the Mediterranean. The U.S. Coast Guard is negotiating with Japan (Northwest Pacific Chain); Norway, Denmark, Iceland, and Germany (Norwegian Sea and Icelandic Sea Chains); and Italy, Spain, and Turkey (Mediterranean Chain) to turn over overseas Loran-C operations by December 31, 1994.

Other nations that have their own loran chains are France (rho-rho or ranging mode), the People's Republic of China, and Saudi Arabia. There are several other countries developing plans for loran chains, including India and Venezuela (this will be the first South American chain).

D. Outlook

The FAA and USCG jointly sponsored expansion of the Loran-C system to complete coverage over the United States. This expansion was driven by the need to economically provide reliable and accurate en route and nonprecision approach navigation capability to improve the accessibility of a greater number of airports to commercial and private aviation. The interest in Loran-C service by the aviation community brings not only expanded service, but improved system integrity and reliability as well. Critical aviation demands drive improvements to the Loran-C system nationwide. An example is the improved synchronization of master stations to UTC.

The DOD termination of requirements will not affect civil use of Loran-C in the continental U.S., but the Hawaiian (Central Pacific) Loran-C chain has been shut down. This chain was not designed for civil use but for a DOD missile test range. To encourage and assist planning for orderly turn over of European and Far East Loran-C systems to the host nations, the U.S. will allow host nations to upgrade capital plants and add stations to existing Coast Guard operated chains to expand coverage on a not to interfere basis with existing service.

Several Northern European nations and Canada are developing an agreement concerning a mutual cost-sharing arrangement to take over and continue operation of USCG Loran-C stations in Northern Europe after the DOD requirement ends. Their plans are to upgrade equipment, add stations, and reconfigure new and existing stations to greatly expand coverage. The U.S. Government is pursuing transfer arrangements and anticipates an orderly turn over and continuation of service. The affected Northern European stations are now operated by the host nations for, and funded by, the USCG.

The U.S. has approached Mediterranean nations where Coast Guard stations are located with overtures to operation by host nation crews; this is in preparation for turn overs of facilities to continue operation past 1994. Agencies in Spain and Italy have responded favorably and are discussing technical details with the USCG. As of the publication of this document, Turkey has not indicated a desire to take over operation of the station in their country.

The Republic of Korea has taken over ownership and operation of the stations in their country previously owned and operated by the U.S. Air Force. The chain is now called the East Asian Loran-C Chain (formerly the Commando Lion Chain). United States participation in the chain continues under an agreement to provide the monitor and control functions, communications, and Loran-C signal transmissions from the U.S. stations in Japan. Korea is working toward upgrading the station equipment to satisfy the reliability and availability requirements of a U.S. Coast Guard civil-use chain, and to take over monitor, control, and communications responsibilities by 1993, per the conditions of the agreement.

Progress continues toward implementing the joint U.S./Russia chain agreed to at the 1988 Moscow Summit. Equipment for the Alaskan station at Attu was installed in 1991 and ongoing tests and evaluations are continuing.

3.2.2 Omega

The Omega system was developed and implemented by the Department of the Navy, with the assistance of the USCG and with the participation of several partner nations. It provides worldwide, all-weather radionavigation capability to air and surface users and was selected by the U.S. to be the Federally provided radionavigation system for the ocean phase of marine navigation. The U.S. responsibility for operation of the system rests with the USCG.

A. *Operating Plan*

The permanent eight-station Omega configuration has been operational since August 1982, although, in earlier configurations, the system was widely used for more than five years before this date. Omega stations are currently located in Norway, Liberia, North Dakota, Hawaii, La Reunion Island, Argentina, Australia, and Japan. The USCG operates the two stations located in the U.S. Bilateral agreements between the U.S. and the partner nations govern partner-nation operation, and the varying amounts of technical/logistic support. The Coast Guard has operational control of the system; the International Omega Technical Commission (IOTC), which is composed of one representative from the operating agency of each country involved with the Omega system, is the forum for consultation regarding operational maintenance of Omega. Figure 3-2 outlines the operating plan for the Omega system.

B. User Community

In addition to the DOD air and marine users, civil ships and aircraft are using the Omega system. A number of air carriers and general aviation aircraft operators have received approval to use Omega as an update for their self-contained systems or as a primary means of navigation on oceanic routes. The system is popular because it provides moderate accuracy coverage where no other continuous-fix systems are available. Receiver innovations have led to the use of VLF communications transmissions to augment the Omega network and improve overall system redundancy and reliability; however, the U.S. Navy has emphasized that VLF communication signals are not intended for navigation purposes and that the use of these signals for navigation is at the risk of the user. Receivers designed to use VLF communication signals as part of the navigation solution should be capable, using Omega signals only, of meeting performance standards contained in FAA Advisory Circular 20-101C and Technical Standard Order TSO-C120. The projected numbers of civil and military users are shown in Table 3-5.

Guidelines for the transmission of differential Omega corrections were established by the Inter-governmental Maritime Consultative Organization (now known as the International Maritime Organization - IMO) in Resolution A.425 (XI), "Differential Omega Correction Transmitting Stations," dated November 15, 1979.

C. Acceptance and Use

Because of its worldwide coverage, international civil use of Omega includes trans-oceanic ship and aircraft navigation. It is also approved by the FAA for use as a supplement for domestic high altitude en route airspace navigation. The precise timing aspects of Omega are used in weather balloons and weather reconnaissance dropsondes to obtain profiles of wind speed and direction from ground level to over 30 km. Over 200,000 Omega-equipped meterological sondes are launched annually from approximately 500 locations around the world.

Current information indicates that the present Omega system covers nearly 100 percent of the Earth's surface. Signal coverage and system accuracy have

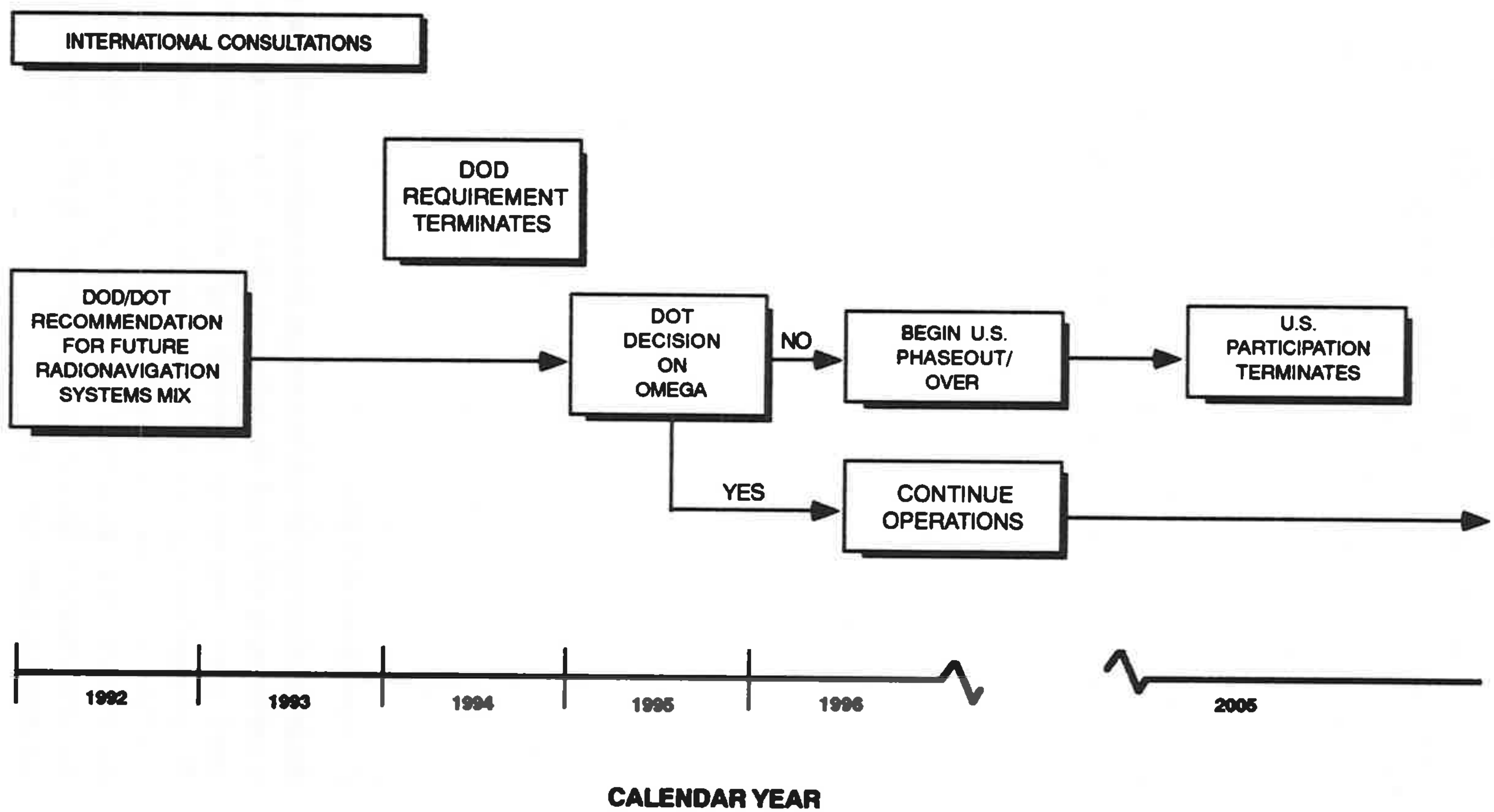


Figure 3-2. Operating Plan for Omega

Table 3-5. Omega Projections

WORLDWIDE FACILITIES/USERS	CALENDAR YEARS													
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
TRANSMITTERS (U.S. - 2)	8	8	8	8	8	8	8	8	8	8	8	8	8	8
CIVIL AVIATION USERS	14,700	16,200	16,200	14,500	10,900	8,100	6,000	4,500	3,400	2,500	1,900	1,400	1,100	800
CIVIL MARITIME USERS	6,800	6,900	6,900	6,200	5,300	4,500	3,800	3,200	2,700	2,300	2,000	1,700	1,400	1,200
DOD USERS	1,900	1,000	1,.000	500	450	400	350	300	250	200	120	0	0	0
OTHER U.S. FEDERAL	350	325	300	225	150	135	120	105	90	75	60	45	30	15
NON-U.S. MILITARY USERS	2,700	2,500	1,300	1,000	800	700	600	500	400	300	200	150	100	50
NON-NAVIGATION USERS [1]	500	500	500	500	500	500	500	400	300	250	200	150	100	50

[1] *Meteorological stations.*

been validated on a regional basis. The data collected from 22 fixed monitor receiver sites, shipboard monitor receivers, and aircraft receivers are being used to correct propagation models and tables and to confirm propagation parameters affecting signal coverage and availability. Results obtained from the validation effort have shown that the Omega system is meeting published performance. Validations began in the mid-1970s, and have been completed in the North Atlantic, North Pacific, South Atlantic, South Pacific, and Indian Oceans as well as the Mediterranean Sea. The validations, completed in 1991, indicate that Omega provides approximately 99 percent coverage worldwide.

Accuracy of the Omega system is limited due to signal propagation characteristics and restrictions on signal selection when in close proximity to transmitting sites. For these reasons, Omega does not meet navigation requirements for vessels in U.S. coastal waters, or aircraft flying in U.S. terminal airspace.

D. Outlook

Recapitalization of the timing and control equipment at transmitting stations is in progress. Other recapitalization efforts are focused on, and dominated by, the transmitting antennas, particularly those at Hawaii and Norway. In addition, the Coast Guard continues to improve user services and system performance. This includes coverage prediction programs, propagation models, and signal timing synchronization efforts. Continued efforts by the USCG to further refine the system may result in improvement in system accuracy.

Because of the international character of the system and international user acceptance, operational decisions regarding system life must be coordinated with the partner nations. The DOD requirement for Omega will end December 31, 1994; however, limited use is expected as long as the system remains operational.

While the Department of Defense will phase out their requirement for Omega by December 1994, the U.S. Air Force Reserve will continue to use the Omega system to support a Department of Commerce requirement for airborne weather reconnaissance activities.

3.2.3 VOR and VOR/DME

VOR was developed as a replacement for the Low-Frequency Radio Range to provide a bearing from an aircraft to the VOR transmitter. A collocated DME provides the distance from the aircraft to the DME transmitter. At most sites, the DME function is provided by the TACAN system which also provides azimuth guidance to military users. Such combined facilities are called VORTAC stations.

A. *Operating Plan*

FAA operates 950 VOR, VOR/DME, and VORTAC stations including 150 VOR-only stations. A small change in the number of stations is planned during the next 5 to 10 years to meet the requirements in specified areas. The DOD also operates a few stations in the U.S. and overseas. These are available to all users. The operating plan for VOR and VOR/DME is shown in Figure 3-3.

B. *User Community*

Approximately 80 percent of the general aviation aircraft are equipped with at least one VOR receiver and over 50 percent of the aircraft have two or more VOR receivers. All air carrier aircraft depend on it for bearing information. DME is used to provide distance information for all U.S. air carrier aircraft and for a large number of general aviation and military aircraft operating in U.S. airspace. The projected civil and military user population is shown in Table 3-6.

C. *Acceptance and Use*

VOR is the primary radionavigation aid in the National Airspace System and is the internationally designated standard short-distance radionavigation aid for air carrier and general aviation IFR operations. It is easy to use and is generally liked by pilots. Because it forms the basis for defining the airways, its use is an integral part of the air traffic control procedures.

D. *Outlook*

Only a small increase in the number of transmitting stations is projected over the next decade in the U.S. to meet requirements for new airports and new airways, as well as special Alaskan requirements.

A substantial increase in the general aviation user category is anticipated with the continuing growth in the number of aircraft being operated in U.S. airspace and the accompanying decrease in avionics equipment cost. Since line-of-sight signal propagation seriously limits coverage at ground level, little or no use of the system by non-aviation vehicles is expected.

VOR/DME supports the current airways structure and is the system used for air traffic control procedures and operations. At present, no system has been identified by the FAA as a replacement. However, Omega and Loran-C have been certified as supplements to VOR/DME in specific areas and GPS has been approved as an input to multisensor RNAV.

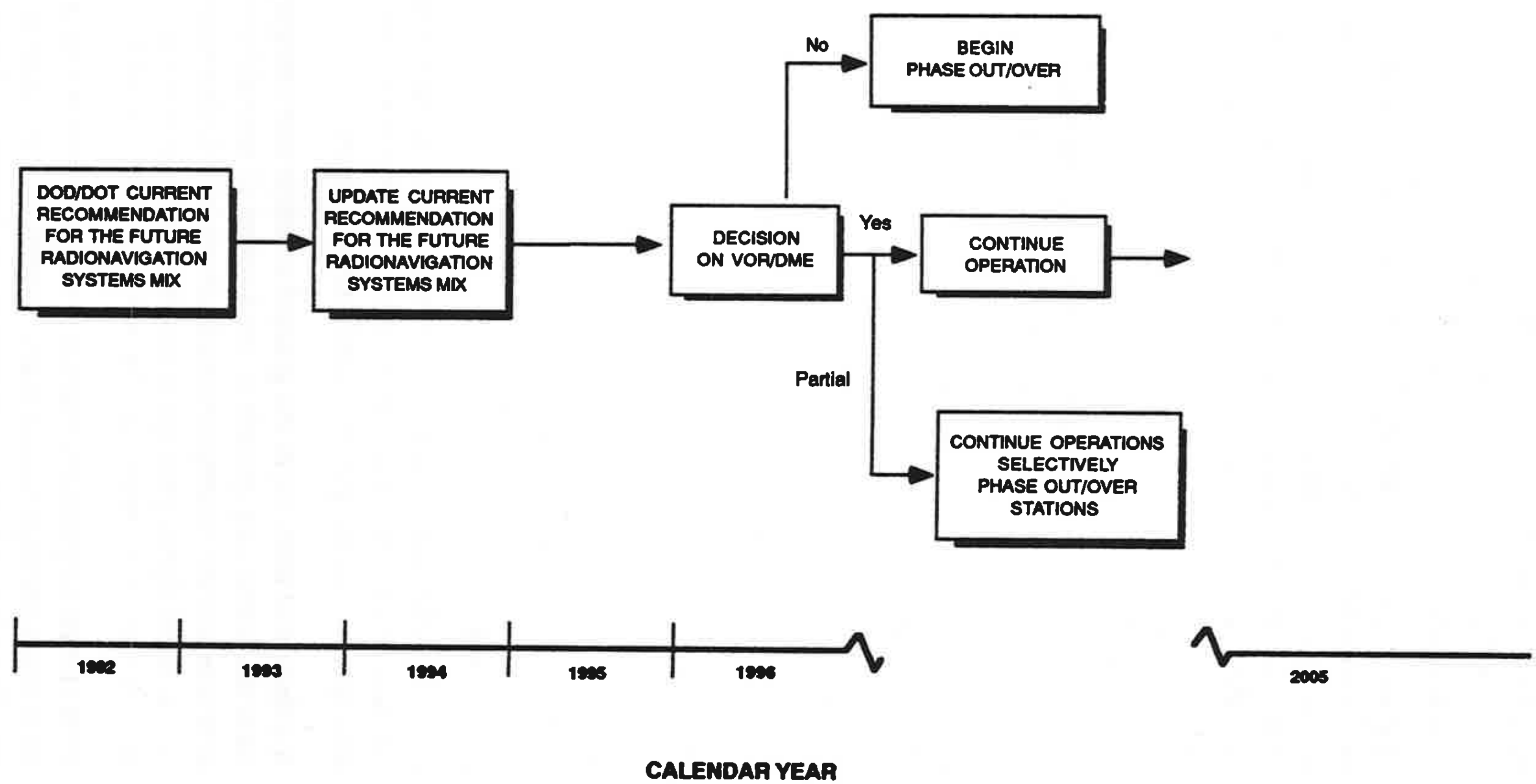


Figure 3-3. Operating Plan for VOR, and VOR/DME

Table 3-6. VOR, VOR/DME, and VORTAC Projections

FACILITIES/ USERS	CALENDAR YEARS													
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
FAA FACILITIES	962	1,020	1,020	1,020	1,020	1,020	1,020	1,020	1,020	1,000	950	900	850	800
DOD FACILITIES[1]	85	85	85	85	85	85	85	85	85	[2]				
CIVIL USERS (VOR)[3]	196,000	197,000	198,000	199,000	200,000	201,000	202,000	203,000	204,000	203,000	202,000	201,000	200,000	198,000
CIVIL USERS (DME)[3]	89,000	89,500	90,000	90,500	91,000	91,500	92,000	92,500	93,000	92,000	91,000	90,000	89,000	87,000
DOD USERS	12,500	12,000	10,000	8,000	6,000	4,000	2,000	1,000	500	[2]				

1 VORTAC stations only.
2 Data beyond this year are not available.
3 Includes non-DOD Federal users.

The VOR/DME system is protected by international agreement until 1995. It is expected to remain in service through the year 2010. If an alternate system such as Loran-C or GPS should prove acceptable to the international aviation community as a replacement for VOR/DME, a significant level of implementation would not occur until the late 1990s. It would require a substantial period beyond that before VOR/DME phase-out could be accomplished.

The DOD VOR/DME operational concept is to maintain present system coverage until a suitable replacement is available. Present plans for expansion of the VOR/DME system are limited to site modernization or facility relocation. GPS is the planned replacement for DOD VOR/DME and VORTAC facilities. This transition started in 1988. The target date for phase-out of the DOD requirement for VOR and VOR/DME is the year 2000. In the case of a military VORTAC site that has developed an appreciable civilian-use community and is due for phase-out, transfer of operational responsibility to the DOT will be discussed between DOD and DOT.

3.2.4 TACAN

TACAN is a UHF radionavigation system which provides a pilot with relative bearing and distance to a beacon on the ground, ship, or to specially equipped aircraft. TACAN is the primary tactical air navigation system for the military services ashore and afloat. TACAN is often collocated with the civil VOR stations (VORTAC facilities) to permit military aircraft to operate in civil airspace.

A. Operating Plan

DOD presently operates 173 TACAN beacons and the FAA operates 663 TACAN beacons for DOD. Present TACAN coverage ashore will be maintained until phased out in favor of GPS. However, GPS without enhancement cannot replace the TACAN function afloat (moving platforms). Civil DME and the distance-measuring functions of TACAN will continue to be the same. The operating plan for TACAN is shown in Figure 3-4.

B. User Community

There are presently approximately 14,500 aircraft which are equipped to determine bearing and distance to TACAN beacons. These consist primarily of Navy, Air Force, and to a lesser extent, Army aircraft. The projected military user populations are shown in Table 3-7. Additionally, allied and third world military aircraft use TACAN extensively. NATO has standardized on TACAN until 1995.

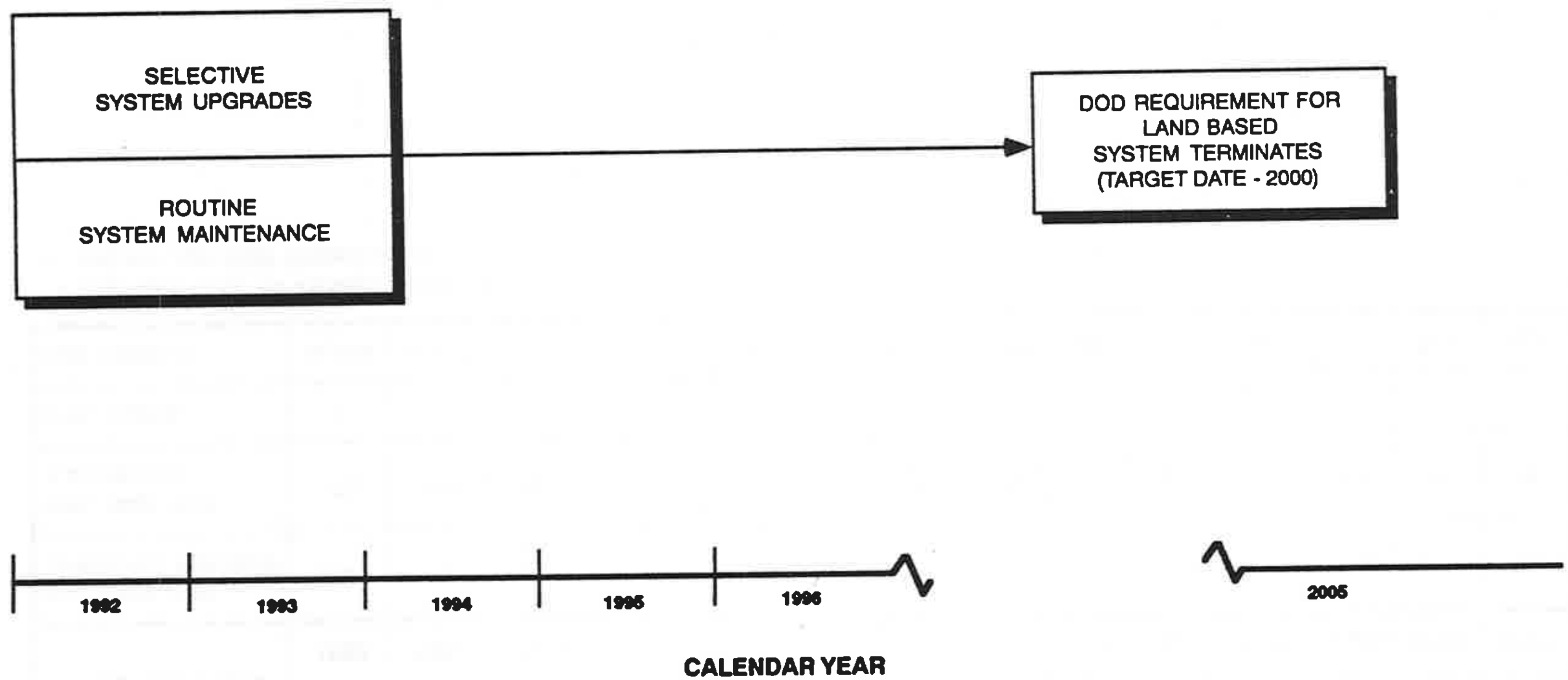


Figure 3-4. Operating Plan for TACAN

Table 3-7. TACAN Projections

FACILITIES/USERS	CALENDAR YEARS													
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
FAA FACILITIES OPERATED FOR DOD	648	640	633	633	633	600	550	500	450	400	350	300	250	250
DOD FACILITIES (Land-Based)	173	173	173	173	173	173	173	173	173	50	50	40	40	30
CIVIL USERS	*													
DOD USERS**	14,000	13,000	12,000	11,000	10,000	8,000	6,000	4,000	3,000	2000	1000	800	700	600

** Less than 100, no increase expected.*
*** Includes non-DOD Federal users.*

C. Acceptance and Use

TACAN is used by DOD and NATO aircraft operating under IFR ashore and IFR and VFR for tactical and en route navigation afloat. TACAN provides range and azimuth information and is easy to use.

Because of propagation characteristics and radiated power, TACAN is limited to line-of-sight and is limited to approximately 180 miles at higher altitudes. As with VOR/DME, special consideration must be given to location of ground-based TACAN facilities, especially in areas where mountainous terrain is involved due to its line-of-sight coverage.

D. Outlook

The DOD requirement for and use of land-based TACAN will terminate when aircraft are properly integrated with GPS and when GPS is certified to meet RNP in national and international controlled airspace. The target date is the year 2000. The requirement for shipboard TACAN will continue until a suitable replacement is operational.

3.2.5 ILS

ILS provides aircraft with precision vertical and horizontal navigation (guidance) information during approach and landing. Associated marker beacons or DME equipment identify the final approach fix, the point where the final descent to the runway is initiated.

A. Operating Plan

In 1992, there were 974 ILS sites. Eventually, about 1,094 ILS sites will exist. In addition, there are approximately 165 ILS facilities operated by DOD in the United States. The operating plan is shown in Figure 3-5.

B. User Community

Federal regulations require U.S. air carrier aircraft to be equipped with ILS avionics. It is also extensively used by general aviation aircraft. Since ILS is the ICAO standard landing system, it is extensively used by air carrier and general aviation aircraft of other countries. The projected civil and military user population is shown in Table 3-8.

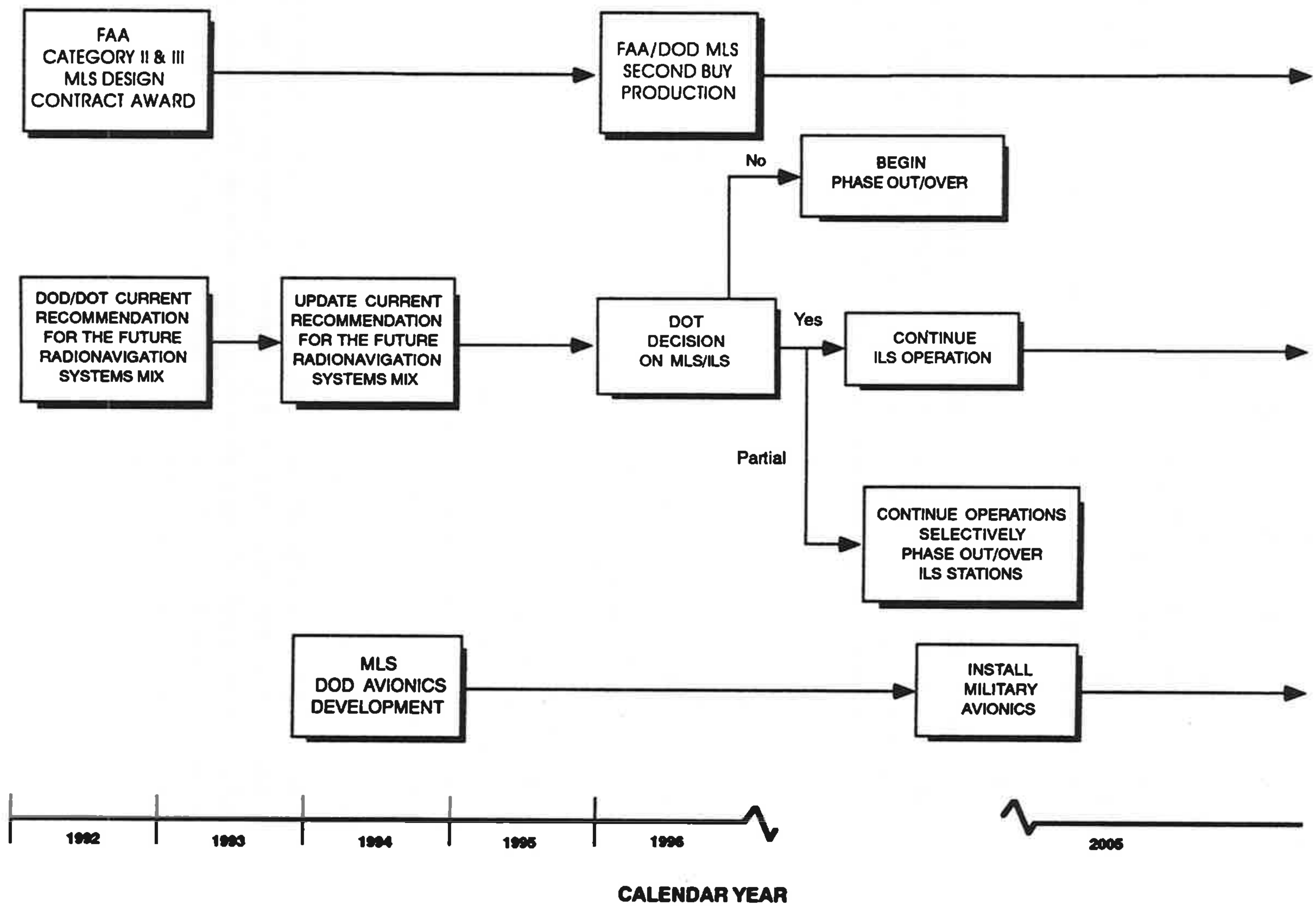


Figure 3-5. Operating Plan for ILS/MLS

Table 3-8. ILS Projections

FACILITIES/ USERS	CALENDAR YEARS													
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
FAA FACILITIES	974	989	1,004 [1]	1,019	1,034	1,049	1,064	1,079	1,094	1,094	1,094	1,094	1,050	1,020
DOD FACILITIES	165	165	164 [1]	165	165	165	165	165	165	160	150	100	50	40
CIVIL USERS	125,000	127,000	129,000 [1]	131,000	131,000	131,000	131,000	131,000	131,000	129,000	125,000	120,000	115,000	110,000
DOD USERS	10,500	9,500	10,000 [1]	9,000	8,500	8,000	7,500	7,000	6,500	5,000	4,000	2,000	1,000	1,000

[1] *A decision on a landing system architecture may alter projections beyond 1994.*

C. Acceptance and Use

ILS is the standard civil landing system in the U.S. and the international standard for aircraft operating under IFR conditions. Since its introduction in the 1940s, it has been installed in steadily growing numbers throughout the world. Part of its attractiveness to aircraft owners lies in the economy of avionics costs. Since the ILS localizers and VOR stations operate in the same frequency band, common receivers are used.

Military services use ILS at fixed bases in the U.S. and overseas. Special systems are used to meet unique military requirements, including shipboard operations. Precision Approach Radar (PAR) is the NATO interoperable landing aid.

D. Outlook

User Base Expansion: Based on a 1990 user survey, the number of civil aircraft equipped with ILS is estimated to be 125,000. This number is expected to increase until MLS is fully deployed.

Expected System Life: ILS is the standard civil landing system in the U.S. and abroad, and is protected by ICAO (International Civil Aviation Organization) agreement to January 1, 1998. ICAO has selected the MLS as the international standard precision approach system, with implementation targeted for 1998. MLS is expected to gradually replace ILS in national and international civil aviation. The FAA and DOD plan to have MLS collocated with ILS to minimize the transition impact.

System Limitations: ILS limitations manifest themselves in three major areas:

1. Performance of individual systems can be affected by terrain and man-made obstacles, e.g., buildings and surface objects such as taxiing aircraft and snow banks. These items may impose permanent use constraints on individual systems or limit their use at certain times.

2. The straight-line approach path inherent in ILS constrains airport operations to a single approach ground track for each runway. In contrast, MLS will allow multiple ground track paths for approaches to the active runway as well as provide a steeper glide slope capability for STOL aircraft.

3. Even though the new 50 kHz frequency spacing will eventually double the ILS channel availability, frequency saturation limits the number of systems that can be installed. Frequency saturation occurs when ILS facilities, in close proximity with inadequate frequency separation, produce mutual interference.

3.2.6 MLS

MLS is a joint development of DOT, DOD, and NASA under FAA management. Its purpose is to provide a civil/military, Federal/non-Federal standardized approach and landing system with improved performance compared with existing landing systems.

A. *Operating Plan*

The U.S. Time Reference Scanning Beam (TRSB) MLS technique was selected by ICAO as the international standard in 1978. MLS is expected to replace ILS, and an MLS transition plan was approved in July 1981. The current operating plan is shown in Figure 3-5. Precision DME (DME/P) will be included with this system. A limited procurement of Category I MLS equipment was initiated in 1992. Contracts for development of Category II/III equipment were also awarded in 1992. A production decision will be made in 1995.

B. *User Community*

MLS applications are limited to aviation. Widespread use by the U.S. civil and military aviation community is anticipated. Potential users include all segments of international civil and military aviation including NATO. The projected civil and military user population is shown in Table 3-9.

C. *Acceptance and Use*

Within the U.S., there has been support for a common civil/military MLS. MLS does not have the siting problems of ILS and offers higher accuracy and greater flexibility, permitting precision approaches at more airports. MLS provides DOD tactical flexibility due to its ease in siting and adaptability to mobile operations.

D. *Outlook*

MLS is expected to coexist with and then gradually replace ILS in national and international civil aviation. Production MLS equipment would replace or limit the deployment of nonstandard or interim MLS systems now in use. MLS is expected to operate beyond the year 2025. Inclusion of the L-band DME/P with MLS would require extension of the DME segment of VOR/DME through the same period.

3.2.7 Transit

The Navy Navigation Satellite System (NNSS), also referred to as Transit, is a satellite-based positioning system which provides submarines, surface ships, and a few specially equipped aircraft with an accurate two-dimensional

Table 3-9. MLS Projections

FACILITIES/ USERS	CALENDAR YEARS													
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
FAA FACILITIES	28	28	28 [1]	28	112	252	492	632	772	912	1,052	1,192	1,222	1,250
DOD FACILITIES [2]	24	71	80 [1]	89	114	145	195	246	299	343	379	408	408	408
CIVIL USERS [3]	50	100	100 [1]	200	500	1,000	5,000	10,000	20,000	30,000	50,000	75,000	100,000	150,000
DOD USERS	700	1,300	1,700 [1]	3,.000	4,300	6,100	7,800	9,200	10,100	10,100	10,100	10,100	10,000	9,500

1 A decision on a landing system architecture may alter projections beyond 1994.
2 Includes 71 mobile MLS.
3 Includes non-DOD Federal users.

positioning capability. The Transit system consists of low-altitude satellites in near polar orbits, ground-based monitor stations to track the satellites, and injection facilities to update satellite orbital parameters.

Developed to support the Navy Fleet Ballistic Missile Submarines, Transit is now installed on domestic and foreign commercial vessels in addition to military surface vessels.

A. Operating Plan

DOD plans to operate Transit until December 1996. Ground-based monitor and injection facilities and satellites will be operated and supported by the Navy.

The current Transit constellation contains ten satellites. Seven satellites are operational and three satellites are stored in orbit.

The Transit launch program ended in 1988. The Navy will terminate operation of the system by the end of 1996. The operating plan is shown in Figure 3-6.

B. User Community

There are currently fewer than 400 military Transit users. Foreign and domestic commercial vessel use of the Transit system has far outpaced the DOD use. It is estimated that 80,000 sets were in commercial use at the end of 1987. Approximately 90 percent of all commercial Transit receiver sales are for the single channel receivers. Determination of precise position (surveying) has become an important use of Transit. The projected user population is shown in Table 3-10.

C. Acceptance and Use

Transit provides periodic, worldwide, position-fixing information for Navy ships and submarines and commercial ships, as well as land users. Its acceptance is indicated by the large increase in commercial sales in recent years. The increased commercial demand for user equipment, and a continuing increase in the number of equipment manufacturers have reduced the user equipment costs.

From a military viewpoint, Transit provides precise positioning for fixed and low dynamic vehicles (ships, submarines, surveying). In a high dynamic, tactical environment (aircraft, missiles), Transit has little use since it is a Doppler system and small errors in user estimates of platform speed can cause large errors in user position. (One knot of unknown speed can cause a position error of 0.2 nm.)

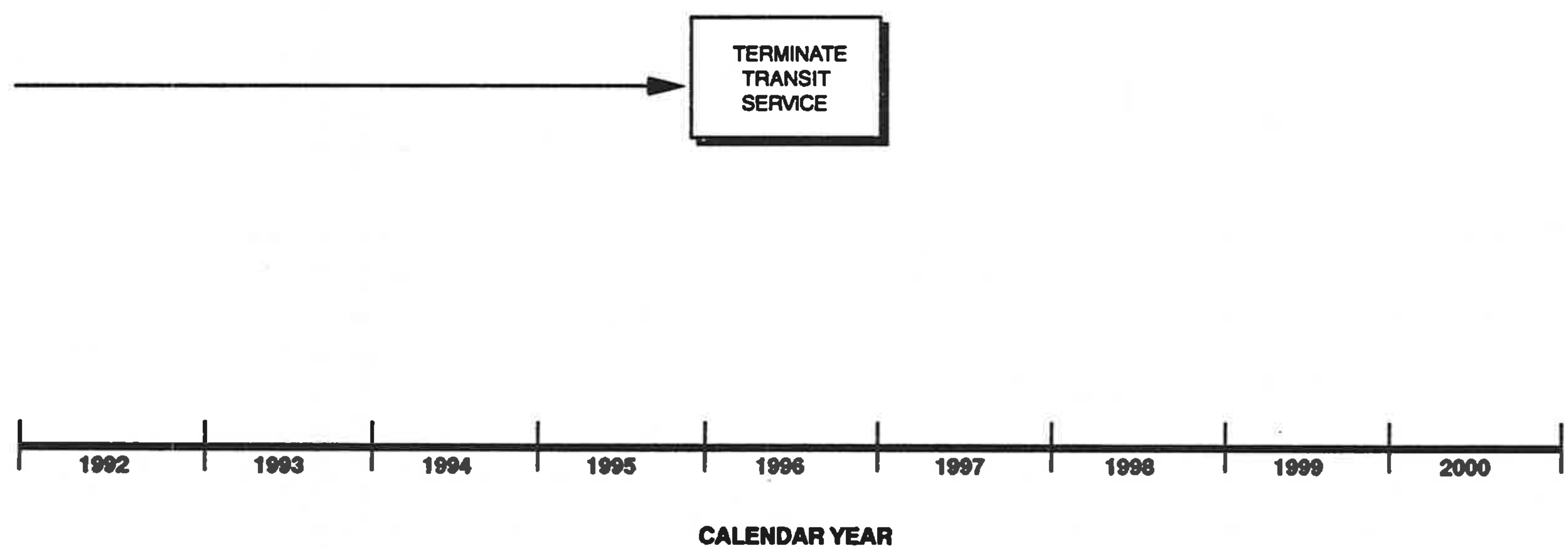


Figure 3-6. Operating Plan for Transit

Table 3-10. Transit Projections

FACILITIES/ USERS	CALENDAR YEARS													
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
SATELLITES	7	7	7	7	7	[1]								
CIVIL USERS (WORLDWIDE) [2]	90,000	85,000	80,000	75,000	70,000	[1]								
DOD USERS	350	100	70	20	10	[1]								

1 System terminated.
2 Includes non-DOD Federal users.

D. Outlook

Transit will be replaced with GPS by 1996. Transit will not be operated by or transferred to a civilian agency of the U.S. Government.

3.2.8 Aeronautical and Maritime Radiobeacons

Aeronautical nondirectional beacons (NDB) are used for transition from en route to precision terminal approach facilities and as nonprecision approach aids at many airports. In addition, many of the nondirectional beacons are used to provide weather information to pilots. In Alaska, NDBs are also used as en route facilities.

Marine radiobeacons provide a backup to more sophisticated radionavigation systems and are the primary low-cost, medium accuracy system for vessels equipped with only minimal radionavigation equipment.

A. Operating Plan

FAA operates over 700 NDBs. In addition, there are about 200 military aeronautical beacons and 800 non-Federally operated aeronautical beacons. During the next 10 years, FAA expenditures for beacons are planned to be limited to the replacement of deteriorated components, modernization of selected facilities, and an occasional establishment or relocation of an NDB used for ILS transition. Approximately 150 marine radiobeacons are operated by the USCG. The operating plan is shown in Figure 3-7.

B. User Community

Aeronautical NDBs: All air carrier, most military, and many general aviation aircraft carry automatic direction finders (ADF).

Marine Radiobeacons: Beacons are utilized by all classes of users within the civil maritime community. They act as a backup for those users having more sophisticated radionavigation capability, and as a primary safety of operation service to the small recreational craft operating in open water. The projected civil and military radiobeacon population is shown in Table 3-11. A plan is underway to use certain radiobeacons to broadcast differential GPS corrections to maritime users.

C. Acceptance and Use

Aircraft use radiobeacons as compass locators to aid in finding the initial approach point of an instrument landing system as well as for nonprecision approaches at low traffic airports without convenient VOR approaches.

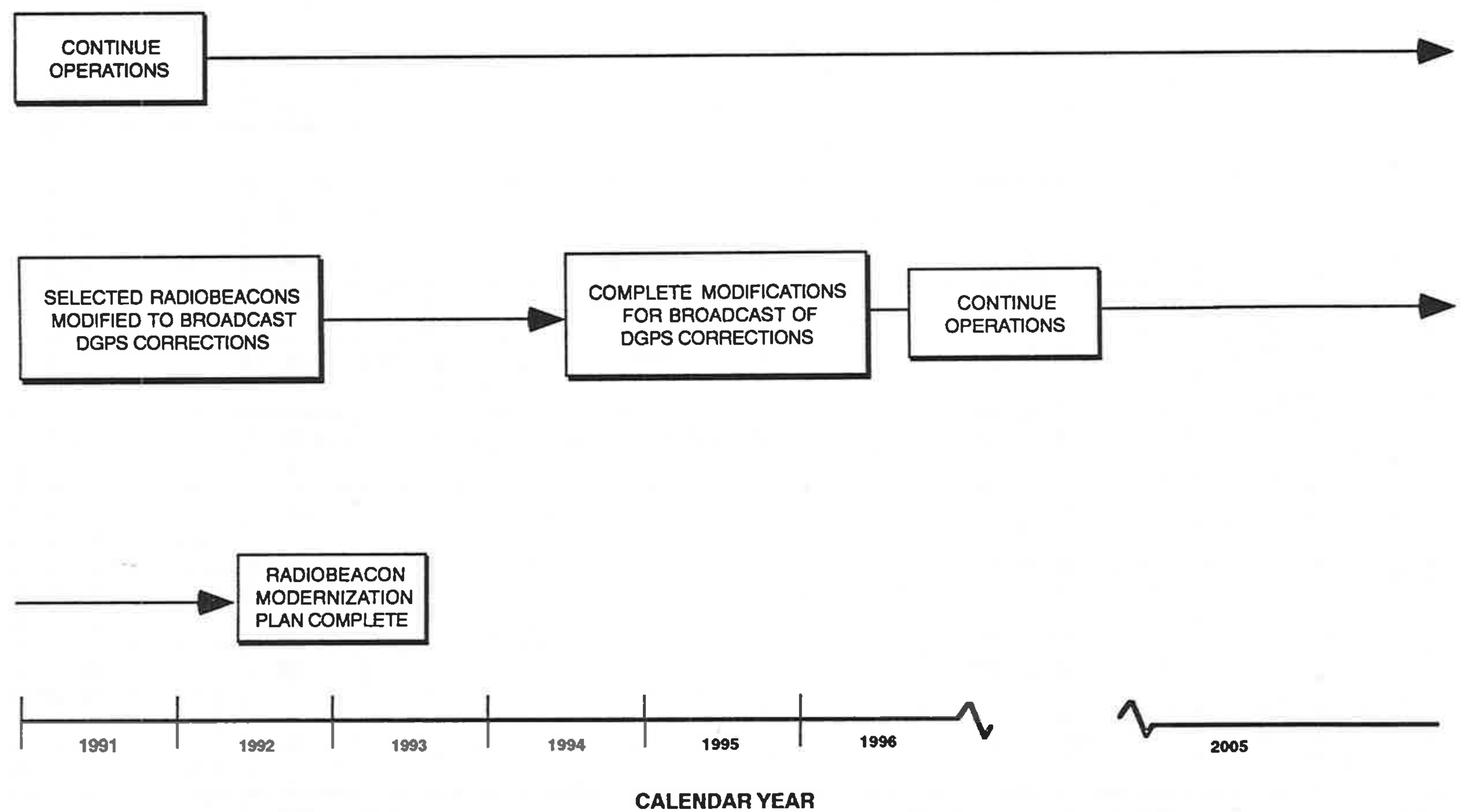


Figure 3-7. Operating Plan for Radiobeacons (Aeronautical and Maritime)

Table 3-11. Radiobeacon Projections

FACILITIES/USERS	CALENDAR YEARS													
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
AVIATION FACILITIES (FEDERAL)	728	728	728	728	728	728	728	728	728	728	700	650	500	300
AVIATION FACILITIES (NON-FEDERAL)	855	855	855	855	855	855	855	855	855	855	800	750	600	400
DOD FACILITIES (AVIATION)	180	170	160	150	120	120	100	100	50	50	50	40	30	20
MARITIME FACILITIES (FEDERAL)	150	150	150	150	150	150	150	150	150	50	50	50	50	50
CIVIL AVIATION USERS[1]	170,000	177,000	184,000	191,000	199,000	206,000	214,000	222,000	230,000	238,000	235,000	230,000	220,000	210,000
DOD AVIATION USERS	11,800	10,900	10,000	9,000	8,000	7,000	6,000	5,000	4,000	3,000	2,000	1,000	500	200
CIVIL MARITIME USERS[1]	500,000	500,000	500,000	490,000	450,000	430,000	410,000	380,000	350,000	320,000	315,000	310,000	300,000	290,000
DOD MARITIME USERS	390	385	380	375	370	350	300	250	200	150	100	50	0	0

[1] *Includes Non-DOD Federal Users.*

The large number of general aviation aircraft and pleasure boats which are equipped with radio direction finders attests to the wide acceptance of radiobeacons by the user community. The primary reason for this acceptance is that adequate accuracy can be achieved with low-cost user equipment.

Marine radiobeacons provide a bearing accuracy relative to vehicle heading on the order of ±3 to ±10 degrees. This might be considered a systemic limitation but, in actual use, it is satisfactory for many navigational purposes. Radiobeacons are not satisfactory for marine navigation within restricted channels or harbors. They do not provide sufficient accuracy or coverage to be used as a primary aid to navigation for large vessels in U.S. coastal areas.

D. Outlook

Growth in aeronautical beacon requirements is primarily non-Federal and is unpredictable. Federal expenditures for aeronautical beacons are planned to be limited to the occasional establishment or relocation of NDB for ILS transition, replacement of deteriorated components, and modernization of selected facilities. Growth in the number of FAA beacons will be a function of these factors.

Frequency congestion is one of the principal constraints which limits the expansion of NDB service. At FAA request, this problem has been addressed by the RTCA, Special Committee 146 (SC-146). This committee developed a MOPS for ADF receivers (RTCA DO-179). As existing ADF equipment is amortized, the tighter selectivity of new equipment will permit a greater number of NDB frequency assignments and will result in more efficient use of the radio spectrum.

Recent information shows that marine radiobeacons are used primarily by pleasure boaters in the homing mode. A reconfiguration of the marine radiobeacon facilities is in progress to eliminate sequenced radiobeacons and to relocate some radiobeacons for the best application of the homing mode.

At present, there is no known alternative system which would be as cost-effective for the user and the Government. Maritime and aeronautical radiobeacons serve the civilian user community with low-cost navigation and will remain part of the radionavigation systems mix through the year 2000; however, many of the maritime radiobeacons not modified to carry DGPS correction signals may be phased out after the year 2000.

Radar transponder beacons (RACONs) used for navigation are short-range radio devices used to provide fixed radar reference points in areas where it is important to identify a special location. Currently, they are only used in the marine environment. Examples of the use of RACONs are: landfall identification; improvement of ranging to and identification of an inconspicuous coastline; improvement of identification of coastlines permitting good ranging but which are otherwise featureless; improvement of the identification of a particular aid to navigation in an area where many radar returns appear on the radar display; provision of a lead to a specific point such as into a channel or under a bridge; warning to temporarily mark a new obstruction, or other uncharted or especially dangerous fixed hazard to navigation.

Though RACONs offer a unique possibility of positive aid identification, uncontrolled proliferation could lead to an unacceptable increase in responses presented on a ship's radar display. This could degrade the usefulness of the display and cause confusion. In 1986, the Code of Federal Regulations was changed (33 CFR 66.01-1 (d)) to allow private operation of RACONs with USCG approval. The USCG expects to have 110 frequency agile RACONs operating by early 1993.

3.2.9 Global Positioning System (GPS)

GPS is a space-based positioning, navigation, and time distribution system designed for worldwide military use. Special capabilities of particular interest to DOD include precise, continuous, all-weather, common-grid positioning, velocity and timing. Additionally, the weapon system enhancement features of the GPS can be denied to enemy forces, and the system has features to prevent spoofing and to reduce susceptibility to jamming. Although designed for military use, GPS will be available for civil use at the highest accuracy consistent with U.S. national security interests.

A. *Operating Plan*

GPS is a DOD-developed, worldwide, satellite-based radionavigation system that will be the DOD's primary radionavigation system well into the next century. The constellation will ultimately consist of 24 operational satellites. DOD Full Operational Capability (FOC) will occur when 24 operational (Block II/IIA) satellites are operating in their assigned orbits and have been tested for military functionality. An Initial Operational Capability (IOC) will be attained when 24 GPS satellites (Block I/II/IIA) are operating in their assigned orbits and are available for navigation use. IOC is planned to occur in mid-1993, and military FOC is planned to occur in 1995.

The GPS Master Control Station in Colorado Springs, Colorado, and its remote monitor stations and antennas are all operational. The Master Control Station controls the GPS satellite constellation. As soon as satellites are added to the operational constellation and have passed specific tests, the Master Control Station will turn on Selective Availability (SA). SA is a method to control the availability of the system's full capabilities. During the

GPS constellation buildup to 24 satellites, the control segment will test various satellite capabilities including encryption of the precise (P) pseudorandom tracking code. The P code will not normally be available to users who do not have valid cryptographic keys.

The operating plan for GPS and DGPS is shown in Figure 3-8.

B. User Community

DOD expects extensive use of GPS in almost every military mission area. The projected user population is shown in Table 3-12. DOT and others are evaluating use and potential applications of GPS to meet civil navigation requirements.

The U.S. encouraged NATO participation in the development and deployment of GPS military user equipment. In response, ten NATO nations signed a Memorandum of Understanding in June 1978 (updated in 1984) for participation in the development of GPS. These nations are Belgium, Canada, Denmark, France, Germany, Italy, the Netherlands, Norway, Spain, and the United Kingdom. Australia has signed a similar agreement.

The objective of this agreement is to establish a flow of information among the participating nations regarding all GPS program activities to facilitate national decisions supporting the application and use of GPS. To this end, personnel of participating nations are fully integrated within the GPS Joint Program Office to contribute to the U.S. development program and to coordinate NATO applications, development, and testing.

In addition to formal NATO involvement in the development of military GPS user equipment, DOD has working relationships with other friendly nations and is sharing information that is designed to create interest in the military use of GPS.

Widespread national and international civil use of the GPS Standard Positioning Service (SPS) is anticipated. Because of national security considerations, the GPS Precise Positioning Service (PPS) will be restricted to U.S. Armed Forces, U.S. Federal agencies, and selected allied Armed Forces and governments. While GPS/PPS has been designed primarily for military radionavigation needs, it will nevertheless be made available on a very selective basis to U.S. and foreign private sector (nongovernmental) civil organizations. Access determinations will be made by the Government on a case-by-case evaluation that:

- Access is in the U.S. national interest.
- There are no other means reasonably available to the civil user to obtain a capability equivalent to that provided by GPS/PPS.

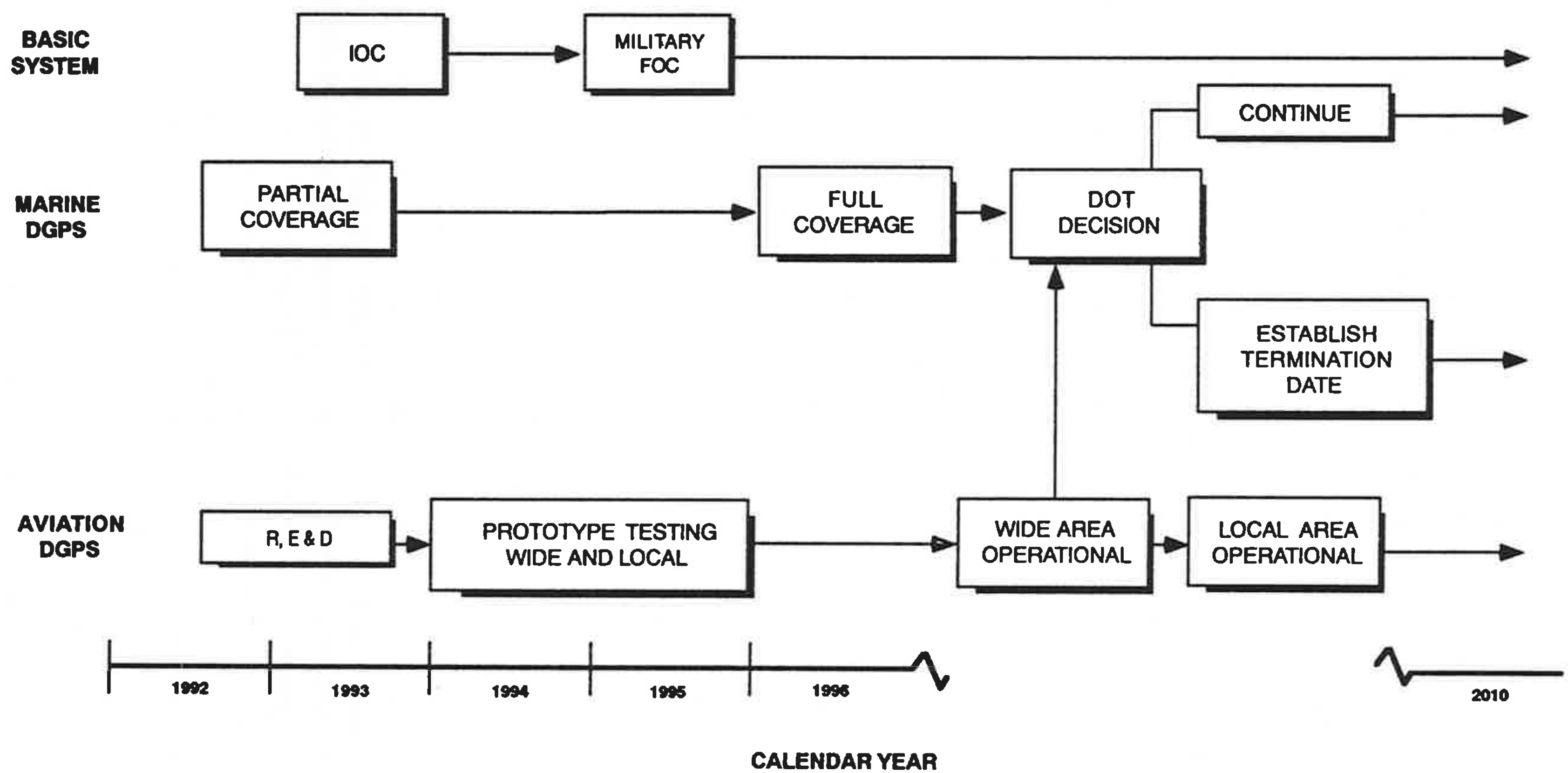


Figure 3-8. Operating Plan for GPS/DGPS

Table 3-12. GPS Projections

FACILITIES/ USERS	CALENDAR YEARS													
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
DEVELOPMENT SATELLITES	4	3	0	0	0	0	0	0	0	0	0	0	0	0
OPERATIONAL SATELLITES	20	24	24	24	24	24	24	24	24	24	24	24	24	24
DOD USERS	16,000	17,000	19,000	21,000	25,000	26,000	28,000	30,000	32,000	34,000	35,000	36,000	37,000	38,000
CIVIL AVIATION USERS[1,2,3]	1,200	1,800	2,400	4,000	6,000	10,000	20,000	40,000	80,000	100,000	150,000	200,000	300,000	500,000
CIVIL LAND USERS[1,3,4]	5,600	8,400	12,600	18,900	28,400	3 50,000	100,000	150,000	200,000	300,000	500,000	1.5M	2M	2.5M
CIVIL MARITIME USERS [1,3]	9,000	13,500	20,250	30,375	45,600	3 60,000	75,000	90,000	105,000	120,000	135,000	150,000	165,000	180,000

1 Includes non-DOD Federal users.
2 Civil use of GPS/SPS is not authorized for IFR until civil user equipment is approved by FAA.
3 Worldwide.
4 Includes survey and time users.

M = Million

- Security requirements can be met.

The Government is currently developing policy for submitting applications, granting approval for user access, and establishing operational procedures and compliance requirements for accessing the data from GPS/PPS. This guidance will be published in detail prior to GPS/PPS being made available to the private sector civil community.

In response to a DOD request, DOT has established the Civil GPS Service (CGS), consisting of the GPS Information Center (GPSIC) and the PPS Program Office (PPSPO). The GPSIC provides information to and is the point of contact for civil users of the GPS system. The PPSPO administers GPS/PPS service to approved civil users.

Subsequent to IOC, any planned disruption of the SPS in peacetime will be subject to a minimum of 48-hour advance notice provided by the DOD to the Coast Guard GPS Information Center (GPSIC) and the FAA Notice to Airmen (NOTAM) system. A disruption is defined as periods in which the GPS is not capable of providing SPS as specified. Unplanned system outages resulting from system malfunctions or unscheduled maintenance will be announced by the GPSIC and NOTAM systems as they become known. The Coast Guard and the FAA will notify civil users when the GPS is approved for navigation.

C. Acceptance and Use

When GPS becomes operational, DOD plans to phase out its requirements for and use of other common-use radionavigation systems. There are positive indications that the military forces of the NATO nations, as well as other allied countries, will use GPS. Because of the accuracy, worldwide coverage and flexibility provided by GPS, nongovernment civil use has grown rapidly and exceeds military use. User population estimates will be influenced by many factors, such as the resolution of civil aviation system coverage and integrity issues currently being addressed by the FAA and DOD.

D. Outlook

The GPS constellation and control segments are planned for IOC in mid-1993, and military FOC in 1995. Initially, GPS will be integrated into military aircraft which are instrumented for instrument flight and contain inertial navigation systems or other forms of suitable attitude heading reference systems. These aircraft will be flight tested to ensure that they meet established standards for operation in the national airspace. Prior to military FOC, there is expected to be significant civil use of the system for navigation, to obtain accurate positioning, velocity and time, for geodetic surveying, and for many other applications. Initial civil aircraft use will probably be as a supplementary system for en route domestic and international operations.

On July 12, 1991, the RTCA, Inc. Special Committee 159 published the Minimal Operational Performance Standards (MOPS) for airborne supplemental navigation equipment using GPS.

For GPS to meet RNP for civil aviation (for oceanic en route, domestic en route, terminal, and nonprecision approaches), it must provide at least five satellites in view above a mask angle of 7.5 degrees in which all combinations of four out of five satellites provide horizontal position accuracy required for the different phases of flight. At least five satellites are required so that if one satellite fails, unaided GPS navigation may continue. The current civil aviation integrity requirement for nonprecision approaches is that the navigation system provide a warning to the pilot or removal of the signal from service within 10 seconds after the signal has gone out-of-tolerance.

Interim guidance for installation and approval of GPS equipment in aircraft is given in Appendix B.

In light of recommendations of the ICAO Special Committee on the Future Air Navigation System (FANS) and to further the development of the ICAO Communications, Navigation, and Surveillance/Air Traffic Management (CNS/ATM) system concept, the U.S. decided to make available the SPS of the GPS at the Tenth Air Navigation Conference in September 1991. The U.S. offer at the Tenth Air Navigation Conference was: "GPS-SPS is planned to be available beginning in 1993 on a continuous, worldwide basis with no direct user charges for a minimum of ten years. The service will provide horizontal accuracies of 100 meters (2 drms - 95% probability) and 300 meters (99.99% probability)." Beyond the original offer of GPS-SPS for a minimum of ten years, the U.S. intends to continue operation of GPS and to offer GPS-SPS for the foreseeable future free of direct user fees. In addition, the U.S. intends, subject to the availability of funds, to provide a minimum six-year advance notice of termination of GPS operations or elimination of the GPS-SPS.

3.2.10 *Differential 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.

Adverse effects of these variances may be substantially reduced, if not practically eliminated, by differential techniques. In such differential operation, a facility may be located at a fixed point (or points) within an area of interest. GPS signals are observed in real time and compared with signals expected to be observed at the fixed point. Differences between observed signals and predicted signals are transmitted to users as differential corrections to upgrade the precision and performance of the user's receiver processor.

The area over which corrections can be made from a single differential facility depends on a number of factors, including timeliness of correction dissemination, range of the correction transmission, area and uniformity of the system's grid, and user equipment implementations. A differential facility might serve an area with a radius of several hundred miles, depending on the system used and the method of implementation.

Recent innovations in carrier phase tracking differential GPS positioning systems have undergone considerable development and manufacturers are now providing DGPS receivers with carrier phase tracking capabilities. These systems are currently being used for obtaining centimeter accuracies with post processing of data by the U.S. Army Corps of Engineers and others. Similar systems are under development to provide real-time carrier phase tracking on dynamic platforms and will include on-the-fly initialization capabilities in the near future.

Operating Plan

The USCG plans to provide DGPS service for the harbor and harbor approach phase of maritime navigation. Maritime DGPS will use fixed GPS reference stations which will broadcast pseudo-range corrections using maritime radiobeacons. The USCG DGPS system will provide radionavigation accuracy better than 10 meters (2 drms) for U.S. harbor and harbor approach areas by 1996, free of charge to the user. Until the DGPS service is declared operational by the USCG, users are cautioned that signal availability and accuracy are subject to change due to the dependence on GPS, testing of this developing service, and the uncertain reliability of prototype equipment.

Recommended standards for maritime DGPS corrections have been developed by the Radio Technical Commission for Maritime Services (RTCM) Special Committee 104. The USCG is represented on this subcommittee and is using the SC-104 standard for its DGPS system. There are DGPS reference stations available in the market today which are compatible with RTCM Special Committee 104 standard.

Limited testing of differential GPS is being conducted within the ongoing IVHS operational test in Orlando, Florida. Vehicle navigation may require DGPS to discriminate between adjacent roads.

The FAA, in cooperation with DOD, is planning to use differential corrections to GPS/SPS in the provision of required navigation performance (RNP) in the National Airspace System.

The operating plan for GPS/DGPS is shown in Figure 3-8.

3.2.11 *Vessel Traffic Services (VTS)*

Title 14 U.S.C. requires the Coast Guard to safeguard the nation's ports, waterways, port facilities, vessels, persons, and property in the vicinity of the port from accidental or intentional destruction, damage, loss, or injury. These requirements are addressed by the Coast Guard's Port Safety and Security Program, Marine Environmental Protection Program, and Waterways Management Program. In the course of administering these programs, the Coast Guard assumes responsibility for vessel traffic management and navigation safety regulations. In responding to these requirements, and in furtherance of the National Transportation Plan, the Coast Guard operates Vessel Traffic Services (VTS) to provide active vessel traffic management in eight selected ports and waterways (see Figure 3-9).

The mission of VTS is to facilitate the safe and efficient movement of vessel traffic to prevent collisions, rammings, groundings, and the loss of lives, property and environmental quality associated with these accidents. Vessel Traffic Services, by their command and control facilities, also integrate and support other Coast Guard missions including search and rescue, maritime law enforcement, anchorage administration, aids to navigation, port safety and security and national defense.

The Saint Lawrence Seaway Development Corporation (SLSDC), created by Public Law 83-358 in 1954 (68 Stat. 93, 33 U.S.C. 981), is responsible for the development, operations and maintenance of the portion of the Saint Lawrence Seaway between Montreal, Quebec, and Lake Erie and within the territorial limits of the United States. In close coordination with the Canadian counterpart, the SLSDC maintains and operates a vessel traffic control center in Massena, New York (see Figure 3-9).

A. *Operating Plan*

Vessel traffic management can be either passive or active. Passive management involves compliance with the Rules of the Road and other rules and regulations. Active traffic management requires interaction and transfer of information between a shore station and a vessel. The Coast Guard's objective in both passive and active vessel traffic management is to create a disciplined structure of order and predictability.

Coast Guard authority, derived from the Ports and Waterways Safety Act (PWSA), allows for varying levels of vessel traffic management. The level of active management to be exercised is determined on a case by case basis and is directed at a specific vessel in a specific situation.

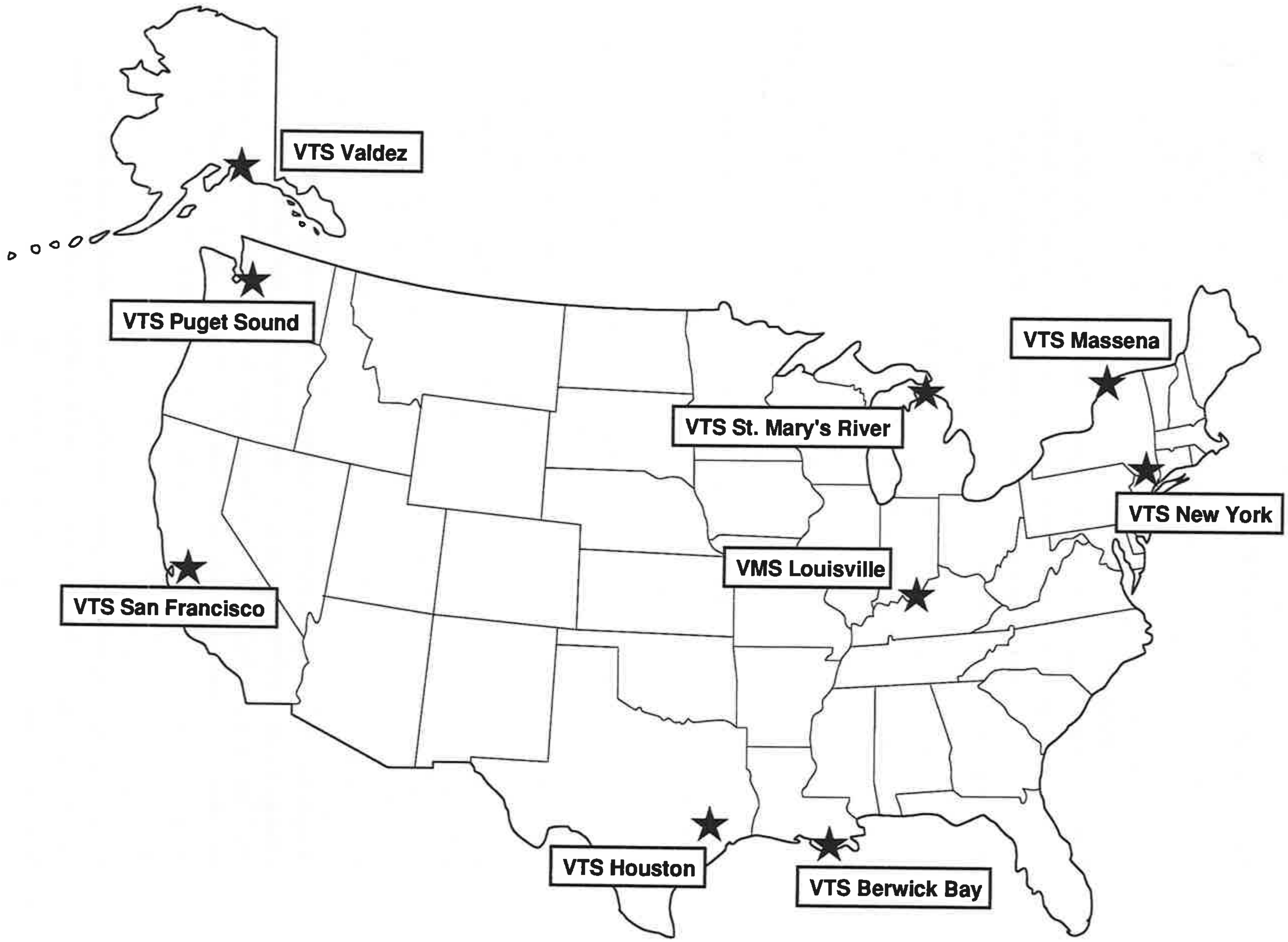


Figure 3-9. Vessel Traffic Service (VTS) Locations

It is a generally accepted principle that VTS functions primarily as an advisory service to coordinate vessel movements through the collection, verification, organization, and dissemination of information. There are times, however, when the maintenance of good order on a waterway requires a VTS to be more directive in its dealings with a vessel. In the exercise of its authority, a VTS can be viewed as three-tiered relative to the level of direction it will exercise:

1. Informational/advisory - the most common use. The great majority of VTS operations are advisory or informative. The vessel operator receives information, determines if action is necessary, and makes adjustments in time to reduce the risks.

2. Recommendations - used occasionally. The VTS determines that action is necessary, and the vessel operator determines what specific action is required to comply, i.e., slow, change course, stop, etc.

3. Specific directions or orders - used in an emergency situation. The most common use of this authority is a VTS directing a vessel not underway to remain at berth or at anchor until an unsafe condition abates. In these cases, the VTS determines necessary and specific action to avoid a potentially dangerous situation.

"Positive Control," as distinguished from the above examples, is any order directed at a vessel by a VTS that affects the vessel's course or speed through the issuance of specific helm or engine commands. This level of involvement is inconsistent with the currently accepted practice within VTS, which is to manage the waterway through varying degrees of VTS interaction, and not by attempting to navigate a vessel from the shore. VTS maintains an informative and advisory role by providing mariners with as much information as is available to assist them in making sound judgements. VTS is active waterways management, not active vessel control. However, the PWSA provides the authority for the Coast Guard to exercise positive control when deemed necessary. Although modern VTSs have the capability to exercise their authority to actively direct a vessel's movement, Coast Guard policy regarding VTS operations is that ultimate responsibility for safe navigation always remains with the master.

B. User Community

Mandatory participation by vessels is necessary for a successful VTS. Mandatory participation in the Coast Guard's VTS program is aimed at vessels that are required to comply with the Bridge-To-Bridge Radiotelephone Act. In general terms, these are:

- Each vessel 20 meters or more in length.

- Each towing vessel 8 meters or more in length while towing.
- Each vessel of 100 or more gross tons carrying passengers for hire.
- Dredges and floating plants engaged in or near a channel or fairway.

Vessels that are specifically required to participate will be identified in VTS regulations and user's manuals.

In addition to participation requirements, vessel operators must be aware of the radiotelephone frequencies and assigned call signs for each VTS. Table 3-13 shows each VTS and its sectors, assigned frequencies, and voice call sign.

C. Acceptance and Use

VTS, as an international philosophy, continues to gain wide acceptance. Although VTS in some nations still tends to focus on economic issues, the trend is now toward safety of vessels, lives, and protection of the environment. Environmental issues are more in the forefront and initiatives are underway to ascertain how VTS can help protect the marine environment, while at the same time supporting a productive maritime economy.

As VTS becomes better known, and its international acceptance grows, the user community also grows. Table 3-14 shows the number of vessels that transited seven of the eight Coast Guard VTSs from January 1990 through December 1991. Statistics for the Vessel Traffic Management System in Louisville are not included in this list because this service is only temporarily activated during certain stages of high water.

D. Outlook

In August 1991, the Coast Guard completed a VTS Port Needs Study to provide an economic framework for VTS capital investment decisions into the next century. This project examined 23 potential sites for VTSs and determined the benefit to be gained by establishing a VTS in terms of losses and damages avoided. Based on the results of this study, expansion of the program beyond the eight existing units is expected.

Several initiatives are underway to upgrade and improve equipment at existing Vessel Traffic Centers. New surveillance techniques and equipment as well as enhanced displays are areas the Coast Guard is emphasizing to improve service to the public.

Table 3-13. Vessel Traffic Services Designated[1] Radiotelephone Frequencies and Assigned Call Signs

VESSEL TRAFFIC SERVICES[2] SECTOR	CARRIER FREQUENCY[3] (CHANNEL DESIGNATION)	CALL SIGN
NEW YORK	156.550 MHz (Ch.11) 156.600 MHz (Ch.12) 156.700 MHz (Ch.14)	NEW YORK TRAFFIC
LOUISVILLE	156.650 MHz (Ch.13)	LOUISVILLE TRAFFIC
HOUSTON	156.550 MHz (Ch.11) 156.600 MHz (Ch.12)	HOUSTON TRAFFIC
SARNIA[4]	156.550 MHz (Ch.11) 156.600 MHz (Ch.12)	SARNIA TRAFFIC
MASSENA[5]	156.600 MHz (Ch.12) 156.650 Mhz (Ch. 13)	SEAWAY EISENHOWER SEAWAY CLAYTON
BERWICK BAY	156.550 MHz (Ch.11)	BERWICK TRAFFIC
ST. MARY'S RIVER	156.600 MHz (Ch.12)	SOO CONTROL
SAN FRANCISCO	156.600 MHz (Ch.12) 156.700 MHz (Ch.14)	SAN FRANCISCO TRAFFIC
PUGET SOUND[4]		
Seattle Sector	156.250 MHz (Ch.5A) 156.700 MHz (Ch.14)	SEATTLE TRAFFIC
Tofino Sector	156.725 MHz (Ch.74)	TOFINO TRAFFIC
Vancouver Sector	156.550 MHz (Ch.11)	VANCOUVER TRAFFIC
PRINCE WILLIAM SOUND	156.650 MHz (Ch. 13)	VALDEZ TRAFFIC

Notes

1 The bridge-to-bridge navigational frequency, 156.65 MHz (Channel 13), is used in those vessel traffic service areas where the level of radiotelephone transmissions does not warrant the impact of requiring a designated vessel traffic service frequency. The U.S. Coast Guard will continue to monitor vessel traffic service's use of this frequency and will petition the Federal Communications Commission for designated VTS frequencies if the need should arise.

2 Vessel traffic service geographical areas, sectors, and operating procedures are denoted in 33 CFR 161.

3 In the event of a communication failure on a designated frequency, either by the vessel traffic center or the vessel, communications may be established on an alternate VTS frequency, or 156.650 MHz (Channel 13); however, only to the extent that doing so provides a level of safety beyond that provided by other means.

4 A Cooperative Vessel Traffic Service established by the United States and Canada within adjoining waters. The appropriate vessel traffic center administers the rules issued by both nations; however, it will enforce only its own set of rules within its jurisdiction.

5 The Canadian St. Lawrence Seaway Authority operates Seaway Beauharnois, Seaway Iroquois, and Seaway Welland for the Canadian sectors of the Seaway.

Table 3-14. Vessel Traffic Services Currently Operating

FACILITIES	TOTAL VESSEL TRANSITS		
	1990	1991	1990+1991
NEW YORK, NY	Not on line	120,892	120,892
PRINCE WILLIAM SOUND, AK	3,038	2,705	5,743
HOUSTON/GALVESTON, TX	177,300	171,132	348,432
PUGET SOUND, WA	246,893	244,057	490,950
SAN FRANCISCO, CA	91,388	83,670	175,058
BERWICK BAY, LA	61,738	78,177	139,855
ST. MARY'S RIVER, MI	27,646	49,788	77,434
TOTALS	608,003	750,361	1,358,364
AVERAGE			56,599/month

3.3 Interoperability of Radionavigation Systems

Radionavigation systems are sometimes used in combination with each other or with other systems. These combined systems are often implemented so that a major attribute of one system will supplement a weakness of another. For example, a system having high accuracy and a low fix rate might be combined with a system with a lower accuracy and higher fix rate. The combined system would demonstrate characteristics of a system with both high accuracy and a high fix rate.

3.3.1 Integrated Navigation Receivers

Integrated navigation receivers combine the signals from multiple sensors to determine position and, often, velocity. Typical sensors include one or more radionavigation receivers and, possibly, compasses and speed sensors. Commercial receivers which combine Transit and Omega or Transit and Loran-C have been widely produced. More recently, numerous receivers have been developed combining GPS with other radionavigation systems to take advantage of the nearly continuous GPS coverage available as the constellation matures.

The FAA has a project to determine the technical feasibility of using both GPS and GLONASS signals in the same user equipment to determine position and be used for navigation. Using information from both these systems would provide more continuous, worldwide coverage than when using either system separately - a benefit especially valuable in aviation. At least one manufacturer is independently developing a GPS/GLONASS receiver.

3.3.2 *Interoperable Radionavigation Systems*

Even better performance might be obtained by a user if the time references of different radionavigation systems were related to one another in a known manner. The systems would then be said to be interoperable, and user equipment could more advantageously combine the lines of position from the different systems.

Section 310 of Public Law 100-223, The Airport and Airway Safety and Capacity Expansion Act of 1987, caused an examination of the benefits of coordinating the time references of the GPS and Loran-C systems. While current national security considerations preclude the direct synchronization of Loran-C transmissions to GPS precise time, the Coast Guard has significantly improved the synchronization of Loran-C master stations to Coordinated Universal Time (UTC). Since GPS is also synchronized to UTC, this provides a de facto synchronization of Loran-C to GPS which might benefit the user. Direct synchronization of Loran-C secondary stations to UTC, as an alternative to the current "System Area Monitor" method of control, provides no significant navigation advantage and would adversely affect a large segment of the user community.

4

Radionavigation Research, Engineering and Development Summary

4.1 Overview

This section describes Federal government research, engineering and development (R,E&D) activities relating to the Federally provided radionavigation systems and their worldwide use by the U.S. Armed Forces and the civilian community. It is organized in two segments: (1) civil R,E&D efforts to be conducted mainly by DOT and to a lesser extent by NASA, and (2) DOD research and engineering (R&E) for military uses.

The DOT R,E&D activities consist of parallel efforts to develop current and future navigation systems to improve existing operations or to identify systems which can replace or supplement those now being used in civil air, land or marine applications. The parallel efforts are described in two major sections, one covering GPS and the other covering all existing systems (such as VOR, Omega, and Loran-C) now in use or being considered by DOT to meet new or emerging navigation requirements.

Although the DOT R,E&D activities for GPS will proceed in much the same manner as those for other systems, GPS has been identified separately because of its potentially broad multimodal civil and military applications and the consequent need for close cooperation between Federal agencies in its evaluation. Such a cooperative effort will minimize duplication of effort and promote maximum productivity from the limited resources available for civil research. DOT's participation in the evaluation and development of GPS ensures that benefits can be derived from DOD's advances in systems technology.

From the point of view of DOT, the analysis of performance requirements of civil navigation systems involves a variety of complex factors before it can be concluded that a specific system satisfies the principal objective to ensure safety and economy of transportation. These factors involve an evaluation of the overall economics of the system in relation to technical and operational considerations, including vehicle size and maneuverability, vehicle traffic patterns, user skills and workload, the processing and display of navigation information, and environmental restrictions (e.g., terrain hazards and other obstructions). For this reason, a DOT comparison of one navigation system to another requires more than just a simple evaluation of accuracy and equipment performance characteristics. As a first step in the comparison of system capabilities, ten parameters, discussed in Appendix A, can be identified and are listed below:

- Signal Characteristics
- Accuracy
- Availability
- Coverage
- Reliability
- Fix Rate
- Fix Dimensions
- System Capacity
- Ambiguity
- Integrity

User equipment costs are a major consideration if universal civil participation is to be achieved. DOT R,E&D activities may involve evaluations and simulations of low-cost receiver designs, evaluation of future technologies, and determination of future requirements for the certification of equipment.

In contrast to DOT, the DOD R&E activities mainly address GPS and MLS evaluations by Armed Forces user groups which are identified by military mission requirements and national security considerations. For this reason, DOD R&E is defined to include all activities before the final acquisition of a navigation system in accordance with detailed system specifications. The DOD view of Transit, Loran-C, TACAN, VOR, ILS, and Omega is that these systems are already developed and, therefore, do not require R&E.

Although there are some similarities between the DOD and DOT analyses of the system parameters, DOD military missions place much greater emphasis on security and anti-jam capabilities. Such factors as anti-jam capabilities, updating of inertial navigation systems, input sensors for weapon delivery, portability, and reliable operation under extreme environmental or combat conditions become very important in establishing the costs of the navigation equipment.

Concurrent with the Federal R,E&D programs, the major cost issues will be evaluated. These evaluations and R,E&D programs will be used to support joint positions related to system mix, phase-in/phase-out, and transition strategies for common-use systems.

The relationship between DOT and DOD R,E&D programs is based on a continuing interchange of operational and technical information on radionavigation systems. DOD R,E&D will be coordinated with DOT R,E&D under the following guidelines:

- DOT will evaluate the costs of all radionavigation systems which meet identified civil user requirements.
- DOT will provide DOD with the most current information on civil user requirements which may have a significant impact on DOD-operated radionavigation systems.
- Consistent with existing DOD policy, DOD will provide information to DOT on GPS receiver designs that may be applicable to civil receiver development.
- DOT will conduct studies of GPS performance capabilities of receivers in order to provide an assessment of their applicability to the civil sector.
- DOD/DOT will not constrain the use of SPS-based differential GPS service as long as applicable U.S. statutes and international agreements are adhered to.
- DOT will support cooperation in development of differential correction reference stations for the best possible differential/integrity network.
- DOT has and is continuing to investigate the use of both GPS and GLONASS signals by the same receiver.

The specific civil R,E&D activities are outlined below in two segments: 1) GPS R,E&D, and 2) R,E&D for other navigation systems including VOR, TACAN, DME, Omega, Loran-C, ILS, and MLS. These activities have been coordinated to achieve efficient use of the limited funds available for R,E&D and to avoid duplication of effort. R,E&D tasks for the individual DOT agencies (FAA, USCG, MARAD, etc.) and related tasks by NASA are addressed and schedules have been specified so that the results of the efforts will be of maximum usefulness to all participants in the program. R,E&D schedules and activities for the FAA, the USCG, and RSPA have been identified respectively under civil aviation, land and marine activities in this document.

4.2 DOT GPS R,E&D

DOT R,E&D activities for GPS have been conducted primarily by the USCG, the FAA, and RSPA. Efforts initially were directed primarily toward determining the capability of GPS to meet civil user needs in the air, land and marine transportation communities. Subsequently, as it became apparent that the GPS capability to be provided to the civil community would not meet all user requirements, efforts have focused on ways of enhancing the system to meet these civil needs. The major DOT air, land and marine R,E&D activities for GPS are described as follows:

A. USCG activities focus on verifying and improving the performance of GPS for maritime navigation. There is particular emphasis upon the harbor/harbor approach phase of marine navigation, where augmentation of visual piloting and positioning of other aids to navigation using radio aids to navigation is needed. Major efforts are to:

- Verify the differential GPS concept and techniques developed by the Radio Technical Commission Maritime Special Committee 104 (RTCM/SC-104) on differential GPS.
- Initiate action to publish a standard for a marine differential GPS system after the RTCM/SC-104 concepts and techniques have been verified.

B. The FAA's basic R,E&D activities for the introduction of GPS into the NAS have been generally completed with coverage, reliability, and integrity being the remaining major issues to be resolved. These activities have also included substantial efforts to evaluate technical, operational, and economic characteristics of future aeronautical navigation systems. Additional R,E&D activities to exploit the full capabilities of GPS for civil aviation are continuing.

C. RSPA will continue to review the results of work in the design of low-cost GPS receivers and field tests of GPS performance conducted by other organizations.

D. The IVHS field operational test ADVANCE in Chicago has plans to use and test DGPS technology for its in-vehicle route guidance and navigation system.

4.2.1 Civil Aviation

The FAA, through its R,E&D GPS program, is developing the requirements for use of GPS in the national airspace to meet RNP. This includes refining the appropriate standards for GPS airborne receivers and developing the air traffic control methodology for handling GPS RNAV aircraft operation in an environment with non-GPS equipped aircraft. FAA expects to certify GPS as a supplemental means of navigation after IOC is attained. There is close cooperation between the FAA, DOD, and industry in these efforts. A Memorandum of Agreement between FAA and DOD to implement GPS for civil aviation was signed on May 15, 1992.

The FAA is actively pursuing technology related to the use of differential corrections to the Standard Positioning Service (SPS) portion of GPS. This pursuit includes, but is not limited to, the examination of both local area differential GPS (LADGPS) and wide area differential GPS (WADGPS). The purpose for examining DGPS is to enable the FAA to solve questions concerning accuracy, integrity, and availability so that the SPS portion of GPS can be utilized for all phases of flight and particularly for precision approaches to landing.

The FAA is actively supporting the activities of the ICAO FANS Special Committee and the RTCA GNSS Task Force in the definition of the Global Navigation Satellite System (GNSS) and the associated implementation planning guidelines. These efforts will assure that satellite navigation capabilities are implemented in a timely and evolutionary manner on a global basis.

The GNSS is intended to be a worldwide position, velocity and time determination system. GNSS will include one or more satellite constellations, end-user receiver equipment, a system integrity monitoring function, and certain ground-based services augmented as necessary to support the Required Navigation Performance (RNP) for a specific phase of operation. GPS will be the primary satellite constellation used for navigation during early GNSS implementation.

A. *Results of FAA R,E&D GPS Efforts to Date:*

- **Accuracy:** GPS accuracy of 100 meters (2 drms, where there is adequate coverage) is suitable for all current civil aviation accuracy requirements except precision approach and landing.

- **Coverage:** The coverage provided by GPS/SPS has the potential to provide RNP for most phases of flight.

- **Integrity:** The current DOD GPS satellite and control segment failure warning system does not provide warnings soon enough after an out-of-tolerance condition occurs to be suitable for civil GPS approach integrity.

- **Economic Factors:** GPS user equipment will probably cost more than VOR receivers for general aviation, but will be about the same as other RNAV equipment.

- **Interoperability:** Investigations of GPS/Loran-C integrated operations and interoperability have been completed.

- **Standards:** A MOPS for GPS avionics for supplemental use has been prepared, and a Technical Standard Order (TSO) for GPS avionics is being developed. A MOPS for NAS/RNP is being developed. A National Aviation Standard for GPS has been developed.

B. Planned FAA R,E&D GPS Activities:

The FAA has currently provided interim guidance for the use of GPS as an input to multisensor RNAV systems with automatic comparison with an approved system providing the navigation integrity function (see Appendix B). After IOC is attained, the FAA plans to approve use of GPS as a supplemental civil aviation navigation system including the nonprecision approach phase of flight. To support the nonprecision approach capability, there is an R&D effort to determine the flight technical error (FTE) when using GPS in the approach phase. If the results of this test meet current requirements, there will be about 5,000 approaches where properly equipped aircraft can make GPS nonprecision approaches. Receiver autonomous integrity monitoring (RAIM) using barometric altitude as an input is being developed to increase the availability of integrity for these approaches. A U.S. National Aviation Standard for GPS has been prepared to support the supplemental use of GPS.

A DGPS is required to support landing approaches at lower minimum altitudes than possible using GPS/SPS signals. There is an R&D effort to develop the criteria for the DGPS and integrity function to support this approach phase of flight. This effort will result in a standard for the monitor, the data link, and the avionics for a local area DGPS.

The primary difference between a supplemental system and a system which meets RNP for the NAS is availability of both the navigation signal and integrity. There is an R&D effort to determine a suitable means of providing augmentations to GPS to meet RNP requirements for the NAS. The approaches being investigated include:

- Additional GPS satellites.

- The use of both GPS and GLONASS satellite information in the determination of position, navigation, and integrity.

- The use of other navigation systems, such as Loran-C.
- The use of a ground-based monitoring network to provide a GPS Integrity Broadcast (GIB) which can also include a differential signal for accuracy improvement and ranging to provide additional navigation and integrity availability.

Long-term R&D is being conducted for augmented GPS to be used in the approach and landing phase of flight. This work is investigating tracking the RF carrier phase using high-dynamic movement of an aircraft. The goal is to obtain sub-meter accuracy for navigation, real-time (1 second or less) integrity, and continuity of service which can meet requirements for landing and roll-out under very low visibility weather conditions.

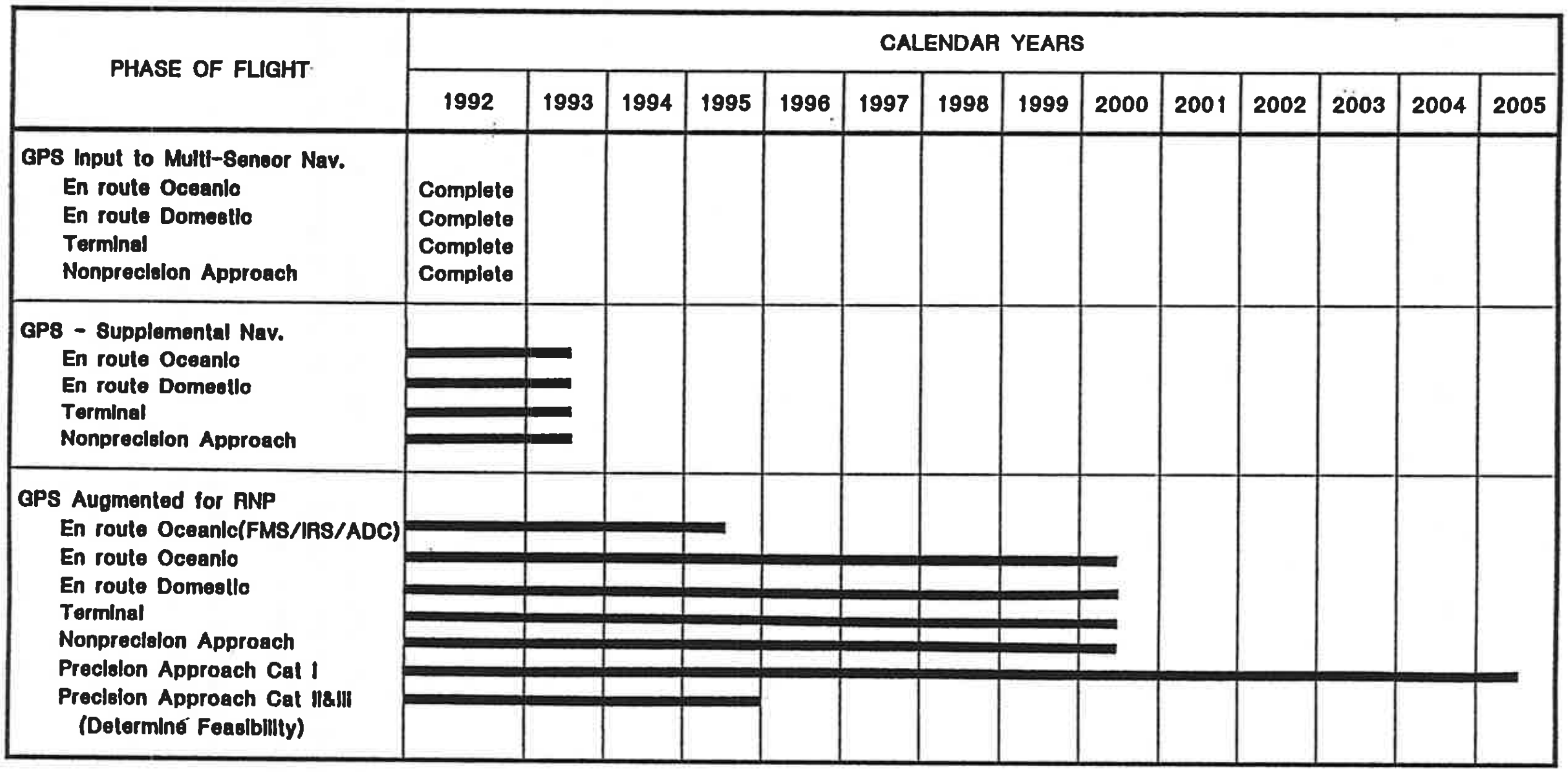
Table 4-1 shows the FAA schedule for development of GPS performance standards for civil avionics.

4.2.2 Civil Marine

The R,E&D activities of the USCG related to marine uses of GPS have historically been: (1) user field tests for comparative assessment of GPS versus alternative aids to navigation; (2) assessment of SPS performance potential; and (3) assessment of using differential GPS for various applications including harbor/harbor approach navigation. The purpose of the marine program is to acquire a sufficient base of knowledge to determine those missions of the marine fleet for which the GPS system can satisfy the navigation performance requirements. Issues important to the use of GPS for marine navigation include:

- **Accuracy:** GPS cannot provide the accuracies needed by marine users in some applications, including commercial fishing, where repeatable accuracies of 50 meters using Loran-C are commonplace; the offshore industry, which requires 1 meter accuracy; harbor/harbor approach, which requires 8-20 meter accuracy; and inland waterway navigation, the requirements of which are undefined, but will surely be greater than that of harbor navigation.
- **Technical and Economic Factors:** Technology, and a rapidly-developing satellite constellation, have driven the costs of GPS equipment dramatically lower over the last two years. Government research in this area is no longer required. This trend should also occur over the next two years with DGPS receivers. Government activity in this area will be limited to participation with industry in the development of performance

Table 4-1. Development of GPS Performance Standards for Civil Avionics



standards and functional requirements for receivers to support carriage requirements for vessels.

- **Use With Electronic Chart Displays:** DGPS receivers are most effective when used with some form of automated chart display. Its extreme accuracy (small fractions of a minute of latitude and longitude) are difficult to plot manually, and its capability of outputting position data at intervals of one second or less are far beyond the ability of the human to plot the information in real time. Research into the integration of highly accurate position sensors such as DGPS is ongoing.

The USCG completed its proof-of-concept for DGPS use in harbor/harbor approach navigation. It has been proven suitable for this use. A standard data format for transmission of wide area DGPS (WADGPS) correction data has been developed by the RTCM. Future developments in GPS will focus on WADGPS techniques. WADGPS involves the processing of GPS data from more than one reference station, yielding correction data applicable over a wider area than that of a stand-alone reference station.

4.2.3 Civil Land

Land radionavigation users, unlike air and marine users, do not come under the legislative jurisdiction of any agency. For this reason, RSPA has attempted to monitor their activities and identify R,E&D activities applicable to their needs. Limited RSPA R,E&D performed in past years through the Volpe Center indicated some limitations to the serviceability of GPS to land users in certain urban areas. Fiscal limitations have prevented further specific RSPA R,E&D activities. RSPA will monitor technology developments in the private sector and the results of other government sponsored R,E&D in the following areas:

- Land user equipment availability and cost.
- GPS land performance.
- Differential GPS technology development and system performance.
- Land navigation and radiolocation applications.
- Commercial RDSS system development status, performance, and applications.
- Possible government use of commercial navigation, radiolocation, and/or communication systems for air, land, and marine users.

The FHWA is evaluating requirements for DGPS and various means of providing differential data to mobile receivers.

RSPA, FHWA, and NHTSA will also participate in industry/user/government groups developing standards for using radionavigation equipment displays and databases in land vehicles.

4.3 DOT R,E&D for Other Navigation Systems

4.3.1 General

The main purposes of DOT navigation systems R,E&D are to improve reliability and service, decrease costs, and satisfy new requirements. The major DOT R,E&D for systems other than GPS is outlined in the context of air, land and marine areas of operation.

A. Air

The FAA will continue its ongoing modernization, maintenance, and sustaining engineering of VOR/DME to reduce operation and maintenance costs and to improve the performance of these aids in the NAS. The FAA will also continue to monitor the performance of Omega on oceanic air routes and the use of Omega and Loran-C as supplements to VOR/DME. Implementation of Loran-C as a nonprecision approach aid will continue. The developmental activities for MLS will continue.

B. Marine

The DOT marine R,E&D for existing systems is composed of several programs. USCG R,E&D projects focus on system enhancements and techniques for improving navigation safety in the harbor/harbor approach phase of marine navigation, principally involving shipboard displays as well as enhanced VTS equipment designs to prevent vessel casualties, loss of life, or pollution of the marine environment. A project is also under way to evaluate the requirements for harbor/harbor approach navigation system performance.

MARAD, in cooperative research with the private sector and the USCG, is developing a navigation support technology which will combine expert systems, artificial intelligence, electronic chart data, and precise positioning information to enhance piloting performance in the harbor/harbor approach and coastal phases.

C. Land

As navigation benefits to land users become more apparent, and as receiver equipment costs decrease due to technology improvements and expanding user markets, adaptation of the existing navigation systems to serve a variety of land users will prove cost-effective. Typical applications include site registration for remote site location, highway records, land management, and resource exploration; AVM/AVL for truck fleets, railroad transportation management, buses, and police and emergency vehicles; driver information systems for highway vehicles; and navigation applications for highways and remote areas.

4.3.2 Specific Civil R,E&D Activities

A. Civil Aviation

The R,E&D activities of the FAA are broadly directed toward improving navigation systems serving civil and military air users. The activities cover five phases of flight: (1) oceanic and domestic en route; (2) nonprecision approach; (3) remote areas; (4) helicopter IFR operations; and (5) precision approach and landing. The FAA navigation program has three specific goals: (1) to provide information that will support FAA recommendations on the future mix of navigation aids; (2) to assist in the near-term integration of existing navigation aids into the NAS as supplements to VOR/DME; and (3) to provide information that will support the definition of long-term navigation opportunities.

In the long term, communications, navigation, and surveillance (CNS) may be combined into an integrated system (ICNS) providing a single satellite-based system for civil users. Low-altitude users, including VFR as well as IFR traffic, could be accommodated more easily in the NAS since one ICNS system would respond to the needs of all users.

ICNS services would extend ATC service to more airspace in support of flexible routes. This airspace includes extreme (low and high) altitudes, oceanic, offshore, remote, and urban environments.

Time-based navigation and ATC practices in the en route and terminal environment would involve issuing time-based clearances to certain aircraft which can navigate with sufficient precision to fly space-time profiles and arrive at points in space at specified times. Aircraft equipped with advanced flight navigation and management systems may be able to receive clearances directly from ground automation equipment, and follow such clearances automatically along trajectories of their choice, either to maximize fuel efficiency or to minimize time.

The flight management system (FMS) has evolved to the point where it integrates the navigation, flight guidance, flight control, and performance management functions in the cockpit. The FMS can be used to recompute the reference vertical profile (RVP) (altitude and airspeed) of the aircraft in en route or oceanic airspace to minimize direct operating cost. If this profile is cleared, the FMS can guide the aircraft automatically along this path. In addition, the FMS can control flight speed to achieve required time-of-arrival (RTA) at specific waypoints along the intended flight path. This so-called four-dimensional FMS (also referred to as reference vertical profile with time, or RVPT) can be used in conjunction with air traffic management sequencing and scheduling processes to achieve precise timing control of the aircraft for improved airspace/runway capacity and throughput. To reap the benefits of such 4-D RNAV with the involvement of the FMS, the FAA initiated a technology thrust known as Flight Operations and Air Traffic Management Integration (FTMI) in 1991.

Today, the FMS-guided precision approach and departure capability is being demonstrated with in-service operations at selected airports using DME-DME navigation. In the future, even greater precision will be achieved using GPS navigation and data exchange between pilot and controller via data link.

Automatic dependent surveillance is defined as a function in which aircraft automatically transmit navigation data derived from onboard navigation systems via a datalink for use by air traffic control. Automatic dependent surveillance R,E&D will develop functions to permit tactical and strategic control of aircraft. Automated position report processing and analysis will result in nearly real-time monitoring of aircraft movement. Automatic flight plan deviation alerts and conflict probes will support reductions in separation minima and increased accommodation of user-preferred routes and trajectories. Graphic display of aircraft movement and automated processing of data messages, flight plans, and weather data will significantly improve the ability of the controller to interpret and respond to all situations without an increase in workload.

Opportunities exist to develop receiver avionics which combine two radionavigation signals, such as GPS/Loran-C, GPS/GLONASS, GPS/Omega, and GPS/VOR/DME, and thereby significantly improve user navigation performance.

FAA is developing standards under which an individual system or combination of systems may be certified to meet RNP in an aircraft conducting Instrument Flight Rules (IFR), en route, and terminal area operations, including nonprecision approach, in controlled U.S. airspace.

Oceanic and Domestic En Route

FAA has approved the use of Omega in some oceanic areas as a primary means of navigation. Limited supplemental approval has also been granted for use of Omega/VLF avionics in the NAS with the provision that VOR/DME be available on the aircraft. U.S. National Aviation Standards have been prepared for NDBs, Loran-C, and GPS. Loran-C has also been approved as a supplemental system where there is coverage.

Nonprecision Approach

GPS will be evaluated for potential operational benefits for nonprecision approaches.

Remote Areas (including offshore)

Although VOR/DME coverage meets most civilian user requirements, there are areas, such as some mountainous regions and low-altitude airspace areas, where there is a requirement for air navigation service that VOR/DME does not presently provide. Alternatives being investigated to provide the required coverage include additional VOR/DME facilities, and supplementing the existing VOR/DME system with GPS or Loran-C. Currently, Omega/VLF and Loran-C (in specific areas) are approved as a supplement to VOR/DME.

Helicopter IFR Operations

FAA is addressing special helicopter navigation requirements attributable to operations at low altitudes and in remote areas which are frequently below and beyond service volumes associated with conventional VHF navigation aids. The examination of Loran-C and GPS for use in en route, terminal, and approach phases of operation continues. The feasibility of enhancing ADF/NDB systems and the suitability of military Doppler navigators for civil helicopter use is also being explored. Approach capabilities using airborne radar approach have been established for offshore platforms. Further target and target processing enhancement work, to improve operational capabilities at poorly equipped landing sites, will be conducted with NASA using the airborne radar approach, a technique which uses airborne weather radar in the ground mapping mode. Also in support of helicopter approach operations, data for revised helicopter Terminal Instrument Procedures (TERPS) criteria are being collected with various helicopters and navigation aids, including VOR/DME, Loran-C, NDB, ILS, and MLS.

A navigation-based system of automatic aircraft position reporting and display for ATC is being evaluated for application in areas lacking radar surveillance. The system, Loran-C Flight Following, has been installed in the Houston Air Route Traffic Control Center (ARTCC) and will be used to enhance ATC operations in the offshore helicopter sector of the Gulf of Mexico.

FAA is also addressing the proper integration of the helicopter, with its unique set of characteristics and attributes, into the air traffic control system. Activities establishing the foundation for direct random routing are being planned for helicopters. Fixed, indirect routes have a most adverse effect on helicopters which predominantly operate on relatively short flights. Separate, reduced-width routes are also being used in high traffic-density areas where it is desirable to segregate helicopters and other low-speed aircraft. Simultaneous airport landings and departures of helicopters and fixed-wing aircraft are being used today and will increase with the introduction of MLS with its flexible approach path capability. The special nature of navigation requirements for these helicopter operations, as well as for others, such as holding airspace and curvilinear/decelerating approaches, are aimed at the integration of helicopters into the NAS.

Precision Approach and Landing

The objective of the FAA is to support the integration of MLS, in an evolutionary manner, into the NAS.

B. Civil Marine

The USCG plans for improving marine navigation systems, which serve the civil maritime user, are described below. They cover the following phases of marine navigation: inland waterway, harbor/harbor approach, coastal, and ocean.

Inland Waterway and Harbor/Harbor Approach

No efforts are being expended by the USCG to develop any radionavigation systems for inland waterways.

There is no existing Federally provided radionavigation system capable of meeting the 8 to 20 meter accuracy required for marine navigation in harbor/harbor approach areas. Loran-C can meet these requirements in a few selected areas. The USCG developed and demonstrated a differential Loran-C system which nearly met these accuracy requirements in many, but not all, major harbor areas. This effort has been terminated in favor of efforts involving differential GPS.

The USCG is working with other DOT modes and members of the civil community to develop a differential GPS system which will meet or exceed the harbor/harbor approach accuracy requirements. The system will use fixed GPS reference stations which will broadcast differential corrections over USCG radiobeacons. The system has potential application in marine and terrestrial navigation and survey operations. The system is based on differential message and data standards developed by a multidisciplinary committee under the sponsorship of the RTCM. A proof of concept differential system, including the radiobeacon data link and user equipment, was tested in 1990. It is being refined in preparation for deployment to the field.

A series of ship simulator studies is planned to evaluate the minimum radionavigation sensor accuracy and display requirements for piloting in restricted waterways. These studies will be used to provide a basis for establishing requirements for harbor/harbor approach navigation system performance.

Coastal

The primary system in use for U.S. coastal marine radionavigation is Loran-C. No R,E&D activities are ongoing or planned.

Oceanic

The primary terrestrial-based system in use for oceanic navigation is Omega. No R,E&D activities are ongoing or planned.

C. Civil Land

DOT does not have any specific R,E&D activities planned for existing radionavigation systems that will directly affect the land user community. Use of the existing radionavigation systems for land applications will be monitored to determine if there is a need for future DOT R,E&D on existing systems. RSPA will also monitor private sector R,E&D for use of existing radionavigation systems for land applications.

In recent years, several departments and agencies of the Federal government sponsored R,E&D activities that use existing radionavigation systems for various land uses. Examples of such applications include monitoring the position of automobiles, trucks, buses, rapid transit vehicles and trains from remote sites; monitoring hazardous materials shipments; and registering the location of and boundaries for natural and agricultural resources.

There are several cooperative research studies among state and Federal governments and private industry to assess the feasibility of using in-vehicle highway navigation and motorist information systems to improve safety and reduce traffic congestion in urban areas. The Pathfinder study, a relatively small-scale field experiment, was conducted on a section of the Santa Monica Freeway and its adjacent arterials in Los Angeles, California. The experiment included 25 vehicles with dead-reckoning map-matching navigators that were designed to function with route guidance equipment using real-time traffic data transmitted from the Traffic Operations Center (TOC). The experiment, one of the first small-scale IVHS field tests using land navigation, was successful and has aided in designing larger ongoing experiments.

TravTek (Travel Technology) represents a public/private partnership of the city of Orlando, Florida, the Florida DOT, FHWA, General Motors (GM), and the American Automobile Association (AAA). The goal of TravTek is to provide traffic congestion information, motorist services ("yellow pages") information, tourist information, and route guidance to operators of 100 test vehicles equipped with an in-vehicle TravTek device. Route guidance reflects real-time traffic conditions in the TravTek traffic network. A Traffic Management Center obtains traffic congestion information from various sources and provides this integrated information, via digital data broadcast, to the test vehicles and the sources. GPS technology is being used as a navigation aid for vehicle position location. Differential GPS is also planned for limited testing in later phases.

ADVANCE (Advanced Driver and Vehicle Advisory Navigation Concept) is a cooperative effort to evaluate the performance of the first large-scale, dynamic route guidance system in the United States. Participants include the Illinois DOT, Motorola, Inc., the Illinois Universities Transportation Research Consortium, and FHWA. Up to 5,000 private and commercial vehicles in the northwestern suburbs of Chicago will be equipped with in-vehicle navigation and route guidance systems. Vehicles will serve as probes, providing real-time traffic information. This information will then be transmitted to the equipped vehicles and used to develop a preferred route. The routing information will then be presented to the driver in the form of dynamic routing instructions. GPS technology is included as a system component for testing.

The major ongoing IVHS field operational tests in the U.S. are shown in Figure 4-1.

One large freight railroad is developing a train control and transportation management system that will depend upon GPS for determination of train locations. Train locations will be transmitted to dispatching offices which will in turn transmit movement authorities to the trains. The dispatching offices will monitor the progress of trains, as well as many other factors bearing on the operation of the railroad, and will continually update movement authorities in order to achieve optimum efficiency. This research is being conducted by private industry. FRA will eventually be responsible

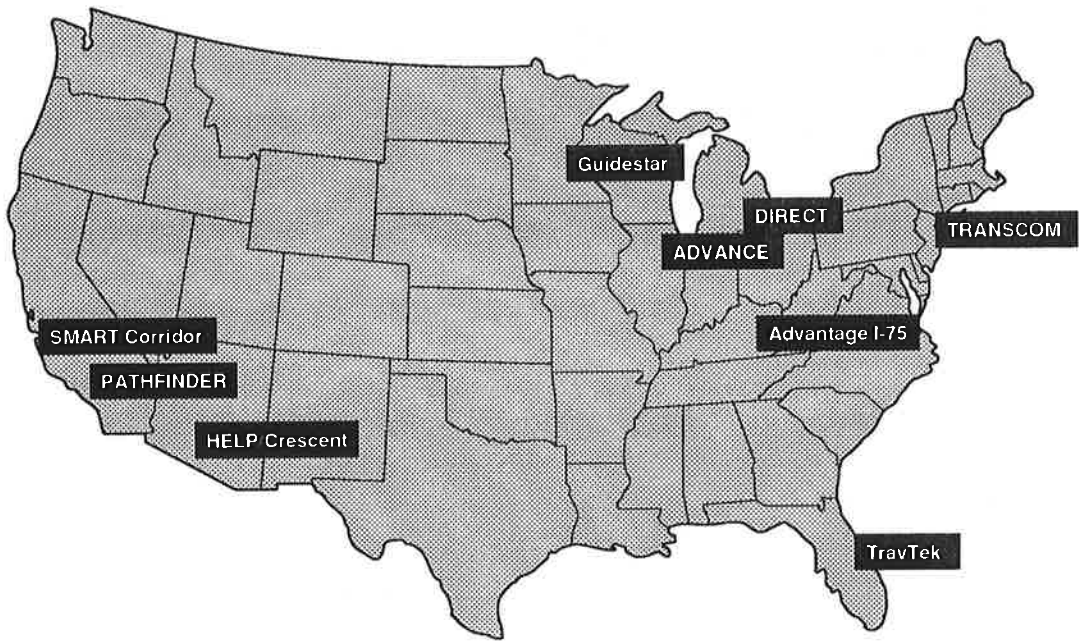


Figure 4-1. Selected IVHS Operational Tests Conducted with Federal Participation

for decisions on the safety of the system if it is to be utilized for the purpose of train control.

A number of services are evolving that make use of GPS. For example, within the trucking industry, companies have equipped vehicles with GPS receivers to aid in fleet management. Knowing the location of every vehicle across the nation at any instant in time will allow more efficient planning and operations. Urgent pick-up and delivery services to customers will be possible and rapid and optimal rescheduling of each vehicle's itinerary is expected to result in improved productivity.

4.4 GPS R,E&D Planned By NASA

NASA is cooperating with FAA, DOD, and industry in research of GPS capabilities and techniques for aircraft navigation. NASA Langley Research Center has flight tested a hybrid navigation system integrating a differential GPS receiver with an inertial navigation system (INS), and has assembled a database for comparing its performance in automated landing phase operations with other navigation systems.

NASA Ames Research Center has flight tested a differential GPS receiver integrated with an INS during approach and landing operations, and has evaluated the navigation performance to be expected with different levels of component integration through Kalman filtering. NASA Ames and FAA are arranging cooperative investigations of the performance gains to be expected from kinematic carrier phase tracking of GPS signals.

A number of NASA scientific missions require that the orbits of their spacecraft be determined within approximately 50 meters in real or near-real time. NASA is investigating whether space-qualified GPS receivers onboard the spacecraft, alone or in combination with other navigation systems, can meet this requirement.

Certain missions conducted or supported by NASA require post-fit orbit reconstruction to the sub-meter level for scientific applications. For example, if the accuracy of orbit determination for orbiting Very Long Baseline Interferometry (VLBI) observatories can be improved from tens of meters to approximately 25 cm, a major increase in the scientific returns will be realized. Orbit determination at this level will allow VLBI observatories to map galactic and extra-galactic radio sources with high fidelity. This will allow direct, accurate distance measurements to several nearby galaxies. Among the benefits are improved calculations of the Hubble constant, a critical astrophysical parameter related to the age of the universe.

One of the candidates for achieving decimeter orbit accuracy for these spacecraft in the future is a space-qualified GPS instrument. The Japanese space agency LSAS plans to equip its VLBI Space Observatory Program (VSOP) with a GPS receiver on an experimental basis (NASA will use ground-based systems to provide operational tracking support to VSOP). Though VSOP does not have a decimeter orbit requirement, future missions being studied may require 25 cm orbit determination over altitudes from 1,000 to over 40,000 km. NASA is sponsoring investigations of the ability of GPS to support this requirement.

NASA has investigated the development of a standard space-qualified GPS receiver. Ongoing efforts include studies of integration of GPS instruments and other navigation systems on spacecraft in highly elliptical Earth orbits. In related efforts, radionavigation satellites and receivers for operation in the vicinity of other planets have been considered as part of the Space Exploration Initiative. These systems could provide a precision navigation capability for interplanetary missions, enabling critical real-time maneuvering and navigation near these planets.

As an approach to providing low cost, high accuracy real-time onboard navigation capability for NASA spacecraft using the Tracking and Data Relay Satellite System (TDRSS), NASA has developed a TDRSS Onboard Navigation System (TONS). The underlying element in providing this capability was a systems engineering approach which capitalized on the expensive, mission critical components already onboard the customer spacecraft; namely, the communications transponders and antennae, the spacecraft computers, and the stable frequency source within the spacecraft clocks. By simply connecting these elements, accurate Doppler measurements, and in the future, pseudo range, can be made and provided in real time to the spacecraft computer for maintaining accurate trajectory determination.

Although the TDRSS constellation is not dynamic and three-dimensionally dense as is the GPS constellation, accurate navigation of free flying orbital spacecraft does not require such a complex environment, since the satellite equations of motion are extremely well defined and the measurements are accurate to a noise level of a few tenths of a millimeter per second. An experimental set of flight software (in Ada for 1750A flight computer) and a ground support system for performance analysis and system refinement have been developed and are being applied to a flight experiment aboard the Extreme Ultraviolet Explorer (EUVE) Platform mission launched in June 1992.

With the described architecture, no additional components are required on the spacecraft, and a prototype of the flight software exists, making the recurring cost to integrate TONS on a TDRSS compatible spacecraft close to nil. Achievable accuracies for TONS range from 10 meters (1 sigma) for near continuous forward signal availability, to 50-60 meters for sparse signal availability (5 minutes every other orbit). The next generation of TDRSS spacecraft (TDRSS II) is baselined to provide a continuous navigation beam signal. This signal capability will, therefore, enable the 10-meter accuracy as well as provide a time transfer and synchronization capability in the sub-microsecond range. In summary, the TONS can provide 10-meter real-time onboard navigation while adding zero power, weight, and volume to the customer spacecraft, and negligible integration cost.

4.5 DOD MLS R&D

DOD is committed to a transition to MLS in conjunction with FAA and NATO. The USAF as lead service has initiated a 15-year program to phase out ILS airborne and ground equipment. The program is timed to coincide with FAA, ICAO, and NATO transition plans. Maximum use will be made of avionics and ground equipment developed for civil applications. USAF R&D will be limited to developing ground equipment for use in mobile or high-threat applications and to acquiring military avionics for those platforms for which commercial civil avionics are not suitable.

Fixed Base Systems: MLS ground systems identical to those purchased by the FAA for civil airports will be purchased by the USAF, the Navy, and the Army.

Mobile MLS: The USAF as lead service will develop a mobile MLS ground system compatible with fixed-base systems for DOD, and will provide precision approach capability at tactical, expeditionary, or austere locations. The MLS equipment must be small, easily sited, relocatable, reliable, and sufficiently rugged for wartime operations.

Avionics: Military cargo, tanker, transport, and support aircraft will be equipped with commercial MLS avionics that will meet FAA requirements. Special military avionics will be developed by the USAF and the Navy for combat aircraft.

4.6 DOD Differential GPS R&D

The DOD, in coordination with the FAA, is investigating the feasibility of developing differential GPS for use at improvised aircraft landing sites (jungle clearings, interstate highways, etc.). The concept is to assemble light, person-transportable components that are currently available and that may be able to provide a differential data link. Every attempt will be made to avoid the requirement for additional aircraft avionics. The objective of this R&D effort is to enhance the benefits of GPS rather than to develop a new precision landing aid.

The U.S. Army Corps of Engineers is investigating, with the intention of developing, a real-time differential GPS carrier phase tracking system for very accurate positioning (a few centimeters) of dynamic platforms. These platforms are used in hydrographic surveying and dredging to construct and maintain U.S. ports, harbors, and waterways.

This application of carrier phase tracking is a differential technique that requires coded GPS information for initialization.

Recent developments in differential GPS carrier phase tracking have included centimeter accuracies on dynamic platforms using post processing. Manufacturers are now providing receivers which provide carrier phase tracking differential services. The real-time differential GPS carrier phase tracking hardware now available provides sub-meter accuracies on dynamic platforms.

Appendix A

System Descriptions

This appendix addresses the characteristics, capabilities, and limitations of existing and proposed common-use radionavigation systems. The systems covered are:

- Loran-C
- Omega
- VOR, VOR/DME, and TACAN
- ILS
- MLS
- Transit
- Radiobeacons (including RACONs)
- GPS
- Differential GPS
- VTS

A.1 System Parameters

All of the systems described are defined in terms of system parameters which determine the use and limitations of the individual navigation system's signal in space. These parameters are:

- Signal Characteristics
- Accuracy
- Availability
- Coverage
- Reliability
- Fix Rate
- Fix Dimensions
- System Capacity
- Ambiguity
- Integrity

A.1.1 Signal Characteristics

Signals-in-space are characterized by power levels, frequencies, signal formats, data rates, and any other information sufficient to completely define the means by which a user derives navigational information.

A.1.2 Accuracy

In navigation, the accuracy of an estimated or measured position of a craft (vehicle, aircraft, or vessel) at a given time is the degree of conformance of that position with the true position of the craft at that time. Since accuracy is a statistical measure of performance, a statement of the accuracy of a navigation system is meaningless unless it includes a statement of the uncertainty in position which applies.

Statistical Measure of Accuracy

Navigation system errors generally follow a known error distribution. Therefore, the uncertainty in position can be expressed as the probability that the error will not exceed a certain amount. A thorough treatment of errors is complicated by the fact that the total error is comprised of errors caused by instability of the transmitted signal, effects of weather and other physical changes in the propagation medium, errors in the receiving equipment, and errors introduced by the human navigator. In specifying or describing the accuracy of a system, the human errors usually are excluded. Further complications arise because some navigation systems are linear (one-dimensional) while others provide two or three dimensions of position.

When specifying linear accuracy, or when it is necessary to specify requirements in terms of orthogonal axes (e.g., along-track or cross-track), the 95 percent confidence level will be used. Vertical or bearing accuracies will be specified in one-dimensional terms (2 sigma), 95 percent confidence level.

When two-dimensional accuracies are used, the 2 drms (distance root mean squared) uncertainty estimate will be used. Two drms is twice the radial error drms. The radial error is defined as the root-mean-square value of the distances from the true location point of the position fixes in a collection of measurements. It is often found by first defining an arbitrarily-oriented set of perpendicular axes, with the origin at the true location point. The variances around each axis are then found, summed, and the square root computed. When the distribution of errors is elliptical, as it often is for stationary, ground-based systems, these axes can be taken for convenience as the major and minor axes of the error ellipse. Then the confidence level depends on the elongation of the error ellipse. As the error ellipse collapses to a line, the confidence level of the 2 drms measurement approaches 95 percent; as the error ellipse becomes circular, the confidence level approaches 98 percent. The GPS 2 drms accuracy will be at 95 percent probability.

DOD specifies horizontal accuracy in terms of Circular Error Probable (CEP--the radius of a circle containing 50 percent of all possible fixes). For the FRP, the conversion of CEP to 2 drms has been accomplished by using 2.5 as the multiplier.

Types of Accuracy

Specifications of radionavigation system accuracy generally refer to one or more of the following definitions:

- Predictable accuracy: The accuracy of a radionavigation system's position solution with respect to the charted solution. Both the position solution and the chart must be based upon the same geodetic datum. (Note: Appendix C discusses chart reference systems and the risks inherent in using charts in conjunction with radionavigation systems).
- Repeatable accuracy: The accuracy with which a user can return to a position whose coordinates have been measured at a previous time with the same navigation system.
- Relative accuracy: The accuracy with which a user can measure position relative to that of another user of the same navigation system at the same time.

A.1.3 Availability

The availability of a navigation system is the percentage of time that the services of the system are usable by the navigator. Availability is an indication of the ability of the system to provide usable service within the specified coverage area. Signal availability is the percentage of time that navigational signals transmitted from external sources are available for use. It is a function of both the physical characteristics of the environment and the technical capabilities of the transmitter facilities.

A.1.4 Coverage

The coverage provided by a radionavigation system is that surface area or space volume in which the signals are adequate to permit the navigator to determine position to a specified level of accuracy. Coverage is influenced by system geometry, signal power levels, receiver sensitivity, atmospheric noise conditions, and other factors which affect signal availability.

A.1.5 Reliability

The reliability of a navigation system is a function of the frequency with which failures occur within the system. It is the probability that a system will perform its function within defined performance limits for a specified period of time under given operating conditions. Formally, reliability is one minus the probability of system failure.

A.1.6 Fix Rate

The fix rate is defined as the number of independent position fixes or data points available from the system per unit time.

A.1.7 Fix Dimensions

This characteristic defines whether the navigation system provides a linear, one-dimensional line-of-position, or a two- or three-dimensional position fix. The ability of the system to derive a fourth dimension (e.g., time) from the navigational signals is also included.

A.1.8 System Capacity

System capacity is the number of users that a system can accommodate simultaneously.

A.1.9 Ambiguity

System ambiguity exists when the navigation system identifies two or more possible positions of the vehicle, with the same set of measurements, with no indication of which is the most nearly correct position. The potential for system ambiguities should be identified along with provision for users to identify and/or resolve them.

A.1.10 Integrity

Integrity is the ability of a system to provide timely warnings to users when the system should not be used for navigation.

A.2 System Descriptions

This section describes the characteristics of those individual radionavigation systems currently in use or under development. These systems are described in terms of the parameters previously defined in Section A.1. All of the systems used for civil navigation are discussed. The systems which are used exclusively to meet the special applications of DOD are discussed in the CJCS MNP.

A.2.1 Loran-C

Loran-C was developed to provide DOD with a radionavigation capability having longer range and much greater accuracy than its predecessor, Loran-A. It was subsequently selected as the Federally provided radionavigation system for civil marine use in the U.S. coastal areas. For further Loran-C coverage information, consult the Loran-C Users Handbook (available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402).

A. Signal Characteristics

Loran-C is a pulsed, hyperbolic system operating in the 90 to 110 kHz frequency band. The system is based upon measurement of the difference in time of arrival of pulses of radio frequency (RF) energy radiated by a chain of synchronized transmitters which are separated by hundreds of miles. The measurements of time difference (TD) are made by a receiver which achieves high accuracy by comparing a zero crossing of a specified RF cycle within the pulses transmitted by master and secondary stations within a chain. Making this signal comparison early in the ground wave pulse assures that the measurement is made before the arrival of the corresponding sky waves. Precise control over the pulse shape ensures that the proper comparison point can be identified by the receiver. To aid in preventing sky waves from affecting TD measurements, the phase of the 100 kHz carrier of some of the pulses is changed in a predetermined pattern. Envelope matching of the signals is also possible but cannot provide the advantage of cycle comparison in obtaining the full system accuracy. The characteristics of Loran-C are summarized in Table A-1.

B. Accuracy

Within the published coverage area, Loran-C will provide the user who employs an adequate receiver with predictable accuracy of 0.25 nm (2 drms) or better. The repeatable accuracy of Loran-C is usually between 18 and 90 meters. Accuracy is dependent upon the Geometric Dilution of Precision (GDOP) factors at the user's location within the coverage area.

Loran-C navigation is predominantly accomplished using the ground wave signal. Sky wave navigation is feasible, but with considerable loss in accuracy. Ground waves and to some degree sky waves may be used for measuring time and time intervals. Loran-C was originally designed to be a hyperbolic navigation system. However, with the advent of the highly stable frequency standards, Loran-C can also be used in the range-range (rho-rho) mode of navigation. This is accomplished by a comparison of the received signal phase to a known time reference to determine propagation time and, therefore, range from the stations. It can be used in situations where the user

Table A-1. Loran-C System Characteristics (Signal-In-Space)

ACCURACY (2 drms)		AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE	REPEATABLE							
0.25nm (460m) 1:3 SNR	60-300 ft. (18-90m)	99+%	U.S. coastal areas, continental U.S., selected overseas areas.	99.7%*	10-20 fixes/min.	2D	Unlimited	Yes, easily resolved

* *Triad reliability.*

SYSTEM DESCRIPTION: LORAN-C is a Low Frequency (LF) 100kHz hyperbolic radionavigation system. The receiver computes lines of position (LOP) based on the time of arrival difference between two time synchronized transmitting stations of a chain. Three stations are required (master and two secondaries) to obtain a position fix in the normal mode of operation. LORAN-C can be used in the Rho-Rho mode and accurate position data can be obtained with only two stations. Rho-Rho requires that the user platform have a precise clock. The United States is the primary provider of LORAN-C coverage, although several nations in Europe and the Middle East have or are planning to initiate LORAN-C service.

is within reception range of individual stations, but beyond the hyperbolic coverage area. Because the position solution of GPS provides precise time, the interoperable use of rho-rho Loran-C with GPS appears to have merit.

The inherent accuracy of the Loran-C system makes it a suitable candidate for many land radiolocation applications. The purely numeric TD readings (no names, words, or narratives) are easy and efficient to both store and retrieve in automated form. Since the data are purely numeric, there can be none of the ambiguity that results from attempting to retrieve narrative descriptors from traffic accident reports and highway inventory data. While the 100 kHz signal is affected to some extent by soil conductivity and terrain, it can be received in mountainous areas (where VHF and UHF systems can be terrain limited); however, some distortion of the hyperbolic grid has been noted. Propagation anomalies may be encountered in urban areas where the proximity of large manmade structures affects the signal. The existence of these anomalies is predictable and can be compensated for, usually by surveying the area. The long range of the Loran-C system makes it particularly desirable for application to remote areas, or where the user population is too low to justify the cost of a large number of short-range facilities.

By monitoring Loran-C signals at a fixed site, the receiver TD can be compared with a computed TD for the known location of the site. A correction for the area can then be broadcast to users. This technique (called differential Loran-C), whereby real-time corrections are applied to Loran-C TD readings, provides improved accuracy. This method shows promise of providing the higher precision needed for marine navigation in harbor approaches and inland waterways. Another technique involves installing short-baseline, low-power chains to serve specific restricted areas. In other locations, a low-power transmitter could serve as an additional secondary station to improve the grid geometry and signal strength in a local area.

Loran-C signal monitors have been installed throughout the NAS to support the use of Loran-C as a nonprecision approach aid. The monitors will be operated and maintained by the FAA. Each monitor will provide both long-term signal data for use in the prediction of signal corrections at individual airports and the status of Loran-C signals for the local area. Predicted corrections will be published periodically with approach procedures. Signal status information will be used by air traffic personnel as necessary.

Loran-C receivers are available at a relatively low cost and achieve the 0.25 nm (2 drms) accuracy that Loran-C provides at the limits of the coverage area. A modern Loran-C receiver automatically acquires and tracks the

Loran-C signal and is useful to the limits of the specified Loran-C coverage areas.

C. Availability

The Loran-C transmitting equipment is very reliable. Redundant transmitting equipment is used to reduce system downtime. Loran-C transmitting station signal availability is greater than 99.9 percent, providing 99.7 percent triad availability.

D. Coverage

The Loran-C system has been expanded over the years to meet the requirements for coverage of the U.S. coastal waters and the conterminous 48 states, the Great Lakes, the Gulf of Alaska, the Aleutians, and into the Bering Sea. Based on DOD requirements, the USCG also operates Loran-C stations in the Far East, Northern Europe, and the Mediterranean Sea. Loran-C coverage is shown in Figure A-1.

Expansion of the Loran-C system into the Caribbean Sea, the North Slope of Alaska, and Eastern Hawaii has been investigated. Studies have shown, however, that the benefit/cost ratio is currently insufficient to justify expansion of Loran-C into any of these areas.

E. Reliability

Loran-C stations are constantly monitored. The accuracy of system timing is maintained to half the system tolerance. Stations which exceed the system tolerance are "blinked." Blink is the on-off pattern of the first two pulses of the secondary signal indicating that a baseline is unusable. System tolerance within the U.S. is $\pm$100 nanoseconds of the calibrated control value. Individual station reliability normally exceeds 99.9 percent, resulting in triad availability exceeding 99.7 percent.

F. Fix Rate

The fix rate available from Loran-C ranges from 10 to 20 fixes per minute.

G. Fix Dimensions

Loran-C will furnish two or more LOPs to provide a two-dimensional fix.

H. System Capacity

An unlimited number of receivers may use Loran-C simultaneously.

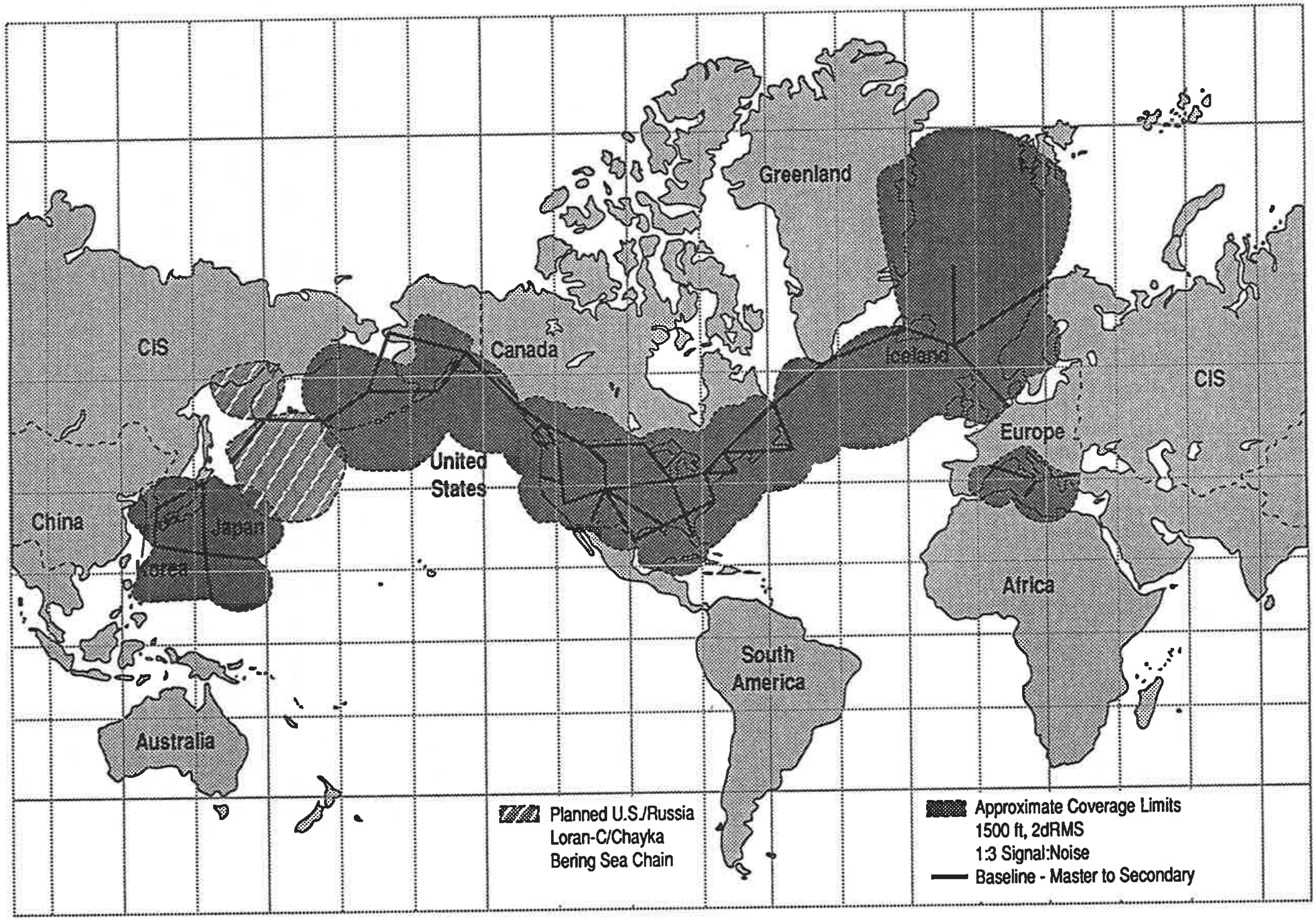


Figure A-1. Coverage Provided by U.S. Operated or Supported Loran-C Stations

I. Ambiguity

As with all hyperbolic systems, theoretically, the LOPs may cross at more than one position on the earth. However, because of the design of the coverage area, the ambiguous fix is at a great distance from the desired fix and is easily resolved.

J. Integrity

Loran-C stations are constantly monitored to detect signal abnormalities which would render the system unuseable for navigation purposes. The secondary stations "blink" to notify the user that a master-secondary pair is unuseable. Blink begins immediately upon detection of an abnormality. The USCG and the FAA are also developing automatic blink equipment and concept of operations based on factors consistent with aviation use.

A.2.2 Omega

The Omega system initially was proposed to meet a DOD need for worldwide general en route navigation but has now evolved into a system used primarily by the civil community. The system is comprised of eight continuous wave (CW) transmitting stations situated throughout the world. Worldwide position coverage was attained when the station in Australia became operational in 1982. For further information, contact the U.S. Coast Guard's Omega Navigation System Center (ONSCEN), 7323 Telegraph Road, Alexandria, Virginia, 22310-3998 by mail, or telephone 703-866-3800 (voice), 703-866-3866 (fax), or 703-866-3801 (Omega status recording). Omega information can also be obtained via the GPS Information Center Bulletin Board Service.

A. Signal Characteristics

Omega utilizes CW phase comparison of signal transmission from pairs of stations. The stations transmit time-shared signals on four frequencies, in the following order: 10.2 kHz, 11.33 kHz, 13.6 kHz, and 11.05 kHz. In addition to these common frequencies, each station transmits a unique frequency to aid station identification and to enhance receiver performance. The signal characteristics of Omega are summarized on Table A-2. For further information on the Omega systems, consult the Omega User's Guide (available from the USCG Omega Navigation System Center, 7323 Telegraph Road, Alexandria, Virginia 22310-3998).

B. Accuracy

The inherent accuracy of the Omega system is limited by the accuracy of the propagation corrections that must be applied to the individual receiver

Table A-2. Omega System Characteristics (Signal-In-Space)

ACCURACY (2 drms)			AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE	REPEATABLE	RELATIVE							
2-4nm (3.7-7.4km)	2-4nm (3.7-7.4km)	0.25-0.5nm (463-926m)	99+%	Worldwide continuous	97%*	1 fix every 10 seconds	2D	Unlimited	Requires knowledge to ± 36nm**

** Three station joint signal availability.*
*** Three frequency receiver (10.2, 11.33, 13.6kHz).*

SYSTEM DESCRIPTION: OMEGA is a Very Low Frequency (VLF) 10.2 - 13.6kHz hyperbolic radionavigation system. There are eight transmitting stations now in full operation. Position information is obtained by measuring relative phase difference of received OMEGA signals. The system is multinational, being operated by seven nations with day-to-day operational control exercised by the U.S. Coast Guard.

readings. The corrections may be in the form of predictions from tables which can be applied to manual receivers or may be stored in memory and applied automatically in computerized receivers. The system was designed to provide a predictable accuracy of 2 to 4 nm (2 drms). That accuracy depends on location, station pairs used, time of day, and validity of the propagation corrections.

Propagation correction tables and formulas are based on theoretical models calibrated to fit worldwide monitor data taken over long periods. A number of permanent monitors are maintained to assess the system accuracy on a long-term basis. The system currently provides coverage over most of the Earth. The specific accuracy attained depends on the type of equipment used as well as the time of day and the location of the user. In most cases, the accuracies attained are consistent with the 2 to 4 nm system design goal and in some cases much better accuracy is reported. A validation program conducted by the USCG indicated that the Omega system meets its design goal of 2 to 4 nm accuracy.

Although not part of any current U.S. effort, a differential Omega system has been developed and there are now differential stations in operation along the coast of Europe, in the Mediterranean, and in Southeast Asia areas. Differential Omega stations operate on the principle of a local area monitor system comparing the received Omega signal with the predicted signal for the location and then transmitting a correction factor based on the observed difference. The correction factor is usually transmitted over an existing radiobeacon system and can provide an accuracy ranging from 0.3 nm at 50 miles to 1 nm at 500 miles. The range of transmission of the correction factor varies with the range of the beacon, but is roughly three times the advertised range of the beacon. Reception of the differential Omega signal requires the use of a differential Omega receiver.

C. Availability

Exclusive of infrequent periods of scheduled off-air time for maintenance, Omega availability is greater than 99 percent per year for each station and 95 percent for three stations. Annual system availability has been greater than 97 percent with scheduled off-air time included.

D. Coverage

Omega provides essentially worldwide coverage.

E. Reliability

Omega system design requirements for reliability called for 99 percent single station availability and 95 percent three-station joint signal availability.

Three-station joint signal availability exceeds 97 percent, including both emergency shutdowns and scheduled off-air periods.

F. Fix Rate

Omega provides independent positional fixes once every ten seconds.

G. Fix Dimensions

Omega will furnish two or more lines of position (LOPs) to provide a two-dimensional fix.

H. System Capacity

An unlimited number of receivers may be used simultaneously.

I. Ambiguity

In this CW system, ambiguous LOPs occur since there is no means to identify particular points of constant phase difference which recur throughout the coverage area. The area between lines of zero phase difference are termed "lanes." Single-frequency receivers use the 10.2 kHz signals whose lane width is about eight nautical miles on the baseline between stations. Multiple-frequency receivers extend the lane width, for the purpose of resolving lane ambiguity. Lane widths of approximately 288 nm along the baseline can be generated with a four-frequency receiver. Because of the lane ambiguity, a receiver must be preset to a known location at the start of a voyage. The accuracy of that position must be known with sufficient accuracy to be within the lane that the receiver is capable of generating (i.e., 4 nm for a single-frequency receiver or approximately 144 nm for a four-frequency receiver). Once set to a known location, the Omega receiver counts the number of lanes it crosses in the course of a voyage. This lane count is subject to errors which may be introduced by an interruption of power to the receiver, changes in propagation conditions near local sunset and sunrise, and other factors. To use the single frequency Omega receiver effectively for navigation, it is essential that a DR plot or similar means be carefully maintained and the Omega positions compared to it periodically so that any lane ambiguities can be detected and corrected.

The accuracy of an Omega phase-difference measurement is independent of the elapsed time or distance since the last update. Unless the Omega position is verified occasionally by comparison to a fix obtained with another navigation system or by periodic comparison to a carefully maintained plot, the chance of an error in the Omega lane count increases with time and distance. These errors are reduced in multiple frequency receivers since they are capable of developing larger lane widths to resolve ambiguity problems.

J. Integrity

Omega transmissions are monitored constantly to detect signal abnormalities that affect the useable coverage area. Emergency advisories for unplanned status changes (reduced power, off-airs, Polar Cap Absorption, etc.) are provided by the Omega Navigation System Center within 24 hours. This notification is distributed by the National Bureau of Standards (WWV/WWVH announcements), Broadcast Notice to Mariners, Notice to Airmen, HYDROLANT/HYDROPAC messages, and recorded telephone messages. Scheduled off-air periods are announced up to 30 days before the off-air is to occur using the same distribution mechanisms as for unplanned status changes.

A.2.3 VOR, VOR/DME, and TACAN

The three systems that provide the basic guidance for en route air navigation in the United States are VOR, DME, and TACAN. Information provided to the aircraft pilot by VOR is the azimuth relative to the VOR 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.

I. VOR

A. Signal Characteristics

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. The signal characteristics of VOR are summarized in Table A-3.

Table A-3. VOR and VOR/DME System Characteristics (Signal-In-Space)

ACCURACY (2 Sigma)			AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE	REPEATABLE	RELATIVE							
VOR: 90m (± 1.4°)*	23m (± 0.35°)**	--	Approaches 100%	Line of sight	Approaches 100%	Continuous	Heading in degrees or angle off course	Unlimited	None
DME: 185m (± 0.1nm)	185m (± 0.1nm)	--					Slant range (nm)	100 users per site, full service	

** The flight check of published procedures for the VOR signal is ± 1.4°. The ground monitor turns the system off if the signal exceeds ± 1.0°. The cross track error used in the chart is for ± 1.4° at 2nm from the VOR site. However, some uses of VOR are overhead and or 1/2nm from the VOR.*

*** Test data shows that 99.94% of the time the error is less than ± .35°. These values are for ± .35° at 2nm from the VOR.*

SYSTEM DESCRIPTION: VOR provides aircraft with bearing information relative to the VOR signal and magnetic north. The system is used for landing, terminal and en route guidance. VOR transmitters operate in the VHF frequency range. DME provides a measurement of distance from the aircraft to the DME ground station. DME operates in the UHF frequency range.

B. Accuracy (2 sigma)

- Predictable - The ground station errors are approximately ±1.4 degrees. The addition of course selection, receiver and flight technical errors, when combined using root-sum-squared (RSS) techniques, is calculated to be ±4.5 degrees.

- Relative - Although some course bending could influence position readings between aircraft, the major relative error consists of the course selection, receiver and flight technical components. When combined using RSS techniques, the value is approximately ±4.3 degrees. The VOR ground station relative error is ±0.35 degrees.

- Repeatable - The major error components of the ground system and receiver will not vary appreciably in the short term. Therefore, the repeatable error will consist mainly of the flight technical error (the pilots' ability to fly the system) which is ±2.3 degrees.

C. Availability

Because VOR coverage is overlapped by adjacent stations, the availability is considered to approach 100 percent for new solid state equipment.

D. Coverage

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 nm, and above 20,000 feet, the range will approach 200 nm. 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. Actual VOR coverage information is contained in FAA Order 1010.55C.

E. Reliability

Due to advanced solid state construction and the use of remote maintenance monitoring techniques, the reliability of solid state VOR approaches 100 percent.

F. Fix Rate

This system allows a continuous update of deviation from a selected course. Initialization is less than one minute after turn-on and will vary as to receiver design.

G. *Fix Dimensions*

The system shows magnetic bearing to a VOR station and deviation from a selected course, in degrees.

H. *System Capacity*

The capacity of a VOR station is unlimited.

I. *Ambiguity*

There is no ambiguity possible for a VOR station.

J. *Integrity*

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

II. DME

A. *Signal Characteristics*

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.

The capability to use Y-channel service has been developed and implemented to a very limited extent (approximately 15 DMEs paired with localizers use the Y-channel frequencies). The term "Y-channel" refers to VOR frequency spacing. Normally, X-channel frequency spacing of 100 kHz is used. Y-channel frequencies are offset from the X-channel frequencies by 50 kHz. In addition, Y-channel DMEs are identified by a wider interrogation pulse-pair time spacing of 0.036 msec versus X-channel DMEs at 0.012 msec spacing. X- and Y-channel applications are presently limited to minimize user equipment changeovers. The signal characteristics of DME are summarized in Table A-3.

B. *Accuracy (2 sigma)*

- Predictable - The ground station errors are less than ±0.1 nm. The overall system error (airborne and ground RSS) is not greater than ±0.5 nm or 3 percent of the distance, whichever is greater.
- Relative - Although some errors could be introduced by reflections, the major relative error emanates from the receiver and flight technical error.
- Repeatable - Major error components of the ground system and receiver will not vary appreciably in the short term.

C. *Availability*

The availability of DME is considered to approach 100 percent, with positive indication when the system is out-of-tolerance.

D. *Coverage*

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

E. *Reliability*

With the use of solid state components and remote maintenance monitoring techniques, the reliability of the DME approaches 100 percent.

F. *Fix Rate*

The system essentially gives a continuous update of distance to the facility. Actual update rate varies with the design of airborne equipment and system loading.

G. *Fix Dimensions*

The system shows slant range to the DME station in nm.

H. *System Capacity*

For present traffic capacity 110 interrogators are considered reasonable. Future traffic capacity could be increased when necessary through reduced individual aircraft interrogation rates and removal of beacon capacity reply restrictions.

I. Ambiguity

There is no ambiguity in the DME system.

J. Integrity

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

III. TACAN

A. Signal Characteristics

TACAN is a short-range UHF (960 to 1,215 MHz) radionavigation system designed primarily for 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. The signal characteristics of TACAN are summarized in Table A-4.

B. Accuracy (2 sigma)

- Predictable - The ground station errors are less than ± 1.0 degree for azimuth for the 135 Hz element and ± 4.5 degrees for the 15 Hz element. Distance errors are the same as DME errors.
- Relative - The major relative errors emanate from course selection, receiver and flight technical error.
- Repeatable - Major error components of the ground station and receiver will not vary greatly in the short term. The repeatable error will consist mainly of the flight technical error.

C. Availability

The availability of TACAN service is considered to approach 100 percent.

D. Coverage

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

E. Reliability

With the use of solid state electronics and remote maintenance monitoring techniques, the reliability of the TACAN system approaches 100 percent.

Table A-4. TACAN System Characteristics (Signal-In-Space)

ACCURACY (2 Sigma)			AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE	REPEATABLE	RELATIVE							
Azimuth ± 1° (± 63m at 3.75km)	Azimuth ± 1° (± 63m at 3.75km)	Azimuth ± 1° (± 63m at 3.75km)	98.7%	Line of sight	99%	Continuous	Distance and bearing from station	110 for distance. Unlimited in azimuth	No ambiguity in range. Slight potential for ambiguity at multiples of 40°
DME: 185m (± 0.1nm)	DME: 185m (± 0.1nm)	DME: 185m (± 0.1nm							

SYSTEM DESCRIPTION: TACAN is a short range navigation system primarily used by the military. The system provides range, bearing and station identification. TACAN operates in the UHF band. When TACAN is collocated with a VOR it is called a VORTAC facility.

F. Fix Rate

TACAN provides a continuous update of the deviation from a selected course. Initialization is less than one minute after turn on. Actual update rate varies with the design of airborne equipment and system loading.

G. Fix Dimensions

The system shows magnetic bearing, deviation in degrees, and distance to the TACAN station in nautical miles.

H. System Capacity

For distance information, 110 interrogators are considered reasonable for present traffic handling. Future traffic handling could be increased when necessary through reduced airborne interrogation rates and increased reply rates. Capacity for the azimuth function is unlimited.

I. Ambiguity

There is no ambiguity in the TACAN range information. There is a slight probability of azimuth ambiguity at multiples of 40 degrees.

J. Integrity

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

A.2.4 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. Scanning beam MLS, an alternate system, has been developed and approved by the ICAO, and is expected to be implemented to eventually replace ILS.

A. Signal Characteristics

The localizer facility and antenna are typically located 1,000 feet beyond the stop end of the runway and provides a VHF (108 to 112 MHz) signal. The glide slope facility is located approximately 1,000 feet from the approach end of the runway and provides a UHF (328.6 to 335.4 MHz) signal. Marker beacons are located along an extension of the runway centerline and identify particular locations on the approach. Ordinarily, two 75 MHz beacons are included as part of the instrument landing system: an outer marker at the initial approach fix (typically four to seven miles from the approach end of the runway) and a middle marker located 3,500 feet plus or minus 250 feet from the runway threshold. The middle marker is located so as to note impending visual acquisition of the runway in conditions of minimum visibility for Category I ILS approaches. An inner marker, located approximately 1,000 feet from the threshold, is normally associated with Category II and III ILS approaches. The signal characteristics of ILS are summarized in Table A-5.

B. Accuracy

For typical air carrier operations at a 10,000 foot runway, the course alignment (localizer) at threshold is maintained within ±25 feet. Course bends during the final segment of the approach do not exceed ±0.06 degrees (2 sigma). Glide slope course alignment is maintained within ±7.0 feet at 100 feet (2 sigma) elevation and glide path bends during the final segment of the approach do not exceed ±0.07 degrees (2 sigma).

C. Availability

To further improve the availability of service from ILS installations, vacuum tube equipment has been replaced with solid state equipment. Service availability is now approaching 99 percent.

D. Coverage

Coverage for individual systems is as follows:

Localizer: $\pm 2^{\circ}$ centered about runway centerline.

Glide Slope: Nominally 3° above the horizontal.

Marker Beacons: $\pm 40^{\circ}$ (approximately) on minor axis (along approach path) $\pm 85^{\circ}$ (approximately) on major axis.

E. Reliability

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

Table A-5. ILS Characteristics (Signal-In-Space)

ACCURACY AT DECISION HEIGHT (Meters - 2 Sigma)			AVAILABILITY*	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
CATEGORY	AZIMUTH	ELEVATION							
1	± 9.1	± 3.0	Approaches 100%	Normal limits from center of localizer ± 10° out to 18nm and ± 35° out to 10nm	98.6% with positive indication when the system is out of tolerance	Continuous	Heading and deviation in degrees	Limited only by aircraft separation requirements	None
2	± 4.6	± 1.4							
3	± 4.1	± 0.4							

** Signal availability in the coverage volume.*

SYSTEM DESCRIPTION: The Instrument Landing System (ILS) is a precision approach system consisting of a localizer facility, a glide slope facility and two or three VHF marker beacons. The VHF (108-112MHz) localizer facility provides accurate, single path horizontal guidance information. The UHF (328.6-335.4MHz) glide slope provides precise, single path, vertical guidance information to a landing aircraft.

glide slope, use has been made of wide aperture, two-frequency image arrays and single-frequency broadside arrays to provide service at difficult sites.

F. Fix Rate

The glide slope and localizer provide continuous fix information. Marker beacons which provide an audible and visual indication to the pilot are sited at specific points along the approach path as indicated in Table A-6.

Table A-6. Aircraft Marker Beacons

MARKER DESIGNATION	TYPICAL DISTANCE TO THRESHOLD	AUDIBLE SIGNAL	LIGHT COLOR
Outer	4-7nm	Continuous dashes (2/sec)	Blue
Middle	3,250-3,750 ft	Continuous alternating dot-dash	Amber
Inner	1,000 ft	Continuous dots (6/sec)	White

G. Fix Dimensions

ILS provides both vertical and horizontal guidance with glide slope and localizer signals. At periodic intervals (passing over marker beacons) distance to threshold is obtained.

H. System Capacity

ILS has no capacity limitations except those imposed by aircraft separation requirements since aircraft must be in trail to use the system.

I. Ambiguity

Any potential ambiguities are resolved by imposing system limitations as described in Section A.2.4.E.

J. Integrity

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 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

A.2.5 *MLS*

MLS is being developed by DOT, DOD, and NASA. It will provide 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 is intended as a replacement for ILS used by both civil and military aircraft and the Ground Controlled Approach (GCA) system used primarily by military operators. The 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 manuevers. 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.

A. Signal Characteristics

MLS transmits signals that enable airborne units to determine the precise azimuth angle, elevation angle, and range. The technique chosen for the angle function of the MLS is based upon Time-Referenced Scanning Beams (TRSB). All angle functions of MLS operate in the 5.00 to 5.25 GHz band. Ranging is provided by DME operating in the 0.96 to 1.215 GHz band. An option is included in the signal format to permit a special purpose system to operate in the 15.4 to 15.7 GHz band. The system characteristics of MLS are summarized in Table A-7.

B. Accuracy (2 sigma)

The azimuth accuracy is ±13.0 feet (±4.0m) at the runway threshhold approach reference datum and the elevation accuracy is ±2.0 feet (±0.6m). The lower surface of the MLS beam crosses the threshold at 8 feet (2.4 meters) above the runway centerline. The flare guidance accuracy is ±1.2 feet throughout the touchdown zone and the DME accuracy is ±100 feet for the precision mode and ±1,600 feet for the nonprecision mode.

Table A-7. MLS Characteristics (Signal-In-Space)

ACCURACY AT DECISION HEIGHT (Meters - 2 Sigma)			AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
CATEGORY	AZIMUTH	ELEVATION							
1	± 9.1	± 3.0	Expected to approach 100%	± 40° from center line of runway out to 20nm in both directions*	Expected to approach 100%	6.5-39 fixes/sec depending on function	Heading and deviation in degrees. Range in nm	Limited only by aircraft separation requirements	None
2	± 4.6	± 1.4							
3	± 4.1	± 0.4							

** There are provisions for 360 ° out to 20nm.*

SYSTEM DESCRIPTION: The Microwave Landing System (MLS) is a common use precision landing system that will replace ILS and GCA/PAR. MLS operates in the 5-5.25 GHz band. Ranging is provided by precision DME operating in .96-1.22 GHz band.

C. Availability

Equipment redundancy, as well as remote maintenance monitoring techniques, should allow the availability of this system to approach 100 percent.

D. Coverage

Current plans call for the installation of systems with azimuthal coverage of $\pm 40^{\circ}$ on either side of the runway centerline, elevation coverage from 0° to a minimum of 15° over the azimuthal coverage area, and out to 20 nm. A few systems will have $\pm 60^{\circ}$ azimuthal coverage. MLS signal format has the capability of providing coverage to the entire 360° area but with less accuracy in the area outside the primary coverage area of $\pm 60^{\circ}$ of runway centerline. There will be simultaneous operations of ILS and MLS during the transition period.

E. Reliability

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.

F. Fix Rate

Elevation angle is transmitted at 39 samples per second, azimuth angle at 13 samples per second, and back azimuth angle at 6.5 samples per second. Usually the airborne receiver averages several data samples to provide fixes of 3 to 6 samples per second. A high rate azimuth angle function of 39 samples per second is available and is normally used where there is no need for flare elevation data.

G. Fix Dimensions

This system provides signals in all three dimensions and can provide time if aircraft are suitably equipped.

H. System Capacity

DME signals of this system are capacity limited; the system limits are approached when 110 aircraft are handled.

I. Ambiguity

No ambiguity is possible for the azimuth or elevation signals. Only a very small probability for ambiguity exists for the range signals and then only for multipath caused by moving reflectors.

J. Integrity

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

A.2.6 Transit

Transit is a space-based radiodetermination system consisting of satellites in approximately 600 nm polar orbits. The phasing of the satellites is deliberately staggered to minimize time between fixes for users. In addition, Transit has four ground-based monitors. The monitor stations track each satellite while in view and provide the tracking information necessary to update satellite orbital parameters every 12 hours.

A. Signal Characteristics

The satellites broadcast ephemeris information continuously on 150 and 400 MHz. One frequency is required to determine a position. However, by using the two frequencies, higher accuracy can be attained. A receiver measures successive Doppler, or apparent frequency shifts of the signal, as the satellite approaches or passes the user. The receiver then calculates the geographic position of the user based on knowledge of the satellite position that is transmitted from the satellite every two minutes, and knowledge of the doppler shift of the satellite signal. The characteristics of Transit are summarized in Table A-8.

B. Accuracy

Predictable positioning accuracy is 500 meters for a single frequency receiver and 25 meters for a dual frequency receiver. Repeatable positioning accuracy is 50 meters for a single frequency and 15 meters for a dual frequency receiver. Relative positioning accuracy of less than 10 meters has been measured through translocation techniques. Navigational accuracy is heavily dependent upon the accuracy to which vessel course, speed, and time are known. A one knot velocity input error can cause up to 0.2 nm fix error.

C. Availability

Availability is better than 99 percent when a Transit satellite is in view. It depends on user latitude, antenna mask angle, user maneuvers during a satellite pass, the number of operational satellites and satellite configuration.

D. Coverage

Coverage is worldwide but not continuous due to the relatively low altitude of the Transit satellites and the precession of satellite orbits.

Table A-8. Transit System Characteristics (Signal-In-Space)

ACCURACY* (Meters-2 Sigma)			AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE**	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE	REPEATABLE	RELATIVE							
Dual Frequency 25m	15m	Under 10m with translocation techniques	99% when satellite is in view	Worldwide non-continuous	99%	Every 30 seconds	2D	Unlimited	None
Single Frequency 500m	50m								

** Position accuracy is highly dependent on the user's knowledge of his velocity.*
*** Maximum satellite waiting time varies with latitude. (30 minutes at 80 °, 110 minutes at equator)*

SYSTEM DESCRIPTION: TRANSIT nominally consists of four operational satellites in polar orbits. The satellites broadcast information on 150 and 400 MHz. A receiver measures the apparent frequency shift of the signals (doppler) as the satellite approaches and passes the user. The receiver then calculates the geographic position of the user, based on satellite position knowledge and corrections received from the transmitted signal.

E. Reliability

The reliability of the Transit satellites is greater than 99 percent.

F. Fix Rate

Fix rate varies with latitude, theoretically from an average of 110 minutes at the equator to an average of 30 minutes at 80 degrees. Presently, due to non-uniform orbital precession, the Transit satellites are no longer in evenly spaced orbits. Consequently, a user can occasionally expect a period greater than 6 hours between fixes. This condition exists for less than 5 percent of system availability.

G. Fix Dimensions

Transit satellites provide a two-dimensional fix.

H. System Capacity

Transit satellites have unlimited capacity.

I. Ambiguity

There is no ambiguity.

J. Integrity

Transit satellite signals are monitored by the Naval Astronautics Group (NAG) at Point Mugu, California, which serves as the satellite constellation ground control facility. Whenever a satellite-transmitted signal is out-of-tolerance or otherwise unsuitable for use, NAG will issue a "SPATRAK" alerting message to all known U.S. Navy Transit users, with an information copy to DMA. DMA then ensures that the alert is entered into the Notice to Mariners system for distribution to civil users. The same procedure is used for scheduled test or preventative maintenance periods on selected satellites. Transit receivers do not possess inherent signal integrity monitoring capabilities, other than the ability to recognize and reject the scrambled signal format broadcast by selected satellites during certain NAG-implemented system tests.

A.2.7 Radiobeacons

Radiobeacons are nondirectional radio transmitting stations which operate 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.

Presently, there are 1,575 low- and medium-frequency aeronautical nondirectional beacons (NDBs). These are distributed as follows: FAA-operated Federal facilities: 728; non-Federally owned facilities: 847. No change in the navigational status of the civil facilities is expected before the year 2000. At this time, the probability of change beyond the year 2000 cannot be accurately predicted.

There are approximately 150 USCG-operated marine radiobeacons. Some maritime radiobeacons will be modified to carry differential GPS correction signals. These maritime radiobeacons will remain part of the radionavigation systems mix into the next century. Many of the remaining marine radiobeacons may be phased out after the year 2000.

A. *Signal Characteristics*

Aeronautical NDBs operate in the 190 to 415 kHz and the 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.

Marine radiobeacons operate in the 275 to 335 kHz band. Some of the longer-range marine radiobeacons operate in groups on the same frequency and are time sequenced to prevent mutual interference. However, the Coast Guard is modernizing the radiobeacon system to replace the sequenced beacons with continuous beacons. The signal characteristics for the aeronautical and marine beacons are summarized in Table A-9.

B. *Accuracy*

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 because these signals are not calibrated. For FAA flight inspection, NDB system accuracy is stated in terms of permissible needle swing: ±5 degrees on approaches and ±10 degrees in the en route area.

Table A-9. Radiobeacon System Characteristics (Signal-In-Space)

ACCURACY (2 Sigma)			AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE	REPEATABLE	RELATIVE							
Aeronautical $\pm$ 3-10°	N/A	N/A	99%	Maximum service volume - 75nm	99%	Function of the type of beacon continuous or sequenced	One LOP per beacon	Unlimited	Potential is high for reciprocal bearing without sense antenna
Marine $\pm$ 3°	N/A	N/A	99%	Out to 50nm or 100 fathom curve					

SYSTEM DESCRIPTION: Aircraft nondirectional beacons are used to supplement VOR-DME for transition from en route to airport precision approach facilities and as a nonprecision approach aid at many airports. Only low frequency beacons are considered in the FRP since there is little common use of the VHF/UHF beacons. Marine radiobeacons are used to identify the entrance to harbors and also provide a means for low cost navigation in the coastal areas.

C. Availability

Availability of marine radiobeacons and aeronautical NDBs is in excess of 99 percent.

D. Coverage

The coverage of marine radiobeacons is shown in Figures A-2 and A-3. Extensive NDB coverage is provided by 1,575 ground stations, of which the FAA operates 728.

E. Reliability

Reliability is in excess of 99 percent.

F. Fix Rate

The fix rate is a function of whether the beacon is continuous or sequenced. In general, at least one line of position, or relative bearing, is provided continuously. If sequenced, fixing a position may require up to six minutes, depending on the LOPs selected. The modernization effort will convert each radiobeacon to continuous service which will improve the fix rate.

G. Fix Dimensions

In general, one LOP is available from a single radiobeacon. If within range of two or more beacons, a fix may be obtained.

H. System Capacity

An unlimited number of receivers may be used simultaneously.

I. Ambiguity

The only ambiguity which exists in the radiobeacon system is one of reciprocal bearing provided by some receiving equipment which does not employ a sense antenna to resolve direction.

J. Integrity

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. Marine radiobeacons are monitored either continuously or perodically, depending on equipment configuration. Notification of outages

Figure A-2. Conterminous U.S. Marine Radiobeacon Coverage

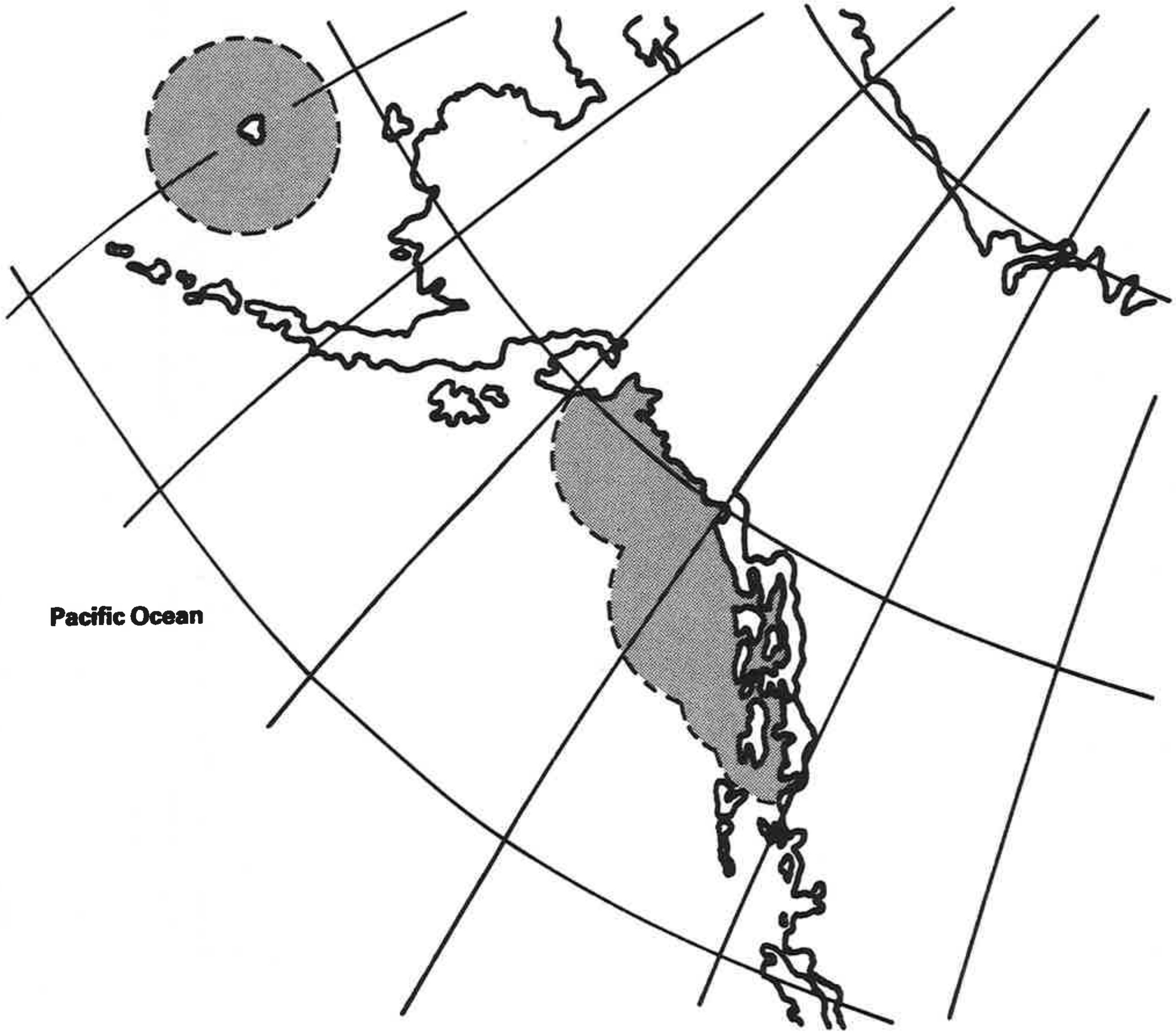


Figure A-3. Alaskan Marine Radiobeacon Coverage is provided by a broadcast Notice to Mariners. Outages of long duration are announced in both the Local Notice to Mariners and the Notice to Mariners.

A.2.8 GPS

GPS is a space-based positioning, velocity, and time system that has three major segments: space, control, and user. The GPS Space Segment, when fully operational, will be composed of 24 satellites in six orbital planes. The satellites operate in circular 20,200 km (10,900 nm) orbits at an inclination angle of 55 degrees and with a 12-hour period. The spacing of satellites in orbit will be arranged so that a minimum of five satellites will be in view to users worldwide, with a position dilution of precision (PDOP) of six or less. Each satellite transmits on two L band frequencies, L1 (1575.42 MHz) and L2 (1227.6 MHz). L1 carries a precise (P) code and a coarse/acquisition (C/A) code. L2 carries the P code. A navigation data message is superimposed on these codes. The same navigation data message is carried on both frequencies.

The Control Segment has five monitor stations, three of which have uplink capabilities. The monitor stations use a GPS receiver to passively track all satellites in view and thus accumulate ranging data from the satellite signals. The information from the monitor stations is processed at the Master Control Station (MCS) to determine satellite orbits 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 satellite control information.

The user segment consists of antennas and receiver-processors that provide positioning, velocity, and precise timing to the user.

A. Signal Characteristics

The GPS concept is predicated upon accurate and continuous knowledge of the spatial position of each satellite in the system with respect to time and distance from a transmitting satellite to the user. Each satellite transmits its unique ephemeris data. This data is periodically updated by the Master Control Station based upon information obtained from five widely dispersed monitor stations.

Each satellite continuously transmits a composite spread spectrum signal at 1227.6 and 1575.42 MHz. The GPS receiver makes time-of-arrival measurements of the satellite signals to obtain the distance between the user and the satellites. These distance calculations, together with range rate information, are combined to yield system time and the user's three-dimensional position and velocity with respect to the satellite system.

A time coordination factor then relates the satellite system to Earth coordinates. The characteristics of GPS are summarized in Table A-10.

B. Accuracy

Accuracy projections for the operational satellite constellations are based upon computer simulations. At a specifed time of day, the programs calculate the positions of the GPS satellites and determine which ones are visible at a given location on earth. They select four of the visible satellites and calculate the location solution that a GPS receiver would provide. Since a GPS receiver determines location by estimating the user's range to each of the four satellites, the simulations mimic the real errors in this process by introducing a range error for each of the simulated satellites, using Monte Carlo techniques. The range data are used to solve for the user's location, and the instantaneous position error is determined by subtracting the true position from the calculated position.

By repeating this process at many locations around the Earth, and over a 24-hour period, the simulations produce a composite view of system performance. These results are dependent upon several program inputs:

- The number of satellites in the GPS constellation.
- The orbits chosen for the satellites.
- The locations of the simulated users.
- The local visibility contraints on receiving signals from satellites.
- The criteria for selecting four satellites from among the visible ones.
- The magnitude of the User Range Errors (URE) experienced by users.

URE is an aggregate of all the range measurement uncertainties, including the GPS receiver itself. It can be expressed as a zero-mean Gaussian distribution with a specified standard deviation.

The position errors calculated by the simulations are normalized by dividing them by the standard deviation of the URE originally used to generate the Monte Carlo range errors. Normalized error curves are often confused with Dilution of Precision (DOP) curves. DOP is a geometric quantity that depends upon the relative positions of the user and the selected satellites. Statistically, high values of DOP cause small range measurement errors to be amplified into large position errors. GPS constellations are selected to minimize these high-DOP areas of reduced accuracy. Normalized position

Table A-10. GPS Characteristics (Signal-In-Space)

ACCURACY (METERS)*			AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE	REPEATABLE	RELATIVE							
PPS Horz - 21 Vert - 29 Time - 200ns	Horz - 21 Vert - 29	** Horz - 1 Vert - 1.5	Expected to approach 100%	Worldwide continuous (PDOP $\leq$ 6)	98% probability that a 21-satellite constellation will be operating	Essentially continuous	3D + Velocity (***) + Time	Unlimited	None
SPS Horz - 100 Vert - 140 Time - 340ns	Horz - 100 Vert - 140	** Horz - 1 Vert - 1.5							

* *Horizontal (2 drms); Vertical (95%); Time (95%).*
** *Preliminary estimates.*
*** *System specifications not defined for SPS.*

SYSTEM DESCRIPTION: GPS is a space-based radio positioning navigation system that will provide three-dimensional position, velocity and time information to suitably equipped users anywhere on or near the surface of the Earth. The space segment will consist of 24 satellites in 6 orbital planes of 12 hour periods. Each satellite will transmit navigation data and time signals on 1575.42 and 1227.6 MHz.

error distributions are preferable to DOP distributions; the position error distributions implicitly include not only the overall error amplification of the DOP curves, but also the fact that north-south, east-west, and vertical location errors all have different trends.

All accuracy projections are based upon a fully operational system: 24 healthy satellites, normal uploads by the Control Segment, etc. The accuracy simulations use the 24 satellites. Satellite visibility depends upon local conditions. Some users may be able to track satellites less than 5 degrees above the horizon, while other users may have difficulty even at 10 degrees. DOD accuracy simulations use 5 degrees.

Accuracy simulations use the four-satellite combination that minimizes three-dimensional position DOP (PDOP). In some applications, a user receiver may have access to additional information, such as being at a known altitude (relative to mean sea level), or may have a more accurate atomic clock in place of the usual crystal clock. In general, such information improves location accuracy substantially. When discussing horizontal accuracy it is important to differentiate between a user whose horizontal errors are based upon the use of four satellites that minimize DOP, and one based upon a known altitude and the use of three satellites that minimize horizontal DOP (HDOP). As noted above, the GPS accuracy simulations are usually based solely upon the four satellites that minimize PDOP.

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

1. Standard Positioning Service (SPS)

SPS is the standard specified level of positioning and timing accuracy that is available, without qualification or restrictions, to any user on a continuous worldwide basis. The accuracy of this service will be established by the U.S. Department of Defense based on U.S. security interests. When GPS is declared operational, the DOD plans to provide, on a daily basis at any position worldwide, horizontal positioning accuracy within 100 meters (2 drms) and 300 meters with 99.99 percent probability.

2. Precise Positioning Service (PPS)

PPS is the most accurate positioning, velocity, and timing information continuously available, worldwide, from the basic GPS. This service will be limited to authorized U.S. and allied Federal Governments; authorized foreign and military users; and eligible civil users. Unauthorized users will be denied access to PPS through the use of cryptography. P code capable military user equipment will provide a predictable positioning accuracy of at least 22 meters (2 drms) horizontally and 27.7 meters (2 sigma) vertically and timing/time interval accuracy within 90 nanoseconds (95 percent probability).

C. Availability

GPS will provide availability approaching 100 percent to be refined based on orbital experience. This is based upon a 24 satellite constellation with at least four satellites in view above a 5^{o} masking angle.

D. Coverage

A 24-satellite constellation will provide worldwide three-dimensional coverage.

E. Reliability

GPS operational (Block II) satellites have a design life of 7.5 years. Reliability figures can only be determined after satellites are launched and data are collected and evaluated. With the planned replenishment strategy, a constellation of 24 satellites will provide a 98 percent probability of having 21 or more satellites operational at any time.

F. Fix Rate

The fix rate is essentially continuous. Actual time to a first fix depends on user equipment capability and initialization with current satellite almanac data.

G. Fix Dimensions

GPS provides three-dimensional positioning and velocity fixes, as well as extremely accurate time information.

H. System Capacity

The capacity is unlimited.

I. Ambiguity

There is no ambiguity.

J. Integrity

According to DOD's concept of operation, GPS satellites are monitored more than 95 percent of the time by a network of five monitoring stations spread around the world. The information collected by the monitoring stations is processed by the Master Control Station at Colorado Springs, Colorado, and used to periodically update the navigation message (including a health message) transmitted by each satellite. The satellite health message, which is not changed between satellite navigation message updates, is transmitted as part of the GPS navigation message for reception by both PPS and SPS users. Additionally, satellite operating parameters such as navigation data errors, signal availability/anti-spoof failures, and certain types of satellite clock failures are monitored internally within the satellite. If such internal failures are detected, users are notified within six seconds. Other failures detectable only by the control segment may take from 15 minutes to several hours to rectify.

DOD GPS receivers use the information contained in the navigation and health messages, as well as self-contained satellite geometry algorithms and internal navigation solution convergence monitors, to compute an estimated figure of merit. This number is continuously displayed to the operator, indicating the estimated overall confidence level of the position information.

Both DOT and DOD have recognized the requirement for additional integrity for aviation and all other users of GPS. The development of integrity capabilities to meet flight safety requirements is underway.

A.2.9 Differential GPS

DGPS is an enhancement of the Department of Defense's Global Positioning System, through the use of differential corrections to the basic satellite measurements performed within the user's receiver. DGPS is based upon accurate knowledge of the geographic location of a reference station, which is 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 meters (2 drms) to better than 10 meters (2 drms). A DGPS reference station is fixed at a geodetically surveyed position. From this position, the reference station 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 is often difficult to achieve.

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 pseudorange measurement 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 the U.S. Coast Guard DGPS Service.

A.2.9.1 Maritime DGPS

Figure A-4 shows the USCG system concept using pseudorange corrections. 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.

A. Signal Characteristics

Maritime radiobeacons are being modified to accept minimum shift keying (MSK) modulation. Real-time differential GPS corrections are input in the RTCM SC-104 format and broadcast to all users capable of receiving the signals. The Coast Guard 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 Radio Technical Commission for Maritime Services (RTCM) established Special Committee (SC) 104 in November 1983. Coast Guard and Volpe National Transportation Systems Center (Volpe Center) personnel worked closely with this committee in the development of the recommended standards. By 1986, a set of recommendations was made available. The recommended standards considered the widest possible uses of DGPS, not just marine navigation, to provide a format with flexibility as well as uniformity. The committee also examined the communication of the corrections to the users. Based on data supplied to DOT by the GPS Joint Program Office concerning SA variations, a transmission rate of 50 bits per second was determined to be the minimum transmission rate for differential corrections. The committee went on to review the radio frequencies allocated in the U.S. for radionavigation and evaluate their suitability for use with DGPS. The committee concluded that the radiobeacon band of 285-325 kHz was the only band that met the needs of DGPS for radionavigation use without requiring changes in international frequency allocations. This conclusion was supported by the results of a 1984 Radiobeacon Data Link Workshop held at Coast Guard Headquarters. This workshop evaluated the suitability of radiobeacons for DGPS and developed a preliminary design for test and demonstration hardware. The radiobeacon network operated by the Coast Guard promised to be a convenient conduit for the DGPS corrections.

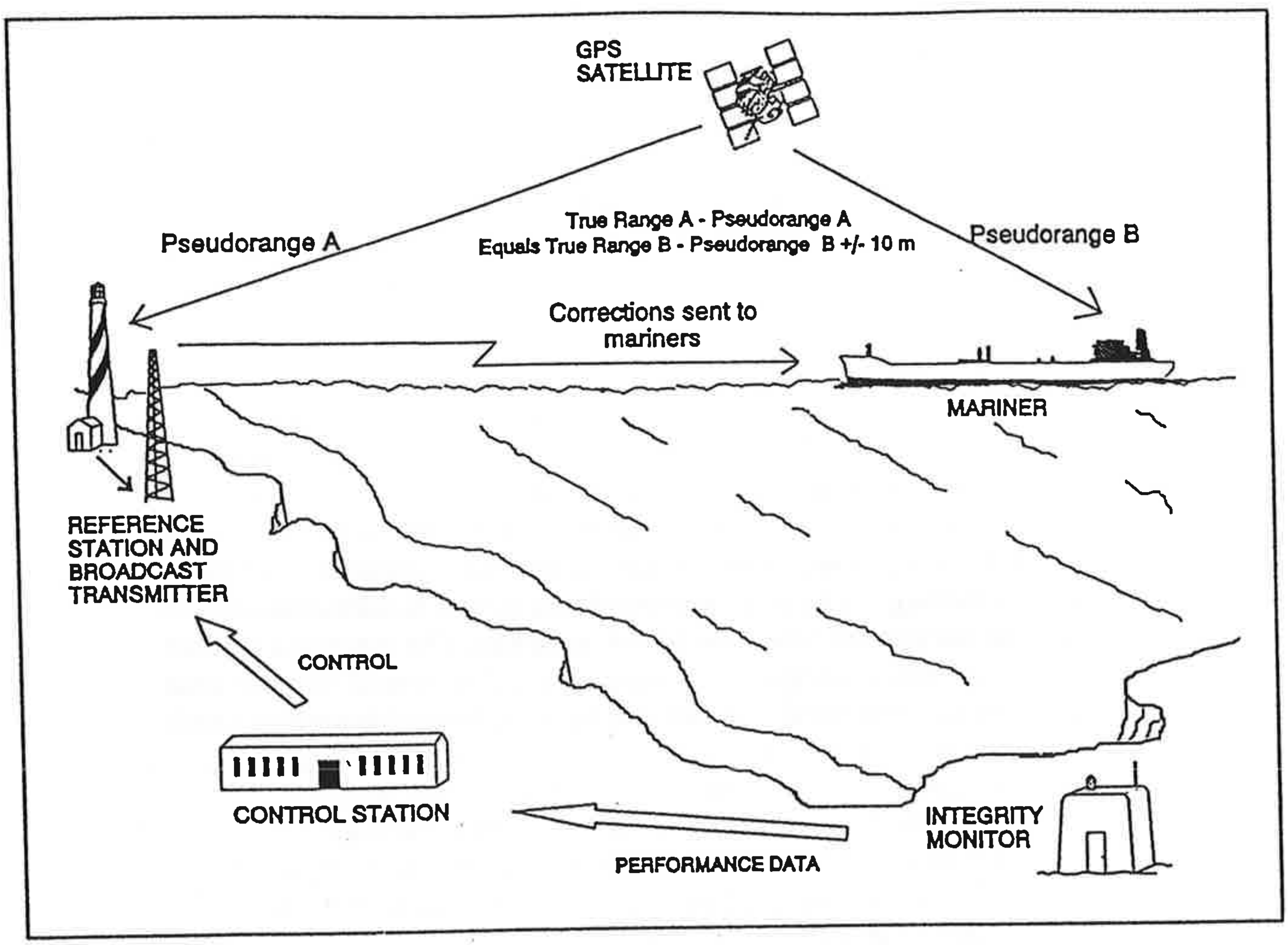


Figure A-4. DGPS System Concept

The beacons were already located in sites where marine navigators needed coverage, the effects of blockage and multipath were small in this band compared to higher frequencies, radiobeacons had already been used successfully for other differential navigation application, and the range of the radiobeacon signal roughly corresponded to the applicable range of the DGPS corrections.

The Coast Guard'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. Several different messages were defined, some "fixed" and some "tentative." The fixed messages are:

- **Type 1** Differential GPS Corrections. This message contains the psuedorange corrections (PRC) and range-rate corrections (RRC) for all satellites in view of the reference station. The message also indicates the nominal time (shown below as t_o) for which this data was valid. The user computes the current differential correction as follows:

  $$PRC(t) = PRC(t_o) + RRC \cdot (t-t_o),$$

  where $PRC(t_o)$ is the PRC value in the type 1 message. The user then applies the PRC by adding it to their pseudorange measurement. The RRC is included in an attempt to extend the life of the PRC, as the RRC is a "rate" term which is used to propagate PRCs in time.

- **Type 2** Delta Differential GPS Corrections. Special Committee 104 considered that oftentimes a reference station may update its ephemeris earlier than the users. This message provides "delta" PRCs and RRCs for each satellite. The user applies them if its "issue of data" is different than that indicated in the type 1 message, but identical to that indicated in the type 2 message. The delta corrections are added to corrections found in the current type 1 (or type 9) message. The reference station will broadcast type 2 messages for the first several minutes after a change in satellite ephemeris data. Because this message adds considerable latency to the corrections that can be applied by the user, a review of the need for this message is being conducted. A cost/benefit analysis will be conducted, considering the additional latency (and attendant degradation of accuracy) imparted by this message vs. the additional accuracy it provides on its own.

- **Type 3** <u>**Reference Station Parameters**</u>. The Earth-Centered-Earth-Fixed (ECEF) coordinates of the reference station with a resolution of 0.01 meter are found here. This message will normally be broadcast every five minutes. User derived atmospheric corrections are possible through use of this message type.

- **Type 6** <u>**Null Frame**</u>. This message is used to maintain data link synchronization in the event there are no other RTCM messages to transmit. In the operational GPS scenario, transmission of this message will be rare indeed.

- **Type 9** <u>**High Rate Differential GPS Corrections**</u>. This message is similar to the type 1 message, but individual type 9 messages will be generated only for those satellites with high pseudorange rates. This is likely to be needed with "operational" S/A, when one or several satellites exhibit very fast acceleration due to S/A effects. The use and frequency of this message is the subject of current research and it may fully replace the type 1 message.

- **Type 16** <u>**Special Message**</u>. This is an ASCII message up to 90 characters long. It can be sent by service providers to broadcast warning information, such as scheduled outages. User equipment should have the ability to display this information to the navigator, with audible warning of receipt. The type 16 message will be supplemented by the proposed type 22 message.

The following "tentative" messages will be used by the Coast Guard:

- **Type 5** <u>**Constellation Health**</u>. The main use of this message type will be to notify the user equipment suite that a satellite which is deemed unhealthy by its current navigation message is usable for DGPS Navigation.

- **Type 7** <u>**Radiobeacon Almanac**</u>. This message provides location, frequency, service range and health information for adjacent broadcast transmitters. When broadcast from a given radiobeacon, it can be used to acquire the next transmitter when in transit down the coast. This message will nominally be sent every 10 minutes.

- **Type 22** <u>**Integrity Message**</u>. This message will provide the user with information on both the current and future status of the broadcast. This message is being submitted to the RTCM SC-104 by the Coast Guard.

A requirement for velocity accuracy of 0.05 knots exists in Vessel Traffic Service (VTS) coverage areas which employ automated dependent surveillance. (Prince William Sound, Alaska is the only such VTS planned at this time.)

B. Accuracy

The accuracy of the Coast Guard's DGPS service is expected to be better than 10 meters (2 drms) in all approaches to major U.S. harbors.

C. Availability

To be determined.

D. Coverage

Figure A-5 shows the expected coverage of the Coast Guard's maritime DGPS system.

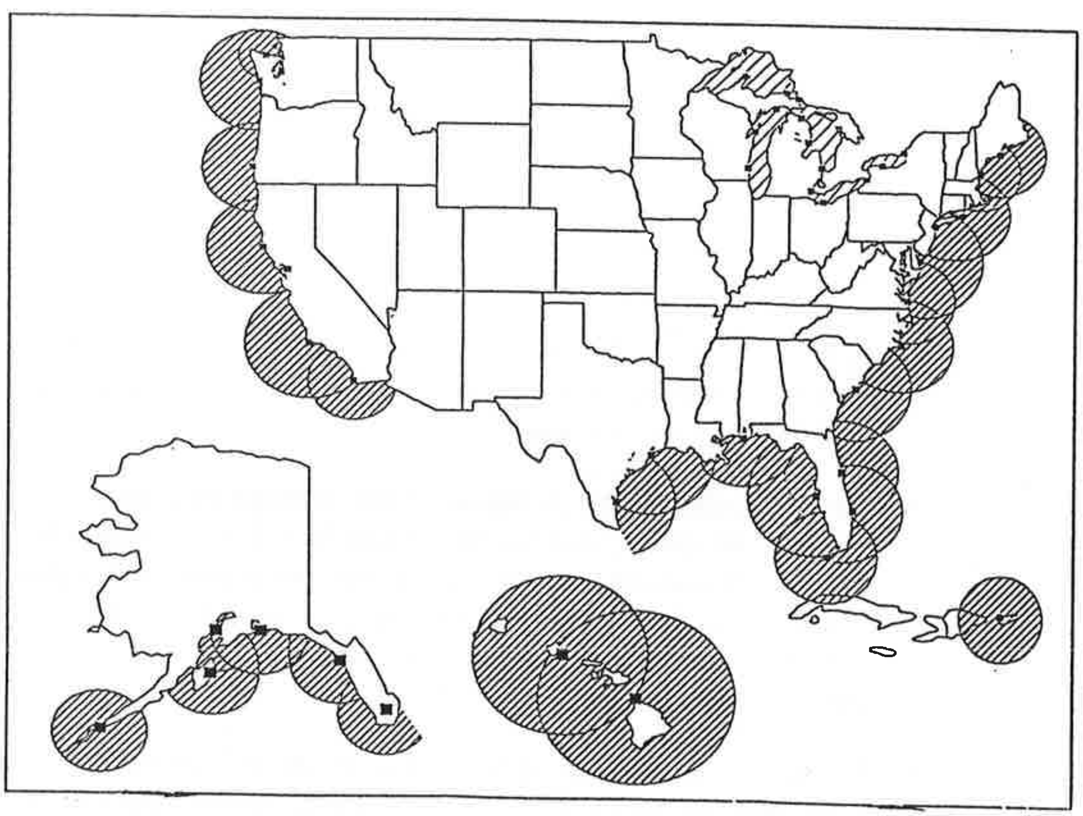


Figure A-5. Proposed Conus, Alaska and Hawaii Maritime DGPS Coverage

E. Reliability

To be determined.

F. Fix Rate

At least once per second.

G. Fix Dimensions

Maritime differential GPS provides three-dimensional positioning and velocity fixes.

H. System Capacity

Unlimited.

I. Ambiguity

None.

J. Integrity

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.

A.2.9.2 Aviation DGPS

The FAA is considering three types of differential GPS service for aviation use: (1) local area DGPS (LADGPS), which would be located at each airport or closely grouped airports to support instrument approaches to current CAT I weather minimums; (2) wide area DGPS (WADGPS), which would provide GPS integrity broadcast (GIB) and accuracy improvements for all of North America; and (3) use of kinematic carrier phase positioning for instrument approach and landing.

All three types of DGPS service are still under develoment; however, WADGPS/GIB is in the FAA budget for procurement and installation. The basic concept for WADGPS/GIB is to have several GPS ground monitoring stations (about 20 for North America) with two master control stations where differential corrections and integrity for each satellite are determined. This information will be sent to two communications satellite earth stations and relayed to the aircraft via a satellite signal that is similar to a GPS signal with unique codes. This signal may also be suitable for ranging providing improved navigation availability.

A.2.10 VTS

For information on VTS system characteristics, please contact the U.S. Coast Guard (G-NVT).

A.3 GPS Information Center (GPSIC)

The U.S. Coast Guard's GPS Information Center (GPSIC) is the operational entity of the Civil GPS Service (CGS) which provides GPS status information to civilian users of the Global Positioning System. Its input is based on data from the GPS Control Segment, Department of Defense, and other sources. The mission of the GPSIC is to gather, process and disseminate timely GPS status information to civil users of the GPS navigation system. Specifically, the functions performed by the GPSIC include the following:

- Provide the Operational Advisory Broadcast Service (OAB).
- Answer questions by telephone or written correspondence.
- Provide information to the public on the GPSIC services available.
- Provide instruction on the access and use of the information services available.
- Maintain tutorial, instructional, and other relevant handbooks and material for distribution to users.
- Maintain records of GPS broadcast information, GPS databases or relevant data for reference purposes.
- Maintain bibliography of GPS publications.
- Maintain and augment the computer and communications equipment as required.
- Develop new user services as required.

The GPSIC also provides information on the status of Loran-C and Omega.

Table A-11 and Figure A-6 show the services through which the GPSIC provides Operational Advisory Broadcasts.

Table A-11. GPSIC Services

Service	Availability	Information Type	Contact Number
GPSIC Watchstander	8 am - 4 pm Monday through Friday	User Inquiries	(703) 866-3806 FAX (703) 866-3825
GPSIC Computer Bulletin Board Service	24 hours	Status Forecasts/Historic Outages NGS Data Omega/FRP Misc Information	(703) 866-3890 300-14,400 bps Sprintnet (X.25) 311020201328
GPSIC Voice Tape Recording	24 hours	Status Forecasts Historic	(703) 866-3826
WWV	Minutes 14 & 15	Status Forecasts	2.5, 5, 10, 15 and 20 MHz
WWVH	Minutes 43 & 44	Status Forecasts	2.5, 5, 10, and 15 MHz
USCG MIB	When Broadcasted	Status Forecasts	VHF Radio, Marine Band
DMA Broadcast Warnings	When Broadcasted	Status Forecasts Outages	
DMA Weekly Notice to Mariners	Published & Mailed Weekly	Status Forecasts Outages	(301) 227-3126
DMA NAVINFONET Automated Notice to Mariners System	24 hours	Status Forecasts Historic Almanacs For More Information Call	(301) 227-3351 300 Baud (301) 227-5925 1200 Baud (301) 277-4360 2400 Baud (301) 227-3296
NAVTEX Data Broadcast	When broadcasted 4 - 6 time/day	Status Forecasts Outages	518 kHz

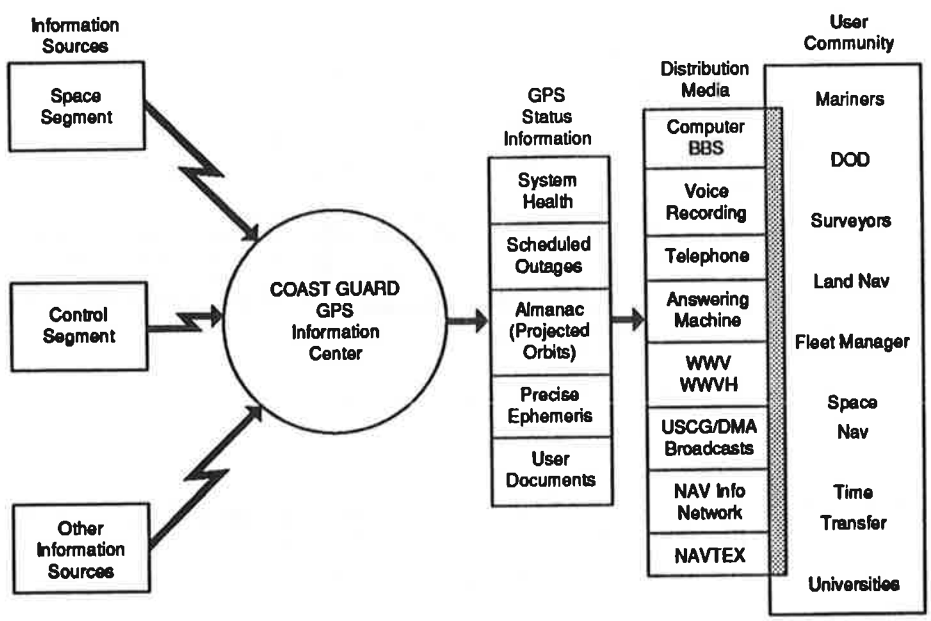


Figure A-6. GPSIC Information Flow

A.4 Intelligent Vehicle Highway Systems (IVHS)

The aim of IVHS is to apply advanced concepts and technology in communications, controls, navigation, and information systems to improve highway safety, provide solutions to traffic congestion problems, and reduce harmful environmental effects from automotive traffic. The IVHS program has evolved to include five major system areas (see Figure A-7). Each of these focuses on different applications of IVHS technology to highway system needs and opportunities. All have early opportunities for deployment of individual elements. Over time, the five system areas will become more interdependent and evolve into a comprehensive system.

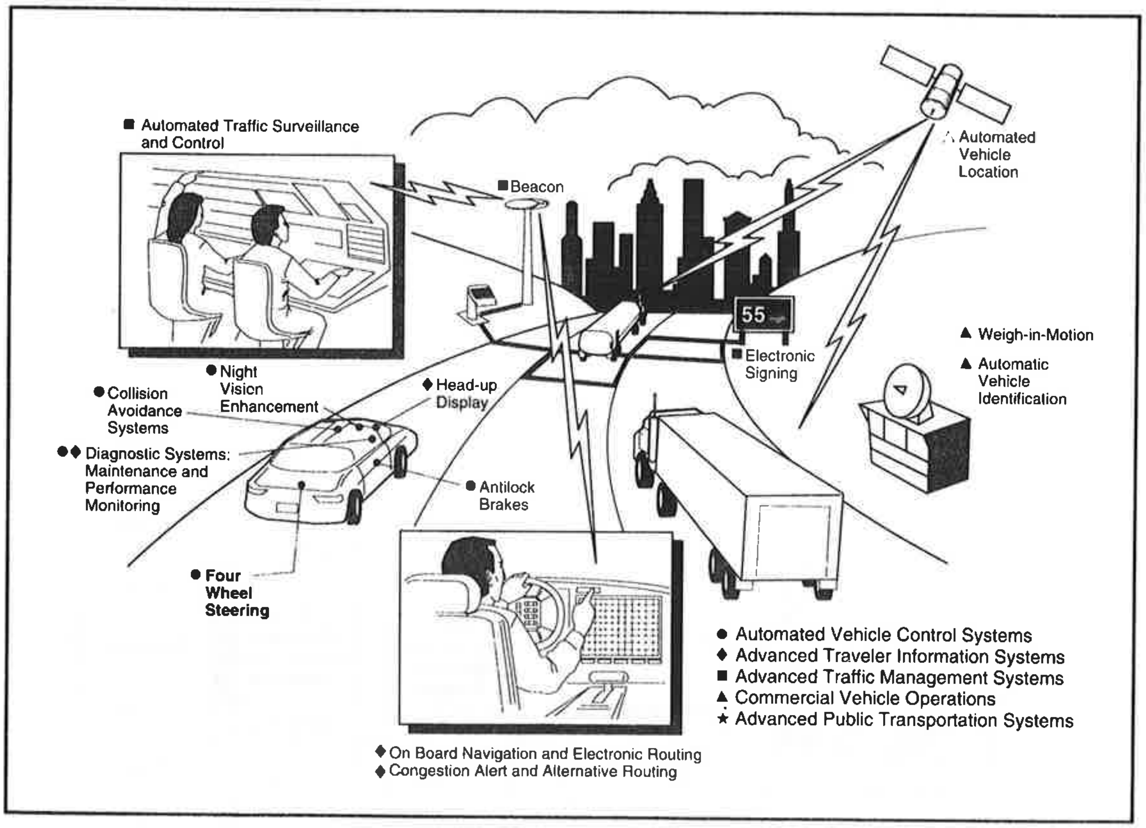


Figure A-7. Basic Components of an Intelligent Vehicle Highway System

These five are:

- **Advanced Traffic Management Systems (ATMS):** Permit real-time adjustment of traffic control systems and variable signing for driver advice. Applications in selected corridors have reduced delay, travel time, and accident incidence. ATMS uses coordinated signaling systems, video surveillance of corridors, ramp metering, automated toll collection, and variable message signs (VMS).

- **Advanced Traveler Information Systems (ATIS):** Deal with the acquisition, analysis, communication, presentation, and use of information to assist the surface transportation traveler in moving from origin to destination in the way which best satisfies the traveler's needs for safety, efficiency, and comfort. Travel may involve a single mode or linked, multiple modes. These systems will let travelers know their locations and how to find services, and will permit communication between travelers and ATMS for continuous advice on traffic conditions and alternate routes. In addition, ATIS provides the driver with warnings related to road safety.

- **Commercial Vehicle Operations (CVO):** Expedite deliveries, improve operational efficiency, improve incident response, and increase safety. CVO makes use of ATIS features critical to commercial and emergency vehicles. A primary goal of CVO is to reduce regulatory burdens and inefficiency. Many of the technologies related to CVO are already available in the marketplace. Automatic Vehicle Identification (AVI) devices are used in several locations to allow the electronic transfer of funds so travelers can pay tolls without stopping. Global Positioning System (GPS) and Loran-C technologies can be used to track the location of individual vehicles for fleet management. Weigh-in-Motion (WIM), combined with Automatic Vehicle Classification (AVC), sorts vehicles for weight inspections. Onboard computers are available to monitor track performance.

- **Advanced Vehicle Control Systems (AVCS):** Enhance the control of vehicles by facilitating and augmenting driver performance and, ultimately, relieving the driver of most tasks on designated, instrumented roadways. AVCS includes vehicle- and/or roadway-based electromechanical and communications devices.

- **Advanced Public Transportation Systems (APTS):** Work in conjunction with ATMS and ATIS to provide mass transportation users and operators (e.g., buses, vanpools, high-occupancy vehicle (HOV) lanes, carpools, taxi cabs) with up-to-date information on status, schedules, and availability of public transit systems. Automatic vehicle location and monitoring systems will provide information to improve fleet management and inform riders of their connections. Electronic fare media will reduce the inconvenience of cash handling, provide new marketing data, and integrate third party billing for transit services. New HOV priority schemes using IVHS technologies will be devised and monitored automatically to enforce HOV facility use. Other examples of diverse transit applications are fixed routine transit, demand responsive transit, transit mobile supervisors, and passenger/consumer information.

Appendix B

Interim Guidance for Installation and Approval of Global Positioning System (GPS) Equipment In Aircraft*

The presently deployed GPS satellite constellation does not provide the coverage, availability, and integrity necessary for civil aircraft instrument flight rules (IFR) navigation, except as provided for in this Appendix. In addition, the GPS constellation has not been declared operational by the Department of Defense and is in a developmental testing phase. Deliberate signal degradations can be introduced and frequent satellite outages can occur without advance notice during this development and test phase.

The Federal Aviation Administration (FAA) is currently developing a technical standard order (TSO) which will establish minimum requirements for approval of airborne navigation equipment using GPS as a supplemental means of navigation. An advisory circular (AC) outlining methods for approval of GPS equipment as a supplemental means of navigation is also being developed.

Stand-Alone GPS System. A stand-alone system is not integrated with any other navigation system to derive its position.

Multiple Sensor Navigation System. A multiple sensor navigation system may include a GPS sensor with one or more FAA approvable navigation

* (Source: Federal Aviation Administration, July 20, 1992)

sensors, all of which operate independently (not integrated). Such systems do not provide a blended position solution or position integrity comparison. An IFR approval non-GPS sensor can retain its approval for use under IFR conditions, in accordance with the applicable advisory circular. Each sensor must be selectable by the flight crew.

The installation of GPS equipment used as a stand-alone system or as part of a multiple sensor navigation system, as defined above, can be approved using the following considerations:

GPS Installations Used For Operations Under Visual Flight Rules (VFR) Only. Operators wishing to use GPS for operations limited to VFR may obtain approval of the installation by type certification (TC), supplemental type certification (STC), the FAA field approval process, or by use of previously approved data. The approval for return to service should be signed by one of the entities noted in FAR 43; i.e., repair station, manufacturer, holder of an inspection authorization, etc. The installation verification should ensure, but is not limited to, the following:

1. **The GPS installation does not interfere** with normal operation of other equipment installed in the aircraft. This is accomplished by a ground test and flight test to check that the GPS equipment is not a source of objectionable electromagnetic interference (EMI), is functioning properly and safely, and operates in accordance with the manufacturer's specifications.

2. **The structural mounting of the GPS equipment** is sufficient to ensure the restraint of the equipment when subjected to the emergency landing loads appropriate to the aircraft category.

3. **A navigation source annunciator is provided** on or adjacent to the display if the GPS installation supplies any information to displays, such as a horizontal situation indicator (HSI) or course deviation indicator (CDI), which can also display information from other systems normally used for aircraft navigation.

4. **The GPS controls and displays are installed** with a placard(s) which states "GPS Not Approved for IFR."

5. **The GPS may be coupled to the "radio nav" function** of an autopilot provided the system has a CDI or steering output that is compatible with the autopilot.

6. **The outputs from a non-integrated GPS receiver** providing any information to displays (i.e., CDI, HSI, etc.) must be designed using accepted aeronautical practices, perform their intended function, and have no complex switching or operational features. Such installations

may use the limitations and normal or emergency procedures supplied by the system manufacturer for the end user.

Installations that require complex switching procedures or have functions that may result in information or maneuvers that are misleading or unacceptable must have a flight manual supplement (or a supplemental flight manual for aircraft without an FAA approved flight manual) that includes any limitations or cautions and operating procedures.

7. The GPS equipment may include other features such as altimetry smoothing, clock coasting, etc.

Multi-Sensor Navigation System. A multi-sensor navigation system incorporating a GPS sensor may be approved for IFR or VFR use provided:

a. The airworthiness considerations contained in AC 20-130 or equivalent (for use in the U.S. National Airspace System (NAS) and Alaska) and AC 120-33 (for operation in the North Atlantic Minimum Navigational Performance Specifications (MNPS) airspace and other oceanic or remote areas), if applicable, are followed.

b. A flight manual supplement (or supplemental flight manual for aircraft without an FAA approved flight manual) is required that includes any limitations, operating instructions, and the following caution:

Caution

Except as specified by this flight manual, the GPS satellite constellation may not meet the coverage, availability, and integrity requirements for civil aircraft navigation equipment. Users are cautioned that satellite availability and accuracy are subject to change, and appropriate GPS status information should be consulted.

c. Position information must be available, at all times, from at least one other approved or approvable sensor, appropriate for geographic area and flight phase, for IFR operations. The multi-sensor navigation system must monitor the integrity of the GPS information by comparing the difference between the position computed using GPS information and the position computed from the other approved sensor(s). Although a system may provide the necessary level of integrity in various ways, such as using comparisons related to a system mode or configuration rather than flight condition (phase of flight), the difference between GPS and other sensor positions should not exceed the following values, unless approved by the FAA:

Flight Condition	Monitor Limit
Oceanic or Remote Areas	12.6 nm
En route IFR along random routes	3.8 nm
En route IFR on airways in the NAS	2.8 nm
Terminal IFR operations in the NAS	1.7 nm
Instrument approach operations in the NAS	0.3 nm

d. The system must detect when any sensor cannot provide the accuracy required or is not available. An advisory indication must be provided to the flight crew.

e. The system must detect when sensors (other than GPS) required for en route, terminal, or nonprecision approach operations are not of the required accuracy or not available. Under such conditions, the flight crew must be alerted that the system does not meet IFR requirements.

f. In the approach mode, the system must detect when sensors (other than GPS) are not of the required accuracy or not available. Under such conditions, a failure indication must be displayed on the dedicated navigational display.

g. For IFR multi-sensor systems, the minimum performance standards specified in TSO C115a or an acceptable alternate means must be met.

The multi-sensor approval option requires a type certificate or supplemental type certificate for the initial approval. Follow-on installation approvals may be accomplished by TC or STC or may be in the form of a field approval on an FAA Form 337 provided the data initially approved is applicable to the follow-on approval. The applicant or installing entity accomplishing a follow-on multi-sensor system installation utilizing this field approval method should follow the procedure in AC 20-130, para. 9.b.(1) - (6).

Follow-on installations using the field approval process should use the sample aircraft flight manual supplement in Appendix 2 of AC 20-130 based on the data from the initial approval. The FAA inspector signing the supplement should consider the note on page 3 of Appendix 1 in AC 20-130.

This guidance is applicable only to equipment which uses U.S. Air Force NAVSTAR GPS signals. The use of other satellite systems, such as GLONASS, will be addressed at a future date.

This guidance may be subject to future revision and updating as the GPS satellite constellation matures and the means of system integrity monitoring are refined.

Appendix C

Chart Reference Systems

C.1 Chart Reference Systems

Geodetic datums are basic control networks used to establish the precise geographic position and elevation of features on the surface of the Earth. They are established at all levels of government (international, national, and local) and form the legal basis for all positioning and navigation. Within the last 20 years, there have been great advances in our knowledge of the shape and size of the Earth (i.e., our geodetic knowledge). The old datums are no longer scientifically relevant (although otherwise still relevant). In recent years, geodesy and navigation tended toward Earth Centered Body Fixed (ECBF) coordinate systems. These are cartesian coordinate systems with origins at the center of mass of the Earth and whose axes rotate with the Earth. The old datums have generally been based on localized surface monumentations (and associated agreements) and defined by a reference ellipsoid that was not Earth centered.

The Department of Defense (DOD) Global Positioning System (GPS) is based on the World Geodetic System of 1984 (WGS 84). WGS 84 is an ECBF coordinate system upon which all U.S. military and much civilian navigation, geodesy, and survey will be based. Within the U.S., the National Geodetic Survey (NGS) is the primary civilian legal authority for the establishment of U.S. datums. Until recently, the datum used throughout most of the U.S. and Canada was the North American Datum of 1927 (NAD 27). NAD 27 is a surface or horizontal datum. Until recently, nearly all nautical charts, aeronautical charts, Federal surveys, and associated data provided by the National Ocean Service (NOS) of the National Oceanic and Atmospheric Administration (NOAA) were legally established with respect to NAD 27. In

1986, NGS completed a new horizontal datum known as the North American Datum of 1983 (NAD 83) which, for purposes of navigation and relative survey, is effectively equivalent to WGS 84. Although NAD 27 is still heavily used, increasingly datum products and activities are being converted to NAD 83.

There is also a vertical (i.e., height) datum. Until recently, there has been the National Geodetic Vertical Datum of 1929 (NGVD 29). In 1991, the NGS completed the North American Vertical Datum of 1988 (NAVD 88). Vertical datum products and activities have begun the conversion from NGVD 29 to NAVD 88. The conversion between GPS determined heights (i.e., ellipsoid heights) and vertical datum (i.e., orthometric) heights is made by using a geoid model associated with the respective vertical datum. NGS has developed a geoid model, GEOID 90, to support such conversions.

C.2 Nautical Charts

Most nautical charts are based on regional horizontal datums which have been defined over the years independently of each other. These include charts published by the Defense Mapping Agency and the National Ocean Service (NOS) of NOAA. In addition, in many parts of the world, the positional accuracy of chart features (such as hazards to navigation) sometimes varies from chart to chart and, in some cases, within a chart. Certain charts for waters in the southern hemisphere, for example, do not show islands in their correct geodetic positions, absolute or relative. Therefore, datums and limited chart accuracy must be considered when a navigational fix is plotted by a navigator on a nautical chart.

Modern navigational positioning is based on satellite systems which are geocentric by definition, and these satellite coordinate systems differ significantly in many cases with the local or regional datums of nautical charts. In addition to this difference, the plotted detail, such as soundings and navigational aids, contain a minimum plottable error that ranges between 0.5 mm to 1.0 mm on paper.

Virtually all radionavigation equipment incorporating coordinate converters (automated computation of geodetic latitude and longitude from data received from a radionavigation system) were, until recently, programmed with the World Geodetic System of 1972 (WGS 72) datum parameters. In January 1987, WGS 84 began to replace WGS 72. Today, new radionavigation equipment coordinates are computed based on WGS 84.

The large majority of the nautical charts published by NOS have been compiled based on a regional datum: NAD 27. The remaining NOS nautical charts were published on eight other local or regional datums. As stated, NOS has now adopted a geocentric datum: NAD 83. NOS has begun the conversion of its nautical charts to NAD 83. The charts of the Pacific islands, published by NOS, will be compiled based on WGS 84. For charting purposes, however, NAD 83 is equivalent to WGS 84. As charts are converted, datum transformation notes will be added which report the amount of the shifts from NAD 27 coordinates for each chart.

Improvements in worldwide navigational accuracy, which are anticipated with the implementation of GPS in the early 1990s, will be significant. However, the ability to navigate safely along the coastlines of the world and on the high seas will remain limited where accurate, up-to-date hydrography and associated topographic features are not all positioned on the same satellite-based WGS reference system.

C.3 Aeronautical Charts

The ultimate responsibility for the accuracy of air cartographic positional data rests with NOS. Section 307(b)(3) of the Federal Aviation Act authorizes the FAA, subject to available appropriations, to arrange for the publication of aeronautical maps and charts necessary for the safe and efficient movement of aircraft in air navigation utilizing the facilities and assistance of other Federal agencies. NOS, in turn, performs many of these services. Within the National Airspace System (NAS), the NGS establishes the basic U.S. datum that legally controls all positioning with the U.S. The Nautical Charting Division (NCD) of NOS conducts the Airport Obstruction Clearance Surveys (OC Surveys) which establish the positioning for 750 U.S. major civil airports and all navigational aids to existing U.S. datums. The NGS has completed the Airport Datum Monument Program (ADAM) which established datum monuments on 1400 non-OC surveyed airports. The ADAM data, which include end-of-runway coordinates, were determined using GPS and are available in NAD 27 and NAD 83 datums. The FAA began the conversion from NAD 27 to NAD 83 on October 15, 1992. The Aeronautical Charting Division verifies all other positions before they are charted.

The FAA conversion from NAD 27 to NAD 83 has a major impact on FAA. All positional data currently used within the NAS will require conversion. The NGS has determined that the horizontal differences between NAD 27 and NAD 83 are as large as 450 meters in Hawaii, 160 meters in Alaska, and 100 meters in the central U.S. The horizontal differences are not uniformly distributed. Vertical datum differences are relatively minor and transformation will be performed after horizontal datum conversion. The new NAD 83 coordinate system will be, for all practical purposes, identical to the WGS 84 employed by DOD for GPS and inertial navigation systems.

Appendix D

Definitions

Accuracy - The degree of conformance between the estimated or measured position and/or velocity of a platform at a given time and its true position or velocity. Radionavigation system accuracy is usually presented as a statistical measure of system error and is specified as:

- Predictable - The accuracy of a radionavigation system's position solution with respect to the charted solution. Both the position solution and the chart must be based upon the same geodetic datum. (Note: Appendix C discusses chart reference systems and the risks inherent in using charts in conjunction with radionavigation systems.)

- Repeatable - The accuracy with which a user can return to a position whose coordinates have been measured at a previous time with the same navigation system.

- Relative - The accuracy with which a user can measure position relative to that of another user of the same navigation system at the same time.

Air Traffic Control (ATC) - A service operated by appropriate authority to promote the safe, orderly, and expeditious flow of air traffic.

Approach Reference Datum - A point at a specified height above the runway centerline and the threshold. The height of the MLS approach reference datum is 15 meters (50 ft). A tolerance of plus 3 meters (10 ft) is permitted.

Area Navigation (RNAV) - A method of navigation that permits aircraft operations on any desired course within the coverage of station-referenced navigation signals or within the limits of self-contained system capability.

ARISTOTELES - European/U.S. gravity mission planned for 1996.

Automatic Dependent Surveillance - A function in which aircraft automatically transmit navigation data derived from onboard navigation systems via a datalink for use by air traffic control.

Availability - The availability of a navigation system is the percentage of time that the services of the system are usable. Availability is an indication of the ability of the system to provide usable service within the specified coverage area. Signal availability is the percentage of time that navigational signals transmitted from external sources are available for use. Availability is a function of both the physical characteristics of the environment and the technical capabilities of the transmitter facilities.

Block II/IIA - The satellites that will form the initial GPS constellation at FOC.

Cellular Triangulation - A method of location determination using the cellular phone system where the control channel signals from a mobile phone are captured by two or more fixed base stations and processed according to an algorithm to determine the location of the mobile receiver.

Circular Error Probable (CEP) - In a circular normal distribution (the magnitudes of the two one-dimensional input errors are equal and the angle of cut is 90^{o}), circular error probable is the radius of the circle containing 50 percent of the individual measurements being made, or the radius of the circle inside of which there is a 50 percent probability of being located.

Coastal Confluence Zone (CCZ) - Harbor entrance to 50 nautical miles offshore or the edge of the continental shelf (100 fathom curve), whichever is greater.

Common-use Systems - Systems used by both civil and military sectors.

Conterminous U.S. - Forty-eight adjoining states and the District of Columbia.

Coordinate Conversion - The act of changing the coordinate values from one system to another; e.g., from geodetic coordinates (latitude and longitude) to Universal Transverse Mercator grid coordinates.

Coordinated Universal Time (UTC) - UTC, an atomic time scale, is the basis for civil time. It is occasionally adjusted by one-second increments to ensure that the difference between the uniform time scale, defined by atomic clocks, does not differ from the earth's rotation by more than 0.9 seconds.

Coverage - The coverage provided by a radionavigation system is that surface area or space volume in which the signals are adequate to permit the user to determine position to a specified level of accuracy. Coverage is influenced by system geometry, signal power levels, receiver sensitivity, atmospheric noise conditions, and other factors which affect signal availability.

Differential - A technique used to improve radionavigation system accuracy by determining positioning error at a known location and subsequently transmitting the determined error, or corrective factors, to users of the same radionavigation system, operating in the same area.

Distance Root Mean Square (drms) - The root-mean-square value of the distances from the true location point of the position fixes in a collection of measurements. As used in this document, 2 drms is the radius of a circle that contains at least 95 percent of all possible fixes that can be obtained with a system at any one place. Actually, the percentage of fixes contained within 2 drms varies between approximately 95.5 percent and 98.2 percent, depending on the degree of ellipticity of the error distribution.

En Route - A phase of navigation covering operations between a point of departure and termination of a mission. For airborne missions the en route phase of navigation has two subcategories, en route domestic and en route oceanic.

En Route Domestic - The phase of flight between departure and arrival terminal phases, with departure and arrival points within the conterminous United States.

En Route Oceanic - The phase of flight between the departure and arrival terminal phases, with an extended flight path over an ocean.

Flight Technical Error (FTE) - The contribution of the pilot in using the presented information to control aircraft position.

Full Operational Capability (FOC) - For GPS, this is defined as the capability that will occur when 24 operational (Block II/IIA) satellites are operating in their assigned orbits and have been tested for military functionality and meet military requirements.

Geocentric - Relative to the Earth as a center, measured from the center of mass of the Earth.

Geodesy - The science related to the determination of the size and shape of the Earth (geoid) by such direct measurements as triangulation, leveling, and gravimetric observations; which determines the external gravitational field of the Earth and, to a limited degree, the internal structure.

Geometric Dilution Of Precision (GDOP) - All geometric factors that degrade the accuracy of position fixes derived from externally-referenced navigation systems.

Inclination - One of the orbital elements (parameters) that specifies the orientation of an orbit. Inclination is the angle between the orbital plane and a reference plane, the plane of the celestial equator for geocentric orbits and the ecliptic for heliocentric orbits.

Initial Operational Capability (IOC) - For GPS, this is defined as the capability that will occur when 24 GPS satellites (Block I/II/IIA) are operating in their assigned orbits and are available for navigation use.

Integrity - Integrity is the ability of a system to provide timely warnings to users when the system should not be used for navigation.

Meaconing - A technique of manipulating radio frequency signals to provide false navigation information.

Nanosecond (ns) - One billionth of a second.

National Airspace System (NAS) - The NAS includes U.S. airspace; air navigation facilities, equipment and services; airports or landing areas; aeronautical charts, information and service; rules, regulations and procedures; technical information; and labor and material used to control and/or manage flight activities in airspace under the jurisdiction of the U.S. System components shared jointly with the military are included.

National Command Authority (NCA) - The NCA is the President or the Secretary of Defense, with the approval of the President. The term NCA is used to signify constitutional authority to direct the Armed Forces in their execution of military action. Both movement of troops and execution of military action must be directed by the NCA; by law, no one else in the chain of command has the authority to take such action.

Nautical Mile (nm) - A unit of distance used principally in navigation. The International Nautical Mile is 1,852 meters long.

Navigation - The process of planning, recording, and controlling the movement of a craft or vehicle from one place to another.

Nonprecision Approach - A standard instrument approach procedure in which no electronic glide slope is provided (e.g., VOR, TACAN, Loran-C, or NDB).

Precise Time - A time requirement accurate to within 10 milliseconds.

Precision Approach - A standard instrument approach procedure using a ground-based system in which an electronic glide slope is provided (e.g., ILS).

Radiodetermination - The determination of position, or the obtaining of information relating to positions, by means of the propagation properties of radio waves.

Radiolocation - Radiodetermination used for purposes other than those of radionavigation.

Radionavigation - The determination of position, or the obtaining of information relating to position, for the purposes of navigation by means of the propagation properties of radio waves.

Reliability - The probability of performing a specified function without failure under given conditions for a specified period of time.

Required Navigation Performance - A statement of the navigation performance accuracy necessary for operation within a defined airspace, including the operating parameters of the navigation systems used within that airspace.

RHO (Ranging Mode) - A mode of operation of a radionavigation system in which the times for the radio signals to travel from each transmitting station to the receiver are measured rather than their differences (as in the hyperbolic mode).

Roadside Beacons - A system using infrared or radio waves to communicate between transceivers placed at roadsides and the in-vehicle transceivers for navigation and route guidance functions.

Sigma - See Standard Deviation.

Spherical Error Probable (SEP) - The radius of a sphere within which there is a 50 percent probability of locating a point or being located. SEP is the three-dimensional analogue of CEP.

Standard Deviation (sigma) - A measure of the dispersion of random errors about the mean value. If a large number of measurements or observations of the same quantity are made, the standard deviation is the square root of the sum of the squares of deviations from the mean value divided by the number of observations less one.

Supplemental Air Navigation System - An approved navigation system that can be used in controlled airspace of the National Airspace System in conjunction with a primary means of navigation.

Surveillance - The observation of an area or space for the purpose of determining the position and movements of craft or vehicles in that area or space.

Survey - The act of making measurements to determine the relative position of points on, above, or beneath the Earth's surface.

Surveying - That branch of applied mathematics which teaches the art of determining accurately the area of any part of the Earth's surface, the lengths and directions of the bounding lines, the contour of the surface, etc., and accurately delineating the whole on a map or chart for a specified datum.

Terminal - A phase of navigation covering operations required to initiate or terminate a planned mission or function at appropriate facilities. For airborne missions, the terminal phase is used to describe airspace in which approach control service or airport traffic control service is provided.

Terminal Area - A general term used to describe airspace in which approach control service or airport traffic control service is provided.

Theta - Bearing or direction to a fixed point to define a line of position.

Time Interval - The duration of a segment of time without reference to where the time interval begins or ends.

TOPEX/POSEIDON - TOPographic EXperiment/POSEIDON mission, a joint U.S./French oceanic mapping mission launched in August 1992.

Universal Transverse Mercator (UTM) Grid - A military grid system based on the Transverse Mercator projection applied to maps of the Earth's surface extending to 84^{o}N and 80^{o}S latitudes.

Vehicle Location Monitoring - A service provided to maintain the orderly and safe movement of platforms or vehicles. It encompasses the systematic observation of airspace, surface and subsurface areas by electronic, visual or other means to locate, identify, and control the movement of platforms or vehicles.

World Geodetic System (WGS) - A consistent set of parameters describing the size and shape of the Earth, the positions of a network of points with respect to the center of mass of the Earth, transformations from major geodetic datums, and the potential of the Earth (usually in terms of harmonic coefficients).

Appendix E

Glossary

The following is a listing of abbreviations for organization names and technical terms used in this plan:

AAA	American Automobile Association
AC	Advisory Circular
ADAM	Airport Datum Monument Program
ADF	Automatic Direction Finder
ADS	Automatic Dependent Surveillance
ADVANCE	Advanced Driver and Vehicle Advisory Navigation Concept
AGL	Above Ground Level
APTS	Advanced Public Transportation System
ARTCC	Air Route Traffic Control Center
ASD/C^3I	Assistant Secretary of Defense for Command, Control, Communications and Intelligence
ATC	Air Traffic Control
ATIS	Advanced Traveler Information System
ATMS	Advanced Traffic Management System

ATMSMN	Air Traffic Management System Material Need
AVC	Automatic Vehicle Classification
AVCS	Advanced Vehicle Control System
AVI	Automatic Vehicle Identification
AVL	Automatic Vehicle Location
AVM	Automatic Vehicle Monitoring
C/A	Coarse/Acquisition
CCW	Coded Continuous Wave
CCZ	Coastal Confluence Zone
CDI	Course Deviation Indicator
CEP	Circular Error Probable
CGS	Civil GPS Service
CIA	Central Intelligence Agency
CIS	Commonwealth of Independent States
CJCS	Chairman, Joint Chiefs of Staff
CNI/NAV	Communications, Navigation & Identification/Navigation
CNS	Communication, Navigation and Surveillance
CONUS	Continental United States
CS	Control Segment
CSE	Course Selection Error
CVO	Commercial Vehicle Operations
CW	Continuous Wave
DGPS	Differential Global Positioning System
DH	Decision Height
DIA	Defense Intelligence Agency
DMA	Defense Mapping Agency
DME	Distance Measuring Equipment

DME/P	Precision Distance Measuring Equipment
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DOP	Dilution of Precision
DOS	Department of State
DOT	Department of Transportation
DR	Dead Reckoning
drms	Distance Root Mean Squared
DSARC	Defense System Acquisition Review Council
DSN	Deep Space Network
DT&E	Development Test & Evaluation
ECBF	Earth Centered Body Fixed
ECCM	Electronic Counter-Countermeasures
ECD	Envelope-to-Cycle Difference
ECEF	Earth Centered Earth Fixed
EHF	Extremely High Frequency
EMI	Electromagnetic Interference
EMP	Electromagnetic Pulse
EOS	Earth Observing System: late 1990s mission
EUVE	Extreme Ultraviolet Explorer
FAA	Federal Aviation Administration
FAATC	Federal Aviation Administration Technical Center
FAF	Final Approach Fix
FAR	Federal Aviation Regulation
FCC	Federal Communications Commission

FHWA	Federal Highway Administration
FL	Flight Level
FM	Frequency Modulation
FMS	Flight Management System
FOC	Full Operational Capability
FRA	Federal Railroad Administration
FRP	Federal Radionavigation Plan
FSD	Full-Scale Development
FTA	Federal Transit Authority
FTE	Flight Technical Error
FTMI	Flight Operations and Air Traffic Management Integration
GA	General Aviation
GBF/DIME	Geographic Base File/Dual Independent Map Encoding
GCA	Ground Control Approach
GDOP	Geometric Dilution of Precision
GHz	Gigahertz
GIB	GPS Integrity Broadcast
GLONASS	Global Navigation Satellite System (CIS system)
GM	General Motors
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPSIC	GPS Information Center
GSFC	Goddard Space Flight Center
GSTDN	Ground Satellite Tracking and Data Network
HDOP	Horizontal Dilution of Precision
HF	High Frequency
HHA	Harbor/Harbor Approach

HHE	Harbor/Harbor Entrance Area
HOV	High-Occupancy Vehicle
HSI	Horizontal Situation Indicator
Hz	Hertz (cycles per second)
IALA	International Association of Lighthouse Authorities
IAP	Improved Accuracy Program
ICAO	International Civil Aviation Organization
ICNS	Integrated Communication, Navigation and Surveillance
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMO	International Maritime Organization
INMARSAT	International Maritime Satellite Organization
INS	Inertial Navigation System
IOC	Initial Operational Capability
IOTC	International Omega Technical Commission
IOT&E	Initial Operational Test & Evaluation
IVHS	Intelligent Vehicle Highway Systems
IVS	International VLBI Satellite
JCS	Joint Chiefs of Staff
JPO	Joint Program Office
JTIDS	Joint Tactical Information Distribution System
JTMLS	Joint Tactical Microwave Landing System
kHz	Kilohertz
LADGPS	Local Area Differential GPS
LF	Low Frequency
LOFF	Loran Flight Following
LOP	Line of Position

Loran	Long-Range Navigation
MAP	Missed Approach Point
MARAD	Maritime Administration
MEP	Midcontinent Expansion Plan
MCS	Master Control Station
MCW	Modulated Carrier Wave
MDA	Minimum Descent Altitude
MF	Medium Frequency
MHz	Megahertz
MIJI	Meaconing, Interference, Jamming, and Intrusion
MLS	Microwave Landing System
mm	Millimeters
MNP	Master Navigation Plan
MNPS	Minimum Navigational Performance Specifications
MOA	Memorandum of Agreement
MOPS	Minimum Operational Performance Standard
MPA/TAC	Maritime Patrol Aircraft/Tactical Support Center
MSK	Minimum Shift Keying
MSS	Mobile Satellite Service
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
NAD	North American Datum
NAG	Naval Astronâutics Ground
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NATO	North Atlantic Treaty Organization

NAVD	North American Vertical Datum
NCA	National Command Authority
NCD	Nautical Charting Division
NDB	Nondirectional Beacon
NGS	National Geodetic Survey
NGVD	National Geodetic Vertical Datum
NHTSA	National Highway Traffic Safety Administration
nm	Nautical Mile
NNSS	Navy Navigation Satellite System (Transit)
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NOTAM	Notice to Airmen
NPN	National Plan for Navigation
ns	Nanosecond
NSF	National Science Foundation
NSWC	Naval Surface Weapon Center
NTIA	National Telecommunications and Information Agency
NWG	Navigation Working Group
O&M	Operation & Maintenance
OAB	Operational Advisory Broadcast
OC	Obstruction Clearance
OCS	Operational Control Segment
OCST	Office of Commercial Space Transportation
OMB	Office of Management and Budget
Omega	Ground-based VLF Navigation System (not an acronym)
ONSCEN	Omega Navigation System Center
OPS/QTV	Operations/Qualification Test Vehicle

OSD	Office of the Secretary of Defense
OTP	Office of Telecommunications Policy
P-code	Pseudorandom Tracking Code
PAR	Precision Approach Radar
PDOP	Position Dilution of Precision
PILOT	Precision Intracoastal Loran Equipment
PLAD	Portable Loran Assist Device
POS/NAV	Positioning and Navigation
PPS	Precise Positioning Service
PPSPO	Precise Positioning Service Program Office
PRC	Pseudorange Corrections
PRN	Pseudo-Random Noise
PSE	Peculiar Support Equipment
PTTI	Precise Time Time Interval
PWSA	Ports and Waterways Safety Act
RACON	Radar Transponder Beacon
RAIM	Receiver Autonomous Integrity Monitoring
RBN	Radiobeacon
R&D	Research & Development
RD&D	Research, Development & Demonstration
RDF	Radio Direction Finder
RDSS	Radiodetermination Satellite Service
R&E	Research & Engineering
R,E&D	Research, Engineering & Development
RF	Radio Frequency
RFI	Radio Frequency Interference
RNAV	Area Navigation (Radio)

RNP	Required Navigation Performance
RRC	Range-Rate Corrections
RSPA	Research and Special Programs Administration
RSS	Root Sum Square
RTA	Required Time-of-Arrival
RTCM	Radio Technical Commission for Maritime Services
RVP	Reference Vertical Profile
RVPT	Reference Vertical Profile with Time
RVR	Runway Visual Range
SA	Selective Availability
SAFI	Semi-Automatic Flight Inspection
SAR	Search and Rescue
SARPS	Standard and Recommended Practices
SC	Special Committee
SEP	Spherical Error Probable
SHF	Super High Frequency
SLSDC	Saint Lawrence Seaway Development Corporation
SPS	Standard Positioning Service
ST	Supplemental Type Certification
STOL	Short Take-Off and Landing
STS	Satellite Test System
SV	Space Vehicle
TACAN	Tactical Air Navigation
TC	Type Certification
TCV	Terminal Configured Vehicle
TD	Time Difference
TDRSS	Tracking and Data Relay Satellite System

TDSS	Time Difference Survey System
TERPS	Terminal Instrument Procedures
TIP	Transit Improvement Program
TIWG	Test Integration Working Group
TMC	Traffic Management Center
TOA	Time of Arrival
TOC	Traffic Operations Center
TONS	TDRSS Onboard Navigation System
Transit	Satellite-based Navigation System (not an acronym)
TravTek	Travel Technology
TRSB	Time Referenced Scanning Beam
TSO	Technical Standard Order
TT&C	Telemetry Tracking and Control
TVOR	Terminal VOR
UE	User Equipment
UHF	Ultra High Frequency
URE	User Range Error
USAF	United States Air Force
U.S.C.	United States Code
USCG	United States Coast Guard
USDA	United States Department of Agriculture
USGS	United States Geological Survey
USNO	United States Naval Observatory
UTC	Coordinated Universal Time
VFR	Visual Flight Rules
VHF	Very High Frequency
VLBI	Very Long Baseline Interferometry

VLF	Very Low Frequency
VMS	Variable Message Sign
VNAV	Vertical Navigation
VOR	Very High Frequency Omnidirectional Range
VORTAC	Collocated VOR and TACAN
VSOPVLBI	Space Observatory Program
VTOL	Vertical Take-Off and Landing
VTS	Vessel Traffic Services
WADGPS	Wide Area Differential GPS
WARC	World Administrative Radio Conference
WGS	World Geodetic System
WIM	Weigh-in-Motion

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