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Federal Radionavigation Plan

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March 1982

Volume IV (of 4)
Radionavigation Research, Engineering and Development

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and
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16. Abstract

The second edition of the Federal Radionavigation Plan (FRP) has been jointly developed by the U. S. Departments of Defense and Transportation to ensure efficient use of resources and full protection of national interests. The plan sets forth the Federal interagency approach to the implementation and operation of radionavigation systems.

Volume IV is a summary of the Federal Radionavigation R,E&D plan together with individual R,E&D plans for military and civil air, land, and marine applications. Open issues, and means for their resolution, are addressed. A key feature is a discussion on how the individual agency R,E&D plans will be coordinated to help assure that all aspects of each system are thoroughly evaluated while avoiding duplication of activities.

Volume I, Radionavigation Plans and Policy, has 80 pages; Volume II, Requirements, has 48 pages; and Volume III, Radionavigation System Characterisitcs, has 47 pages.

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PREFACE

The Departments of Defense and Transportation have developed the second edition of the Federal Radionavigation Plan (FRP) to ensure efficient use of resources and full protection of national interests. The plan sets forth the Federal interagency approach to the implementation and operation of radionavigation systems.

Various existing and planned radionavigation systems used in air, land, and marine navigation are reviewed in terms of user requirements and current status. The FRP contents reflect a response to a unique combination:

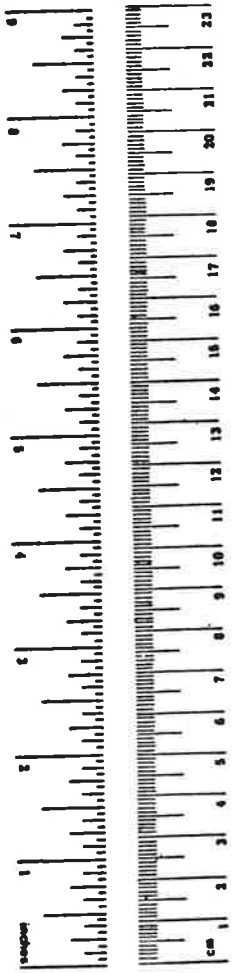
- DOT responsibilities for public safety and transportation economy.
- DOD responsibility for national security in normal and stressed situations.

This plan will be updated annually. The established DOD/DOT interagency management approach will enable continuing control and review of U.S. radionavigation systems. For further explanation of navigational terms used in this plan consult the American Practical Navigator, Volume 2, Publication No. 9, Defense Mapping Agency Hydrographic/Topographic Center, 1981.

METRIC CONVERSION FACTORS

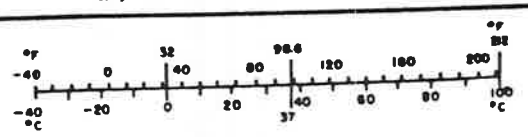
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



FEDERAL RADIONAVIGATION PLAN

VOLUME IV

RADIONAVIGATION RESEARCH, ENGINEERING AND DEVELOPMENT

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VOLUME IV

CHAPTER 1

CIVIL RADIONAVIGATION RESEARCH, ENGINEERING AND DEVELOPMENT SUMMARY

1.0 SUMMARY AND ORGANIZATION

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

The DOT R,E&D activities consist of parallel efforts to develop current and future navigation systems in order to improve existing operations or to identify systems which can replace or supplement those now being used in civil air, marine, or land applications. The parallel efforts are described in two major sections, one covering NAVSTAR 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 navigational requirements.

Although the DOT R,E&D activities for NAVSTAR GPS will proceed in much the same manner as those for other systems, NAVSTAR GPS has been identified separately because of its potentially broad multimodal civil and military application and the consequent need for close cooperation between Federal agencies in its evaluation. Such cooperative effort will minimize duplication of effort and promote maximum productivity from the limited resources available for civil research. The cooperation should also insure DOT participation in the early stages of DOD evaluation and development of NAVSTAR GPS so that benefits can be derived from a continued assessment of DOD's advances in receiver technology and an improved government planning process.

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 factors, 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 man-made 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, nine performance parameters, discussed in Volume III (System Characteristics), have been identified and are listed below:

1. Signal Characteristics

2. Accuracy

    a. Predictable Accuracy

    b. Repeatable Accuracy

    c. Relative Accuracy

3. Availability

4. Coverage

5. Reliability

6. Fix Rate

7. Fix Dimension

8. System Capacity

9. Ambiguity.

As implied above, for DOT, the user's equipment cost is a major consideration if universal civil participation is to be achieved. DOT R,E&D activities will therefore also involve evaluations and simulations of low-cost receiver designs, evaluation of future technologies (in conjunction with NASA) and determination of future requirements for the certification of equipment.

In contrast to DOT, the DOD R,E&D activities mainly address NAVSTAR GPS evaluation by user groups in the Armed Forces which are identified by military mission requirements and national security considerations. For this reason, DOD R,E&D 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, TACAN, VOR, and OMEGA is that these systems are already developed and, therefore, do not require R,E&D. This leaves NAVSTAR GPS as the only military radionavigation system which must be evaluated in order to make a DOD decision on the best mix of Federal radionavigation services.

Although there are some similarities between the DOD and DOT analyses of the nine system performance parameters, DOD military missions place much greater emphasis on security and anti-jam than those for civil systems. Such factors as anti-jam, updating of inertial navigation systems, 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 and benefit issues will be evaluated with the aid of a Federal Navigation Economic Model. This model is being constructed in two parts, one for DOT and one for DOD. Outputs of these models and R,E&D programs will be used to form joint positions related to system mix, phase in/phase out, and transition strategies for "common-user" (joint military/civilian) systems and individual agency positions on non-common-user systems.

The relationship between DOT and DOD R,E&D programs is based on a continuing interchange of operational and technical information to allow preliminary recommendations of the best future mix of radionavigation systems in 1983. DOD R,E&D will be coordinated with DOT R,E&D under the following guidelines:

A. DOT will evaluate the costs and benefits of all radionavigation systems, including NAVSTAR GPS, which meet identified sets of civil user requirements.

B. DOD will provide an annual specification update of NAVSTAR GPS capabilities which are to be made available for civil uses.

C. DOT will provide DOD with the most current information on user requirements which may have a significant impact on the selection or performance specifications of DOD-operated radionavigation systems.

D. Consistent with existing DOD policy, DOD will provide information to DOT on possible low-cost NAVSTAR GPS receiver designs that may be applicable to low-cost civil receiver development.

E. DOT will conduct studies of NAVSTAR GPS performance capabilities using low-cost receiver designs in order to provide an assessment of its applicability to the civil sector.

Prior to 1983, the current DOD NAVSTAR GPS program and the DOD provision of receivers for civil field testing will allow DOT to perform its NAVSTAR GPS R,E&D at both Precise Positioning Service and Standard Positioning Service signal accuracies. DOT can obtain data on the cost-effectiveness of the entire spectrum of NAVSTAR GPS performance in time for presenting NAVSTAR GPS user requirements to DOD. This includes the important effects of denial of the full NAVSTAR GPS signal accuracy to the civil community. Moreover, if DOT selects NAVSTAR GPS for civil applications, the results of the DOT NAVSTAR GPS R,E&D will allow five years for private industry to develop receivers for the civil sector by 1988, when DOD plans to have NAVSTAR GPS fully operational.

After 1983, the DOT R,E&D with the NAVSTAR GPS system will consist of programs which are based on the results of prior R,E&D, the identification of the NAVSTAR GPS accuracy available for civil use, and a continuing evaluation of alternative system configurations which satisfy institutional constraints, e.g., degrees of user cost sharing, international acceptance by the International Civil Aviation Organization (ICAO) and Inter-Governmental Maritime Consultive Organization (IMCO), safety requirements, and equipment standards.

VOLUME IV

CHAPTER 2

CIVIL RADIONAVIGATION RESEARCH, ENGINEERING AND DEVELOPMENT ACTIVITIES

2.0 CIVIL RESEARCH, ENGINEERING AND DEVELOPMENT ACTIVITIES

The specific civil R,E&D activities and their relationships to the Federal Radionavigation Plan and the major Federal decisions on system implementations described in Volume I (Radionavigation Plans and Policy) are outlined below in two parts: 1) NAVSTAR GPS R,E&D, and 2) R,E&D for all existing civil navigation systems which include VOR, TACAN, DME, OMEGA, LORAN-C, and MLS. These two parts 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 the 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 the Research and Special Programs Administration (RSPA) have been identified respectively under civil aviation, marine, and land activities in this document.

2.1 DOT NAVSTAR GPS R,E&D

2.1.1 General

The major DOT marine, air, and land R,E&D activities for NAVSTAR GPS are described as follows:

A. Coast Guard activities focus on establishing the performance of NAVSTAR GPS for maritime navigation. There is a particular focus upon the Harbor Approach and Harbor phases of marine navigation, where augmentation of visual piloting using radio aids to navigation is needed. Three major efforts are involved:

1. An evaluation of the ultimate accuracy potential of NAVSTAR GPS for vessel navigation in the Harbor and Harbor Approach phases will be conducted. The evaluation will establish the technical capability of NAVSTAR GPS in its Standard Positioning Service mode to meet the stringent requirements of these phases.

2. A comparative evaluation of NAVSTAR GPS and existing aids to navigation will be performed. This evaluation will compare the relative cost and performance trade-offs of NAVSTAR GPS with those existing systems (LORAN-C, TRANSIT, OMEGA) for all phases of marine navigation as an input to Federal decisions on the mix of future radionavigation systems.

3. An evaluation of marine receiver designs will be conducted under the guiding principle that marine users choose navigational aids for their vessels based on cost and performance assessments. There are few governmental regulations that influence their decision.

Consequently, development of low-cost receiver designs must precede the use of NAVSTAR GPS by the civil user population. Further, evaluation of receiver designs could ultimately permit the development of minimum performance standards for NAVSTAR GPS receivers.

B. The R,E&D activities of the FAA are equally varied and are larger in scope because of the many different aspects of air operations. They include substantial efforts to evaluate the technical, operational and economic characteristics of future aeronautical navigation systems, including NAVSTAR GPS. The FAA also has underway a comprehensive effort in the development of a low-cost NAVSTAR GPS receiver design to establish minimum acceptable performance. These activities will include an extensive flight test program using single and dual channel receivers to obtain flight data aboard general aviation (GA) aircraft and helicopters. Electromagnetic noise and interference in the NAVSTAR GPS L1 frequency band (1575 MHz) and its impact on receiver operation will be determined during this test program.

C. RSPA land R,E&D activities in connection with NAVSTAR GPS will include review of the results of work in the design of low-cost NAVSTAR GPS receivers and field tests of system performance by the FAA, USCG, and DOD. A simulation and analysis will also be conducted to assist in defining system performance and user equipment cost.

D. The DOT Navigation Economic Model and the FAA, USCG, and other DOT agency analyses and systems will be compared at various stages of the R,E&D program. Other factors which influence each individual agency's R,E&D on NAVSTAR GPS will be assessed. These include FAA evaluations of the ability of NAVSTAR GPS to meet user performance requirements, the preparation of national standards for avionics, and USCG receiver studies and field evaluations.

2.1.2 Civil Aviation

The possibility of using NAVSTAR GPS as the primary navigation aid for the civil aeronautical community is dependent on an investigation and analysis by the FAA of the following major topics:

A. NAVSTAR GPS technical and operational performance capability for the various classes of civil users.

B. The feasibility of low-cost NAVSTAR GPS avionics that is both affordable by the general aviation user and meets all current navigation requirements for two-dimensional area navigation (2D RNAV).

C. Overall cost-effectiveness of NAVSTAR GPS versus alternative system mixes in satisfying the post-1990 aeronautical navigation requirements.

D. International acceptance by ICAO.

A. NAVSTAR GPS Performance Capability for Civil Aviation

Analyses of the basic NAVSTAR GPS performance available to the civil user have been underway by the FAA for several years and are planned to continue. The objective of these studies is to determine the NAVSTAR GPS navigation performance realizable by the civilian fleet, ranging from air carrier to single-pilot, low-cost general aviation aircraft. These studies include a determination of basic accuracy and repeatability and an analysis of errors due to signal variations (such as those caused by various antenna configurations), acquisition and re-acquisition times, multipath, radio frequency interference, satellite geometry, and Flight Technical Errors. Computer simulations of NAVSTAR GPS navigation performance will be performed to assess the suitability of NAVSTAR GPS for en route and terminal navigation and non-precision approach guidance, using DOD error models and test data along with FAA developed information.

Human factors must also be considered since the NAVSTAR GPS system, by definition, is an area navigation system of a type that has not been evaluated. The NAVSTAR GPS system potentially represents a change in procedures and an increase in pilot workload (with an increased possibility for blunders) over the VOR system, particularly for single-pilot IFR operations. In 1980, flight tests were initiated to evaluate the performance of existing NAVSTAR GPS user equipment and software, and also for assessing the noise and radio frequency environment at airports where non-precision approaches are used. The objective of these tests is to determine if the accuracy achievable with NAVSTAR GPS will be adequate to support non-precision approaches to these airports.

B. Low-Cost NAVSTAR GPS Avionics

A major goal of the FAA NAVSTAR GPS R,E&D program is to assess the feasibility of low-cost NAVSTAR GPS avionics with performance and cost levels acceptable to the general aviation user. A 1979 FAA sponsored industry study of NAVSTAR GPS avionics costs for units which might be suitable to general aviation resulted in cost estimates between $3600 and $4000. These must be compared with the cost of the current VOR equipment which is widely used by general aviation and is generally available at unit cost in the vicinity of $1000. An early 1978 FAA cost analysis indicated that NAVSTAR GPS should not be considered as a replacement for VORTAC until avionics were available in the $2500 or lower price range, and until it was certain that such avionics can provide an adequately high level of reliability and failure detection.

An additional factor to be addressed in this area is the current commonality between low-cost communication and low-cost navigation equipment. Because communication and navigation currently share the same VHF frequency band, combined communication/navigation units can be purchased for a small increment over separate equipment. Design studies are currently underway addressing low-cost receivers and antennas. Candidate low-cost antennas have been built and are being tested. While it is believed that cost-effective avionics can be built for large air carrier aircraft, there is still a question of the feasibility of developing low-cost NAVSTAR GPS user equipment of adequate performance for general aviation. The ability to achieve the necessary accuracy for non-precision approaches using low-cost equipment, when the aircraft is in a maneuvering configuration at low altitudes in the terminal area, is of particular concern.

Studies, analyses, and computer simulations involved in answering the above issues will continue. In addition to the studies the FAA has initiated development of an engineering model low-cost set for general aviation and is performing evaluation tests on this low-cost set in the field and in the laboratory.

C. FAA Recommendation

The FAA plans to have sufficient information from the investigation of NAVSTAR GPS by the end of 1982 to make a recommendation on its potential use in air navigation. The FAA will also submit their recommendation to the Secretary of Transportation by the end of 1982 on the best future mix of air radionavigation. The recommendation will be based on two major factors:

1. Acceptable NAVSTAR GPS performance in the non-precision approach and en route terminal phases of air navigation and in accordance with the user requirements specified in Volume II.

2. The cost-effectiveness of NAVSTAR GPS as an alternative to other existing or proposed navigation systems. Cost effectiveness will be assessed for the entire aviation community over all phases of operation. The assessment will utilize the results of an FAA economic model which addresses cost to individual user categories and to the FAA.

If the recommendation is favorable for use of NAVSTAR GPS to provide one or more navigation services, work on a national performance standard for NAVSTAR GPS civil avionics will be initiated in FY 1983. If not, studies will be initiated to investigate new navigation systems or to continue the improvement of existing systems. In either case, the economic factors relating to the international acceptance of alternative systems will be studied in terms of their effect on the FAA and aviation community comparing the overall costs with the government and with the air, marine, and land users.

2.1.3 Civil Marine

The major R,E&D activities of the U.S. Coast Guard related to marine uses of NAVSTAR GPS are low-cost receiver technology studies, user field tests for comparative assessment of NAVSTAR GPS versus alternative aids to navigation, and assessment of Standard Positioning Service performance potential. The objective of the marine program is to acquire a sufficient data base to determine those missions of the marine fleet for which the NAVSTAR GPS system can satisfy the navigation performance requirements. Issues important to the use of NAVSTAR GPS for marine navigation include:

1. ACCURACY: Can it serve only as a one-quarter nautical mile navigator suitable for en route navigation through the U.S. coastal area? Can it provide the higher accuracies needed by commercial fishing and offshore industry? Can it give the accuracy required for Harbor Approach and Harbor Navigation?

2. TECHNICAL AND ECONOMIC: What are the technical and economic issues that dominate a NAVSTAR GPS receiver designed for civil marine use? What is a realistic estimate of receiver cost, and what technological factors might significantly alter this estimate? What receiver performance and cost trade-offs are feasible to develop NAVSTAR GPS equipment acceptable for: (1) commercial ships over 1600 gross tons, and (2) smaller ships or tugs with barges?

3. COMPARISON WITH MARINE RADIONAVIGATION SYSTEMS: Comparison of NAVSTAR GPS with current marine radionavigation systems is required. This comparison must be made with regard to navigational accuracy and repeatability, operational features and human factors considerations. Various missions must be considered, as well as a range of vessels from supertankers to Coast Guard cutters. This work must also consider the effect on electronics design and installation of the peculiarities of operations in protected waters and on the open ocean.

4. OPERATIONAL TEST RESULTS: What are the practical results of testing NAVSTAR GPS receivers in the marine environment, such as: installation criticalities, marine and harbor environment peculiarities (RFI/multipath), and the suitability of performance and display for typical operations (e.g., fishing)?

The Coast Guard plans to have completed its initial studies and tests for the Harbor and Harbor Approach phases of navigation by the end of 1982. If NAVSTAR GPS is found to have potential use in these phases, the extent to which that potential may be realized will depend upon the eventual decision concerning the accuracy of NAVSTAR GPS service that will be made available for civil use. If feasible, within constraints imposed upon NAVSTAR GPS accuracy, additional Coast Guard R,E&D may be indicated, as follows:

1. Develop low-cost NAVSTAR GPS receivers for marine use, specifying modifications to basic FAA low-cost receiver designs, to meet requirments for precise navigation in Harbor Approach and Harbor Navigation.

2. Evaluate the potential of NAVSTAR GPS for navigation on inland waterways.

3. Define the role of harbor surveillance systems and alternative navigation systems as a backup for NAVSTAR GPS where requirements exist for additional reliability, special vessel activities, or during emergencies.

If NAVSTAR GPS does not satisfy the performance and cost-effectiveness requirements for the Harbor and Harbor Approach phases, studies will be initiated in 1983 to evaluate the increased use of alternative systems in these phases. Among these are harbor surveillance systems, improved aids to navigation, and Differential LORAN-C with retransmissions from shore-based monitor stations.

Regardless of the results of the initial NAVSTAR GPS R,E&D, cost and benefit information for the Coast Guard and maritime users will be provided in 1982 to the DOT Navigation Economic Model. After 1982, future NAVSTAR GPS performance

and cost improvements will be included in the model to provide an annual assessment of alternative systems.

The near-term U.S. Coast Guard R,E&D program has the following elements:

A. Receiver Technology Studies

The initial effort in the study of NAVSTAR GPS receiver technology is directed toward:

1. A thorough understanding of the receiver design characteristics required for NAVSTAR GPS system operation in the marine environment.

2. An analysis of the NAVSTAR GPS system identifying all performance factors and error sources, and assessing the effect of alternative receiver designs on system performance.

3. An in-depth survey of current and projected technology for all components of the NAVSTAR GPS receiver system.

Other USCG studies and developments included in this part of the program are not finalized beyond the initial phase identified above. Hardware developments of critical receiver subsystems and components may also be pursued. However, the specific efforts of the future will depend on the results of the present research and the adequacy of the resultant information in predicting the performance of NAVSTAR GPS receivers in an operational marine environment. A receiver study report will be completed in 1982 and become an input for the formulation of a Coast Guard recommendation on NAVSTAR GPS for marine applications.

B. Marine User Field Tests

These tests will be a cooperative program involving the Coast Guard and MARAD in which MARAD provides the NAVSTAR GPS receiver system (a DOD procured "low-cost" receiver) and the Coast Guard provides the data collection system and acquires the data for use by both agencies. The objectives of these tests are: (1) to assess the performance characteristics of a NAVSTAR GPS receiver operating in typical marine environments, and (2) to compare the accuracy of NAVSTAR GPS relative to other aids to navigation such as LORAN-C and OMEGA/TRANSIT in a series of field tests.

In May 1979, the Coast Guard began static tests and familiarization training using a single channel sequential receiver. In April 1980, shipboard evaluation testing was initiated on the Texas A&M University oceanographic vessel which traveled throughout the Caribbean and along the Atlantic Coast. The shipboard evaluation was completed in December 1981. The results of these tests will be presented in a preliminary report on this phase of the Coast Guard program.

Beginning in 1982 and continuing for approximately two years, one or more receivers will be used for testing on Coast Guard or commercial vessels. Software and hardware modifications may be made to the receiver to optimize it for marine use. A final report on NAVSTAR GPS receiver field evaluation will be issued in

1983 with these results being an input into the Coast Guard recommendation on future navigation systems.

C. Assessment of Standard Positioning Service (SPS) Performance Potential

The objective of this effort is to determine the maximum accuracy obtainable with the NAVSTAR GPS Standard Positioning Service (SPS). A dual channel receiver modified to process only the SPS signals will be used in these tests to measure those errors that are irreducible, e.g., propagation variations, RFI, and multipath. This study includes the development of analysis software in 1979-80 and tests running from late 1980 through 1981. Concurrent with this study, data will be acquired from the DOD and FAA tests and reviewed for additional SPS performance and error information.

The information gained from this study is expected to indicate if the NAVSTAR GPS SPS is potentially accurate enough for Harbor Approach and Harbor Navigation or if it is useful only for less accurate navigation in the open sea. This important finding will be a significant factor in the direction of the follow-on Coast Guard NAVSTAR GPS R,E&D activities and also in the Coast Guard recommendation to DOT on the marine applications for NAVSTAR GPS.

D. Coast Guard Recommendation

Coast Guard NAVSTAR GPS R,E&D activities will lead to a 1983 Coast Guard recommendation to the Secretary of Transportation on the best future mix of radionavigation systems for marine users. The recommendation will be based on a comparison of the performance of NAVSTAR GPS to LORAN-C, TRANSIT, and OMEGA, and the results of studies of NAVSTAR GPS receiver costs and SPS channel performance. The Coast Guard will also monitor the results of NASA low-cost receiver studies, FAA NAVSTAR GPS R,E&D, and DOD progress before making its recommendation.

2.1.4 Civil Land

A. NAVSTAR GPS R,E&D

In contrast to the case with the air and marine communities, most land applications of NAVSTAR GPS are relatively new and do not fall under the jurisdiction of a single agency (such as the FAA or the U.S. Coast Guard). For this reason, coordination and identification of user requirements and applications are being performed by the Research and Special Programs Administration (RSPA). The specific task areas of the NAVSTAR GPS Land R,E&D program are described as follows:

1. NAVSTAR GPS Land Analysis and Simulation: An identification of the NAVSTAR GPS receiver performance requirements which are unique to land vehicles and their environments. The identification will include design modifications which may be required of current NAVSTAR GPS receiver equipment for use in land vehicle installations.

2. Land User Equipment Cost: This activity involves a review of the FAA, Coast Guard, NASA, and industry NAVSTAR GPS low-cost receiver design studies.

3. Land Use Cost and Benefit Evaluation: This will be accomplished through the DOT Navigation Economic Model. The Land portion of the DOT Navigation Economic Model will be used to generate NAVSTAR GPS user system implementation and operating costs, user group benefits and cost, and predictions on user equipment purchases, as well as system costs to the government.

B. RSPA Recommendations

In 1982, the RSPA R,E&D efforts will focus on the recommendation to the Secretary of Transportation on the applicability of NAVSTAR GPS to land use. The recommendation will rely on the system performance evaluation and cost study results of the land R,E&D program.

This recommendation will be based on a comparative analysis of the relative attributes of NAVSTAR GPS and existing radionavigation systems applicable to land use.

2.2 DOT R,E&D FOR CIVIL NAVIGATION

2.2.1 General

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

A. Air

The FAA will continue its ongoing modernization and maintenance/sustaining engineering of VOR/DME and TACAN in order to reduce the O&M costs and improve the performance of ground-based air navigation aids in the United States and U.S. territories.

The FAA will continue to monitor the performance of OMEGA on oceanic air routes and the use of OMEGA and LORAN-C as supplements to VOR/DME.

The FAA will evaluate LORAN-C and NAVSTAR GPS as supplements to VOR/DME and possible replacement candidates for VOR/DME. These evaluations will involve field tests, low-cost user set design studies, analysis of accuracy, coverage, reliability, integrity, and operational suitability which includes an assessment of impacts on pilot workload, and blunder potential. In addition Minimum Performance Standards and Certification Criteria including Flight Inspection Requirements for both LORAN-C and NAVSTAR GPS must be established. Also institutional issues, e.g., ICAO acceptance, signal availability, signal degradation, user charges, etc, and economic issues will be assessed. The developmental activities for MLS and ILS will continue.

B. Marine

The DOT marine R,E&D for existing systems is composed of seven U.S. Coast Guard programs and one program being conducted by the St. Lawrence Seaway Development Corporation (SLSDC). These programs can be grouped by agency:

1. Coast Guard advanced R,E&D projects focus on system enhancements and improved techniques for the Harbor and Harbor Approach phases of operation. These include LORAN-C projects on chain enhancements, signal analysis, survey techniques, and projects on shipboard display systems, applicable for NAVSTAR GPS, LORAN-C or other systems and NAVSTAR GPS applications.

2. The SLSDC has an ongoing program, coordinated with the Canadian Seaway Authority and the U.S. and Canadian Coast Guards, aimed at the identification and field testing of one or more precise all-weather navigation systems for the Seaway system, followed by selection and operational implementation. In addition to the obvious safety benefits, the system must provide significant increases in system capacity and attendant reductions in vessel transit times by reducing the frequency and duration of periods when vessel movements are halted due to removal of floating, lighted navigation aids and/or insufficient visibility.

C. Land

As navigation benefits to land users become apparent, and as receiver equipment costs decrease due to technology improvements and expanding user markets, adaptation of the existing navigation systems to serve multimodal civil users may prove cost-effective. RSPA R,E&D activities are planned, therefore, to investigate the potential benefits of radiolocation to both public and private land users, e.g., truck fleets, rail vehicles, buses, and police and emergency vehicles.

The Departments of Energy, Agriculture, Interior, Commerce, Health, and Human Services, and agencies involved in security and law enforcement, as well as a number of states, have conducted or planned projects involving land applications of a radionavigation capability. For example, DOE has investigated the application of NAVSTAR GPS to monitoring the position of vehicles carrying hazardous materials.

These investigations have resulted in identifying land users, and preliminary estimates of users requirements and needs relative to land radiolocation system parameters.

A Land Location, R,E&D program is in progress to obtain data on NAVSTAR GPS signal margins, radio frequency interference, and the effect of signal blockage and multipath on NAVSTAR GPS user equipment performance in the land environment, and on NAVSTAR GPS user equipment performance and cost. The results of this effort will be used by RSPA in developing its recommendations on the future mix of radionavigation systems. Relative attributes of existing systems will be compared to new planned systems such as NAVSTAR GPS.

2.2.2 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. Activities described here have two specific goals: (1) to provide information that will support the FAA recommendation on the future mix of navigation aids, and (2) to assist in the near-term integration of existing aids into the National Airspace System (NAS) as supplements to VOR-DME. The activities will be presented in six categories: (1) Oceanic and Domestic En Route, (2) Non-Precision Approach, (3) Remote Areas, (4) Helicopter IFR Operations, (5) RNAV and (6) Precision Approach and Landing.

1. Oceanic and Domestic En Route

The FAA has approved the use of OMEGA on oceanic routes as a sole means of navigation and when used in conjunction with Doppler or inertial systems. 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. At present LORAN-C is not used extensively on oceanic routes nor in inland domestic areas; the greatest application is by helicopters offshore. However, recent approval has been granted for LORAN-C use as an en route aid in the Continental United States.

To enhance knowledge of OMEGA signal quality along major international routes on a day-to-day basis, an OMEGA Data Bank was established. Digital recorders have been loaned by the FAA to international air carriers with OMEGA equipped aircraft. Data are automatically recorded on scheduled flights and are then analyzed and reported by the FAA Technical Center. Eleven organizations are contributing data to the Data Bank.

Notices-to-Airmen (NOTAMs) are issued for OMEGA and LORAN-C by the FAA as information is received from the Coast Guard. There are no NOTAMs issued for VLF communication signals used for navigation. To examine methods by which FAA could develop NOTAM information on a more real-time basis, monitor systems for OMEGA/VLF and LORAN-C signals have been developed and are being evaluated. Both monitors are self-contained and automatic; they generate operational advisories based on signal deviations from the normal conditions at their locations. If implemented as an operational system such monitors would be interconnected as a network to provide wide area information for use by air traffic personnel and by pilots for flight planning.

A study for cost comparison purposes is being made of the number and locations of additional LORAN-C stations needed in the 48 contiguous states to provide complete and redundant signal coverage. The current work will enlarge on a prior study, that dealt with the same subject, by considering potential problems from cross-rate interference, and by using improved computer programs for signal coverage analysis.

Studies will be conducted of the possible impact on FAA operations and services if either LORAN-C or NAVSTAR GPS is selected as the primary air navigation aid of the future. With an increase in use of any wide area system, such as LORAN-C or NAVSTAR GPS, user demand for random routing will expand. Accordingly air

traffic control procedures will change and a mixture of RNAV and non-RNAV aircraft in common airspace will have to be safely controlled through a transition period of several years, and charting and advisory services will change.

OMEGA and LORAN-C are systems in which signals with amplitudes less than ambient noise levels are used for navigation. Noise caused on aircraft by precipitation can overwhelm the desired signals if measures are not taken to reduce such noise. A study, with flight tests, is being conducted on methods by which aircraft electrical noise can be reduced. Effects of nearby lightning are also being examined.

With the increasing use of several navigation aids in common airspace, it has become necessary to consider possible effects resulting from the different error characteristics of these systems. Existing error data will be assembled and areas that lack adequate information will be noted. Additional data will then be collected to make a more complete picture. Since it is impractical to examine all interactions of interest among systems by actual testing, fast-time simulations with system error models may be developed and used to evaluate various operational situations.

2. Non-Precision Approach

Performance requirements for navigation aids are most stringent when used for non-precision approaches. Available LORAN-C receivers will be flight tested and the results compared with established approach accuracy requirements. Measurements of navigation accuracy during approaches will be made with a multiple-DME system developed by the FAA for that purpose. A program will be conducted to examine LORAN-C signal stability along approach paths to several selected airports; daily and seasonal variations and any other instabilities found will be analyzed to determine adequacy. A signal simulator will be developed to permit controlled tests of LORAN-C avionics in approach and other modes of flight. An evaluation of differential OMEGA as a non-precision approach aid has been completed in Alaska; results showed significant merit in the concept. FAA NAVSTAR GPS flight tests will evaluate the suitability of NAVSTAR GPS for non-precision approaches. However, the use of NAVSTAR GPS signals with degraded accuracy for non-precision approaches will be evaluated for its suitability using real time simulation.

3. Remote Areas (Including Off-shore)

While the present 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 NAVSTAR GPS, LORAN-C, OMEGA, OMEGA/VLF and Differential OMEGA. Currently, OMEGA/VLF and LORAN-C in specific areas are approved as a supplement to VOR/DME.

4. Helicopter IFR Operations

The 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 navaid systems. The examination of LORAN-C and NAVSTAR GPS for use in en route, terminal, and approach phases of operation are being emphasized. The feasibility of enhancing ADF/NDB systems and the suitability of military doppler navigators for civil helicopter use are also being explored. Approach capabilities using Airborne Radar Approach (ARA) 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 ARA, 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 navaids, 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 (LOFF), 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.

The 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 National Airspace System.

The FAA flight test program utilizes:

a. Bell 206L, Sikorsky S-76 and CH-53 helicopters operated by the FAA.

b. Other types of helicopters through cooperative efforts with the U.S. Army, U.S. Coast Guard, NASA, and other Federal agencies as well as with industry; e.g., UH-1, S-61, Bell 212, etc.

5. Area Navigation (RNAV)

The FAA has implemented area navigation (RNAV) routes. The objective of the RNAV program is to support integration of RNAV, in an evolutionary manner, into the National Airspace System. At present the main objective is associated with development of avionics standards. This FAA activity will be closely coordinated with the aeronautical industry. The end products of the RNAV program are the development of minimum performance standards for avionics prepared with the coordination of industry.

The advent of latitude/longitude grid navigation systems such as LORAN-C and NAVSTAR GPS has increased awareness of the pilot workload, pilot blunder and

system integration problems involved in using latitude/longitude RNAV equipment. RNAV procedures with such systems may differ from RNAV based on the VOR/DME system.

Typical LORAN-C equipment will be installed in a simulation facility to study problems related to pilot/controller workload, real-time coordination, and minimization of Flight Technical Error for various civil air user groups, e.g., VFR through high density IFR. R,E&D will also be devoted to development of RNAV charting concepts and waypoint definition.

6. Precision Approach and Landing

At the ICAO meeting in April 1978, the member states agreed that the instrument landing system (ILS) would be operated at international airports until at least 1995. ICAO also decided on a specific microwave landing system (MLS) technique to be used as the international standard. While the ILS system currently in use has an excellent safety record, the MLS is being proposed as a replacement because the siting and installation problems are much less pronounced, which makes the MLS usable at more locations and with lower installation costs than ILS. Also, there is a limit on the number of ILS facilities that can be installed in a small geographical area because of radio spectrum crowding problems. The cost impacts of MLS dictate careful and continued consultation and cooperation with both domestic and international interests.

Since 1978, ICAO has proceeded with development of the Standards and Recommended Practices (SARPS) for MLS for inclusion in Annex 10. At the ICAO meeting in April 1981, the SARPS for the MLS angle guidance and data were approved along with the initial ICAO ILS/MLS Transition Plan. Work is continuing on development of SARPS for the precision DME (DME/P) associated with the MLS. These SARPS are expected to be approved by ICAO during 1983.

B. Civil Marine

The plans of the USCG for improving marine navigation systems, which serve the civil maritime user, are described below. The discussions are presented in terms of the phases of marine navigation as follows: Oceanic, Coastal, Harbor Approach, Harbor, and Inland Waterways.

1. Oceanic

The USCG is in the process of validating the coverage and accuracy of the OMEGA system as an oceanic aid to navigation for marine and aviation users. The OMEGA system provides general purpose en route navigation service worldwide for marine and air users from a network of eight stations (the eighth station, in Australia, will be operational in late 1982).

The Coast Guard will promulgate progressively, on a regional basis, the results of a worldwide general assessment of the coverage and accuracy of the OMEGA system. As each given geographic area is thus validated, the OMEGA system users will be advised concerning operational limitations as appropriate. The OMEGA system cannot be declared fully operational, worldwide, until the eighth station is in operation, and the accuracy and coverage is measured and validated. This is

expected to take place sometime in 1985. Operation and validation of the OMEGA navigation system, and the progressive improvement of corrections for OMEGA propagation errors, are the major Coast Guard activities associated with oceanic navigation.

2. Coastal

The primary system in use for U.S. coastal marine navigation is the LORAN-C system. OMEGA is the designated LORAN-A replacement for ocean navigation. A national implementation plan was initiated to provide LORAN-C coverage in the coastal area of the contiguous 48 states, Southern Alaska, and in the Great Lakes. New station implementation and reconfiguration are complete. This plan adds 12 U.S. stations and 2 Canadian stations to the network of stations built originally for the DOD throughout much of the Northern Hemisphere.

Extensions of LORAN-C coverage to the eastern part of Hawaii, and the Alaskan North Slope, are now being considered by the Coast Guard. Decisions will be made by 1983 and will involve an assessment of Federal and user costs and benefits, user requirements, and the extent of geographical coverage to be provided by various LORAN-C configurations and transmitter power levels. The decision to provide additional coverage for the Alaskan North Slope depends on both air and marine navigation requirements. A review of the maritime requirements is scheduled for 1982. In the meantime, the FAA is evaluating LORAN-C, OMEGA/Differential OMEGA, and VOR/DME for air navigation in this region.

The USCG operates a network of marine radiobeacons to provide the primary radio aid to navigation for many smaller vessels and boats. The radiobeacons are also used by many large ships for homing and harbor approach. In the U.S., there are 196 radiobeacons today, and 30 more are being established to meet the increasing use by small vessels. The current improvement program will replace 48 different types of obsolete, unreliable radiobeacon equipment with a standardized design of solid state transmitting equipment which will reduce annual operations and maintenance costs.

3. Harbor and Harbor Approach and Inland Waterways

There are a number of projects to investigate the use of LORAN-C for other than offshore marine navigation in the coastal area. The retransmission of LORAN-C coordinates is being examined for use in surveillance and tracking of marine vessels. The Coast Guard is developing LORAN-C for use as a precision navigation system in Harbor Approach and Harbor areas. A mini-LORAN-C chain was installed in the St. Mary's River in 1976 and was removed in 1981. The results of this experiment are being evaluated to establish the capabilities of a short baseline LORAN-C chain configured specifically for precision navigation in a localized harbor area.

The Saint Lawrence Seaway Development Corporation (SLSDC) has undertaken a program, in cooperation with the Canadian Seaway Authority and the U.S. and Canadian Coast Guards, to provide a precise all-weather navigation system for the Seaway system. The program is expected to result in a three- to four-fold increase in system capacity and similar decreases in vessel transit times during those periods at the beginning and end of the shipping season when conventional, lighted,

floating aids to navigation have been removed because of ice. Improvements in system safety and capacity and transit time improvements during periods of low-visibility are also expected. Under the leadership of an international Seaway/Coast Guard Steering Committee the program will comprise:

a. Establishment of operational requirements such as accuracy, reliability, and minimum allowable visibility for the system.

b. Review of available electronic systems with the potential for application to the Seaway problem.

c. Selection of candidate systems, which may comprise one or more electronic positioning systems, integrated with conventional navigation aids.

d. Field testing of selected candidate systems. A limited demonstration of the PILOT and PLAD, LORAN-C based systems developed by the U.S. Coast Guard is being conducted.

From the results of the field testing, the SLSDC, in consultation with its Canadian counterpart, will assess the costs and benefits of candidate systems. The decision to proceed with an operational system will depend on the results of the field tests and the cost benefit analysis.

2.3 DOT DEVELOPMENT OF A RADIONAVIGATION ECONOMIC PLANNING MODEL

2.3.1 General

The Department of Transportation (DOT) is developing a radionavigation economic planning model which will be used by the DOT Navigation Council and the DOT Navigation Working Group and by the individual DOT administrations in evaluating alternative radionavigation system mixes. The model is being jointly developed by the Research and Special Programs Administration (RSPA), the Federal Aviation Administration (FAA), and the Coast Guard (USCG) and is scheduled to be completed in the summer of 1982. At that time the model will become operational at the Transportation Systems Center (TSC) and at the FAA, Washington, D.C. and will be available for use by the DOT Navigation Council and DOT Navigation Working Group as well as by the DOT administrations.

2.3.2 Model Description

The model is designed to consider various radionavigation system mix scenarios selected by the model user and to provide cost and benefit data associated with the selected scenario. The model will consider the costs, benefits and purchase decisions of each individual navigation user group categorized by mode (air, marine, land), ownership, type of use, type of vehicle, size of vehicle and operating location. The model will predict future populations for each user group and determine what type of radionavigation equipment each user would most likely purchase in any given year. Equipment costs and purchase decisions will be determined based on such factors as: equipment complexity, production volume, production technology rates, inflation rates, and discount rates. Benefits will be

calculated for selected individual user groups and will be sensitive to the parameters of the user equipment and the navigation systems under consideration. Such parameters will include accuracy, coverage, reliability, fix rate and ease of use. For each radionavigation system mix scenario considered the model will provide as an output user and system operator costs as well as selected user benefits.

2.4 NAVSTAR GPS R,E&D Planned by the NASA Office of Aeronautics and Space Technology (OAST)

The currently planned OAST activities are largely associated with the civil application to NAVSTAR GPS and involve both space and aeronautics R,E&D. The space activities are focused on providing accurate onboard time and position which either NAVSTAR GPS or TDRSS might provide. The aeronautics tasks involve antenna-siting investigations and low-cost receiver design concepts for civil aircraft navigation.

While OAST has no requirements per se, survey of potential space users indicates that most scientific and applications missions require position accuracy no greater than 50 meters. However, to perform onboard image registration, position accuracies of 5 to 10 meters will be required.

A detailed outline of space and aeronautics activities is as follows:

2.4.1. Space R,E&D

As part of the NASA End-to-End Data System (NEEDS) program, OAST is developing techniques and procedures to provide accurate onboard orbit, altitude, and time; and defining components necessary for onboard imaging registration capability for earth-pointing imaging spacecraft such as LANDSAT-D. This effort includes the establishment of a simulation laboratory where applicable onboard orbit and attitude determination and control algorithms can be developed and rigorously tested using minicomputers and a group of microprocessors that generate the appropriate sensor data in parallel. This ground breadboard system will be supplied actual SPS and PPS NAVSTAR GPS data.

2.4.2. Aeronautics R,E&D

OAST is in the process of discussions with the FAA on a joint program which could lead to an augmentation of current plans over the next several years. These added tasks might entail, for example, cooperative experimentation and system demonstrations using FAATC facilities, and, if and when they materialize, the current plan will be updated and the information forwarded.

Efforts are limited to antenna-siting investigations. The antenna task will establish siting requirements for various types of civil aircraft and will involve laboratory experiments with about two aircraft models per year.

VOLUME IV

CHAPTER 3

DOD RADIONAVIGATION RESEARCH, ENGINEERING AND DEVELOPMENT

3.0 DOD R,E&D ACTIVITIES

DOD R,E&D activities described in this volume concentrate only on those radionavigation systems that have clearly defined common user (civil/military) characteristics. Common user systems include those which emit signals in space which are available to anyone using properly designed equipment obtainable without restrictions. Further, these systems are available on a full-time basis, and are not dependent on tactical military operations. At this point in time, common-user systems having active R,E&D programs are NAVSTAR GPS, TRANSIT, and MLS.

3.1 Objectives

The DOD R,E&D plan for radionavigation systems describes only engineering development activities affecting common user radionavigation systems. These activities are primarily driven by the mission requirements of the commanders of the Unified and Specified Commands and the Military Departments/Services. These mission requirements normally include accurate navigation within the continental United States, in oceanic areas, and in overseas theaters. Other requirements include security, resistance to meaconing, interference, jamming and intrusion and saturation limit and world-wide coverage. These radionavigation requirements form the basis for the overall DOD R,E&D program which impacts a wide range of equipments, some of which have common user characteritics.

3.2 Responsibilities

DOD and its component elements are responsible for developing, testing, evaluating, operating, and maintaining aids to navigation and user equipment for military missions. DOD is also responsible for assuring that military vehicles, operating in consonance with civilian vehicles, have the required navigation capabilities to operate in a safe and expeditious manner.

3.3 R,E&D Effort

3.3.1 NAVSTAR GPS

3.3.1.1 Background

Since the early 1960's both the Air Force and Navy have actively pursued the idea that navigation and positioning could best be performed using signals transmitted from space vehicles. The impetus for developing a space-based system was the desire for an accurate, continuous, all-weather, global radionavigation system that could meet the diverse needs of a broad spectrum of both military and civil users. Additionally, considerable cost benefits could be realized by reducing the proliferation of specialized navigation and positioning systems that are limited in coverage and capabilities.

The U.S. Navy has sponsored two navigation satellite programs, TRANSIT and TIMATION. TRANSIT became operational in 1964 and was made available to non-military users in 1967. TIMATION was a high-technology program to advance the state of the art of two-dimensional navigation. The Air Force concurrently conducted preliminary concept formulations and system design studies for a high accuracy three-dimension system called 621B.

In April 1973 the Deputy Secretary of Defense issued a memorandum designating the Air Force as the lead Service to evaluate the concepts of all previous systems and to mold those concepts into an acceptable, comprehensive, and cohesive all-weather satellite navigation system program. A system concept designated NAVSTAR GPS emerged as a combination of the best features of the previous navigation satellite concepts.

NAVSTAR GPS, a major DOD R,E&D project, is presently in the Full Scale Development (FSD) phase. The system, when fully operational and certified for use in controlled airspace, will replace DOD use of LORAN-C, OMEGA, TACAN, TRANSIT, VOR/DME and other military and common user radionavigation systems. Civil applications of NAVSTAR GPS are under study by the Department of Transportation. It is current DOD policy to make the system continuously available on an international basis for civil, commercial and other use at the highest level of accuracy consistent with national security interests.

3.3.1.2 Description

NAVSTAR GPS is a space-based radio positioning, navigation and time-transfer system that operates on two L-band frequencies of 1575.42 MHz (L1), and 1227.6 MHz (L2). NAVSTAR GPS is composed of three major segments: Space, Control and User.

A. Space Segment

The Space Segment, when fully operational in 1988, will be composed of 18 satellites, with possible expansion to a 24-satellite constellation at some future date. The 18-satellite constellation will consist of six evenly spaced orbital planes with three satellites in each. The satellites will be in a 12 hour circular orbit of 20,200 km (10,900 nm). Precise spacing in each plane will ensure a minimum of four satellites in view to a user at all times (5^{o} masking angle). World-wide three-dimensional positioning accuracy is provided by both the Precise Positioning Service (PPS) and the Standard Positioning Service (SPS). The Precise Positioning Service (PPS) will provide predictable and repeatable accuracies of 18.1 m (2 drms) horizontally and 29.7 m (2 sigma) vertically and a relative accuracy of 10 m (2 drms) horizontally and 16.4 m (2 sigma) vertically. PPS also provides precise time and time transfer of 35 nanoseconds with a minimum offset of 120 nanoseconds from UTC. The Standard Positioning Service (SPS) will provide predictable and repeatable accuracies of 500 m (2 drms) horizontally and 820 m (2 sigma) vertically and a relative accuracy of 10 m (2 drms) horizontally and 16.4 m (2 sigma) vertically. The above accuracies will be available anywhere on the surface of the earth and to an altitude of 600 nm. Each satellite will transmit both the PPS and SPS signals to properly equipped users. Sufficient spare satellites will be maintained in orbit to ensure an operational constellation of 18 satellites.

B. Control Segment

The Control Segment includes a number of monitor stations and ground antennas located at various fixed sites around the world. The monitor stations will use NAVSTAR GPS receivers to passively track all satellites in view, accumulate orbital data and transmit information back to the Master Control Station (MCS) for processing. After processing, corrections will be uploaded to each satellite to correct the information in the navigation satellite data message so that user information received from the satellite is current and accurate.

C. User Segment

The User Segment will consist of user equipment, test instrumentation and peculiar support equipment. The user equipment, utilizing data transmitted by the satellites, will derive navigation and time information for use in a number of different types of vehicles.

3.3.1.3 System Development Phases

The NAVSTAR GPS program was divided into three discrete phases: Concept Validation (Phase I); Full Scale Development (Phase II); and Production and Deployment (Phase III).

A. Phase I (Concept Validation) 1973-79

During this phase a number of test satellites were launched to provide a constellation to permit testing of conceptual user equipment and prove the viability of the overall system concept. The constellation provided up to four hours per day of accurate navigation and timing signals over a western test site. During this phase four contractors were selected to develop conceptual user equipment for validation and testing.

B. Phase II (Full Scale Development) 1979-84

Phase II, currently underway, will verify the operational effectiveness of the GPS concept for both military and civilian users. Two of four contractors, previously selected to develop conceptual user equipment, were chosen to develop prototype user equipment and appropriate support hardware and software to be installed on a variety of test vehicles for Development Test & Evaluation/Initial Operational Test and Evaluation (DT&E/IOT&E) testing. The results of the DT&E/IOT&E testing, cost, production and support considerations, will lead to selection of one prime contractor for Phase III production contracts for user equipment. The DT&E/IOT&E testing is now scheduled for completion in 1983 with a production contract for user equipment scheduled for 1984. Throughout Phase II, satellites will be replenished on an as needed basis so that five satellites will be available during all of the testing of prototype user equipment. To achieve an operational 18 satellite constellation in 1988, a satellite production contract is planned to be awarded during 1983 prior to the Phase III segment of the program.

The NAVSTAR GPS Initial Control System at Vandenberg Air Force Base is being upgraded to support the test constellation until the new Master Control Station

(MCS) becomes operational. Work began at Vandenberg in July 1981 and is expected to be completed by June 1982.

C. Phase III (Production and Deployment) 1984

Production of user equipment is scheduled to begin in 1984 with installations starting in 1985 and continuing for at least ten years. Additional production satellites will be produced during this phase and be launched from the space shuttle during the 1985-88 time frame to complete the operational constellation. The new NAVSTAR Master Control Station (MCS) will become fully operational by 1987, to take control of the NAVSTAR GPS system from the Initial Control Station at Vandenberg.

3.3.1.4 Test Planning

During Phase II there are certain questions and areas of risk which must be resolved. It must be determined if NAVSTAR GPS user equipment can (1) be designed and built to integrate efficiently into a wide range of vehicles, (2) achieve the level of immunity to jamming required by the military missions at affordable cost; and (3) demonstrate acceptable values for a reliability and maintainability characteristics prior to Phase III. Additionally, a number of operational questions for all Services must be resolved. DT&E/IOT&E test objectives will determine whether NAVSTAR GPS user equipment can provide adequate positioning, navigation and timing information to accomplish typical missions and operations in a more effective manner.

3.3.1.5 NATO Involvement

The United States encouraged NATO participation in the development and deployment of the NAVSTAR GPS. In response, ten NATO nations signed a Memorandum of Understanding (MOU) in June 1978 for participation in the Phase II development of NAVSTAR GPS. These nations include Belgium, Canada, Denmark, France, Germany, Italy, the Netherlands, Norway and the United Kingdom.

The objective is to establish a flow of information among the participating nations in all NAVSTAR GPS Program activities, which should facilitate national decisions to support the application of NAVSTAR GPS. To this end, personnel of these nations are fully integrated within the NAVSTAR GPS Joint Program Office (JPO) to contribute to the U.S. development program and to advise on and coordinate NATO applications, development and testing. This group is referred to the "NATO team" and is headed by a NATO Deputy Program Manager (DPM) who plans, controls and coordinates the NATO NAVSTAR GPS project. The NATO DPM is directly responsible to a Steering Committee composed of one representative from each participating nation, and which carries the responsibility for the effective implementation of the MOU. Each member of the Steering Committee acts as a national consultant and coordinator for NAVSTAR GPS-related activities.

The NATO NAVSTAR GPS project is financed by the participating nations. The Steering Committee allocates funds for the execution of studies and tests

considered to be of special interest to the NATO community. Major current NATO NAVSTAR GPS activities include:

1. Standardization of User Equipment. Since it is highly desirable to achieve some standardization of NAVSTAR GPS User Equipment, a NATO Standardization Working Group was established. It recommended that, at this stage in the program development, it would be most cost-effective to define a form, fit and function (F^3) specification for NATO NAVSTAR GPS receiver-processor units, thereby enhancing NATO interoperability. This is a significant activity in that standardization is being addressed during R&D for the first time in NATO history.

2. Mission Effectiveness Study. This study was initiated to determine the impact of NAVSTAR GPS on European/Canadian military tactics for various scenarios.

3. Antenna Study. This study is intended to determine the optimal antenna configuration/operation in a jamming environment.

4. High latitude ionospheric testing of Phase I equipments.

5. Polar evaluation of Phase I equipments.

6. System capability demonstrations using the single channel (Manpack) Set in Europe and Canada.

7. NAVSTAR GPS Integration Concept Studies.

In addition, options for possible Phase III participation are being examined. Important issues being considered include cost sharing, system configuration control, logistics and possible second-source production by NATO national industries.

3.3.1.6 Schedule

Figure I-4.8 of Volume I of this plan provides a detailed schedule of events for each segment of the program.

3.3.2 TRANSIT

TRANSIT development is essentially complete. There is a plan to launch a second NOVA satellite in 1982. The first NOVA was launched in May 1981.

3.3.3 Microwave Landing System (MLS)

DOD is committed to transitioning to MLS in conjunction with FAA and NATO. R,DT&E funding in FY-82 for the highly mobile tactical variant was zeroed by Congress without prejudice. The USAF is now planning to initiate a 15 year program in FY-83 to phase out ILS airborne and ground equipment. The program will be 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,DT&E 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.

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